The retrieval of fingerprint friction ridge detail from elephant ivory using reduced-scale magnetic and non-magnetic powdering materials

Kelly A. Weston-Ford [a], Mark L. Moseley [b], Lisa J. Hall [b], Nicholas P. Marsh [b], Ruth M. Morgan [c,d], Leon P. Barron [a]

[a]Analytical & Environmental Sciences Division, King's College London, 150 Stamford Street, London SE1 9NH, United Kingdom

[b]Specialist Forensic Services, Evidence Recovery Unit, Metropolitan Police Service, 109 Lambeth Road, SE1 7LP London ,United Kingdom

[c]Department of Security and Crime Science, University College London, 35 Tavistock Square, London WC1H 9EZ, United Kingdom

[d]UCL Centre for the Forensic Sciences, 35 Tavistock Square, London WC1H 9EZ, United Kingdom

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Article Outline

Highlights

- Reduced scale magnetic powders outperformed conventional powders for mark enhancement on seized elephant ivory.
- The effect of fingermark age on ivory significantly affected enhancement success.
- Usable marks were still recovered after 28 days, but the best results were obtained within 7 days.
- No improvement in mark quality using CNA enhancement or when used in sequence with powders

Abstract

An evaluation of reduced-size particle powdering methods for the recovery of usable fingermark ridge detail from elephant ivory is presented herein for the first time as a practical and cost-effective tool in forensic analysis. Of two reduced-size powder material types tested, powders with particle sizes ≤ 40 μm offered better chances of recovering ridge detail from unpolished ivory in comparison to a conventional powder material. The quality of developed ridge detail of these powders was also assessed for comparison and automated search suitability. Powder materials and the enhanced ridge detail on ivory were analysed by scanning electron microscopy and energy dispersive X-ray spectroscopy and interactions between their constituents and the ivory discussed. The effect of ageing on the quality of ridge detail recovered showed that the best quality was obtained within 1 week. However, some ridge detail could still be developed up to 28 days after deposition. Cyanoacrylate and fluorescently-labelled cyanoacrylate fuming of ridge detail on ivory was explored and was less effective than reduced-scale powdering in general. This research contributes to the understanding and potential application of smaller scale powdering materials for the development of ridge detail on hard, semi-porous biological material typically seized in wildlife-related crimes.

Keywords:
Latent fingerprints, Fingermark enhancement, Wildlife, Forensic science

1. Introduction

The illegal procurement and trade of elephant ivory recently reached its 16-year high in 2011. The latest figures generated by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) under the Monitoring the Illegal Killing of Elephants (MIKE) programme, estimate 22,000 elephants were illegally killed in Africa alone in 2012. In 2011, the mortality estimate via illegal routes was 25,000 animals, and with potentially increased estimates expected for 2013, this suggests that such activity remains critically high [1].

There is an increased demand for ivory, particularly across Asia. The legitimate trade of ivory in countries where elephants are indigenous is often used as a means to maintain economic stability and also perhaps paradoxically to fund conservation projects. However, the sector has become increasingly populated by major organized crime syndicates [2], which promote, amongst others, corruption, terrorism, slavery and the trafficking of weapons and drugs. Unfortunately, the lucrative nature of this market seems to outweigh the risk of prosecution. Several tonnes of raw ivory are now seized on an annual basis globally [[3], [4]]. Lessening of the global trade restrictions has made it easier to transport large amounts of contraband around the world. It is a logical assumption that with the extensive variety of forensic tools now available that more effort would be invested into more effectively implementing existing techniques.

Unfortunately this does not appear to be the case for fingermarks. Retrieval of ridge detail or latent fingermarks is rarely considered when ivory or ivory-containing items are seized. There are many reasons why an examination is not conducted. Not least are the challenges in developing ridge detail on this type of material. When a suitably receptive surface is touched by an area of the friction ridge skin (e.g., the undersides of the hands, fingers and soles of the feet), an impression of the ridge detail, is left behind on the surface. The texture, colour and porosity of the substrate surface assist in determining the most appropriate development method, but there are many factors that influence their effectiveness. To the best of our knowledge, only one relevant scientific paper has been published on the detection of latent fingermarks on African elephant (*Loxodonta africana)* ivory in the past thirteen years [5]. In this work, Azoury et al. found that latent fingermarks on ivory were unstable and did not persist for periods of up to two weeks. This mark instability is to some extent due to the complex physical and chemical structure of the ivory. These authors evaluated a number of widely used development techniques, including powders, small particle reagents (SPR), cyanoacrylate fuming (using a range of dyes) and vacuum metal deposition (VMD). The selected methods, except VMD, performed satisfactorily for fresh fingermark deposits, but only a sequential treatment procedure using cyanoacrylate and black magnetic powder developed any depositions after two weeks. An in-depth assessment of the quality of ridge detail for successful search and/or comparison was not presented as part of this work. It is now critical to extend efforts towards a more comprehensive assessment of fingerprint development on ivory-based materials.

