

A study of the intermolecular interactions of lipid components from analogue fingerprint residues.

Authors

Andrew Johnston¹, Keith Rogers¹

¹Cranfield University, The Defence Academy of the United Kingdom, Shrivenham, SN6 8LA

Abstract

A compositionally simplified analogue of a latent fingerprint was created by combining single representatives of each major component of a natural fingerprint. Further modified analogues were also produced each having one component removed. The aim of this study was to investigate the intermolecular interactions that occurred within these analogue samples using Fourier Transform Infrared (FT-IR) Microspectroscopy. FT-IR microspectroscopy showed that the absence of squalene and cholesterol significantly restricted the interactions between the other organic constituents within the analogue samples. Investigating the intermolecular interactions of organic compounds within a simplified analogue solution could indicate corresponding interactions that occur within natural fingerprints. These potential interactions could go on to be the target of further investigation of latent fingerprint chemistry, and ultimately contribute to a better understanding of the aging processes and degradation mechanisms that take place post-deposition.

Introduction

The dynamic nature of fingerprint chemistry post-deposition is a complex process, yet of great interest to the forensic community. Numerous studies have examined the aging of fingerprints, the oxidation mechanisms that take place, both short and long term [1], [2], and the resulting end products [2-5], [8], [9-12]. However, an in-depth understanding of fingerprint degradation processes remains limited. Various studies have investigated the breakdown of key components within a fingerprint such as squalene[1-3], [9], [13], fatty acids [2-5], cholesterol [4], [9-11], [14] and amino acids [15], [16], although very little research has studied the intermolecular interactions between these constituents and their impact on each other. Ultimately, a better understanding of these intermolecular interactions within a fingerprint will allow for improved modelling of the fingerprint aging process.

Cholesterol and its oxidation products have a significant effect on the decomposition of triglycerides and fatty acids [10], indicating that lipid stability is influenced by these intermolecular interactions within latent fingerprints. Auto-oxidation, oxidation in the absence of enzymatic catalysis, of cholesterol by free radicals and hydroperoxides to form oxysterols is an established degradation mechanism [10], although evidence of these oxidation products are yet to be found in latent fingerprints. It has also been shown that the decomposition of cholesterol can be accelerated by both triglycerides and fatty acids [11], [17], [18]. This suggests a form of positive feedback wherein

cholesterol affects the decomposition of triglycerides resulting in a mixture of saturated and unsaturated fatty acids [6]. This increase in fatty acid concentration could then increase the rate of decomposition of cholesterol.

Squalene is an unsaturated steroid precursor that has received a great deal of attention in previous studies of fingermark degradation mechanisms and the aging of fingermarks [1–3], [9], [13]. In latent fingermarks squalene degrades rapidly over time through direct oxidation and photo-oxidation mechanisms. Measurable reductions in concentration can be demonstrated within 24 hours following deposition and it is almost undetectable after a week [1]. Although this degradation is dependent on light conditions as squalene can still be detected in fingermarks up to 33 days after deposition when stored in the dark [3]. During degradation various intermediary and complete oxidation products have previously been identified [1], [2]. Of particular note is the formation of various hydroperoxides as squalene decomposes through direct oxidation. These hydroperoxides then undergo thermolysis with homolytic scission of the peroxide bond, yielding hydroxyl radicals [18]. Both hydroperoxides and free radicals, such as hydroxyl radicals produced from squalene degradation, would then impact cholesterol breakdown and impact the degradation of triglycerides and fatty acids.

This investigation utilized Fourier transform infrared (FT-IR) microspectroscopy, is a recognised tool for forensic research applications. Previous studies using IR techniques have successfully identified the key components of latent fingermarks [19–25]. FT-IR is ideally suited to the analysis of latent prints due to its non-destructive nature and specificity in identifying functional groups in organic compounds. Of particular relevance to this study FT-IR spectroscopy lends itself to studying the intermolecular interactions within fingermarks as a major contributor to IR band width is the strength of intermolecular interactions. Broader peaks being a function of stronger intermolecular interactions over a wider range and therefore a large number of energy states.

The antisymmetric and symmetric C-H stretch of the CH_2 groups at $3000 - 2850 \text{ cm}^{-1}$ within a fingermark are not truly decoupled due to the slight variation in chemical environment of the differing species present. Intermolecular forces such as hydrogen bonding, dipole/dipole interactions, and London Dispersive Forces all combine to increase organic molecular interactions [26–32]. These interactions will dictate the rate of reaction and therefore the molecular decomposition in the presence of (in particular) long chain unsaturated species. These intermolecular interactions affect the range of vibrational modes of the C-H stretch region of CH_2 groups, increasing variations in bond distance and changing the spring constant [31–35]. The more intermolecular interactions occurring the broader the antisymmetric and symmetric vibrational modes and the coupling effect visible on the spectrum (figure 1). Fewer intermolecular interactions perturb the range of vibrational modes of the C-H stretch mode at $3000 - 2850 \text{ cm}^{-1}$, minimising the coupling effect of the antisymmetric and symmetric C-H peaks, and producing two distinct peaks at $3000 - 2850 \text{ cm}^{-1}$.

