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Quantitative bloodstain analysis: Differentiation of contact transfer patterns versus spatter patterns on fabric via microscopic inspection

Yuen Cho [a], Faye Springer [b], Frederic A. Tulleners [a], William D. Ristenpart [a,c,*]

[a] *Forensic Science Graduate Group, University of California Davis, Davis, CA 95616, USA*
[b] *Sacramento County Laboratory of Forensic Science, Sacramento, CA 95820, USA*
[c] *Department of Chemical Engineering & Materials Science, University of California Davis, Davis, CA 95616, USA*

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ABSTRACT

In crime scene reconstruction, it is often necessary to differentiate "contact transfer" and "spatter" bloodstain patterns found on clothing. Current methodologies, however, are qualitative and prone to context bias. In this work, we demonstrate that microscopic inspection of the stain orientations provides a quantitative differentiation of bloodstains resulting from spatter versus contact transfer. Specifically, common knitted fabrics are comprised of parallel rows of *left loop legs*, in an upward diagonal orientation (/), and *right loop legs* in a downward diagonal orientation (\). Our microscopic examination of more than 65,000 individual stained loop legs shows that spatter stains are approximately evenly distributed between left and right loop legs, but contact transfer stains are unevenly distributed: depending on the type of surface contacted, as many as 82% of the stains were preferentially located on the *left loop legs*. We further show that in these fabrics the *left loop legs* protrude further out than the *right loop legs* by approximately 50 μm, indicating that the observation of *left loop legs* preferentially stained over *right loop legs* is associated with the topography of the fabric. These findings suggest that microscopic quantification of the relative loop leg stain distributions could provide an objective means of differentiating contact transfer versus spatter patterns in crime scene reconstruction.

1. Introduction

A correct distinction between bloodstain patterns formed by "contact transfer" and "spatter" can be essential for the accurate reconstruction of events at crime scene where such bloodstain patterns are found. The Scientific Working Group on Bloodstain Pattern Analysis (SWGSTAIN) defines a transfer stain as "a bloodstain resulting from contact between a blood-bearing surface and another surface", whereas spatter stain is defined as "a bloodstain resulting from a blood drop dispersed through the air due to an external force applied to a source of liquid blood" [1]. Although these definitions are clear, the differentiation between them is challenging, especially when the bloodstain is on fabric. As currently practiced, the interpretations of bloodstain patterns by bloodstain pattern analysts are mostly based upon the experience level of the analysts and the qualitative characteristics of the bloodstain patterns. Because of the analysts' subjective analysis of bloodstain patterns found at the crime scene, however, experts often provide different interpretations of the same bloodstain pattern evidence. For example, in *Indiana v. Camm* [2] the state called four expert witnesses, all of whom testified that some of the bloodstains on the defendant's shirt were the result of high-velocity impact spatter. In contrast, the defense called their own four bloodstain analysis expert witnesses, and these four experts testified that all of the bloodstains on the defendant's shirt resulted from contact transfer. A similar example occurred in the Supreme Court of California case *People v. McWhorter* [3], in which the experts called upon to testify by the prosecution and defense had different interpretations of the bloodstains found on a paper towel collected at the crime scene: the defense expert said the stains were "expectorated" (nasal blowing pattern) whereas the prosecutor's criminalist said the bloodstains were transfer stains. Summing matters up, the National Research Council stated in their recent report that the interpretations of bloodstain pattern analysts "are more subjective than scientific" [4].

A key reason for the subjectivity is the lack of quantitative methods for characterizing bloodstains on fabrics. Arguably the

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[*] Corresponding author at: Department of Chemical Engineering & Materials Science, University of California Davis, Davis, CA 95616, USA. Tel.: +1 530 752 8780.
E-mail address: wdristenpart@ucdavis.edu (W.D. Ristenpart).

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most well-known quantitative methodology in bloodstain pattern analysis is the determination of point-of-origin via triangulation (cf. Refs. [5,6]), a methodology which depends on understanding the complicated physics of drops in flight [7]. This approach does not help, however, in the differentiation of spatter versus contact transfer on fabrics. Previous research specifically on bloodstains located on fabrics has focused primarily on individual drops impacting various types of fabrics at different angles and velocities. Karger et al. investigated and characterized the differences between contact and "dynamic" (spatter) stains on three common types of fabric [8]. They found that individual millimeter scale dynamic stains tended to: (i) be more symmetric, (ii) yield more 'secondary droplets' (presumably from splashing), and (iii) appear darker overall because they tended to lie closer to the fabric surface. In contrast, individual millimeter scale contact transfer stains tended to be asymmetric, lack secondary droplets, and were paler in color. Although Karger's observations provide approximate guidelines for distinguishing contact transfer and dynamic stains, the guidelines are qualitative: for example, different experts can argue about how "symmetric" a stain appears. More recently, Holbrook examined bloodstains on a wider range of fabrics and found that certain fabric characteristics, such as composition and absorbency, appear to be factors for the appearance of bloodstains on clothing materials [9]. This work also suggested that the shape of the stains appeared to be associated with their overall size. Stains that were smaller than the width of a single thread tended to retain highly circular shapes, whereas stains that were wide enough to cover multiple threads were more distorted. Again, however, these characterizations are qualitative and thus subject to debate amongst analysts. Clearly, quantitative characteristics that can serve as objective guidelines for differentiating spatter stains and transfer stains are needed.