One of the oldest, simplest, cost effective and most commonly used technique for the development of latent ridge detail is via contrasting powders. The preferential adherence of a fine powder to a range of components within the latent deposit enables sufficient contrast between the deposit and the underlying surface to be able to visualise the friction ridge detail [[6], [7]]. This development method continues to be the focus of on-going research and application in other areas of wildlife-related crime [8]. Where successful, it could present a viable and sustainable approach to the retrieval of forensic evidence in situ and especially at source such as air or shipping ports. The development and application of novel materials for powdering has recently received particular attention [[9], [10]]. In comparison to traditional powders, a range of reduced-size powder particles are now available for fingermark development purposes. These offer many potential advantages, not least that reduced particle sizes could offer enhanced resolution and allow better discrimination of finer characteristic detail within the friction ridges at the micro- or nano-metre scales. Furthermore, the chemical nature of smaller particles can also be tailored to enhance practical application. For example, powders grafted with fluorophores [9] or near infra-red absorbing materials [11] have recently improved fingermark detection on low-contrast surfaces. In some cases, application of selective powder materials has revealed additional information regarding the depositor (e.g., the presence of drugs or metabolites) [[12], [13]].

The lack of translational research, and owing to the poor prosecution rate of those involved in the illegal wildlife trade with its link to organized crime, has led the Metropolitan Police Service in London to conduct an investigation into efficient methods for the recovery of identifiable friction ridge detail from ivory obtained from a number of different species. The aim of this work was to perform an independent assessment of the potential benefits offered by reduced particle size powders for the retrieval of ridge detail from elephant ivory in comparison to a conventional powder. The objectives were:

(a) to compare the physicochemical properties, sensitivity and practicality of two reduced-size powders (≤40 μm average particle diameter) relative to a conventional powder material (>100 μm average particle diameter) for potential deployment in the field;
(b) to perform an assessment of enhanced ridge detail quality with respect to location on a tusk and the age of deposits; and
(c) to compare reduced-scale powders with fluorescent/non-fluorescent cyanoacrylate and to evaluate any benefits of sequential treatment.

This work, for the first time, presents the most comprehensive assessment of a new method for the recovery of usable ridge detail from elephant ivory tusks and performed within an accredited forensic case-work laboratory environment. Furthermore, the value of such an approach also lies in providing a potentially viable, field deployable tool to combat illegal elephant poaching at source.

2. Experimental

2.1. Materials

The development powders used in this study were SupraNano Black Magnetic and SupraNano Black Powder (ARRO SupraNano Ltd., Newcastle upon Tyne, UK) and also Jet Black magnetic powder (WA Products Ltd., Essex, UK). Standard squirrel brushes (Tetra Scene of Crime Ltd., Essex, UK) or metal magnetic brushes/wands (Tetra Scene of Crime Ltd.) were used for powder application. Adhesive tape (Warrender Products, Gwent, UK) was used for the lifting of all developed areas of ridge detail. Exposed photographic paper (FUJIFILM Europe GmbH, Düsseldorf, Germany) was chosen as the control surface for all donor depositions (i.e., a smooth, glossy surface). Three seized elephant tusks were loaned for this study from the Wildlife Unit of the MPS with the following dimensions: length: 96–112 cm; weight 5.78–6.45 kg. Tusk circumferences were between 9–10 cm at the tip (~2 cm from the end), 25–30 cm across the mid-section and 25–34 cm at the severed end. It was unknown whether the tusks were from African or Asian elephants. All tusks were thoroughly cleaned before each use using ethanol-soaked disinfectant wipes (Premier Healthcare & Hygiene Ltd., Tyne and Wear, UK). One of the tusks was a polished tusk and was only used for the assessment of ridge detail quality across its length for comparison with results obtained from a similar study using the other two unpolished tusks (Section 2.2.5). All developed areas of ridge detail were photographed using a Nikon D4 camera (Nikon Corporation, Tokyo, Japan) fitted with a 105 mm Macro Nikkor lens. The lighting technique for the powdered areas was either specular or oblique lighting [14] and for the fluorescent CNA (Lumicyano Solution™, Global Forensics Ltd. Lab, Coventry, UK) and a 532 nm laser (Laser Innovations, Cambridge, UK) was used. This was carried out in accordance with validated standard operating procedures. The images were captured in the RAW file format and post-production was carried out using Adobe Photoshop CS5 (Adobe Products, UK).