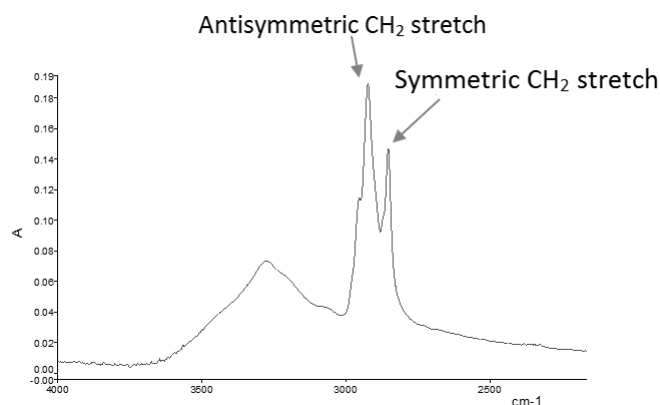


Figure 1: Coupling effect of the antisymmetric and symmetric C-H stretch of CH₂ group

The aim of this study was to generate a simplified chemical analogue of a fingerprint, comprised of a single representative of the major components, in order to better understand the interactions between these compounds. Studying these intermolecular interactions could ultimately enable a better understanding of their effect on the aging of fingerprints post-deposition. Once an acceptable analogue was developed and the IR spectra compared to that of sebaceous-loaded fingerprints, further analogues were developed, each with one component removed, and IR spectra were then obtained. This allowed assessment of how this removed component affected the interactions of the others.

Replicates of latent fingerprints have previously been developed for both research and commercial purposes [5], [36], [37] to provide a 'standardised' deposition model, and with more complexity than the analogue samples developed for this study. The objective of this study however was not to create a complete replicate of a latent fingerprint, but to deliberately develop a much simplified composition that allowed for fundamental analysis of any critical intermolecular interactions that may occur. More complex replicates involving hundreds of compounds would have made analysis of specific intermolecular interactions near impossible, or at least far less conclusive. Another reason why such a simplified composition was used in this study was because, as stated previously [37], synthetic solutions can behave differently to natural fingerprints, and the more complex the solution the more potential there is for inconclusive variability in the results. A primary use for replicate solutions is for identifying effective fingerprint development reagents. The International Fingerprint Research Group (IFRG) have stated that replicates are useful for fundamental research and initial study of molecular interactions, but are not appropriate for optimisation or validation trials [36], and have warned caution about using (particularly) synthetic lipid solutions for direct evaluation with natural latent fingerprints, although this was specifically regarding fingerprint development reagents [38].

It is evident therefore that a degree of caution must be employed when using a simplified analogue solution to study the chemical interactions within fingerprints, and certainly no direct comparisons between the two can be made. This study therefore aimed to provide a general indication of the intermolecular interactions that *may* occur within latent fingerprints, and thus present a target for further work to look for these potential interactions in latent fingerprints and their impact on fingerprint degradation.

Experimental

Sample preparation

Analogue 'fingerprint' preparation

The composition of the analogue solution was based on the principal compounds observed during previous studies of latent fingerprints [2], [5], [19], [37], [39], [40]. Where there was significant variation in the literature regarding the concentration of a component, an average of all available data was used.

Sebaceous and organic eccrine secretions were selected for the analogue. The sebaceous secretions comprised a sterol, sterol precursor, a fatty acid, mixed triglycerides (100 mg triacetin, tributyrin, tricaproin, tricaprylin, tricaprin, all equal amounts by weight), and a wax ester. The eccrine secretions were composed from an amino acid and lactic acid. For simplicity, the most abundant compound within each family (i.e. amino acid, fatty acid, wax ester) was selected to represent the compounds within that family. For example, serine, being the most abundant amino acid [41–43] was selected to represent all amino acids, and palmitic acid, the most abundant fatty acid, represented all fatty acids [2], [3] (Unsaturated fatty acids, although more likely to have an impact on intermolecular interactions due to a targetable functional group [43], were not included in this study due to lack of data on origin or quantity).

This abundance approach was also reflected in the concentrations of each compound that made up the analogue solution, which represented the total concentration of that compound group within a latent fingerprint. For example, the concentration of serine in the analogue was 1.45 mgL^{-1} , equivalent to the typical total concentration of amino acids observed in eccrine sweat [5], [12]. The compounds selected and their concentrations are shown in table 1 (all compounds $\geq 98\%$, obtained from Sigma Aldrich, UK).

Compound	Squalene	Cholesterol	Palmitic acid	Serine	Lactic acid	Mixed triglycerides	myristyl myristate
Concentration	11.2mgL^{-1}	1.1mgL^{-1}	15.4mgL^{-1}	2.5mg/L^{-1}	10mgL^{-1}	42.1mgL^{-1}	29.9mgL^{-1}

Table 1: Compounds and concentrations selected to create analogue fingerprint composition

Table 2 shows the composition of each sample. Each sample was made up to a 1L solution with distilled water. Sample 1, comprised of all the constituents shown in table 1, was used as the control and samples 2-7 all having one of the compounds in table 1 removed.

Sample 1 'complete'	Squalene	Cholesterol	Palmitic acid	Serine	Lactic acid	Mixed triglycerides	Myristyl myristate
Sample 2	-	Cholesterol	Palmitic acid	Serine	Lactic acid	Mixed triglycerides	Myristyl myristate
Sample 3	Squalene	-	Palmitic acid	Serine	Lactic acid	Mixed triglycerides	Myristyl myristate
Sample 4	Squalene	Cholesterol	-	Serine	Lactic acid	Mixed triglycerides	Myristyl myristate
Sample 5	Squalene	Cholesterol	Palmitic acid	-	Lactic acid	Mixed triglycerides	Myristyl myristate
Sample 6	Squalene	Cholesterol	Palmitic acid	Serine	-	Mixed triglycerides	Myristyl myristate

Sample 7	Squalene	Cholesterol	Palmitic acid	Serine	Lactic acid	-	Myristyl myristate
Sample 8	Squalene	Cholesterol	Palmitic acid	Serine	Lactic acid	Mixed triglycerides	-

Table 2: Composition of the eight analogue 'fingerprint' samples

During formulation each sample was heated to 37°C to replicate body temperature and to force any solid compounds into solution with the addition of 50mgL⁻¹ of the emulsifier oleyl alcohol. Immediately after mixing 10 µl of the analogue samples were pipetted onto CaF₂ Infrared (IR) microscope slides (10mm x 10mm, Crystran Ltd) and placed on a Peltier pump heat stage to maintain 'body temperature' and placed under the IR microscope for analysis. Each sample was analysed 20 times and an average spectra obtained.

