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REVIEW

Analysis of fingermark constituents: a systematic review of quantitative studies

Rachel Robson[1] · Tilak Ginige[1] · Saleh Mansour[2] · Iftikhar Khan[3] · Sulaf Assi[3]

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Abstract

Fingermark identification has significance in forensic science, particularly in the processing of crime scene evidence. The majority of literature focused on physical interpretation of fingermarks with limited studies relating to chemical analysis. This systematic review investigated prospective studies dealing with the analysis of latent fingermark constituents. Studies included were those concerned with the analysis of intrinsic organic constituents present in latent fingerprints. Studies with no clear procedure were excluded. Data from the studies were exported into SPSS v22 (IBM, Armonk, NY, USA) where descriptive statistics were applied. The data extraction yielded 19 studies related to identification of lipids ($n=66$) and/or amino acids ($n=27$) in latent fingermarks. The primary lipid identified was squalene and the major amino acids included: alanine, glycine, leucine, lysine, and serine. For identification of the aforementioned constituents both chromatographic and spectroscopic techniques of which the main technique was gas chromatography-mass spectrometry. Prior to analysis, the majority of studies involved collection of fingermarks from both hands at room temperature. Deposition was done on different substrates of which the main were glass, Mylar strips, aluminium sheets or paper. In conclusion, chemical analysis of latent fingermarks enabled identifying key biomarkers of individual that could serve as complementary evidence in crime scene investigation.

Keywords Fingermark analysis · Fingermark components · Fingermark constituents · Fingermarks · Classification · Regression · Extraction techniques

Introduction

A fingermark is formed by a complex mixture of materials resulting when a part of the epidermal skin layer of the hand's palm and feet's sole areas of human beings has a contact with any surface, which leaves a unique pattern for a single source part of the skin. The main components in a latent fingermark comprises of amino acids, inorganic and organic compounds released by many types of glands. These include eccrine or merocrine glands with their number being highest in hands, soles of the feet, and the forehead. Also, the apocrine or exocrine glands; and the holocrine or sebaceous glands (Asano et al. 2002).

Fingerprint analysis is an important form of physical evidence especially in criminal investigations. Fingermark residue preserves exogenous compounds such as drugs of abuse, explosives, and chemical substances (Asano et al. 2002). Historically, the physical properties of latent fingerprints have been used to identify the perpetrator of a crime due to the ridge details giving a unique pattern not only to each individual but rather to each finger of the same individual. In this respect, several areas have been examined in relation to fingermark composition being gender identification, and age assignment (Asano et al. 2002; Bramble 2015).

Fingermark composition has been investigated in the literature using multiple analytical techniques being chromatographic (Bramble 2015), spectroscopic (Ricci et al. 2007a; Williams et al. 2004), and mass spectrometric/hyphenated techniques (Asano et al. 2002; Girod et al. 2012; Archer et al. 2005; Atherton et al. 2012; Croxton et al. 2006, 2010;

✉ Sulaf Assi
s.assi@ljmu.ac.uk

[1] Faculty of Science and Technology, Bournemouth University, Christchurch House, Fern Barrow, Poole BH12 5BB, UK

[2] Faculty of Criminology, Lebanese University, Saqyet El Janzeer, Abd Allah El Machnouk str., Beirut, Lebanon

[3] Pharmacy and Biomolecular Sciences, Liverpool John Moores University, Byrom Street, Liverpool L3 3AF, UK

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Frick et al. 2015; Mountfort et al. 2007). The aforementioned techniques included gas chromatography-mass spectrometry (GC–MS) (Asano et al. 2002; Archer et al. 2005; Croxton et al. 2006, 2010; Frick et al. 2015; Girod and Weyermann 2014), liquid chromatography-mass spectrometry (LC–MS) (Mountfort et al. 2007), capillary electrophoresis-mass spectrometry (CE-MS) (Atherton et al. 2012), thin-layer chromatography (TLC) (Bramble 2015), and Fourier transform infrared (FTIR) spectroscopy (Ricci et al. 2007a; Fritz et al. 2013; Girod et al. 2015; Williams et al. 2004). The aforementioned studies investigated the chemical composition of fingerprints and the influence of environmental, lifestyle, and disease factors on latent fingermarks. GC–MS was the most utilised technique as it offered high sensitivity and specificity to analytes that was down to 5 ng/ml. Nonetheless, the sensitivity was not always reported with other techniques that had been used only for latent fingermark identification purposes. Moreover, the utilised techniques were not consistent in fingermark sample collection, storage, and analysis. None of the mentioned techniques have optimised the fingermark sample selection, sample pre-treatment, extraction methods, and/or data analysis. Furthermore, previous systematic reviews relating to fingermarks focused on determining the composition of fingermarks and the factors affecting them (Girod et al. 2015; Cadd et al. 2015). However, none of the aforementioned reviews considered the validation of the analytical methods deployed for analysis of fingermark composition.

Therefore, our systematic review critically evaluated analytical methods for the determination of latent fingermark composition. More specifically, it considered the latent fingermark collection methods, the analytical approach, and the data processing. The objectives of the review were; (1) identifying the chemical constituents of latent fingermarks; (2) considering the procedures deployed for fingerprint deposition; (3) exploring the effect of different substrates on deposition; (4) appraising the analytical techniques used to determine latent fingermarks.

Methods

Search strategy

Our literature search strategy was predefined and aligned with recommendations outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al. 2009). We searched the following five databases between August 2018 and January 2022: Google, Google Scholar, Science Direct, Scopus, and Web of Science. The search strategy assessed articles retrieved mainly through the aforementioned databases. Moreover, bibliographic lists from other reviews were inspected for relevant articles where applicable. There were no language or time restrictions applied to the studies.

We have used the following search terms: 'fingerprints', 'chemical composition', 'fingermarks' and 'analysis'. The search strategy involved the use of the three terms in each database as follows: 'fingerprint', or 'fingerprints' or 'latent fingerprint' AND 'fingermark' or 'fingermarks' AND 'chemical composition' or 'chemical constituent' or 'chemical constituent(s)' AND 'analysis' or 'determination' or 'identification'.

Inclusion and exclusion criteria

Studies included were those that had investigated chemical composition of fingermarks in relation to individual constituent type, types of donor, and analytical technique analysed. Two types of studies were excluded. The first type was studies that did not state clearly that ethical and correct procedural protocols were followed. The second types of studies were those that presented an evaluation of a technique without showing any factors that affected the data collection and results.

Ethical approval

Ethical approval of the study was granted by Bournemouth University Ethics Committee (Ethics ID 23,010). The study was conducted considering Bournemouth University Ethics Code of Practice and the Data Protection Act 2017 (Available from 2020; Gov 2018). No participants' personal data were identified in this study. The retrospective data extracted were limited to the research question present in the study related to chemical analysis and composition of latent fingerprints.

Quality assessment

In order to evaluate the quality of the studies, the Joanna Briggs Institute (JBI) appraisal checklist was used after modification to suit the type of studies being evaluated (Appendix I) (Briggs 2017). The JBI checklist allowed for scoring system of suitability, and this included studies requiring an overall score above 6/10. It is noteworthy to mention that none of the included studies scored below 6.

Data extraction

Data extraction was carried out by the authors and included the following information for each study: title, aim of study, experimental settings, country settings, participant characteristics, sample type, sample size, and duration of study, fingermark collection, deposition procedure, storage procedure, and constituent identification (Table 1). Articles were

Table 1 Information extracted through the data extraction

Sections	Sub-sections
Title	Aim of study
Study Characteristics	Experimental settings; country settings; participants characteristics; sample type; sample size
Deposition procedure	Fingers used; Latent fingerprint collected; Grooming procedures; Cleaning procedure
Experimental conditions	Experiment duration; storage conditions
Constituent	Constituents analysed; techniques applied

scanned independently by two reviewers (RR and SA), and the screening process included titles, abstracts, and full articles. Disagreement among reviewers was resolved by discussion. Where no consensus was achieved among both reviewers, a discussion was made with the wider team (TG, SM and IK). The inter-rater reliability was excellent (kappa = 0.95) (Cohen 1968).