2.2. Comparison of powdering materials

2.2.1. Comparison of powder materials for fresh latent ridge detail on glass, photographic paper and ivory

To study the interaction of powder materials with the skin deposits, sebaceous and amino acid print pads (Armor Forensics, FL, USA) were used initially. A single donor was used for this experiment for this first phase of testing. Hands were washed and contact made with a sebaceous pad using each finger ten times before depositing n = 6 fingermarks from different fingers on clean glass slides (Menzel-Gläser, Thermo Scientific) using minimal pressure for 1–2 s and each slide then developed with a different powder material following a 30-minute ageing period [15]. This procedure was subsequently repeated using amino acid pads and then natural fingermarks. Though mild risk of skin irritation existed from contact with amino acid/sebaceous pads (as per manufacturer's material safety datasheets), hands were washed with water thoroughly after depositions were made. Natural marks were produced by refraining from hand washing for at least an hour prior to deposition while continuing on with normal activities.

To initially investigate powder effectiveness for natural marks on ivory, a single donor deposited a full set of marks and repeated this on photographic paper as a control. To examine the interaction of powders with the ivory surface, powders were gently applied on multiple ivory sections and across the length of the tusks and observed. As the most promising candidate for ridge detail enhancement on ivory, an extended examination of SupraNano Black Magnetic powder was performed using three different types of fresh deposits (natural, sebaceous and eccrine) for n = 40 areas of ridge detail across 4 donors per deposit type. Deposits were spread evenly across the tusk surface and length.

All deposits were aged for 30 min under ambient conditions, powdered and then any developed ridge detail lifted using adhesive lifting tape. All lifts were transferred to individual cobex (acetate) sheets (Tetra Scene of Crime Ltd.), photographed, examined and scored at the Fingerprint Bureau at New Scotland Yard. Throughout the study, all developed ridge detail was visually examined and assessed based on the contrast between the developed detail and substrate, clarity, definition and visibility of ridge detail. All scoring and observations were made using a fingerprint magnifying glass whilst viewing the original lifts on a flat 'Medalight' white light box. Scoring was based on the scale given in Table 1. The grading system deviated from that proposed by Sears et al., as there was a requirement to maintain consistency with the procedures in place within the Fingerprint Bureau for pseudo-operational and blind testing of all enhanced marks/powder types by identification specialists. Additional practical advice and an instructional video for using these powders are also given in the Supplementary Information (SI).

Table 1

Fingermark scoring and scale used by MPS Fingerprint Bureau specialists in this work.

Grade	Description
6	A clear-cut mark posing no problems for search or comparison and is easy to define and interpret.
5	A good quality mark. The clarity and amount of detail may be compromised a little, but would not be sufficient to impact on interpretation.
4	A mark that reveals detail that could be searched or compared, but requires interpretation as it is affected or compromised by the action of deposition, physiological, biological or external factors.
3	A mark that lies at the threshold of comparison or identification and requires considerable interpretation. It is unlikely to be suitable for search, although not impossible. It would include those marks that you would expect to result in an inconclusive outcome. It may contain enough detail

	to exclude only.
2	A mark that is insufficient for search or comparison and is of very poor quality or has few features.
1	No ridge detail visible

2.2.2. Comparison of powder sensitivity

Sensitivity was assessed for sequentially depleted synthetic sebaceous and amino acid pad-generated deposits as well as natural, eccrine and sebaceous deposits. Ten sequential deposits from the same finger and a single donor were made on ivory and photographic paper (control) using the same finger and medium pressure for 1–2 s. Medium pressure refers to pressure greater than a touch, but less than actively pushing down onto the surface with a great deal of strength. Eccrine deposits were produced by washing the hands thoroughly with soap, air drying and then the donor was instructed to wear Touch N Tuff® latex-free nitrile gloves (Ansell) for 30 min to allow the natural production of eccrine sweat, without contamination as per the recommendations of Sears et al. [16]. Sebaceous type deposits were produced by firstly washing the hands, allowing to air dry, then passing the hands through the hair, forehead, nose and chin areas each for n = 5 repeats.

