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Impact dynamics of porcine drip bloodstains on fabrics

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ABSTRACT

As a passive blood drop impacts a hard surface, it is observed to collapse and spread laterally, then retract and settle. During the spreading phase, the edge of the drop may rise forming a crown extending into spines and breaking up into secondary drops. When a similar drop falls onto a textile surface these same processes may occur, but the process of blood wicking into the fabric complicates stain formation. These processes are described within for passive drip stains collected under controlled conditions using anticoagulated porcine blood. Three stages of this impact process were identified and could be separated into distinct time zones: (1) spreading (time $t \leq 2.5$ ms) and (2) retraction ($2.5 \leq t \leq 12$ ms) on the surface with potential splashing at the periphery, and (3) wicking (30 ms $\leq t \leq$ 30 min) of the blood into the fabric. Although wetting and wicking may also occur for $t < 30$ ms, the vast majority of wetting and wicking occur after this time and thus the short-time wicking can be ignored. In addition, the number of satellite stains correlates with the surface roughness with the number of satellites for jersey knit > plain-woven > cardboard. Conversely, the size of the satellite stains correlates with the amount of wicking in the fabric with the satellite stain size for plain-woven > jersey knit > cardboard.

1. Manuscript

Bloodstains are observed at many violent crime scenes and proper analyses of these stains may assist the investigator in determining what happened; it may corroborate or refute a witness' or suspect's statements. The value of Bloodstain Pattern Analysis (BPA) is well documented in forensic literature [1,2] and its probative value is well known in courtrooms around the world. The increasingly stringent admissibility criteria for forensic evidence have caused the scientific underpinnings of BPA to be critically examined in recent years. As a result, BPA research has undergone resurgence with a particular focus on understanding the fluid dynamics of blood behavior external to the body [3,4]. The majority of studies has focused on bloodstains created on hard, non-porous and non-absorbent surfaces, and has established baselines for the blood drop impact phenomena.

Balthazard et al. [5] reported a systematic study of the effect of bloodstain formation in 1939. Although their study was primarily on cardboard, they included textiles in one set of experiments. They found that the stains depended not only on the impact characteristics, but also the structure of the fabrics and that they were often distorted. White [6] and Slemko [7] both observed passive bloodstains on fabrics to be similarly distorted, the latter attributing this behavior to fabric absorbency and texture. These authors both advised that analysts should not attempt to calculate angles of impact from bloodstains on textiles. Pex and Vaughan [8] reported that blood droplets resulting from simulated gunshot back spatter (<1 mm diameter) penetrated the yarns of a "lab coat" given sufficient impact velocity. Images provided by these authors, however, show that the drop did not penetrate significantly into the yarns but rather sat on top of and between them. The description of the fabric was that it was a "lab coat", but no other details were provided. Holbrook [9] reported blood volume to have a greater influence in determining stain characteristics than the mechanism of bloodshed. This study also found that transfer and spatter stains could mimic each other. De Castro et al. [10] performed a series of drip stain experiments on two fabrics, a rib knitted cotton and a woven cotton drill fabric, similar to denim. When 3–4 mm drops were dripped from heights of 500 mm to

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1500 mm giving impact velocities in the range 3.2–5.3 m/s, little difference was observed in the size of the resulting drip stain, perhaps reflecting the narrow ranges of drop size and impact velocity. However the number of spines around the parent stain and the number of satellite stains both increased with increasing impact velocity. They noticed that there were more satellite stains on the woven drill fabric than on the rib knit fabrics.

Miles et al. [11] compared drip bloodstains on a pair of 98% cotton denim jeans (a woven fabric) and a 95% cotton t-shirt (a single jersey knit fabric) with different surface roughness. Drop heights of between 500–2000 mm were used, but they did not specify the drop volume or size. They found that more satellite stains formed at greater impact velocities and on the rougher denim fabric. They attributed surface roughness differences to the fiber composition of the fabrics.

De Castro et al. [12] performed a similar set of experiments on a set of four fabrics: 100% cotton plain woven, 100% polyester plain woven, a blend of polyester and cotton plain woven, and 100% cotton single jersey knit. Drop diameter varied from 3.2 to 4.0 mm and impact velocities between 1.7 and 5.3 m/s were recorded. The effect of fabric structure, fiber type and laundering was assessed. They found that after six laundering cycles, the fabrics were stable and there was little additional effect on drip stain formation on the fabrics. The authors noted that drip stain sizes were significantly larger on the polyester/cotton blend plain woven fabrics than either the 100% cotton or 100% polyester and speculated that this was due to differences in inter-pore space giving rise to different wicking properties.

Extension of the above studies to other textiles is hindered due to the lack of precise descriptions of the fabric construction variables, such as yarn size and twist level, weave ends/cm and picks per cm, knit wales/cm and courses/cm, fabric weight, and so forth. Yet these fabric structural characteristics have been found to be important in the wetting of and wicking within textiles by liquids other than blood [13–15].