Sebaceous-loaded fingerprints

All fingerprints were obtained from a single donor (38-year-old male, wearing no cosmetics) for this study to maintain a relative consistency between samples, and the spectra obtained were consistent with data from previous studies. Hands were first washed and dried thoroughly. The index finger was then drawn from the bridge of the nose, under the eye to the temple ten times to collect sebaceous secretions and to simulate natural grooming behaviour, and placed directly onto a CaF₂ IR microscope slide (10mm x 10mm, Crystran Ltd) **at an average pressure of 74,800PA**. All prints were deposited between 9am and 10am to avoid significant diurnal variations in composition of the latent fingerprint and analysed immediately. For each print the same index finger was used. 20 samples were analysed at room temperature and **atmospheric** pressure and an average spectra obtained from 10 randomly chosen locations per print.

FT-IR Microspectroscopy

The sebaceous-loaded fingerprints and the analogue compositions were analysed using a PerkinElmer Spectrum™ Spotlight 200 FT-IR imaging System equipped with a liquid-nitrogen cooled MCT linear array detector. Data was analysed using Perkin Elmer software, Spectrum® (v10.02.00), variations in spectra were processed using peak area calculations. Spectra were collected in transmission mode, the IR beam passing through the slide, within 4000 to 750 cm⁻¹ spectral range with 10 scans per pixel at 4 cm⁻¹ spectral resolution and 10 µm spatial resolution, using a 100 x 100 µm aperture.

Results and Discussion

Prior to analysis of the analogue samples, spectra from sebaceous-loaded fingerprints were obtained to serve as a spectral comparison to the complete analogue sample. Figure 2 shows a typical FT-IR spectrum of a fresh fingerprint from this study, the key peaks ranging from 3000 cm⁻¹ to 1100 cm⁻¹.

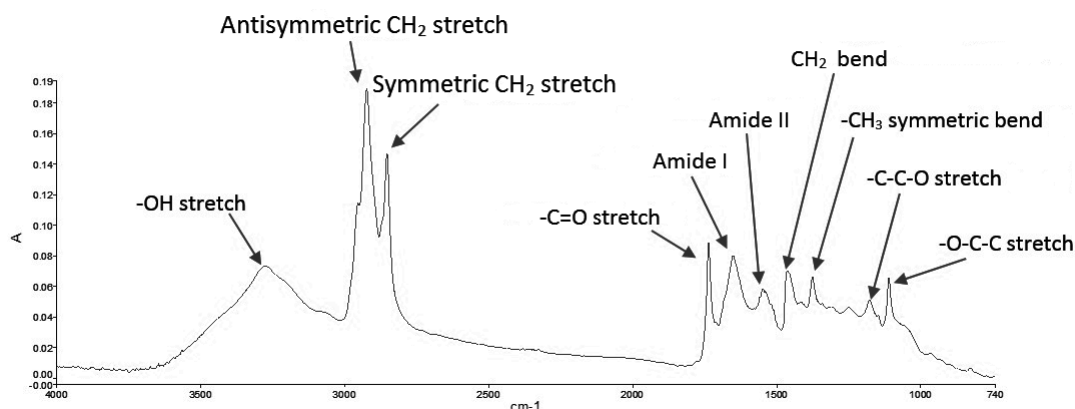


Figure 2: Typical FTIR Spectrum of a fresh fingerprint

This study predominantly focused on the interactions between sebaceous materials within a fingerprint. These sebaceous compounds correspond to the 2920 cm^{-1} and 2854 cm^{-1} antisymmetric and symmetric C-H stretching modes of CH_2 groups, the C=O stretch of lipids (1741 cm^{-1}), the scissoring mode of CH_2 groups and antisymmetric C-H bending mode of CH_3 groups (1463 cm^{-1}), the CH_3 symmetric bend (1380 cm^{-1}), the C-C-O stretch (1160 cm^{-1}), and the O-C-C stretch (1111 cm^{-1}). Variations in quantity of some eccrine secretions were also analysed, amino acids were observed corresponding to the amide I band (1655 cm^{-1}), and amide II band (1545 cm^{-1}) of secondary amides. It is these sebaceous and eccrine absorption bands that correspond to quantity of the related functional groups and therefore the compounds.

Analogue samples

The 'complete' analogue sample demonstrated an accurate IR spectral representation of a sebaceous-loaded fingerprint (figure 3).