2.2.3. Ridge detail consistency along a tusk

The consistency of ridge detail recovered across a tusk was assessed using the SupraNano Black Magnetic and Jet Black Magnetic powders. Four donors were used to each deposit two natural deposits in each of four subdivided and equal length sections along an unpolished tusk from root to tip (contact time was 10 s using medium pressure). This experiment was repeated on another unpolished tusk using the same donors and was also repeated again, except on a polished tusk for comparison purposes. Deposits were processed in the same way as previously described.

2.2.4. Scanning electron microscopy-energy dispersive X-ray spectroscopy (SEM-EDS) of powders materials and enhanced marks

The physicochemical, structural and size differences between the powders, was investigated using SEM-EDS. A small quantity of each powder was placed onto a double-sided adhesive conductive carbon disc (TAAB Laboratories Equipment Ltd., Berks, UK) mounted on a labelled aluminium pin stub (Agar Scientific). The powder sample was evenly distributed over the surface and any excess removed. Images were recorded using a JEOL JSM-6480LV SEM operated at 7 kV. Finally, small sections of ivory, each containing an enhanced natural fingermark were also examined using an FEI Quanta 200 F field emission scanning electron microscope (FEI, OR, USA) operated at 2.5 kV in high vacuum mode. The ivory sections were mounted using carbon cement (TAAB) on an aluminium pin stub.

2.2.5. Age of deposits on ivory

The effectiveness of SupraNano Black Magnetic and Jet Black magnetic powders was examined for deposits aged over 28 days. Six donors seeded natural deposits on ivory and n = 6 deposits per time-point were enhanced after 0, 3, 7, 14, 21 and 28 days with SupraNano Black Magnetic powder. This experiment was repeated using Jet Black Magnetic Powder (at t = 0, 14 and 28 days) on ivory and on photographic paper as a control, all for n = 6. Deposits were applied with medium pressure for 10 s. Tusks were stored in a dark room with a measured daily temperature of between 14.0 and 15.9 °C and a relative humidity of 21.0–28.0% across the duration of the experiment. All developed areas of ridge detail were graded according to Table 1.

2.2.6. Cyanoacrylate fuming

The potential for improved chemical development of ridge detail on ivory was examined using CNA (Tetra Scene of Crime Ltd.) and fluorescently-labelled CNA (Lumicyano Solution™, Global Forensics Ltd. Lab, Coventry, UK). Fuming was performed using 1 g of regular CNA or Lumicyano Powder 135 mg mix with 2.7 g Lumicyano Solution (15-minute fuming cycle for both types of CNA) in a Foster and Freeman MVC 3000 CNA cabinet. Temperature and humidity was maintained between 18.0–18.9 °C and 17–19% respectively. Six donors were used across two ageing periods, 1 day and 1 week. Only n = 6 deposits were made for the 1-day old deposits to preliminarily assess immediate losses or gains in performance. However, and to examine any realistic benefit over longer periods, n = 60 deposits were enhanced after ageing for one week with CNA and n = 30 deposits with Lumicyano CNA. Both sets of enhanced prints were examined under a white light source (Rosco LitePad HO+) and photographed. Lumicyano CNA-treated deposits were additionally examined and photographed using laser-induced fluorescence at a wavelength of 532 nm with a 549 nm filter. Images were then provided to a fingerprint examiner for scoring. Following this, both sets of enhanced deposits were powdered sequentially with SupraNano Black Magnetic, photographed and scored by a qualified fingerprint examiner.

3. Results & discussion

3.1. Comparison of powder materials for fresh latent ridge detail on glass, photographic paper and ivory

Both the SupraNano Black Magnetic and Jet Black magnetic powder types were more easily controlled and applied than the SupraNano Black Powder. The black pigment of both reduced-scale powders was darker than that of Jet Black magnetic, which was grey in colour. Both reduced-scale powders were found to interact well with synthetic fingermark deposits on glass with good contrast, but adhered more strongly in general to the synthetic sebaceous pad-generated deposits. All powders bound to natural deposits on these surfaces, but SupraNano Black Magnetic produced the clearest ridge detail with the greatest contrast. All depositions on ivory (n = 10/powder) were considered suitable for comparison and search by a qualified fingerprint examiner. However, the clarity of ridge detail from both reduced-scale powders were again better overall and exhibited an even coverage of powder with excellent contrast between the ridges and background on the smoother areas of ivory. All ten areas of ridge detail developed using these powders were of Grade 5–6. However, and whilst third level detail was also clear, the morphology of the ivory background was visible in places through reduced-scale particle lodgement in small imperfections in the ivory surface. Despite the reduced contrast with Jet Black Magnetic, seven out of ten deposits were of Grade 6 and the remainder of Grade 5. Ridges and furrows were distinct and the ridge path visible, but visible detail within the ridges was less clear than with the other powders. Ivory imperfections were still visible, but more scrutiny was required to differentiate powdered sections of substrate from ridge features given the reduced contrast. Overall, it was concluded that the reduced-scale powders consistently produced the better quality developed areas of ridge detail in comparison to this conventional magnetic powder.

