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Systematic investigation of drip stains on apparel fabrics: The effects of prior-laundering, fibre content and fabric structure on final stain appearance

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ABSTRACT

Bloodstain pattern analysis is the investigation of blood deposited at crime scenes and the interpretation of that pattern. The surface that the blood gets deposited onto could distort the appearance of the bloodstain. The interaction of blood and apparel fabrics is in its infancy, but the interaction of liquids and apparel fabrics has been well documented and investigated in the field of textile science (e.g. the processes of wetting and wicking of fluids on fibres, yarns and fabrics). A systematic study on the final appearance of drip stains on torso apparel fabrics (100% cotton plain woven, 100% polyester plain woven, blend of polyester and cotton plain woven and 100% cotton single jersey knit) that had been laundered for six, 26 and 52 cycles prior to testing was investigated in the paper. The relationship between drop velocity (1.66 ± 0.50 m/s, 4.07 ± 0.03 m/s, 5.34 ± 0.18 m/s) and the stain characteristics (parent stain area, axes 1 and 2 and number of satellite stains) for each fabric was examined using analysis of variance. The experimental design and effect of storing blood were investigated on a reference sample, which indicated that the day (up to five days) at which the drops were generated did not affect the bloodstain. The effect of prior-laundering (six, 26 and 52 laundering cycles), fibre content (cotton vs. polyester vs. blend) and fabric structure (plain woven vs. single jersey knit) on the final appearance of the bloodstain were investigated. Distortion in the bloodstains produced on non-laundered fabrics indicated the importance of laundering fabrics to remove finishing treatments before conducting bloodstain experiments. For laundered fabrics, both the cotton fabrics and the blend had a circular to oval stain appearance, while the polyester fabric had a circular appearance with evidence of spread along the warp and weft yarns, which resulted in square-like stains at the lowest drop velocity. A significant ($p < 0.001$) increase in the stain size on laundered blend fabric was identified. Bloodstain characteristics varied due to fibre content ($p < 0.001$) and fabric structure ($p < 0.001$). Blood on polyester fabric, after impact, primarily moved due to capillary force and wicking of the blood along the fibres/yarns, while for the cotton fabrics wicking was accompanied by movement of blood into the fibres/yarns. This study highlights the importance for forensic analysts of apparel evidence to consider the age, the fibre type and the fabric structure before interpreting bloodstain patterns.

1. Introduction

Bloodstain pattern analysis (BPA) often provides one of the cornerstones of forensic investigations of violent crime or accidents. Classically, it involves the study of the number, size, shape, pattern, distribution and location of bloodstain on a given surface [1–6]. BPA is a subjective field based on experience, and as with many other divisions within the field of forensics, BPA has also come under scrutiny in the American National Academy of Sciences (NAS) report [7,8]. According to the NAS report: "many sources of variability arise with the production of bloodstain patterns, and their interpretation is not nearly as straightforward as the process implies" [7, pp. 177]. Therefore, the future for

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forensic science is to improve and validate the scientific fundamentals for the various subdivisions. This is required to improve criminal proceedings, and for this to be beneficial more regulated, standardised, reliable and accurate methods and techniques are required.

Scene reconstructions from bloodstain patterns are based on the fact that blood behaviour can be predicted and reproduced, since blood is an elastic, non-Newtonian fluid and obeys fluid dynamic laws [2,9]. Unfortunately, this interpretation is not always possible due to complex scene conditions, environmental factors and target surfaces. Recent research has focused on the factors such as the angle at which droplets impact, distance travelled, their use in determining the area of impact and bloodstain relationships on various surfaces [8–18] and while substantial progress has been made, there are still some problems remaining.

Bloody clothing is a common occurrence at crime scenes and it is a reservoir of information about the crime. Yet little is known about how the blood interacts with, and the final appearance on, different fabric surfaces. A limited number of peer-reviewed studies have been conducted on bloody fabrics [e.g. 19–24], and mainly illustrate the complexity and highlight the limitation in conducting scientific experiments and the reporting requirements on this topic. These studies touched on the three mechanisms, which produce bloodstains: drip [19,21–24], transfer [19–21,23] and spatter [20,23]. Only a select few of these report the properties of the fabrics investigated [19,24] and mention the condition of the fabric: new [23], pre-washed [19,22–24], second hand [20,23], treated with Scotchgard™ [23] and follow the international standards for textiles prior to testing [19]. Due to these differences in methods and missing fabric information, it is difficult to relate them to each other and extract the necessary information for understand of this complex process.

