Forensic Science International 275 (2017) 44–56

Contents lists available at ScienceDirect

Forensic Science International

journal homepage: www.elsevier.com/locate/forsciint

Migration of latent fingermarks on non-porous surfaces: Observation technique and nanoscale variations

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ARTICLE INFO

Article history:
Received 22 July 2016
Received in revised form 10 February 2017
Accepted 16 February 2017
Available online 6 March 2017

ABSTRACT

Latent fingermark morphology was examined over a period of approximately two months. Variation in topography was observed with atomic force microscopy and the expansion of the fingermark occurred in the form of the development of an intermediate area surrounding the main fingermark ridge. On an example area of a fingermark on silicon, the intermediate region exists as a uniform 4 nm thick deposit; on day 1 after deposition this region extends approximately 2 μm from the edge of the main ridge deposit and expands to a maximum of $\sim$4 μm by day 23. Simultaneously the region breaks up, the integrity is compromised by day 16, and by day 61 the area resembles a series of interconnected islands, with coverage of approximately 60%. Observation of a similar immediate area and growth with time on surfaces such as Formica was possible by monitoring the mechanical characteristics of the fingermark and surfaces though phase contrast in tapping mode AFM. The presence of this area may affect fingermark development, for example affecting the gold distribution in vacuum metal deposition. Further study of time dependence and variation with donor may enable assessment of this area to be used to evaluate the age of fingermarks.

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1. Introduction

Freshly deposited latent fingermarks consist of multiple components from eccrine and sebaceous secretions such as water, fatty acids, sterol esters, wax esters, amino acids and inorganic compounds [1–4]. Estimates of water concentration vary from less than 20% [1] to 99% [2,3]. The composition of deposited latent fingermarks may vary as a result of many factors such as: age [5–10], gender [4,6,11,12–14,15], race [16] and diet [11] of the donor as well as the deposition action, contact time, angle, pressure, and substrate nature which includes porosity, curvature, and texture [4,5]. Scruton et al. [17] demonstrated that the chemical composition of the material on the fingers and the substrate nature determines the initial latent fingermark ridge appearance after the deposition which could be either continuous liquid pool or droplet distribution on a thin layer of material. This and many other works refer to “latent fingerprints” [1,3,4,6,7,9–12], however the term “fingerprint” is now more commonly used for an inked deposition, and we use “fingermark” throughout this work to refer to the type of mark left at crime scenes.

The composition of latent fingermarks changes with time after deposition due to chemical, physical and biological processes such as degradation, evaporation, oxidation, and polymerization [4,5,18]. Water concentration is significantly reduced over time after deposition together with other volatile compounds [19–21]. The sebaceous component undergoes the most significant chemical changes with time after the deposition due to presence of saturated and unsaturated fatty acids, wax esters, squalene, cholesterol and cholesterol esters [4–6,11].

The deposition substrate is one of the factors which affect the way a latent fingermark alters with time after deposition [5,22]. High porosity of substrates for example: paper, cardboard and wood leads to increased penetration of the latent fingermark components into the substrate, possibly at differential rates [22,23]. Generally the eccrine components are absorbed more rapidly than the sebaceous components. On non-porous surfaces such as many plastics, glass and metals latent fingermark components remain on the surface and are therefore more

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http://dx.doi.org/10.1016/j.forsciint.2017.02.015
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vulnerable due to environmental exposure [22–24]. Another possibility for time dependent effects is the corrosion process caused by ionic salts when the fingermark is deposited on metal [22,25,26]. Several factors such as surface texture, physicochemical properties, curvature, temperature, electrostatic forces and surface free energy have been also suggested to affect the latent fingermarks [5,22,27,28]. Surfaces which appear smooth to the eye often have micro or sub-micro scale roughness including topographical linear features such as ridges, valleys and scratches which affect the behaviour of the latent fingermark on the surface, as well as the development agent interaction [27,29,30].