Data analysis

We carried out data analysis using SPSS version 22 (IBM, Armonk, NY, USA). The summary statistics included descriptive statistics expressed as percentages, mean/standard deviation or median/interquartile range depending on the normality of each evaluated parameter. Parameters evaluated included: participants' characteristics, amino acids', and lipids' presence in the latent fingerprints.

Results

The initial search yielded 9850 studies. After applying limits and removing duplicates, 9764 were excluded (Fig. 1). This resulted in 86 studies which titles were evaluated according to the inclusion and exclusion criteria and 34 studies were removed. The remaining 52 studies were subject to abstract evaluation and 24 studies were excluded. The full text of the remaining 34 studies was subject to the inclusion/exclusion criteria, and further 15 studies were rejected. This resulted in a total of 19 studies that were included in the review.

Study characteristics

The 19 studies included in the review were conducted between 1995 and 2021 and were from seven different countries (Table 2): Australia (Fritz et al. 2013; Frick et al. 2015; Dorakumbura et al. 2018); Canada (Yeh et al. 2020); Switzerland (Girod et al. 2015, 2012); The Netherlands (Helmond et al. 2017; Helmond et al. 2019); United Kingdom (Bramble 2015; Ricci et al. 2007a; Archer et al. 2005;

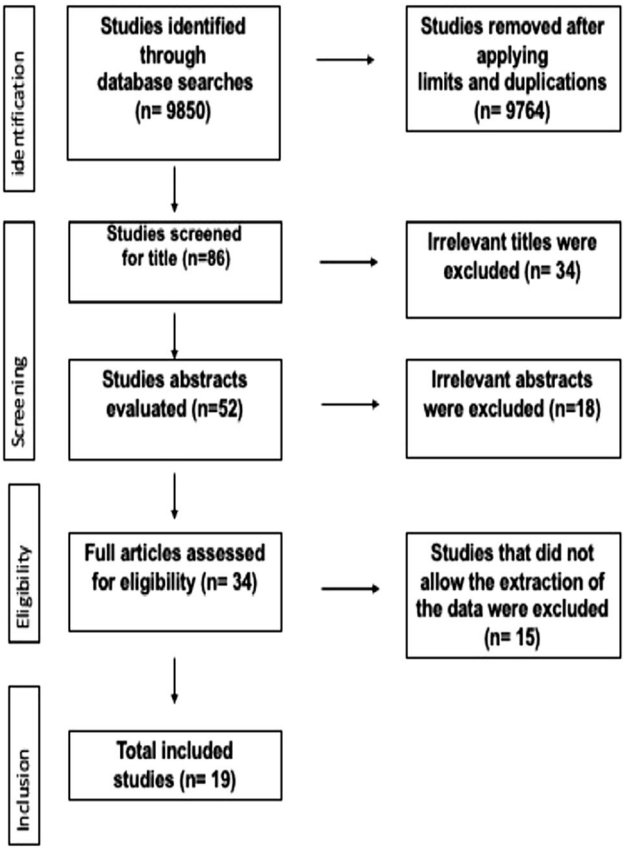

Fig. 1 The identification, screening, eligibility and inclusion of included studies

Croxton et al. 2006, 2010; Ferguson et al. 2012; Wolstenholme et al. 2009); USA (Asano et al. 2002; Williams et al. 2004); Spain/UK (Girod et al. 2012). All of the aforementioned studies evaluated amino acids and/or lipids in latent fingermarks; however, they differed in the analytical technique use, number of donors and donors' characteristics (number, age, gender, and health/lifestyle factors).

Regarding the analytical technique used, GC–MS was the main technique and was utilised by seven studies (Asano et al. 2002; Girod et al. 2012; Archer et al. 2005; Croxton et al. 2006; Croxton et al. 2010; Frick et al. 2015; Helmond et al. 2019). This was followed by FTIR that was used in five studies (Fritz et al. 2013; Girod et al. 2015; Williams et al. 2004; Dorakumbura et al. 2018; Ricci et al. 2007b). Each of LC–MS (Mountfort et al. 2007; Helmond et al. 2017; Helmond et al. 2019) and MALDI-MS (Yeh et al. 2020; Ferguson et al. 2012; Wolstenholme et al. 2009) was used in three studies. On the other hand, each of CE-MS (Atherton et al. 2012), Raman spectroscopy (Dorakumbura et al. 2018) and TLC (Bramble 2015) was used by one study only. The number of donors reported in the 13 studies ranged between 1 and 463 (median, IQR = 5, 17). Where reported, donors were mainly adults in the age range of 18—77 years. Gender

Table 2 Characteristics of the studies that investigated analysis of fingerprint constituents

SN	Study	"Study aim(s)"	"Technique(s) Used"	Nd	Age (years)	Gender	"Study settings"	"Health and lifestyle factors reported"	Country
S1	Archer et al. (2005)	"To identify the changes in amino acids and lipid constituents in latent fingerprint deposition. "	GC–MS	5	18–24	Male	A grooming procedure was carried out prior to deposition onto fibre glass filter paper. The fingerprints were stored in light and dark conditions	"Smokers ($n = 2$) Non-smoker ($n = 3$) Betnovate user ($n = 1$) Pescaterian ($n = 1$)"	UK
S2	Asano et al. (2002)	"To investigate lipid composition to link to personal traits. "	GC–MS	10	NR	"Female ($n = 5$) Male ($n = 5$)"	A grooming procedure was carried out before rubbing fingerprint deposits onto a cleaned glass bead and contained within a cleaned glass jar and sealed	NR	US
S3	Croxton et al. (2006)	"The identification of amino acid and lipid constituents in latent fingerprints, taking into account the influence of time on changes of composition. "	GC–MS	2	"25 ($n = 1$) 45 ($n = 1$)"	"Female ($n = 1$) Male ($n = 1$)"	Grooming procedure had been applied to washed hands prior to deposition upon pre-washed Mylar 002 film	NR	UK
S4	Croxton et al. (2010)[a] E")	"The quantification of amino acid and lipid constituents in latent fingerprints."	"GC–MS GC-FID (squalene only)"	18	"18–29 ($n = 13$) 30–60 ($n = 5$) "	"Female ($n = 9$) Male ($n = 9$)"	Unwashed hands were rubbed together and fingerprints were deposited onto pre-washed Mylar 002 polyester film. The donors then carried out grooming procedure and deposited samples as previously described. The samples were placed in amber vials for analysis	"Smokers ($n = 4$) Non-smokers ($n = 14$) Medication ($n = 7$) No medication ($n = 11$) Cosmetics used ($n = 11$) Omnivore ($n = 14$) Vegetarian ($n = 4$)"	UK

Table 2 (continued)

SN	Study	"Study aim(s)"	"Technique(s) Used"	Nd	Age (years)	Gender	"Study settings"	"Health and lifestyle factors reported"	Country
S5	Frick et al. (2015)	To understand the variabilty of lipid constituents in latent fingerprint composition in order to improve fingerprint detection techniques	GC–MS	5	"20–29 ($n = 3$) 30–39 ($n = 2$) "	"Female ($n = 3$) Male ($n = 2$)"	A grooming procedure was preformed prior to deposition onto an unwashed filter paper circles. Samples were wrapped in foil until analysis within one hour of deposition or stored in screw top jars in -20 °C temperature and samples from remote locations were kept under frozen conditions during transport and in the laboratory	"Skin products ($n = 4$) No skin products ($n = 1$)"	Australia
S6	Girod and Weyermann (2014) E")	To identify and quantify lipid constituents in latent fingerprints	GC–MS	25	25–57	"Female ($n = 13$) Male ($n = 12$)"	Samples were collected onto microfibre filters in the morning over 25 days from donors carrying out normal daily tasks and not washing their hands prior to grooming procedure. Extraction of fingerprint residue occurred within ten minutes of deposition and blank samples were analysed per run for comparison	"Smokers ($n = 4$) Non-smokers ($n = 21$) Vegetarian ($n = 1$) Omnivore ($n = 24$) Hypercholesterolemia ($n = 1$) Hypothyroidism ($n = 1$) Cosmetic use ($n = 13$) Non-cosmetic use ($n = 12$)"	Switzerland