A more detailed evaluation was performed using SupraNano Black Magnetic powder with different fingermark types and more donors in order to further assess suitability for comparison and search. All natural, sebaceous and eccrine fingermarks on ivory could be enhanced, but with varying contrast and detail. There were clear visible differences in quality between the ridge details deposited in the three substances as well as between the donors. As can be observed in Fig. 1, sebaceous deposits generally exhibited the best contrast. However, it was found that natural deposits offered the best chance of producing ridge detail suitable for comparison, search and identification purposes (Table 2). Despite better contrast, marginally worse quality was observed for sebaceous deposits. Overall, ridge detail deposited in eccrine components yielded the poorest results. For comparison purposes, the variance across donors was greater with sebaceous marks and eccrine marks than with natural marks, supporting its use for further experiments in comparison to other mark types. For identification purposes, the variance was least with eccrine marks, but did not reflect any advantage for further testing as scores were generally so low on average.

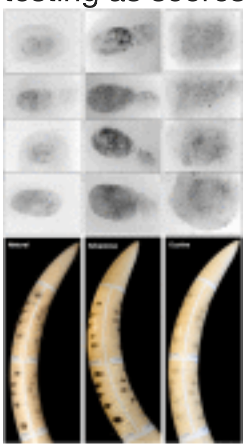

Fig. 1

Images of enhanced fresh natural, sebaceous and eccrine marks on ivory using SupraNano Black Magnetic powder (bottom) and examples of their corresponding tape lifts (top).

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Table 2

Comparison of performance of the SupraNano Black Magnetic powder on three different freshly deposited mark types on unpolished ivory.

Type of finger mark	Donor	Number of prints suitable for comparison[a] (out of 5)	Number of prints suitable for automated database searching (out of 5)
Natural	1	5	5
	2	5	5
	3	5	4
	4	4	1
	Mean ± SD	4.8 ± 0.5	3.2 ± 1.9
	Total %	95	75
Sebaceous	1	5	4
	2	3	1
	3	4	4
	4	5	5
	Mean ± SD	4.3 ± 1.0	3.5 ± 1.7
	Total %	85	70
Eccrine	1	0	0
	2	2	1
	3	0	0
	4	1	1
	Mean ± SD	0.8 ± 1.0	0.5 ± 0.6
	Total %	15	10

SD — standard deviation.

[a]All marks suitable for search were subsequently manually compared with reference prints and positively identified.

3.2. Comparison of powder sensitivity

The testing of powder sensitivity across all deposits revealed differences between each powder. In particular, SupraNano Black Magnetic developed all ten depleted sebaceous and eccrine-type contacts with the best contrast and detail on both ivory and photographic paper (data not shown). For natural depositions on ivory, SupraNano Black Magnetic powder produced more ridge detail of slightly better contrast and still developed most of the fine detail even after ten deposits (although very faint and still classed as unidentifiable). The ridge detail developed with SupraNano Black Powder and Jet Black magnetic powder on ivory was also very faint, but only partially visible after ten depletions. Finally, ridge detail deposited in synthetic material (using amino acid and sebaceous pads) were consistent with the results with those of their non-synthetic counterparts in terms of powder sensitivity. However, all synthetic developed deposits showed better contrast and detail for longer periods across all powders. It is generally accepted however that amino acid and sebaceous pads do not truly reflect the make-up of real ridge detail and these findings should be treated with caution [[16], [17]]. It is also important to note that individuals differ physically and behaviourally and this will affect their natural secretions and hence the quality of the actual deposit and the potential for development. [[15], [18], [19]]. Synthetic marks were not considered in further experiments as a result.