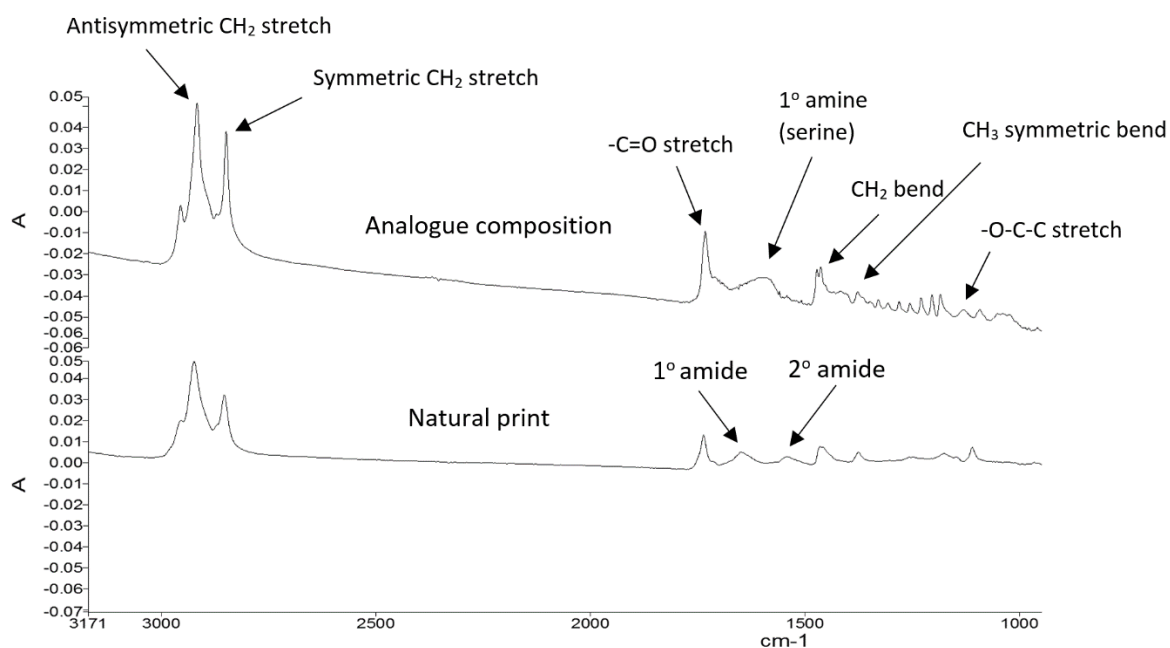


Figure 3: FT-IR spectral comparison between the analogue sample and a natural fingerprint.

The spectra of the 'complete' analogue sample correspond well to that of a sebaceous-loaded fingerprint, all the major peaks were present in relatively accurate quantities, the exception being the 1° amine peak at $\sim 1600\text{cm}^{-1}$ in the analogue sample. This band represents the amino acid serine that was a representative for all the amino acids present in a natural fingerprint. This band is not present in natural fingerprints, instead the 1° and 2° amide peaks from peptides and proteins dominate this region. Due to the stability and unreactive nature of amino acids within latent fingerprints, only degrading at $>100^\circ\text{C}$, and not undergoing photo-degradation [13, 15] it was felt that this would have minimal effect on the dynamics of the analogue composition.

Once it was established that the IR spectra of the 'complete' analogue sample accurately represented that of the sebaceous-loaded fingerprint further samples were created, each with a component from the 'complete' analogue removed. As would be expected removing a component from the sample had a corresponding effect on the spectrum for that sample. For example, removing serine resulted in an absence of the corresponding absorption band at $\sim 1600\text{cm}^{-1}$. Equally, removing the wax ester myristyl myristate resulted in an observable reduction in the antisymmetric and symmetric CH_2 stretching modes at 2920 cm^{-1} and 2854 cm^{-1} , the $\text{C}=\text{O}$ stretch mode at 1736 cm^{-1} , and the CH_2 bend at 1462 cm^{-1} , although the peak distribution within the spectra remained the same. Removing lactic acid from the sample had no observable effect on the spectra, this was to be expected given the small amount of the compound within the sample, also the functional groups within lactic acid, namely the hydroxide and carbonyl groups, are present in a many of the other components within the analogue sample as well as in natural fingerprints.

The 2920 cm^{-1} and 2854 cm^{-1} antisymmetric and symmetric C-H stretching modes of CH_2 groups are a combination of all the organic components within a sample. Removing key constituents such as wax esters or fatty acids had an impact on the height of these absorbance bands, and therefore quantity, as would be expected. As discussed earlier a cause of variation in band width are intermolecular interactions, which, in this study did not significantly vary from the 'complete' analogue sample in the absence of the wax ester, fatty acid, amino acid, mixed triglycerides or lactic acid, although peak height was affected, the coupling effect of the C-H stretch mode was not (figure 4). However, the absence of the steroid precursor squalene and the sterol cholesterol modified the coupling effect of the C-H stretching modes significantly (figure 5).

It could be reasoned that the absence of cholesterol and squalene would reduce peak height and therefore overall peak area simply due to a reduction in quantity of the sample analysed. Peak height however is not significantly different in the absence of these two components and therefore changes in peak area are directly proportional to peak width and therefore bond diversity (figure 5). Additionally, a reduction in peak height alone is not sufficient to explain this decrease in overall peak area in the absence of squalene or cholesterol. These components made up a small proportion of the overall sample, and as figure 5 shows, the absence of these components had no observable effect on peak height and therefore concentration. Also, it is only in the absence of squalene and cholesterol that such distinct C-H stretching modes, with minimal coupling, are generated.

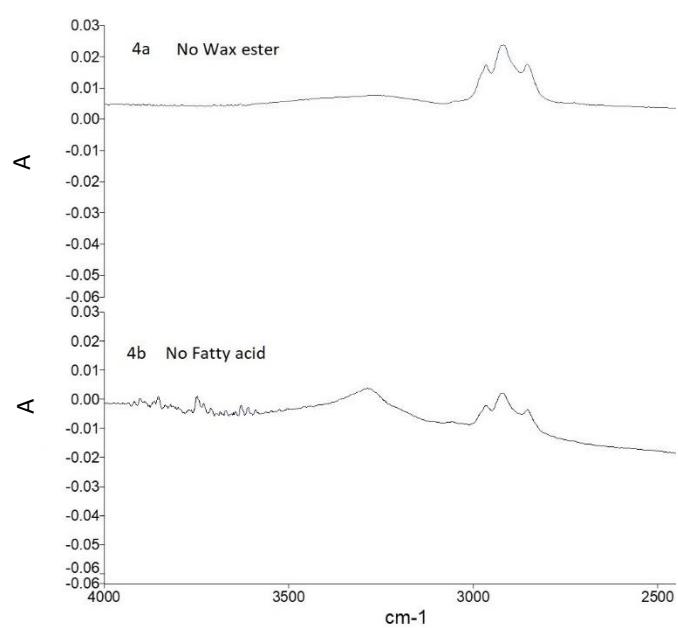


Figure 4: The antisymmetric and symmetric C-H stretch modes of CH₂ groups for analogue samples with the wax ester removed (4a), and with the fatty acid removed (4b).