Table 2 (continued)

SN	Study	"Study aim(s)"	"Technique(s) Used"	Nd	Age (years)	Gender	"Study settings"	"Health and lifestyle factors reported"	Country
S7	Atherton et al. (2012)	The analysis of amino acid of latent fingerprints	CE-MS	1	NR	NR	Eight fingerprint deposits were deposited onto cleaned Mylar strip and stored in dark conditions until required	NR	UK and Spain
S8	Mountfort et al. (2007)	To identify the oxidation products of squalene within latent fingerprints	LC–MS	1	NR	NR	Groomed fingerprint samples were deposited onto glass substrates over one day, they were stored in light conditions, and at selected days in a seven day period they were removed and placed in vials for extraction	NR	UK
S9	Van Helmond et al. (2017)	To determine non-derivatives amino acids in fingerprints	UPLC-MS	19	20–66 years old	10 females and 9 males	Fingerprint deposition was made on 2.5 × 5 cm aluminium foil. Prior to deposition, donors wore nitrile gloves and rubbed their hands together to ensure homogeneity of sampling. Then the samples were subject to extraction	NR	The Netherland

Table 2 (continued)

SN	Study	"Study aim(s)"	"Technique(s) Used"	Nd	Age (years)	Gender	"Study settings"	"Health and lifestyle factors reported"	Country
S10	Van Helmond et al. (2019)	To determine the lipid and amino acid composition of fingerprints of 1852 fingerprints donated by 463 donors during the Dutch music festival Lowlands in 2016	UPLC-MS and GC–MS	463	18–64 years old of which 90% are in the range of 18–40 years old; median age 26 years old	179 males, 280 females and four not disclosed	Participant donated two fingerprint secretions: one eccrine and one sebaceous. Prior to supplying the fingerprints, participants had rubbed their hands to create homogeneity of sampling. Then they donated two fingerprints with their index finger on 2.5 × 5 cm aluminium foil. The samples were then subject to extraction prior to analysis	Gender, smoking habit, diet and drug use	The Netherland
S11	Ferguson et al. (2012)	Detection of peptides in ungroomed fingerprints	MALDI-MS imaging	80	20—45 years old	40 males and 40 females	Ungroomed finger prints were collected in triplicates and submitted to MALDI MSP prior to spotting with a further optimised MALDI matrix	Gender	UK
S12	Wolstenholme et al. (2009)	To determine lipid composition in fingerprints	MALDI-MS imaging	NR	NR	NR	Both groomed and ungroomed fingerprints are deposi-tied on aluminium sheets prior to analysis	NR	UK
S13	Yeh et al. (2020)	To determine fingerprints concealed under bloodstains	MALDI-FT-ICR-MS	1	21	Female	Fingerprints were deposited on MALDI-target plate or aluminium sheet within 15 min of blood deposition	NR	Canada

Table 2 (continued)

SN	Study	"Study aim(s)"	"Technique(s) Used"	Nd	Age (years)	Gender	"Study settings"	"Health and lifestyle factors reported"	Country
S14	Bramble (2015)	"To identify and discriminate amino acid and lipid constituents of latent fingerprints."	TLC	5	20–35	Male	A grooming procedure was carried out prior to fingerprint deposition onto pre-conditioned TLC plates. TLC was carried out in a sealed tank within one hour of collection	NR	UK
S15	Fritz et al. (2013)	To identify the lipid constituents of fingerprints and to determine if there is a relationship between the age of a fingerprint and the lipid constituents	FTIR	13	"< 20 (n = 3) 20–30 (n = 2) 30–40 (n = 1) 40–50 (n = 6)"	"Female (n = 7) Male (n = 6)"	A grooming procedure was carried out on washed hands of donors who had not eaten of touched chemicals. A control of washed hands and no grooming procedure were also carried out, and both samples were deposited onto cleaned potassium bromide discs. Ageing samples were stored at a non-specified ambient temperature	NR	Australia

Table 2 (continued)

SN	Study	"Study aim(s)"	"Technique(s) Used"	Nd	Age (years)	Gender	"Study settings"	"Health and lifestyle factors reported"	Country
S16	Girod et al. (2015) E"	"To investigate the lipid constituents latent fingerprints and determine changes in fingerprints due to ageing."	FTIR	1	27	Female	The hands were washed, and a grooming procedure was carried out prior to two depositions. One onto foil and another onto glass substrates, both were analysed at different days for ageing analysis and samples were stored in light and dark conditions while ageing	"Cosmetic use Type of diet"	Switzerland
S17	Ricci et al. (2007a) E"	"To identify the amino acid constituents and assess their stability over time within latent fingerprints."	FTIR	5	"22 ($n=1$) 30 ($n=1$) 24 ($n=1$) 28 ($n=1$) 21 ($n=1$)"	"Female ($n=2$) Male ($n=3$)"	Groomed fingerprint samples were applied to ZnSe ATR crystal for chemical image collection, this was collected at a range of temperatures all with 40% relative humidty over selected time periods per temperature	Obesity and overweight	UK

Table 2 (continued)

SN	Study	"Study aim(s)"	"Technique(s) Used"	Nd	Age (years)	Gender	"Study settings"	"Health and lifestyle factors reported"	Country
S18	Williams et al. (2004)	To determine the amino acids and lipids of latent fingerprints	FTIR	NR	NR	Male	Three fingerprint deposits per donor were obtained on aluminium coated slides prior to washing hands, after hand washing and the third after grooming procedure was carried out. The samples were observed under a microscope and spectra was obtained of the functional groups within the samples	NR	US
S19	Dorakumbura et al. (2018)	To determine the spatial micro-distribution of the sebaceous and eccrine chemical components within latent fingerprints deposited on non-porous surface	FTIR and Raman imaging	9	20–77 years old	5 males and 4 females	Donors rubbed their fingers on an ethanol cleaned non-porous substrate	NR	Australia

E ethnicity, *Nd* number of donors, *NR* not reported, *SN* study number, *GC–MS* gas chromatography-mass spectrometry, *MS* mass spectrometry, *LC–MS* liquid chromatography-mass spectrometry, *CE-MS* capillary electrophoresis-mass spectrometry, *FTIR* fourier transform infrared, *GC/FID* gas chromatography flame ionisation detection

was reported in 16 out of the 19 studies where: four studies recruited equal representation of males and females (Asano et al. 2002; Croxton et al. 2006, 2010; Ferguson et al. 2012), two studies recruited higher ratio of males (Dorakumbura et al. 2018; Ricci et al. 2007b), five studies recruited higher ratio of females (Fritz et al. 2013; Frick et al. 2015; Girod and Weyermann 2014; Helmond et al. 2017; Helmond et al. 2019), three studies recruited only males (Bramble 2015; Williams et al. 2004; Archer et al. 2005), and two studies had only females (Girod et al. 2015; Yeh et al. 2020). It is noteworthy to mention that the studies that recruited only males or females had only one participant each This showed inconsistency in recruitment of genders across studies and could be related to the difficulty in recruiting participants. Only five studies reported the ethnicity of participants (Ricci et al. 2007a; Girod et al. 2015, 2012; Archer et al. 2005; Croxton et al. 2010). However, this was not included in the overall discussion and evaluation of the included study methodologies due to the lack of specific observational differences associated with ethnicity. Healthcare and lifestyle characteristics among participants were assessed only in eight studies (Girod et al. 2012; Archer et al. 2005; Croxton et al. 2010; Frick et al. 2015; Girod and Weyermann 2014; Helmond et al. 2019; Ricci et al. 2007b). These characteristics ranged from dietary preference (Girod et al. 2015; Archer et al. 2005; Croxton et al. 2010; Girod and Weyermann 2014; Helmond et al. 2019); if they were a smoker or non-smoker (Archer et al. 2005; Croxton et al. 2010; Girod and Weyermann 2014; Helmond et al. 2019); if they used skin products or cosmetics prior to the fingermark deposition (Girod et al. 2015; Croxton et al. 2010; Frick et al. 2015; Girod and Weyermann 2014); medication prescriptions (Girod et al. 2015; Archer et al. 2005; Croxton et al. 2010; Girod and Weyermann 2014); and the weight of the participant (Ricci et al. 2007a). All gave figures per donor group to how many characteristics were identified within except for two studies (Ricci et al. 2007a; Girod et al. 2015), which reported only weight of participants.