3.3. Ridge detail consistency along a tusk

Elephant tusks vary in texture along their surface. The tip is generally smooth, while the end that is rooted in the skull is rougher [[5], [20]]. The quality of the developed ridge detail across the length of unpolished and polished tusks using SupraNano Black Magnetic and Jet Black magnetic powders is shown in Fig. 2. In general, the quality of the ridge detail was better on polished tusks. There were no significant differences in ridge detail quality across the tusk when using Jet Black magnetic powder on unpolished tusks. However, there was a slight reduction in the average quality grades observed at the extremities using SupraNano Black Magnetic. Whilst repetition on more tusks is necessary to show this conclusively, the mid-section of each unpolished tusk was used in subsequent experiments. As can also be seen from Fig. 2, the variability (shown as the standard deviation in each case) across the graded marks was rather large. For details of the variance observed between donors, please refer to the raw data in the SI.

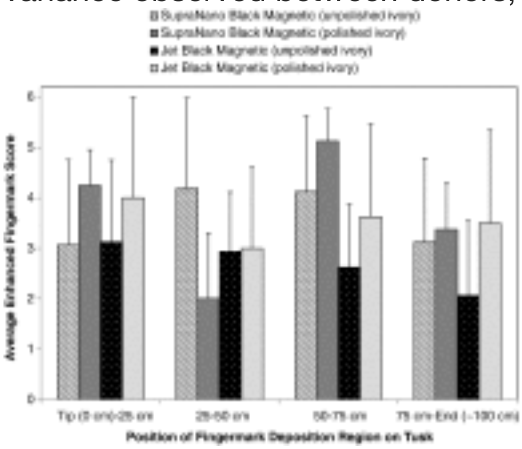

Fig. 2

Quality of enhanced fresh fingermarks across the length of an ivory tusk on unpolished ivory for n = 16 and polished ivory for n = 8 replicates (from 4 donors).

3.4. SEM-EDS of powder materials and enhanced marks

Photomicrographs produced with SEM highlighted differences in particle morphology and size between all powders, and particularly between the

SupraNano powders and the Jet Black magnetic powder. As perhaps expected, the particles of reduced-scale powders were substantially smaller and more regular in shape than that of Jet Black Magnetic. Jet Black Magnetic (Fig. 3(a)) consisted of a much wider particle size distribution with a size >100 μm on average. Furthermore, a large quantity of smaller, rougher and irregular shaped material was present which was likely to arise from larger particle breakage. SupraNano Black Powder (Fig. 3(b)) particles were much smaller (~20 μm) with more consistent overall size distribution and had greater uniformity in shape (primarily spherical, smooth particles). The SupraNano Black Magnetic (Fig. 3(c)) was very similar in its morphology, but, on the whole, particles were slightly larger on average (~40 μm) and exhibited some added size distribution. According to the manufacturer, these smaller micro-scale powders are engineered based on stable silica nanoparticles encapsulated by colourants or with magnetic properties if required. These core silica nanoparticles have been engineered to be both hydrophilic and hydrophobic and can enable adherence to a number of fingermark constituents [[18], [19]]. According to Lim et al., hydrophobic powder particles have been used previously to target lipids and fatty acids in fingermarks [21]. No useful interaction was observed with hydrophilic components (such as amino acids). If the SupraNano powder particles display a range of polar moieties, this could explain their improved performance on ivory. Adherence of Jet Black Magnetic powder to fresh eccrine marks could perhaps be due to the presence of water in the mark rather than the particles binding specifically to amino acids.

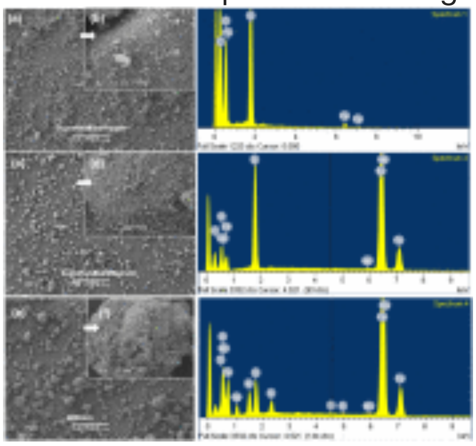

Fig. 3

Left: SEM images of SupraNano Black Powder (a) Black Magnetic (c) and Jet Black Magnetic (e) particles at 50× magnification with insets (b), (d) and (f) showing the morphology of a single particle for each powder type respectively. Right: Example EDS spectra of each powder type.