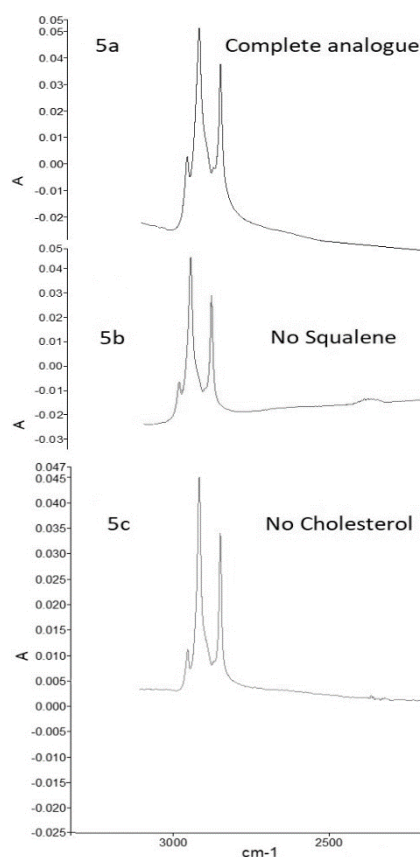


Figure 5: The antisymmetric and symmetric C-H stretch modes of CH_2 groups for a 'complete' analogue sample (5a), with squalene removed (5b), and with cholesterol removed (5c).

The antisymmetric and symmetric C-H stretching modes of CH_2 groups in the absences of squalene and cholesterol (figure 5b & 5c) show two distinct peaks with little overlap when compared to the coupling of the same peaks from the 'complete' analogue (figure 5a). This indicates that the intermolecular interactions in the absence of squalene and cholesterol are significantly reduced in these analogue samples.

Peak area calculations of the antisymmetric and symmetric C-H stretching modes of CH_2 groups quantify the spectral data and show that analogue samples, in the absence squalene or cholesterol, have a significantly lower absorption area between $2780 - 2995 \text{ cm}^{-1}$ than that of the other analogue samples (figure 6).

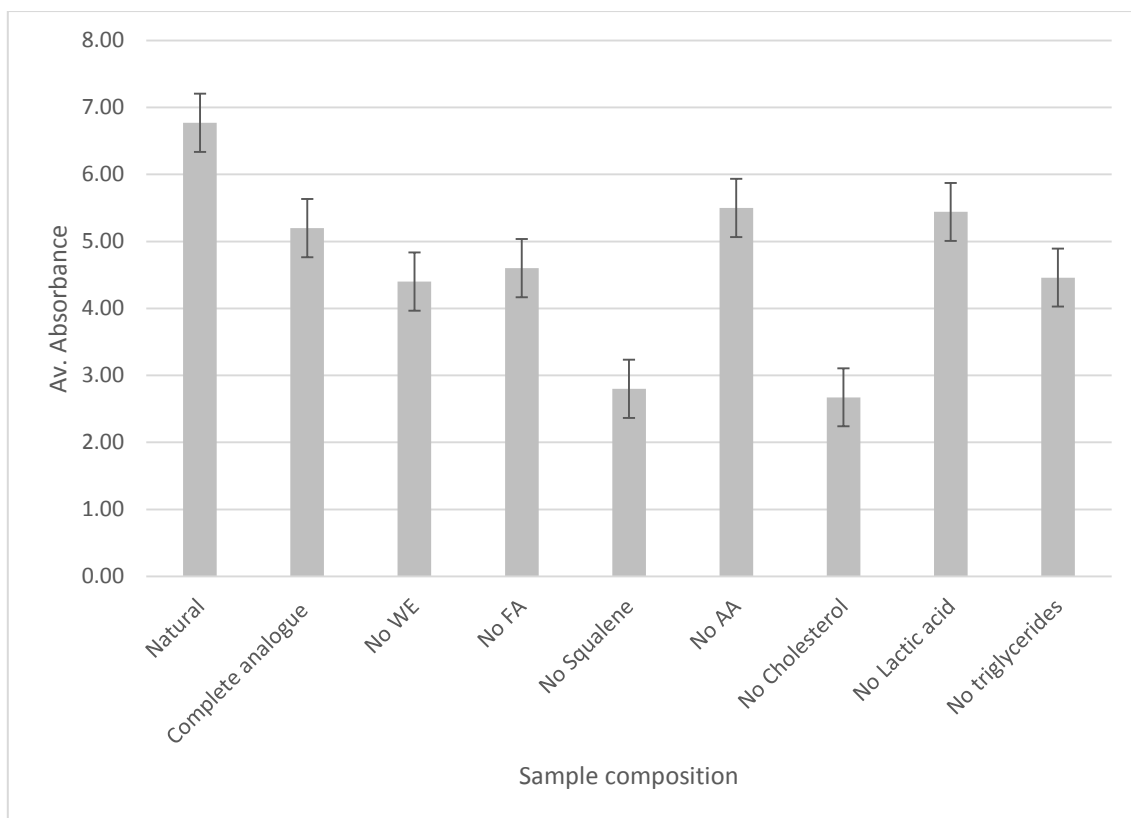


Figure 6: Average absorbance area of C-H stretching modes at $2780 - 2995\text{ cm}^{-1}$ of analogue samples and natural fingerprints.