Deposition procedure

The fingermark deposition procedure differed between studies, and there were three features that encompassed this procedure. The features included the specification of the finger used, the grooming procedure, and the fingermark collection procedure (Table 3).

Regarding the finger used, there were variations in the fingermark collection method. The most commonly used fingers for deposition were the index, middle and ring fingers and were reported in four studies (Archer et al. 2005; Atherton et al. 2012; Ferguson et al. 2012; Wolstenholme et al. 2009). This was followed by using only one finger for deposition (without specifying which one) and that was seen by four studies (Fritz et al. 2013; Girod et al. 2015; Williams et al. 2004; Frick et al. 2015). Three studies reported using all fingers from both hands (Croxton et al. 2006; Yeh et al. 2020; Dorakumbura et al. 2019), and additional three studies reported using the index finger of each hand (Mountfort et al. 2007; Helmond et al. 2017; Helmond et al. 2019). Nonetheless, only one study reported each of using the thumb of each hand (Girod and Weyermann 2014) and the ring and middle finger of both hands (Croxton et al. 2010). The remaining three studies did not report which fingers were used for deposition (Ricci et al. 2007a; Fritz et al. 2013; Girod et al. 2015).

The number of depositions per fingermark ranged between two and 200 fingermarks per donor over the evaluated studies. For grooming procedure, studies had variations in grooming procedures depending whether sebaceous or eccrine constituents were collected. For sebaceous secretions' collection, participants had not undertaken hand washing prior to fingermark deposition in contrary to eccrine secretions' collection. In the latter case, participants either washed their hands with soap and water or cleaned with ethanol solution and then waited between 15 and 30 min before deposition.

Where rubbing was required prior to deposition, patrticipants either rubbed their fingertips on their faces or together. This was reported by the majority of studies ($n=12$) (Asano et al. 2002; Bramble 2015; Ricci et al. 2007a; Fritz et al. 2013; Girod et al. 2015; Williams et al. 2004; Archer et al. 2005; Frick et al. 2015; Mountfort et al. 2007; Girod and Weyermann 2014; Dorakumbura et al. 2018; Yeh et al. 2020). On faces, participants rubbed their fingertips on the forehead, hair, nose, cheeks, and chin with the forehead being the most utilised source. The remaining seven studies asked the donors to rub fingertips together (Atherton et al. 2012; Croxton et al. 2006, 2010; Helmond et al. 2017; Helmond et al. 2019; Ferguson et al. 2012; Wolstenholme et al. 2009). Prior to fingermark grooming, two studies did not report cleaning of fingers (Ricci et al. 2007a; Mountfort et al. 2007)); two studies stated no cleaning of fingers was required (Asano et al. 2002; Atherton et al. 2012). There was a vary in time given to the last time hands could be washed prior to deposition: one hour (Croxton et al. 2006; Croxton et al. 2010); 45 min (Girod et al. 2015, 2012); 30 min (Fritz et al. 2013; Girod et al. 2015; Dorakumbura et al. 2018), no specific time (Croxton et al. 2010); and five minutes (Williams et al. 2004). For the cleaning solution, seven solutions were used and included: acetone (Atherton et al. 2012; Croxton et al. 2010), dichloromethane (Frick et al. 2015), ethanol (Fritz et al. 2013; Girod et al. 2015; Atherton et al. 2012; Girod and Weyermann 2014; Ferguson et al. 2012; Wolstenholme et al. 2009), hexane (Croxton et al. 2006), methanol (Croxton et al. 2006, 2010), soap (Girod et al. 2015; Girod and Weyermann 2014; Dorakumbura et al. 2018; Helmond

Table 3 Latent fingerprint deposition procedure

SN	Study	"Constituents analysed"		"Technique (s) used"
		Amino acids	Lipids	
S1	Archer et al. (2005)	NR	"Oleic acid, Palmitoleic acid, Palmitic acid, Stearic acid, Squalene, Tetradecanoic acid"	GC–MS
S2	Asano et al. (2002)	NR	"Cholesterol, Methyl palmitate, Methyl palmitoleate, Methyl stearate, Mystiric acid, Oleic acid, Pentadecanoic acid, Palmitic acid, Palmitoleic acid, Stearic acid, Squalene"	GC–MS
S3	Croxton et al. (2006)	"Alanine, Glycine, Isoleucine, Phenlyalanine, Leucine, Lysine, Serine, Threonine, Tyrosine"	"Cis-9, cis-12-octadecadienoic acid, Decanoic acid, Dodecanoic acid, Hexadecanoic acid, Glutamic acid, Nonadecanoic acid, Octanoic acid, Pentadecanoic acid, Tetraconsanoic acid, Tetradecanoic acid"	GC–MS
S4	Croxton et al. (2010) *E"	"Alanine, Arginine, Asparagine, Cystine,Cysteine, Glycine, Histidine, Hydroxyproline, Isoleucine, Leucine, Lysine, Methionine, Ornithine, Proline, Serine, Tryptophan, Tyrosine, Valine"	"Aspartic acid, cis-9-octadecanoic acid, cis-9,cis-12-octadecanoic acid, cis-9-tetradecanoic acid, Decanoic acid, Dodecanoic acid, Eicosanoic acid, Glutamic acid, Hexadecanoic acid, Nonadecanoic acid, Octadecanoic acid, p-Chlorophenylalanine, Pentadecanoic acid, Phenylalanine, Tetracosanoic acid, Tetradecanoic acid, Tridecanoic acid, Undecanoic acid"	"GC–MS GC-FID (squalene only)"
S5	Frick et al. (2015)	NR	"Hexadecanoic acid C16:1, Isopropyl decanoate, Octadecenoic acid C18:1, Octadecanoic acid C18, Pentadecanoic acid C15, Tetradecanoic acid (C14)"	GC–MS
S6	Girod and Weyermann (2014) *E"	NR	"Cholesterol, Myristyl palmitoleate, Myristyl palmitate, Palmityl palmitate, Palmityl palmitoleate, Stearyl palmitoleate, Squalene, Wax ester (major 17:0, 16:1), Wax ester (major 20:0, 16:1)"	GC–MS
S7	Atherton et al. (2012)	"Alanine, Arginine, Asparagine, Citrulline, Glycine, Histidine, Isoleucine/leucine, Lysine, Phenylalanine, Serine, Threonine, Tyrosine, Urea and Uric acid, Valine, Taurine"	"Aspartic acid, Cholesterol, Decanoic acid, Dodecanoic acid, Docosanoic acid, Eicosanoic acid, Glutamic acid, Heneicosanoic acid, Heptadecenoic acid, Lactic acid, Linoleic acid, Margaric acid, Methionine, Myristic acid, Myristoleic acid, Nonadecanoic acid, Nonanoic acid, Octanoic acid, Oleic acid, Ornithine, Palmitic acid, Palmitoleic acid, Pentadecenoic acid, Squalene, Stearic acid, Tetracosanoic acid, Tricosanoic acid, Tridecanoic acid"	CE-MS
S8	Mountfort et al. (2007)	NR	"Squalene (SQ), Squalene dihydroperoxide (SQ-[OOH]2), Squalene epoxide, Squalene-monohydroperoxide (SQ-[OOH]), Squalene-pentahydroperoxide (SQ[OOH]5), Squalene-tetrahydroperoxide (SQ[OOH]4), Squalene-trihydroperoxide (SQ-[OOH]3)"	LC–MS