Developed areas of ridge detail on ivory were examined by SEM in an attempt to understand powder interaction with ridge material. Neither of the magnetic powders allowed production of clear images at higher magnifications. Despite this, ridge detail developed with reduced-particle size powders showed excellent definition and contrast between ridges and furrows at lower magnifications on ivory (Fig. 4). Scratches on the surface of the ivory did affect the quality, and more so for reduced-scale powders. At

1200× magnification, ridge detail developed with the non-magnetic SupraNano Black Powder showed excellent definition of the ridge detail from the ivory surface behind it (Fig. 4(d)). Interestingly, this image also showed that the powder partitioned into the deposits to form a sort of paste-like substance.

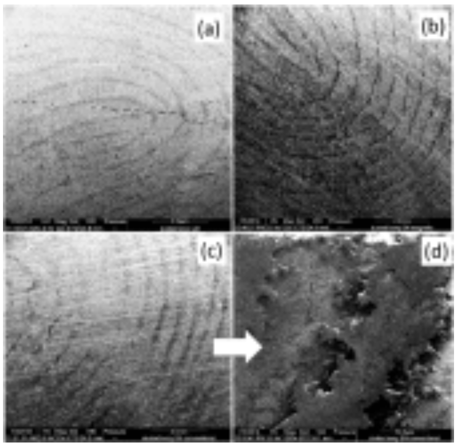

Fig. 4

Enhanced fingermarks on ivory using (a) Jet Black Magnetic, (b) SupraNano Black Magnetic and (c) SupraNano Black Powder imaged with SEM. Image (d) represents a magnified section of enhanced ridge detail showing the formation of a paste-like substance with fingermark constituents when using SupraNano Black Powder.

The effectiveness of powder adherence to friction ridges has been researched significantly and is dependent on its shape and size. Finer particles adhere more easily than large, coarser particles due to their greater surface area to volume ratio and can therefore produce higher resolution marks [[7], [22], [23]]. However, nano-scale particles often aggregate in solution [[24], [25]], which was a concern for this application. Fortunately, no obvious aggregation was observed here with these powders to the extent that ridge detail became distorted in fresh marks. Generally, particles of diameter <10 μm are also considered respirable and could represent a health risk to users [26]. In this study, both reduced-scale particles were on the whole greater than this threshold limit and if inhaled, would likely be captured and eliminated in the naso-pharyngeal region. Ingestion could still pose a risk, naturally, but this could minimise this risk using simple face masks as opposed to more specialist, impractical and expensive technology for field application. On this point alone, the SupraNano Black Magnetic powder was considered most suitable for longer-term forensic practice.

3.5. Age of deposits on ivory

Overall, a clear reduction in the quality of aged marks was observed. No statistical difference was observed between the performances of the magnetic powders in ivory for 0 and 14 day intervals (despite poorer contrast with Jet Black magnetic), but SupraNano Black Magnetic performed best for natural deposits on ivory up to 28 days (Fig. 5(a)). Whilst the quality of ridge detail was much poorer than those at Day 0, the number of areas of ridge detail achieving an average grade ≥2 were higher. Powdering performance using the SupraNano Black Magnetic powder also decreased slightly on average for controls on photographic paper. For the raw data pertaining to this experiment (including variability between donors), please consult the SI.

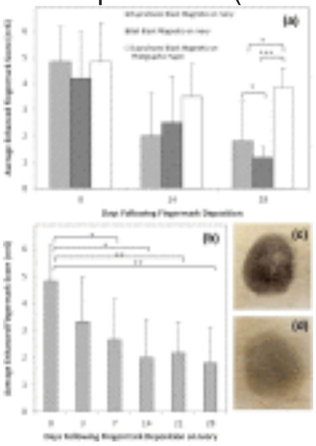

Fig. 5

Effect of fingermark age on enhanced fingermark over 28 days using (a) SupraNano Black Magnetic and Jet Black Magnetic over 0, 14 and 28 days on unpolished ivory and photographic paper and (b) SupraNano Black Magnetic on ivory only at increased time interval frequency. Insets (c) and (d) represent example enhanced marks on ivory after 30 min and 28 days respectively. Key: * = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$. Bars represent the average grade obtained for n = 6 replicates (6 donors) and whiskers represent the standard deviation.