Surprisingly, to date, no comprehensive and fundamental research on bloodstain patterns on textile materials has been undertaken despite the fact that thousands of items of blood-stained clothing and other textile products are examined in forensic laboratories around the world every year. This may be due in part to the wide variety of textiles and their surface treatments. The interpretation of bloodstain patterns on textiles continues to be extremely challenging, ambiguous and often leading to misinterpretation. Bloodstains created on textile surfaces present a far more complex analytical problem for which significant new fundamental research is required.

In an attempt to systematically address the formation of bloodstains on textiles, the study presented below has been limited to two well-characterized fabrics and two types of experiments focused on the time evolution of drip stains. In the first type of experiments, the impact dynamics were examined while in the second type, the wicking behavior of the fabric was measured.

2. Materials and methodology

2.1. Blood

Porcine blood at room temperature was used in all experiments. For experiments focusing on the dynamics of drip stains (Type 1 experiments) described below, blood was collected from an abattoir using the method described by Williams et al. [16] and preserved using aqueous acid citrate dextrose (ACD) anticoagulant (12.5% of blood volume). Experiments were undertaken within two days of collection and blood was stored overnight in a refrigerator at 4 °C. Blood was removed from the refrigerator four hours before testing began and allowed to warm to room temperature. Blood was gently agitated for 10 min prior to each experimental set and kept on a magnetic stirrer throughout the duration of the experiment to maintain a homogeneous mixture.

For experiments focusing on wicking (Type 2 experiments), also described below, porcine blood was obtained from Lee BioSolutions Incorporated (St. Louis, MO, USA) and stored at 2–8 °C. Prior to use, the blood was removed from the refrigerator and placed on a Fisher Scientific™ Digital Bottle Roller and rolled at 30 rpm for 30 min to re-disperse any erythrocytes that may have settled overnight. When the blood warmed to room temperature, it was ready for use.

2.2. Fabrics

Two types of 100% cotton fabrics were used. The first was a plain-woven bleached cotton bed sheeting fabric with optical brightener, product code 439XW (Test Fabrics, Inc., West Pittston, PA, USA) with 51.2 end-per-centimeter (epcm, 130 epi, ends per inch) consisting of Ne40s ring spun warp yarns with 9.9 turns/cm (25 turns/in, 25 tpi) by 27.6 picks-per-centimeter (ppcm, 70 ppi, picks-per-inch) consisting of air jet Ne43 spun weft yarn. The fabric basis weight was 120 g/m^2. The second fabric was a jersey knit fabric (T-shirt material) with 17.3 course-per-centimeter (cpcm, 44 cpi, courses per inch) and 12.6 wales-per-centimeter (wpcm, 32 wpi, wales per inch), i.e. 44 cpi × 32 wpi (Test Fabrics, Inc., product code 437-60). The yarn used in this fabric was a Ne 30s ring spun yarn with 8.7 tpcm (22 tpi) and the fabric basis weight was 124 g/m^2. Each fabric was washed 10 times according to AATCC Monograph M7 standard [17] to remove any surface contamination and ironed prior to use to remove wrinkles, which were found in preliminary experiments to distort the stains.

3. Type 1 experiments – drip stain dynamics

For drip stain dynamics studies, fabrics were cut into 100 mm × 100 mm squares, mounted on A4 or A3 sheets of paper, and stapled to white cardboard. These targets were positioned parallel to the ground and imaged by two high-speed video cameras. An image of a ruler was captured simultaneously to calibrate the images. A piece of the white cardboard test surface was also used for comparison purposes.

Two blood droplet sizes ('small', approximately 2.6 mm diameter i.e. 9.2 μL, and 'large', approximately 5 mm diameter, i.e. 65 μL) were dropped from a height of 500 mm using an Eppendorf Xplorer 200 μL motorized pipette with a dispensing speed of 7 resulting in drop impact velocities of 3.0–3.1 m/s. A Labcon specialty pipette-tip (catalogue number 1039-800) was used to dispense the small drops with a set point dispensing volume of 20 μL, which resulted in the 2.6 mm diameter drops observed. The large drops were produced by cutting 20 mm off the dispensing end of the pipette tip and setting the dispensing volume to 70 μL. High speed video showed that there were no accompanying drops. A new pipette tip was used for each test. This gave droplets with impact Reynolds numbers of between 1730 (small drops) and 3600 (large drops) and impact Weber numbers of between 360 (small) and 810 (large) assuming blood viscosity of 4.5 mPa s and surface tension of 62 mN/m.

The two high speed video cameras were arranged such that one camera (Photron SA1), positioned at right angles to the falling drop trajectory, was used to measure the drop size and velocity; the other (Photron SA-X2) was positioned at 45° to the target surface to capture the stain formation and evolution. The camera settings are given in Table 1.

Time evolution of drip stains of porcine blood drops of 3.2 mm (17 μL) and 3.8 mm (30 μL) diameter was determined by allowing