Table 3 (continued)

SN	Study	"Constituents analysed"		"Technique (s) used"
		Amino acids	Lipids	
S9	Van Helmond et al. (2017)	"Alanine, Arginine, Asparagine, Aspartic acid, Cystine, Glutamic acid, Glutamine, Histidine, Isoleucine, Lysine, Methionine, Ornithine, Phenylalanine, Proline, Threonine, Tryptophan, Tyrosine, Serine, Valine"	NR	UPLC-MS
S10	Van Helmond et al. (2019)	Alanine, Arginine, Asparagine, Glutamine, Guanine, Guanosine, Isoleucine, Phenylalanine, Proline, tryptophan	"Cholesterol fatty acids methylesters, Palmitoleic acid, Squalene"	GC–MS UPLC-MS
S11	Ferguson et al. (2012)	"Psoriasin Dermicidin derived peptides, Serine"	NR	MALDI-MSI
S12	Wolstenholme et al. (2009)	NR	"Oleic acid"	MALDI-MSI
S13	Yeh et al. (2020)	Alanine, Glycine, Methionine	"Linoleic acid, Myristic acid, Octanoic acid, Oleic acid, Palmitic acid, Palmitoleic acid, Pentadecanoic acid, Squalene, Stearic acid"	MALDI-FT-ICR-MS
S14	Bramble (2015)	NR	"Cholesterol, Squalene, Triglycerides, Urocanoic acid"	TLC
S15	Fritz et al. (2013)	Amide	Saturated esters	FTIR
S16	Girod et al. (2015) *E"	Secondary amide	"Saturated esters, Wax esters"	FTIR
S17	Ricci et al. (2007a) *E"	Amide B	"Ceramides, Glycerides, Glycolipids, Phospholipids "	FTIR
S18	Williams et al. (2004)	NR	NR	"FTIR Raman microscopy"
S19	Dorakumbura et al. (2019)	"Phenylalanine, Tyrosine"	Squalene	"FTIR Raman microscopy"

CE-MS capillary electrophoresis-mass spectrometry, *GC-FID*: gas chromatography flame ionisation detection, *GC–MS* gas chromatography-mass spectrometry, *FTIR* Fourier transform infrared, *GC-FIDLC–MS* liquid chromatography-mass spectrometry, *MALDI FT-ICR MS*: matrix-assisted laser desorption/ionisation, *MALDI-MSI*: matrix assisted laser desorption/ionisation mass spectrometry imaging, Fourier-transform ion cyclotron resonance mass spectrometry, *MS* mass spectrometry, *NR* not reported, *SN* study number, *TLC* thin-layer chromatography

et al. 2017; Helmond et al. 2019) and sodium hydroxide (Atherton et al. 2012; Croxton et al. 2010). For the collection procedure, all studies stated that the fingers were pressed onto the selected substrates of which two studies indicated the same exact time and pressure applied for deposition (Girod et al. 2015; Girod and Weyermann 2014). The remaining studies did not specify the pressure applied onto the substrate.

Experimental conditions

Experimental conditions reported included latent fingermark collection and storage methods reported comprised collection substrate type, temperature conditions, light conditions, and duration of the study (Table 4). Seven types of substrates were used for collection of latent fingermarks including: glass ($n=4$), Mylar film or Mylar strips ($n=3$), aluminium coated slide/sheet (n = 6), filter paper (n = 3), microfibre filter (n = 1), TLC plates (n = 1), gold-coated glass plates (n = 1), Mylar strip ($n = 2$), stainless steel plates ($n = 1$), potassium bromide disc ($n = 1$), ZnSe discs ($n = 1$), germanium substrates ($n = 1$), glass slide ($n = 1$), and directly onto the ZnSe ATR crystal or calcium fluoride ($n = 2$). It is noteworthy to mention that the experimental conditions were not specific to the technique utilised. Hence, different conditions were taken between the six studies that utilised GC–MS. Once collected fingermarks were stored at variable temperatures ranging between 4 and 100 °C depending on the substrate. The 100 °C was seen for potassium bromide discs. However, all the other substrates (whether glass, paper, or aluminium), where reported, were stored at a maximal temperature of 25 °C. Both light and dark conditions for storage of substrates were reported and light used included both natural light or light induced via light bulbs (Ricci et al. 2007a; Fritz et al. 2013; Girod et al. 2015, 2012; Williams et al. 2004; Archer et al. 2005; Atherton et al. 2012). Only 11 studies reported the duration which ranged widely between two and 80 days (median, IQR = 27, 28) (Table 4).

Constituents analysed

The studies' results identified qualitatively lipids' or amino acids' composition within fingermark samples. For lipid composition in fingermarks, there was variation in the studies reporting specific lipid derivatives. This depended on the technique used, its sensitivity, specificity as well as the methodological approach. For instance, CE-MS showed the highest specificity in detecting the highest number of lipids and differentiating between them (S7). This was followed by GC–MS that showed high specificity and selectivity in characterising lipids (S1-S6). On the other hand, FTIR spectroscopy showed less sensitivity and specificity in detecting constituents, where it indicated the presence of certain functional groups that were common to multiple derivatives (S15-S19). Where specified, 44 lipids were detected in fingermark secretions. Squalene and its degradation products were the most reported lipid and were reported by 10 studies (Table 5) (Asano et al. 2002; Bramble 2015; Girod et al. 2015; Archer et al. 2005; Atherton et al. 2012; Girod and Weyermann 2014; Helmond et al. 2017; Dorakumbura et al. 2019; Mountfort et al. 2007). This was followed by pentadecanoic acid that was reported in six studies (S2; S3; S4; S5; S7; S13). Moreover, each of cholesterol (S2; S6; S6; S10; S14); palmitoleic acid (S1; S2; S7; S10; S13); pentadecanoic acid (S2; S3; S4; S5; S6; S7); and tricosanoic acid (S1; S3; S4; S5; S7) were reported in five studies. Four studies reported each of oleic acid (S1; S2; S7; S12; S13); palmitic acid (S1; S2; S7; S10; S13); palmitoleic acid (S1; S2; S7; S10; S13); stearic acid (S1; S2; S7; S13); and tetradecanoic acid (S1; S3; S4; S5). Three studies reported ceramides (S4; S7 and S17); decanoic acid (S3; S4 and S7); doecanoic acid (S3; S4; S7); glutamic acid (S3; S4; S7); glycerides (S4; S7; S17); hexadecanoic acid (S3; S4; S5); myristic acid (S2; S7; S13); nonadecanoic acid (S3; S4; S7); octanoic acid (S3; S7; S13); and tetraconsanoic acid (S3; S4; S7).Two studies reported each of aspartic acid (S4; S7); eicosanoic acid (S4; S7); linoleic acid (S7; S13); ocadecanoic acid (S4; S5); octadecadienoic acid (S3; S4); stearyl palmitate (S6; S7); tridecanoic acid (S4; S7); and undecanoic acid (S4; S15). The remaining lipids were less popular where only one study reported each of docosanoic acid (S7); heneicosanoic acid (S7); heptadecenoic acid (S7); isopropyl decanoate (S4); lactic acid (S7); margaric acid (S7); methyl palmitate (S2); methyl palmitoleate (S2); methyl steerage (S2); myristoleic acid (S7); myristyl palmitate (S6); myristyl palmitoleate (S6); nonanoic acid (S7); palmityl palmitate (S6); palmityl palmitoleate (S6); urea (S7); and uric acid (S7) (Table 5).