Environmental factors such as: temperature, light exposure, humidity and air circulation also play a significant role in changing the latent fingermark composition with time. A study of Popa et al. [31] using over 800 latent fingermarks on sterile glass substrates demonstrates a decrease of the fingermark ridge width and corresponding increase in the width of valleys. When stored in an indoor environment fingermark ridge width decreased from 0.30 to 0.34 mm on the day after deposition to 0.24–0.28 mm after 180 days, with similar decrease for an outdoor environment. Changes in the pores were also observed such as opening of the marginal pores after 5 days. In addition to observing fingermark ridge width decrease, De Alcaraz-Fossoul et al. [32] also suggested a horizontal change in time designated "ridge drift". The ridge drift was characterized by random changes of a single ridge original position while adjacent ridges remains unaltered which was suggested to lead to a change of the minutiae distribution. However, as the phenomenon was observed by comparing the same area of separate fresh and aged fingermarks developed with titanium dioxide powder, the observations might be a result of ridge material migration or degradation, surface texture effects or contact dynamics. Moret et al. [33] demonstrated by phase contrast microscopy the disappearance of a sebaceous loaded latent fingermark ridge pattern on polypropylene (PP) and polyvinyl chloride (PVC) from 4 days while on glass the fingermark remained visible for the maximum study period of 58 days. On PP after 4 days a barely seen ridge outline was observed while only certain droplets from the ridges could be observed between 4 and 58 days. On PVC the ridge pattern disappearance was found to be faster than on PP resulting no visible ridge pattern from day 4 onwards. However, only sebaceous loaded latent fingermarks from only one donor were used in this study. Muramoto et al. [34] demonstrated that palmitic acid in a latent fingermark in vacuum migrates across a surface moving from ridge to ridge, a few hundred micrometres, in 4 days on silicon. This study utilized time of flight secondary ion mass spectrometry (TOF–SIMS) to image the changes between 1 and 96 h after deposition of latent fingermarks from one donor on silicon wafers. This is a high vacuum technique which is likely to increase the mobility of material on the surface versus normal air environment. All these four studies are focused on horizontal changes of fingermark ridges while Thomas et al. [35] is focused on the height changes of latent fingermark ridges. Latent fingermark samples on microscope glass slides from each of the four donors in this study were left in six different environments for period up to three months and the thicknesses of three droplets per sample were calculated from the refractive index and the phase shift by the use of Interference microscopy. The droplet cross-section profile changes and maximum droplet thickness and lateral dimension decreases with time in various environments, and the viscosity changes with time were observed. Varying drying rate within the droplet due to chemical inhomogeneity was proposed as a possible cause for the irregular topography observed with time after the deposition. The large initial change in the topography was suggested to be related to evaporation of more volatile components. No dependence between the drying rate and the environment humidity was observed, suggesting a low water concentration at the droplet surface [35]. However the results in the study of Thomas and Reynoldson [35] are obtained by interference microscopy with limited spatial sensitivity, and more sensitive techniques such as AFM were subsequently utilised for fingermark analysis [26,36] enabling sub nanometre resolution. Watson and Watson [36] investigated the possibility of using AFM for study of fresh single and overlapping latent fingermarks on microscope glass in air and liquid environment gathering information on topography and adhesion. However this study involves Contact Mode AFM which can cause damage to delicate materials such as the freshly deposited latent fingermarks. Goddard et al. [26] used Tapping or Intermittent Mode AFM to image corrosion caused by latent fingermark deposits on polished and untreated brass substrates. Fingermarks were removed from all samples prior to examination, the AFM measurements therefore analysed the effects of the fingermark and environment on the underlying substrate material; samples exposed to flames demonstrated measureable corrosion where fingermark ridges were located.

There are many development methods used for visualizing latent fingermarks. In some cases a specific component or group of components is the target of those methods. This coupled with the chemical and topographical changes to the fingermark with time, can provide some explanation for the time-dependent variation of effectiveness of fingermark development methods.

Powder dusting is effective on fresh fingermarks, but decreases in efficacy as the marks age [37]. This is probably due to the hardening of the fingermark as a result of loss of water [38,39], oxidation and saturation of the unsaturated compounds [6,38,40,41] as well as polymerization [7]. Powder suspension development of latent marks is strongly affected by the substrate chemistry and texture [27,28] as well as the formulation of the development agent [28,42]. A surface dependent phenomenon found is the variation of particle distribution on the developed fingermark ridge where the particles appeared concentrated and further surrounded by less concentrated area which ends with highly concentrated edge, this may be related to substrate-dependent lateral changes in the fingermark following deposition.

Vacuum Metal Deposition (VMD) efficacy is also affected by aging of fingermarks, and is particularly useful for old and environmentally exposed fingermarks [43]. In its most common form, VMD is a two stage vacuum process of gold evaporation and deposition followed by evaporation and deposition of zinc. It is suggested [44] that in this process exposed gold particles located between the fingermark ridges serve as binding sites for the zinc while on the ridges the gold particles are submerged into the deposited material and cannot bind the zinc, leading to normal development with zinc between the ridges and surrounding the fingermark. However, reverse development (zinc on the ridges but not between and not surrounding the mark) as well as empty prints (no zinc on the ridges or between them but surrounds the fingermark) and over development (zinc deposited everywhere) are also often found in practice. There are some evidence that these problematic developments are related to the substrate [45,46] although it is not clear if this is caused by direct development agent interaction with the substrate, or the effects of the surface properties on the behaviour of the deposited fingermark.

Earlier research has demonstrated the importance of micro and nano level features on both substrate [27,28,30] and development agent [29,42] in affecting the behaviour and visualization of the fingermark. This work examines latent fingermark topography on a micro and nano level and how this topography varies with time after the deposition of the mark.

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