The analogue samples investigated in this study suggest that the presence of both squalene and cholesterol are essential in driving intermolecular interaction within these samples. This could provide a focus for further research looking at the importance of these compounds within the dynamic environment of latent fingerprint chemistry, and if squalene and cholesterol have an integral role in the aging processes within natural fingerprints.

As mentioned previously cholesterol can influence the degradation of triglycerides producing both saturated and unsaturated fatty acids [10]. The absence of this sterol could significantly slow the degradation of these other lipid compounds and reduce the quantity of degradation end products such as fatty acids. In a natural fingerprint, saturated fatty acids appear to increase during the first few days after deposition [3]. The hydroperoxides and hydroxyl radicals produced during the oxidation of squalene are also likely to affect the degradation of cholesterol and unsaturated fatty acids, and thus have a concomitant effect upon triglyceride decomposition and the initial increase in saturated fatty acids (figure 7).

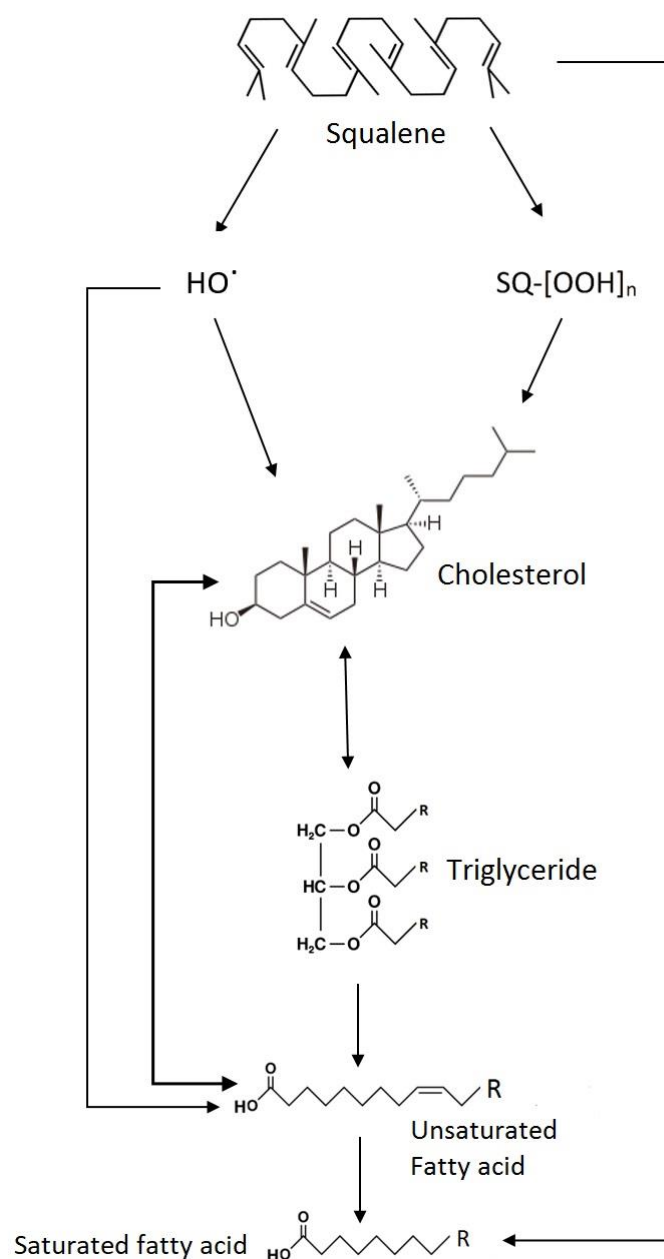


Figure 7: Suggested interaction pathway of lipid compounds within a latent fingerprint.

Assuming that squalene and cholesterol are essential in driving the interactions between the various sebaceous compounds present in a latent fingerprint, then this may, at least in part, explain why children's latent fingerprints are more volatile and tend to 'vanish' instead of adopting the temporal degradation of adult prints [44–46]. Children's latent fingerprints contain very little squalene so interactions between this steroid precursor and other sebaceous compounds (such as unbranched fatty acids) would be limited. Reduced interactions would mean that degradation of these other sebaceous compounds (particularly the more volatile ones) to more stable states would be reduced leaving them more prone to evaporation. The sebaceous components of young children also contain significantly lower levels of triglycerides than that of adults, so the breakdown of cholesterol and fatty acids through interactions with triglycerides (and vice versa) to more stable end products would also be inhibited.

Conclusions

The research presented in this paper demonstrates that squalene and cholesterol affect the intermolecular interactions within the analogue samples studied, this could indicate the importance of these two compounds in influencing intermolecular interactions between lipids within latent fingerprints, and provides a hypothesis for studying these interactions within natural fingerprints. The degradation processes that occur in latent fingerprints are directed by these interactions and only by studying them will it be possible to understand the complex and dynamic nature of fingerprint aging. Future studies using analogue compositions could investigate whether these analogue samples age in similar ways to natural fingerprints by identifying known degradation products that occur in natural latent fingerprints. Analogue compositions of latent fingerprints will always be crude representations of the myriad of interactions that occur within natural fingerprints, but ongoing investigation into these simplified models, utilising various analytical techniques, could direct research that ultimately provides a better understanding of the fingerprint aging process.