On the other hand, less amino acids were reported in studies (n = 24) of which the most common was alanine that had been reported in six studies (S3; S4; S7; S8; S10; S13) (Table 6). This was followed by phenyl alanine (S3; S6; S9; S10; S19) and serine (S3; S4; S7; S9; S11) that were reported by five studies. Four studies reported each of arginine (S4; S7; S9; S10), asparagine (S4; S7; S9; S10), glysine (S3; S4; S7; S13), isoleucine (S4; S7; S9; S10), methionine (S4; S7; S9; S13) and tyrosine (S4; S7; S9; S19). In addition three studies reported each of histidine (S4; S7; S9), leucine (S3; S4; S7); lysine (S3; S4; S7), ornithine (S4; S7; S9), proline (S4; S9; S10), threonine (S3; S7; S9) and tryptophan (S4; S9; S10). Two studies reported each of cystine (S4; S9) and valine (S7; S9). Only one study reported each of cysteine (S4), guanine (S10), guanosine (S10), glutamic acid (S9), glutamine (S9) and hydroxyproline (S4).

Table 4 Latent fingermark and storage methods

SN	Study	Finger(s) used for fingermark(s) collection	"Grooming procedure"	"fingermark collection procedure"		
				Cleaning of substrate	Cleaning of finger	Deposition procedure
S1	Archer et al. (2005)	"Index finger of both hands(n = 1) Middle finger of both hands (n = 1) Ring finger of both hands (n = 1) These fingerprints were collected over one day at unspecified times."	"Fingers were wiped gently across cheeks and from chin centre to edge of chin 10 times. Next they were wiped from forehead centre to temple 10 times and passed through their hair 10 times. Lastly the fingers of both hands were pressed against each other before deposition. "	"No cleaning of glass fibre filter paper. "	"The hands were wiped with tissue soaked in ethanol and dried with a non-ethanol containing tissue. "	Latent fingermarks were superimposed sequentially on a piece of filter paper with a time interval of 20 min between collection
S2	Asano et al. (al. 2002)	NR	"The donors rubbed their fingertips across their forehead before deposition. "	"The glass beads and jars were both washed prior to collection. "	No cleaning procedure	The glass beads were rubbed between the fingers
S3	Croxton et al. (et al. 2006)	One fingermark was deposited from all ten fingers of each donor	"The fingers were rubbed together for an unspecified time before deposition. "	The Mylar strips were pre-washed with hexane and methanol	"The hands were not to be washed one hour prior to deposition. "	fingermarks of both hands being deposited sequentially to collect 2 marks per filter paper
S4	Croxton et al. (2010) [a]E"	"Ring finger of both hands (n = 2) Middle finger of both hands (n = 2) "	Donors rubbed their hands together for even distribution of residues on skin surface to produce a natural sample. The groomed sample was produced from rubbing their fingers across the forehead and nose regions for 10 s and then rub their hands together to even out distribution of residue before deposition	All Mylar strips for the standards and fingermark samples were cleaned with methanol 1% (w/v) sodium hydroxide and acetone	Fingermark donors were asked to refrain from hand washing one hour prior to sampling	Both hands‘ fingermarks were deposited onto one Mylar strip with minimal overlap
S5	Frick et al. (2015)	"36–49 fingermarks per donor. The finger(s) and hand(s) were not specified"	The three middle fingers were rubbed briefly across the forehead and nose before deposition, some followed a modified procedure which involved the fingermarks of both hands	"The screw top glass vials were pre-treated by cleaning them with dichloromethane. "	"The donors were asked to not wash their hands prior to grooming procedure to mimic a realistic fingermark deposition. "	The fingertips were gently pressed onto the filter paper circles
S6	Girod and Weyermann (2014) [a]E"	"Left thumb (n = 1) Right thumb (n = 1)"	Both thumbs were gently rubbed on forehead and edge of nose before deposition and this mimicked a natural movement	"No cleaning of microfibre filter paper. "	"The donors were asked to carry out normal tasks before deposition and not wash hands with soap 45 min before collection "	"The fingermarks were deposited onto 25 mm diameter microfibre filters, and this was also onto a kitchen scale with approximately 500 ± 100 g for 15 s. "
S7	Atherton et al. (2012)	"Index finger of one hand (n = 3) Middle finger of one hand (n = 3) Ring finger of one hand (n = 2) "	Donors were asked to rub fingers together, no hand washing was undertaken before deposition	The strips were pre-cleaned by sonicating for 1 h in each 1%(w/v) sodium hydroxide, ethanol and acetone and then allowed to air dry	No cleaning procedure	Eight fingermarks from one hand were deposited onto one Mylar strip with minimal overlap
S8	Mountfort et al. (2007) (Mountfort et al. 2007)	"Index finger of right hand and amount not specified. Index finger of left hand and amount not specified."	A volunteer carried out a grooming procedure that involved passing the fingertips across the face and through their hair before deposition. This procedure was carried out throughout the course of one day	NR	NR	Fingers were placed onto the glass cover slips

Table 4 (continued)

SN	Study	Finger(s) used for fingermark(s) collection	"Grooming procedure"	"fingermark collection procedure"		
				Cleaning of substrate	Cleaning of finger	Deposition procedure
S9	Van Helmond et al. (2017)	Index finger of each hand	Donors were asked to wear nitrile gloves and rub their hand prior to deposition	The aluminium foil was transferred to conical tube and extracted in methanol containing 5% v/v formic acid after IS was added. Then samples were evaporated under nitrogen transferred to glass vials where methanol was added prior to analysis	NR	Aluminium foil sheets
S10	Van Helmond et al. (2019)	Index finger of each hand	Donors rubbed their hands prior to collecting the fingermarks	The aluminium foil sheets were transferred to two 15 mL conical tubes. To the first tube 2 mL MeOH containing 5% (v/v) formic acid and 0.01 mg/L IS amino acids were added. To the second tube, 2 mL MeOH containing 1.5 mg/L docosane was added	For sebaceous secretion collection, participants washed their hands with soap and water and dried them before collection	Deposition on aluminium foil sheets. Cleaning was done before sebaceous secretion collection
S11	Ferguson et al. (2012)	Three fingers of each hand	For ungroomed fingermarks, tips of fingers were rubbed against each other prior to deposition on aluminium sheets. For groomed fingermarks, fingers were rubbed on forehead, nose and chin five times followed by rubbing fingertips against each other prior to deposition on aluminium sheets	The aluminium sheets were attached to MALDI spotless inserts using double sided carbon conductive tape	In both ungroomed and groomed fingermarks, hands were cleaned with 50% ethanol solution prior to rubbing. Additionally, in ungroomed fingermarks daily activities were carried out for 15 min after cleaning and prior to rubbing	Deposition on aluminium sheets
S12	Wolstenholme et al. (2009	Three fingers of each hand	For ungroomed fingermarks ,tips of fingers were rubbed against each other prior to deposition on aluminium sheets. For groomed fingermarks, fingers were rubbed on forehead, nose and chin five times followed by rubbing fingertips against each other prior to deposition on aluminium sheets	The aluminium sheets were attached to MALDI spotless inserts using double sided carbon conductive tape	In both ungroomed and groomed fingermarks , hands were cleaned with 50% ethanol solution prior to rubbing. Additionally, in ungroomed fingermarks daily activities were carried out for 15 min after cleaning and prior to rubbing	Deposition on aluminium sheets
S13	Yeh et al. (2020)	All fingermarks from one donor	The donor was asked to rub the fingertips on the forehead or sides of the nose before deposition	Cleaned with EDTA solution by dripping it on the target plate surface from alternating angles at a distance of around 1 cm	NR	MALDI target plate or aluminium sheet
S14	Bramble (2015)	NR	The washed fingertips were wiped on the forehead and nose prior to depositon	"The TLC plates were put through a conditioning procedure in a solvent system prior to drying."	"The fingers were washed prior to grooming procedure. "	" Fingermark deposits were applied directly to the TLC plate "
S15	Fritz et al. (2013)	"200 fingermarks were collected per donor. The finger(s) or hand(s) were not specified"	The fingers were rubbed across the face or hair before deposition	"The gold plated glass and polished stainless steelplates were cleaned with a soft tissue and cotton and detergent, then rinsed with ethanol and distilled water. Potassium bromide discs were prepared in a pellet press (8 tonne pressure onto 300 mg of KBr for 1 min)."	The donors were asked to wash their hands 30 min prior to deposition and were asked to not eat or handle chemicals beforehand	"The fingertip was pressed onto the substrate."