BPA on a hard smooth surface is not straightforward (as mentioned above) and the additional obstacle of apparel, which is a complex material (e.g. absorbent, porous, permeable) results in difficulties in understanding blood/fabric interactions. The interactions of fabrics and liquids have been well studied in the field of textile science. Wetting occurs first, this is the process where the fabric-air interface is replaced by a fabric-liquid interface [25]. Secondly, wicking the process of liquid spreading through the porous substrate due to capillary forces, occurs [25]. The four categories of wicking of liquid are (i) wicking with no diffusion into the fibre surface, (ii) wicking accompanied by diffusion into the fibre or finish on the fibre, (iii) wicking accompanied by adsorption of a surfactant on fibres and (iv) all of the above (wicking accompanied by diffusion into the fibre or finish on the fibre and adsorption of a surfactant on fibres) [25].

Preliminary work on understanding the scientific fundamentals of the effects that fibre content, fabric structure and prior-laundering of apparel have on drip bloodstains will be discussed in this article. This was accomplished by performing a systematic study and quantitative analysis on the results obtained from digital images of dried bloodstains. This examination explores the relationship between drop velocity and (1) parent stain size, (2) number of satellite stains, (3) amount of laundering pre-bloodstain formation, and thereafter, the effects of fibre content (4) and fabric structure (5).

2. Materials and methods

2.1. Blood source

Fresh porcine blood was obtained from New Zealand chopper pigs (mass = 200–250 kg).[1] A passive, closed-system apparatus, which incorporated a hollow blood collection knife, was used to collect the blood [26]. Blood was mixed with 300 ml Fenwal anticoagulant citrate dextrose solution A (ACD-A; containing 24.5 g glucose, 22 g sodium citrate and 8 g citric acid)[2] per 2 l of blood. Blood was stored at 4 °C in a refrigerator for up to one week and gently mixed by hand, for 3–5 min daily to avoid excessive settling of the erythrocytes.

Table 1
The blood properties: mean refractive index of the plasma fraction and the mean packed cell volume, as measured before the experiment was executed on each days.

Days	Refractive index of plasma fraction (g/dL)		Packed cell volume (%)	
	Mean	S.D.[a]	Mean	S.D.
1	7.7	n/a[b]	41	0.01
2	7.7	n/a	42	0.02
3	7.7	0.06	43	0.01
4	7.7	0.07	42	n/a
5	7.5	n/a	45	0.01

[a] The variations within three repeated measurements.
[b] When samples had no variation among repeated measurements.

Packed cell volume (PCV; also known as haematocrit) is the ratio of the volume of packed red blood cells (RBCs) to the total sample volume. PCV (%) was measured by centrifugation of capillary tubes three quarters filled with blood, at 12,000 rpm for 4 min (Table 1).

The refractive index (RI) of the plasma fraction, used to measure plasma protein concentration (PPC), was determined using a handheld refractometer[3] after normalisation with distilled water (Table 1).

Haemolysis was visually and qualitatively assessed by recording the colour change of the plasma fraction of the centrifuged samples. The purity of the blood was visually inspected to identify any foreign material and/or the formation of macro blood clots.

2.2. Target surfaces

2.2.1. Apparel

Four fabrics commonly used to manufacture men's torso apparel were investigated: 100% cotton plain woven fabric (CO PW), 100% polyester plain woven fabric (PE PW), 65% polyester/35% cotton plain woven fabric (blend PW) and a 100% cotton single jersey knit fabric (CO SJ).[4] The properties (thickness, mass per unit area, sett count/stitch density and geometric roughness) of these fabrics are listed in Table 2. Knitted fabrics are generally more porous, absorbent and compliant than woven fabrics [27]. All fabrics were white to facilitate bloodstain imaging. Fabrics were domestically laundered for six cycles (L6; to produce dimensionally stable fabrics and to remove any finishing treatments, which could alter the appearance of bloodstains), 26 cycles (L26; representing one wash per week, for half a year) and 52 cycles (L52; representing one wash per week, for a year). To place the research in this paper in real-life scenarios, a domestic washing machine[5] was used for washing, according to BS EN ISO 6330:2012 [28]. Fabrics were washed using 40 °C water, a regular cycle, high level water, fast spinning speed and one full scoop of Persil® Active Clean[6]; the machine was a top loader as commonly used in New

[1] Freshpork NZ, Bay City Pacific Street, Timaru, New Zealand.

[2] Aurora Bioscience, Australia.
[3] ATAGO, Japan.
[4] These fabrics were not specifically manufactured to only have the variable of interested (fibre type or fabric structure) as the only different variable. Some characteristics (e.g. cover factor, thickness and mass per unit area) could be different and therefore could theoretically contribute to a difference in the bloodstain appearance. However, these are real fabrics that are used to manufacture clothing. These fabrics were purchased from the Fabric Magic, Trowbridge, United Kingdom or Ackroyd and Adams Ltd., Shortland Street, Auckland, New Zealand.
[5] Fisher and Paykel QuickSmartTM Clothes Washer, MW613, white, 6.5 kg maximum load.
[6] Top Loader, 2×, Unilever Australasia, New Zealand.