References

- [1] K. A. Mountfort, H. Bronstein, N. Archer, S. M. Jickells, Identification of oxidation products of squalene in solution and in latent fingerprints by ESI-MS and LC/APCI-MS, *Anal. Chem.* 79 (7) (2007) 2650–2657.
- [2] G. M. Mong, C. E. Petersen, and T. R. W. Clauss, Advanced Fingerprint Analysis Project - Fingerprint Constituents, Vol PNNL-13019. U.S. Department of Energy, Pacific Northwest National Laboratory, 1999.
- [3] N. E. Archer, Y. Charles, J. a. Elliott, and S. Jickells, Changes in the lipid composition of latent fingerprint residue with time after deposition on a surface, *Forensic Sci. Int.* 154 (2-3) (2005) 224–239.
- [4] R. S. Croxton, M. G. Baron, D. Butler, T. Kent, and V. G. Sears, Variation in amino acid and lipid composition of latent fingerprints, *Forensic sci. int.* 199 (2010) 93–102.
- [5] R. Ramotowski, *Composition of Latent Print Residues*, in: *Advanced in Fingerprint Technology*, 2nd ed. London: CRC Press, 2001.
- [6] A. Srivastava and R. Prasad, Triglycerides-based diesel fuels, *Renew. Sust. Energy. Rev.* 4 (2) (2000) 111–113.
- [7] B. B. Dent, S. L. Forbes, and B. H. Stuart, Review of human decomposition processes in soil, *Environmental Geology*. (2004) 576–585.
- [8] R. Wolstenholme, R. Bradshaw, M. R. Clench, and S. Francese, Study of latent fingerprints by matrix-assisted laser desorption/ionisation mass spectrometry imaging of endogenous lipids, *Rapid Commun. Mass Spectrom.* 23 (19) (2009) 3031–3039.
- [9] C. Weyermann, C. Roux, and C. Champod, Initial Results on the Composition of Fingerprints and its Evolution as a Function of Time by GC/MS Analysis, *J. Forensic Sci.* 56 (1) (2011) 102–108.
- [10] L. Iuliano, Pathways of cholesterol oxidation via non-enzymatic mechanisms, *Chemistry and Phys of Lipids*, 164 (6) (2011) 457–468.
- [11] S. K. Kim and W. W. Nawar, Oxidative interactions of cholesterol with triacylglycerols, *J. Am.*

- Oil Chem. Soc.*, 68 (12) (1991) 931–934.
- [12] A. Girod, R. Ramotowski, and C. Weyermann, Composition of fingermark residue: A qualitative and quantitative review, *Forensic Sci. Int.*, 223 (1–3) (2012) 10–24.
 - [13] T. Atherton, R. Croxton, M. Baron, J. Gonzalez-Rodriguez, L. Gámiz-Gracia, and A. M. García-Campaña, Analysis of amino acids in latent fingerprint residue by capillary electrophoresis-mass spectrometry, *J. Sep. Sci.* 35 (2012) 2994–2999.
 - [14] A. Stadtman, A. Cherkes, C. Anfinsen, Studies on the microbiological degradation of cholesterol, *J. Biol. Chem.* 206 (2) (1954) 511–523.
 - [15] A. Richmond-Aylor, S. Bell, P. Callery, and K. Morris, Thermal degradation analysis of amino acids in fingerprint residue by pyrolysis GC-MS to develop new latent fingerprint developing reagents, *J. Forensic Sci.* 52 (2) (2007) 380–382.
 - [16] G. De Paoli, S. A. Lewis, E. L. Schuette, L. A. Lewis, R. M. Connatser, T. Farkas, Photo- and thermal-degradation studies of select eccrine fingerprint constituents, *J. Forensic Sci.* 55 (4) (2010) 962–969.
 - [17] S. K. Kim and W. W. Nawar, Parameters influencing cholesterol oxidation, *Lipids.* 28 (10) (1993) 917–922.
 - [18] L. L. Smith, Cholesterol autoxidation 1981–1986, *Chem. Phys. Lipids.* 44 (2–4) (1987) 87–125.
 - [19] A. Girod, L. Xiao, B. Reedy, C. Roux, and C. Weyermann, Fingermark initial composition and aging using Fourier transform infrared microscopy (μ -FTIR), *Forensic Sci. Int.* 254 (2015) 185–196.
 - [20] P. Fritz, W. van Bronswijk, K. Lepkova, S. W. Lewis, K. F. Lim, D. E. Martin, L. Puskar, K. F. Lim, D. E. Martin, L. Puskar, K. F. Lim, D. E. Martin, and L. Puskar, Infrared microscopy studies of the chemical composition of latent fingermark residues, *Microchem. J.* 111 (2013) 40–46.
 - [21] C. Ricci and S. G. Kazarian, Collection and detection of latent fingermarks contaminated with cosmetics on nonporous and porous surfaces, *Surf. Interface Anal.* 42 (5) (2010) 386–392.
 - [22] D. K. Williams, R. L. Schwartz, and E. G. Bartick, Analysis of Latent Fingerprints Deposits by Infrared Microspectroscopy, *Appl. Spectrosc.* 58 (3) (2004) 313–316.
 - [23] N. J. Crane 3, E. G. Bartick, R. S. Perlman, and S. Huffman, Infrared spectroscopic imaging for noninvasive detection of latent fingerprints, *J. Forensic Sci.* 52 (1) (2007) 48–53.
 - [24] A. Hemmila, J. McGill, and D. Ritter, Fourier transform infrared reflectance spectra of latent fingerprints: a biometric gauge for the age of an individual, *J. Forensic Sci.* 53 (2) (2008) 369–376.
 - [25] A. Johnston and K. Rogers, The Effect of Moderate Temperatures on Latent Fingerprint Chemistry, *Appl. Spectrosc.* 71 (9) (2017) 2102–2110.
 - [26] N. B. Colthup, L. H. Daly, S. E. Wiberley, N. B. Colthup, L. H. Daly, and S. E. Wiberley, “Chapter 4 – The Vibrational origin of group frequencies, in *Introduction to Infrared and Raman Spectroscopy*. (1990) 171–213.
 - [27] G. Socrates, Infrared Characteristic Group Frequencies. Tables and Charts, Second Ed. John Wiley & Son Ltd. (1994) 34–41.
 - [28] F. M. Fowkes, Donor-Acceptor Interactions at Interfaces, *J. Adhes.* 4 (2) (1972) 155–159.
 - [29] N. Israelachvili, J. N., Tabor, The Measurement of Van Der Waals Dispersion Forces in the