Table 4 (continued)

SN	Study	Finger(s) used for fingermark(s) collection	"Grooming procedure"	"fingermark collection procedure"		
				Cleaning of substrate	Cleaning of finger	Deposition procedure
S16	Girod et al. (2015) [a]E"	120 fingermarks were collected and the The finger(s) or hand(s) were not specified	Both thumbs were gently rubbed on forehead and edge of nose before deposition and this mimicked a natural movement	NR	The donor performed normal tasks before deposition with the condition of not washing her hands with soap within 45 min preceeding the deposition. The donor performed her normal tasks for another 30 min and then another deposition was carried out	Pressure and time was controlled for deposition (15 s/ 500 ± 100 g pressure)
S17	Ricci et al. (2007a) [a]E"	NR	Donors were asked to rub their fingers across forehead before depostion	NR	NR	Deposition directly onto a ZnSe ATR crystal
S18	Williams et al. (2004)	"One unspecified finger was used and hand was not known. "	"The groomed sample was produced from rubbing fingers across forehead before deposition. "	NR	"1 × print obtained prior to washing hands 1 × print obtained after hands were washed and rinsed for 5 min with water. 1 × print obtained after washing, rinsing and rubbing fingers across forehead. "	Deposited onto aluminium slides after each cleaning or grooming procedure
S19	Dorakumbura et al. (2018)	10 fingers from each donor	For eccrine deposits donors washed their hands with soap and water and waited 30 min before deposition. For natural deposit, not control was applied but food control and washing was stopped 30 min before deposition	NR	For eccrine donors, washing was done with soap and water	Zinc selenide and calcium fluoride were used for FTIR. Glass slides were used for Raman

ATR attenuated total reflection, *CE-MS* capillary electrophoresis-mass spectrometry, *EDTA* ethylenediaminetetraacetic acid, *FTIR* Fourier transform infrared, *GC-FID* gas chromatography flame ionisation detection, *GC–MS* gas chromatography-mass spectrometry, Fourier *IS*: internal standard, *KBr* potassium bromide, *LC–MS* liquid chromatography-mass spectrometry, *MALDI FT-ICR MS*: matrix assisted laser desorption/ionisation Fourier-transform ion cyclotron resonance mass spectrometry, *MeOH* methanol, *MS* mass spectrometry, *NR* not reported, *SN* study number, *TLC* thin-layer chromatography, *ZnSe ATR crystals* zinc selenide attenuated total reflection crystals

[a]Room temperature or ambient temperature: 20 °C

Discussion

This systematic review investigated the endogenous fingermark composition from 19 studies. To our knowledge, this is the first systematic review that investigated fingermarks' chemical constituents, analytical techniques, deposition procedures and storage of substrates. The literature reported three similar reviews by Cadd et al. 2015; Girod et al. 2012 and Gonazales et al. 2020. The first, by Girod et al. (2012), provided a qualitative overview regarding the fingermark composition and highlighted the gap in quantitative studies, ageing kinetics and influencing factors. Subsequently, the second review findings complemented the gap in the aforementioned review by critically evaluating how fingermark composition can be used to differentiate donors and how it changes over time and with different environmental factors (Cadd et al. 2015). The third review was more methodological in nature and focused more on the analytical techniques rather than sample collection procedures (González et al. 2020). Consequently, our review complemented the findings of the previous three reviews' findings, by exploring findings beyond the chemical constituents and techniques utilised.

Our findings suggested the lack of consistency in studies in relation to participants' characteristics, number of participants, healthcare- and sociodemographic-related factors. Hence, the number of participants between studies varied between one participant in some studies (S7; S8; S13; S18) and 463 (Helmond et al. 2019). This could be attributed to difficulty in recruiting participants considering the differences in ethical procedures and timeline of each study. This influenced the heterogeneity of the findings between the study in terms of the lipids and amino acids constituents' detection. A further challenge in interpreting the findings was introduced by the underreporting of participants' sociodemographic factors such as ethnicity, social situation and disease. Though the studies were sampled from seven countries the ethnicity had not been stated within any of the studies. On the other hand, gender was reported in the majority of studies where different genders could be identified through differences in lipid compositions of fingermark secretions and that was key for forensic intelligence (Helmond et al. 2019; Ferguson et al. 2012).

Yet many factors influenced fingermark composition determination in addition to the participants characteristics and number of participants. These factors are related to grooming procedure, deposition procedure and storage of the sample. Grooming procedures varied whether detecting eccrine or sebaceous secretions. Eccrine sweat glands are predominant in soles of hand and feet and secrete water (that is rapidly lost), organic (e.g. amino acids) and inorganic compounds. On the contrary, sebaceous glands are more prevalent on the face and hair and get transferred upon rubbing and consist mainly of lipids (e.g. cholesterol, fatty acids, phospholipids and esters). Hence, the sebaceous secretion is relatively slow compared to the eccrine secretion and varies between individuals depending on their diet, lifestyle and behaviour (Champod et al. 2004; Scruton et al. 1975). Hence, using different grooming procedures and different washing procedures (before grooming) affected the differences in findings between the studies. This identified that studies showing higher lipid content were the ones where participants rubbed their fingers together, on the forehead and/or nose with no hand washing procedure prior deposition (S4; S7). Both studies also utilised the donors rubbing their hands together (with no pre washing) prior to deposition.

It is noteworthy to mention that the previous studies reported more lipids than other studies where participants rubbed their hands on the face and/or hair (e.g. S11; S12; S14; S16-S19). This latter findings could be attributed to the differences in deposition substrate and/or analytical techniques used within the study. Hence, both S4 and S7 involved the use of Mylar strip as a substrate for fingermark deposition rather than aluminium foil/sheets or crystals as reported in other studies. Mylar strips are made of polyester on which retain fatty acids depending on their saturation, length of carbons and the number of double bonds (Ackman 1963). Polyester is a synthetic fibre based on petroleum with no natural property and hence has poor absorption capacity due to its molecular structure and that allowed the retain of the sebaceous secretion of fingermarks on the surface (Shorter 1924). The chemical nature of the substrate played a role in fingermark deposition (Thornbury et al. 2021). For instance, glass is made of silicon that is highly polar and would deposit less lipids in contrary to other non-polar substrates (Hughes et al. 2021).

Moreover, surface roughness plays a significant role in the fingermark deposition. Hence, a study by Huges et al. 2021 has shown that aluminium and synthetic polymers had rougher surfaces than glass and were more likely to show more fingermark secretions. A study in the literature regarding fingermark deposition on glass and polypropylene showed that the deposition of fingermarks on glass had an average thickness of 0.25 µm. Contrary to polypropylene that showed deposition thickness of 0.19 µm (Luda et al. 2018). With glass being the smoothest surface, it will deposit less lipids and more eccrine sections (Hughes et al. 2021), whereas Mylar strips and aluminium showed higher amount of lipids (sebaceous secretions) due to their surface.