In a parallel experiment, the effect of the age of a deposit was studied across more time intervals for SupraNano Black Magnetic in particular (Fig. 5(b)). A statistically significant ($p \leq 0.05$) reduction in ridge detail quality was observed from seven days after deposition. Variance in enhanced mark grade was again observed, and perhaps as expected given that donors were chosen randomly for pseudo operational trialling within this case-work active environment (see SI for raw data recorded for each donor mark). Fresh and aged marks from one donor were lower on average on photographic paper in comparison to the other five, but this variance was not reflected for this donor in marks graded on ivory. Overall, the proportion of the developed ridge detail considered suitable for search and comparison decreased below 50% after Day 7 using the SupraNano Black Magnetic powder. That said, enhancement of ridge detail past the 7-day point may still serve as a useful means to recover biological evidence for subsequent DNA analysis [[27], [28]].

Ivory is a porous material, but at first glance it appears to have a smooth, non-porous surface [14]. The morphology of the mantle layer of ivory is highly striated and the furrows between these ivory deposition ridges contain dense numbers of micro-scale odontogenic pores. Therefore, coupled with ivory being an uneven surface, loss of applied biological fluid may occur through these pores over time [29]. It is also suggested that any latent or enhanced ridge detail is immediately photographed in situ and before tape-lifting to maintain ridge detail quality.

3.6. Cyanoacrylate fuming and sequential treatment with reduced particle size powders

Although CNA and Lumicyano CNA fuming methods could develop deposition areas after one day and yielded some ridge detail, both fuming approaches were not found to be useful for ridge detail recovery from ivory after one week. Fig. 6(a) shows the effectiveness of fluorescently-active CNA treatment in particular. After a one-day ageing period, ridge detail could be detected generally. Following sequential treatment with SupraNano Black Magnetic, ridge detail could be enhanced and photographed relatively easily. Worthy of note was that two days after fuming deposits with Lumicyano CNA, all detectable fluorescence was lost. For 1-week old deposits treated with CNA (n = 60) and Lumicyano-CNA (n = 30), no marks with either white light or under fluorescent light (Grade = 1) were detectable. However, when marks were sequentially enhanced with reduced-scale powders, the median grade increased to 2 for both CNA polymer types, meaning that biological trace evidence could at least be located using this means, but they were on the whole not suitable for search (only 3/60 deposits were deemed as suitable for search with conventional CNA fuming + powdering and 1/30 with Lumicyano-CNA fuming + powdering). Therefore, it was concluded that no obvious benefit was offered by CNA fuming or via the sequential treatment approach. Obviously, CNA fuming is also a less practical option for use in the field. Perhaps some additional ivory treatment with newer treatments such as infra-red powders could be used to improve this detection window if necessary, but arguably also at the cost of field-deployability for subsequent mark visualisation.

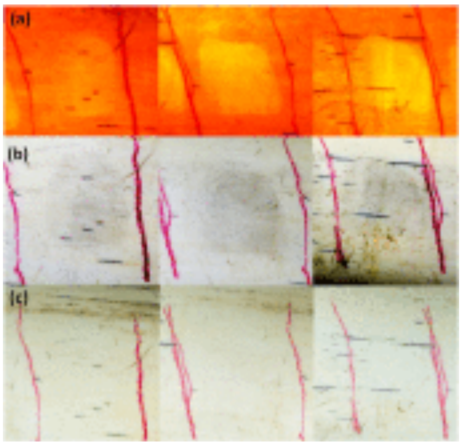

Fig. 6

Ridge detail recovered from (a) n = 3 one-day old marks on ivory fumed using Lumicyano CNA and visualised by laser-induced fluorescence, (b) n = 3 one-day old marks following sequential Lumicyano CNA-SupraNano Black Powder enhancement methods and (c) n = 3 seven-day old marks following sequential Lumicyano CNA-SupraNano Black Powder enhancement methods.

4. Conclusion

This research has enabled a better understanding of the potential for improved detection of usable latent ridge detail on elephant ivory using reduced-scale powders. All powders developed more ridge detail and with better quality ridge detail in comparison to cyanoacrylate. All development techniques were less effective with ageing of deposits on ivory. However, reduced-scale powder could enhance latent ridge detail up to 28 days after deposition, but the best results were achieved within one week. Cyanoacrylate was not effective for development of ridge detail on ivory and offered no obvious advantage even when used before powdering in sequence. This research has demonstrated that there is great potential to recover more latent ridge detail from ivory in the future that is of a quality that can be used to identify the donor. Ultimately, identification of the donors could help to detect and disrupt criminal networks profiting from the slaughter of elephant species.

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Appendix A. Supplementary data

Further Experimental Details, Application to Other Ivory Types and Practitioner's Guide.
Individual Donor Grading for Mark Age and Location on a Tusk as CNA Enhancement.
Instructional Video.

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