- Range 1.5 to 130 nm, in *Proceedings of The Royal Society A*, (1972) 19-38.
- [30] J. Israelachvili, *Intermolecular and Surface Forces*, 3rd ed. Elsevier, 2011.
 - [31] X. Li, Q. Pan, J. Chen, S. Liu, A. He, C. Liu, Y. Wei, K. Huang, L. Yang, J. Feng, Y. Zhao, Y. Xu, Y. Ozaki, I. Noda, and J. Wu, Asynchronous Orthogonal Sample Design Scheme for Two-Dimensional Correlation Spectroscopy (2D-COS) and its Application in Probing Intermolecular Interactions from Overlapping Infrared (IR) Bands, *Appl. Spectrosc.* 65 (8) (2011) 901–917.
 - [32] J. Chen, Q. Bi, S. Liu, X. Li, Y. Liu, Y. Zhai, Y. Zhao, L. Yang, Y. Xu, I. Noda, and J. Wu, Double Asynchronous Orthogonal Sample Design Scheme for Probing Intermolecular Interactions, *J. Phys. Chem.* 116 (45) (2012) 10904–10916.
 - [33] N. B. Colthup, L. H. Daly, S. E. Wiberley, N. B. Colthup, L. H. Daly, and S. E. Wiberley, Chapter 5 – Methyl and Methylene groups, in *Introduction to Infrared and Raman Spectroscopy*. (1990) 215–233.
 - [34] A. L. Steber, J. L. Neill, D. P. Zaleski, B. H. Pate, A. Lesarri, R. G. Bird, V. Vaquero-Vara, and D. W. Pratt, Structural studies of biomolecules in the gas phase by chirped-pulse Fourier transform microwave spectroscopy, *Faraday Discuss.* (2011) 227-242.
 - [35] B. K. Sharma, *Instrumental Methods of Chemical Analysis*, Twenty Fourth Edition. Meerut: GOEL, 2005.
 - [36] J. Almog, A.A. Cantu, C. Champod, T. Kent, C. Lennard, Guidelines for the assessment of fingermark detection techniques. International Fingerprint Research Group (IFRG), *J. Forensic Identif.*, 64, (2) (2014) 174–200
 - [37] A. Girod, C. Weyermann, Lipid composition of fingermark residue and donor classification using GC/MS, *Forensic Sci. Int.*, 238 (2014) 68–82
 - [38] S. Zadnik, W. Van Bronswijk, A. Frick, P. Fritz, S.W. Lewis, Fingermark simulants and their inherent problems: A comparison with latent fingermark deposits, *J. of Forensic. Identif.*, 63 (5) (2013) 593–608
 - [39] M. J. Bailey , N. J. Bright, S. Hinder, B. N. Jones, R. P. Webb, R. S. Croxton, S. Francese, L. S. Ferguson, R. Wolstenholme, S. Jickells, B. J. Jones, J. J. Ojeda, S. G. Kazarian, and S. Bleay, Chemical characterization of latent fingerprints by matrix-assisted laser desorption ionization, time-of-flight secondary ion mass spectrometry, mega electron volt secondary mass spectrometry, gas chromatography/mass spectrometry, X-ray photoelectron spec, *Anal. Chem.* 84 (20) (2012) 8514–8523.
 - [40] S. Cadd, M. Islam, P. Manson, and S. Bleay, Fingerprint composition and aging: A literature review, *Sci. Justice.* 55 (4) (2015) 219–238.
 - [41] P. Hamilton, Amino-acids on Hands, *Nature.* 205 (1965) 284–285.
 - [42] J. Oro and H. Skewes, Free Amino-Acids on Human Fingers: The Question of Contamination in Microanalysis, *Nature.* 207 (1) (1965) 1042–1045.
 - [43] B. Hadorn, F. Hanimann, P. Anders, H. Curtius, and R. Halverson, Free Amino-acids in Human Sweat from Different Parts of the Body, *Nature.* 215 (99) (1965) 416–417.
 - [44] K. M. Antoine, S. Mortazavi, L. M. Miller, A. D. Miller, K. M. Antoine, S. Mortazavi, A. D. Miller, L. M. Miller, Chemical differences are observed in children’s versus adults’ latent fingerprints as a function of time, *J. Forensic Sci.* 55, (2) (2010) 513–518.
 - [45] D. K. Williams, C. J. Brown, and J. Bruker, Characterization of children’s latent fingerprint

residues by infrared microspectroscopy: Forensic implications, *Forensic Sci. Int.* 206 (1–3) (2011) 161–165.

- [46] D. Noble, Vanished into thin air. The search for children's fingerprints, *Anal. Chem.* 67 (13) (1995) 435A–438A.



DSPACE

<https://dspace.org/>

A study of the intermolecular interactions of lipid components from analogue fingerprint residues

Johnston, Andrew; Rogers, Keith

2017-11-24

Elsevier

<https://doi.org/10.1016/j.scijus.2017.11.004>

Johnston A, Rogers K. (2018) A study of the intermolecular interactions of lipid components from analogue fingerprint residues. Science and Justice, Volume 58, Issue 2, March 2018, pp.121-127