Additional factors could have played a role in fingermark deposition related to the differences in the pressure of applying, angle of application and the analytical technique used. These differences existed between individual studies that had different protocols, despite the presence of

Table 5 List of lipid constituents identified in the studies

Study number (S)	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8	S 9	S1 0	S1 1	S1 2	S1 3	S1 4	S1 5	S1 6	S1 7	S1 8	S1 9
Aspartic acid				■			■												
Ceramides				■			■										■		
Cholesterol		■				■	■			■				■					
Decanoic acid			■	■			■												
Dodecanoic acid			■	■			■												
Docosanoic acid							■												
Eicosanoic acid				■			■												
Glutamic acid			■	■			■												
Glycerides				■			■										■		
Glycolipids				■			■										■		
Heneicosanoic acid							■												
Heptadecenoic acid							■												
Hexadecanoic acid			■	■	■														
Isopropyl decanoate					■														
Lactic acid							■												
Linoleic acid							■						■						
Margaric acid							■												
Methyl palmitate		■																	
Methyl palmitoleate		■																	
Methyl stearate		■																	
Myrstic acid		■					■						■						
Myristoleic acid							■												
Myristyl palmitate						■													
Myristyl palmitoleate						■													
Nonadecanoic acid			■	■			■												
Nonanoic acid							■												
Octadecadienoic acid			■	■															
Octadecanoic acid				■	■														
Octanoic acid			■				■						■						
Oleic acid	■	■					■					■	■						
Palmitic acid	■	■					■						■						
Palmitoleic acid	■	■					■			■			■						
Palmityl palmitate						■													
Palmityl palmitoleate						■													
Pentadecanoic acid		■	■	■	■		■						■						
Phospholipids (unspecified)				■			■										■		
Saturated esters (unspecified)				■	■		■								■	■		■	
Squalene	■	■				■	■	■		■			■	■				■	■

unified guidelines from the UK Home Office for deposition of fingermarks (Sears et al. 2012). Reed et al. (2016) demonstrated that the different contact time, pressure and angle affected the fingermarks even within the same donor. Subsequently, electro-mechanical device control gave variabilities between different fingermarks. They controlled variables

Table 5 (continued)

Study number (S)	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8	S 9	S1 0	S1 1	S1 2	S1 3	S1 4	S1 5	S1 6	S1 7	S1 8	S1 9
Squalene degradation products																			
Stearic acid																			
Stearyl palmitoleate																			
Tetraconsanoic acid																			
Tetradecanoic acid																			
Triconsanoic acid																			
Tridecanoic acid																			
Triglycerides (unspecified)																			
Undecanoic acid																			
Urea																			
Uric acid																			

Reported squalene degradation products include squalene dihydroperoxide, epoxide, monohydroperoxide, pentahydroperoxide, trihydroperoxide and tetrahydroperoxide

related to pressure, angle of deposition and/or contact time (Reed et al. 2016; Fieldhouse 2010). Such devices improve the reproducibility of fingermarks between the same donor and decreased variations between multiple donors. However, further research is needed regarding the influence of different factors on fingermark composition.

Moreover, the techniques used for collection of fingermarks played a role in the amount and type of substances detected. The highest number of analyses was detected through CE-MS followed by GC–MS, LC–MS and MALDI-MS. Our findings were consistent with the review (González et al. 2020). Mass spectrometric techniques have demonstrated high specificity and sensitivity in analysis, where they gave information about molecular structure of the sample (Bécue et al. 2020). When combined with imaging, MS offered further advantages regarding the spatial distribution of the different analytes within the sample. Nonetheless, considering the extraction, sample preparation and presentation involved in MS-based techniques with other techniques were reported in the literature. For instance, TLC was used in one of the studies for detecting lipids in fingermark secretions (Bramble 2015). This could be due to cross-reactivity between structurally similar derivatives that could be encountered in TLC. In this respect to spectroscopic techniques including infrared and Raman spectroscopy. Offered an alternative to destructive techniques (such as TLC) and addressed challenges relating to cross-reactivity of analytes. FTIR and Raman were used for both amino acids and lipid contents with few derivatives reported (S15-S19). Both techniques gave fingermarks of measured samples, which requires building libraries and chemometric models for tracing individual samples. Moreover, the sensitivity of both spectroscopic techniques could be enhanced in further, by using surface enhanced infrared (SEIRA) or Raman (SERS) spectroscopy. Therein, SEIRA and SERS substrates that are based on metallic nanoparticles can enhance the infrared or Raman signal in a magnitude between 100 and 100,000 of a conventional infrared or Raman signal. Yet still the technique is in its infancy for detection of fingerprint secretions, and further work is needed for method development and optimisation (42,43).

Strengths and limitations

The systematic review showed strengths in the type of data extracted and quality of studies that were thoroughly assessed by having two independent reviewers and verified by a third reviewer in order to avoid bias in study selection. Nonetheless, several limitations were encountered in this review. Due to the limited number of studies that were from seven countries, generalisability of the findings was not possible. Moreover, the inconsistency in reporting participants' characteristics and sampling approached hindered reported concisely differences between methods and validation. This further affected the reliability of the reported results as it was not a clear representation of all information collected. The use of appraisal tools ensured that the appropriate studies were included. In this case of the JBI appraisal tool was utilised and amended to suit the data being collected, which evaluates its potential for the study. However, the appraisal tools did not add to the limitations but aided in identifying what area they were more apparent in. Another limitation highlighted was the length of time for the data collection, this did affect the study as the number of search engines

Table 6 List of amino acid constituents identified in the included studies

Amino acid	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19
Alanine			■	■			■		■	■			■						
Amide															■				
Amide B																	■		
Secondary amide																■		■	
Arginine				■			■		■	■									
Asparagine				■			■		■	■									
Cystine				■					■										
Cysteine				■															
Guanine										■									
Guanosine										■									
Glutamic acid									■										
Glutamine									■										
Glysine			■	■			■						■						
Histidine				■			■		■										
Hydroxyproline				■															
Isoleucine				■			■		■	■									
Leucine			■	■			■												
Lysine			■	■			■												
Methionine				■			■		■				■						
Ornithine				■			■		■										
Phenyl alanine			■			■			■	■									■
Proline				■					■	■									
Serine			■	■			■		■		■								
Threonine			■				■		■										
Tryptophan				■					■	■									
Tyrosine				■			■		■										■
Valine							■		■										

was constricted to fit into the time constraints for data collection. This all may have allowed for selection bias of the studies as there was not a larger pool of search engines to analyse. Every effort was taken to minimise bias in the selection process by following the set protocol and criteria of the methodology.

Conclusion

Latent fingermark secretions are complex and influenced by participants characteristics and methodological considerations (e.g. grooming and extraction procedures). Lipids' and amino acids' secretions can serve as biomarkers to indicate differences between participants, particularly in a forensic context. However, many factors play a role relating to the detection of the two types of secretions related to participants, grooming procedure, fingermark deposition and detection technique. The choice of pre-grooming and/or grooming procedures depended on the types of secretions sought whether sebaceous or eccrine. Moreover, the quality of the fingermark deposition depended on the substrate and deposition angle, pressure and duration.

Analytical techniques for detecting fingermarks residues included mainly mass spectrometric-based techniques that offered high selectivity and specificity but were destructive and time consuming. Subsequently, spectroscopic techniques offered a more rapid and non-destructive alternative to mass spectrometric ones. However, spectroscopic applications are still in their infancy for fingermark applications. They

require further development in relation to enhancing spectroscopic signals and constructing spectral libraries that could be conducted in future work.

Appendix

JBI critical appraisal checklist questions	Modified appraisal checklist questions
Were the criteria for inclusion in the sample clearly defined?	Were the criteria for inclusion in the sample clearly defined?
Were the study subjects and the setting described in detail?	Were the samples and the techniques described in detail?
Was the exposure measured in a valid and reliable way?	Was the exposure measured in a valid and reliable way?
Were the objective, standard criteria used for measurement of the condition?	Were the objective, ICH and BP criteria used for measurement of the condition?
Were confounding factors identified?	Were confounding factors identified?
Were strategies to deal with the confounding factors stated?	Were strategies to deal with the confounding factors stated?
Were the outcomes measured in a valid and reliable way?	Were the outcomes measured in a valid and reliable way?
Was appropriate statistical analysis used?	Was appropriate statistical analysis used?
	Were the aims of the study clearly stated?
	Was the sample size justified?

Author contribution RR performed the literature search; RR and SA performed the data synthesis; RR, SA, SM and TG drafted the manuscript; and SM and IK critically revised the manuscript.

Declarations

Conflict of interest All authors have declare that they have no conflict of interest.

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