The objective of this study is to develop a quantitative methodology to differentiate contact transfer from spatter bloodstain patterns on the face side of common knitted fabrics. We focus here on microscopic examination of bloodstains on the "stockinette" knitting pattern, which is ubiquitous in modern mass produced clothing (e.g., T-shirts, polo shirts, etc.) Stockinette patterns involve stitch loops of yarn repeated throughout the fabric [10]; each loop contains a loop head, two loop legs and the loop feet (Fig. 1a). Importantly, on the face side (i.e., on the side of the fabric typically worn away from the body) the loop legs are apparent as parallel rows of alternate opposing orientations, upward diagonal (/) and downward diagonal (\), cf. Fig. 1b. *The key finding in this work is that blood preferentially absorbs into the upward diagonal (left) loop legs during contact transfer, whereas spatter is more evenly distributed between the two orientations.* We further show via confocal microscopy that the upward diagonal (left) loop legs protrude further outward by about 50 μm compared to the downward diagonal (right) loop legs, indicating that the fabric topography determines the preferential absorption during contact transfer. The results point toward an objective and quantitative means of differentiating contact transfer and spatter on fabrics that contain similar topographical asymmetries.

2. Study design and methodology

2.1. Materials and methods

Porcine (pig) blood, obtained from freshly killed pigs at the Animal Science meat lab on the UC Davis campus, was used for all experiments in this study. Standard BD EDTA tubes (ethylenediaminetetraacetic acid) were used as anticoagulant containers. The blood samples were stored in a refrigerator at 4 °C shortly after collection from the pigs.

All blood was used within 1–5 days from collection date. Prior to an experiment, the blood samples were warmed up to human body temperature (37 °C) in a circulating water bath for 30–45 min. The blood was then transferred to a pre-warmed atomizer (a standard perfume bottle) and left in the water bath for another 15–20 min until the experiments were performed. The temperature of the water bath was monitored to ensure the temperature was kept constant throughout the experiments.

The fabrics were purchased from a local clothing store as white T-shirts. Two fabric materials were tested: 100% cotton and 50% cotton/50% polyester. White fabrics were chosen to simplify visualization of the blood. The stockinette weaving of the two fabrics was verified via microscopic examination to follow the same pattern.

The fabrics were stained with the blood in two distinct manners (Fig. 2). For the "spatter" patterns (Fig. 2a each stain pattern was formed by a single spray of the atomizer directly onto the fabric. The atomizer was held approximately 10 cm above from the fabric surface, which was placed horizontally on a bench surface in lab. Ten replicates of this procedure were performed with both types of fabric (20 trials in total).

In contrast, the contact transfer bloodstain patterns were generated by first spraying the blood onto a "donor" surface (Fig. 2b). The blood was sprayed from the atomizer in an identical fashion as in the spatter replicates (10 cm above the horizontal donor surface). Two types of donor surfaces were tested: leather, to represent a more pliable surface comparable to human skin, and glass, to represent a rigid and smooth surface. Immediately after spraying the blood onto the donor surface, the fabric of interest was then pressed by hand onto the donor surface to transfer the blood via direct contact. Similarly, we performed 10 replicates of

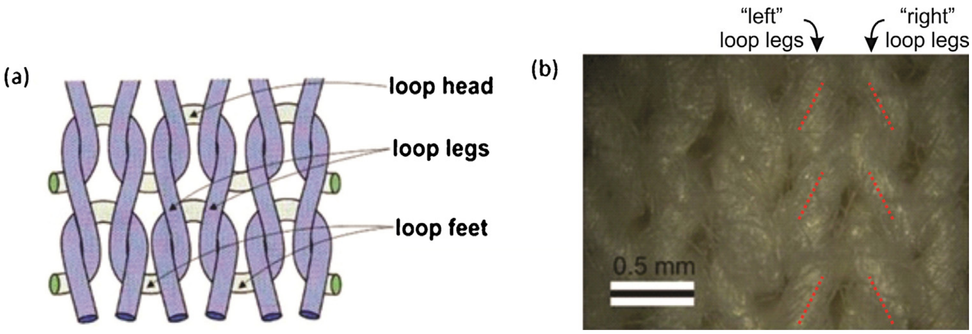

Fig. 1. (a) A schematic diagram in the Stockinette knitting pattern, as viewed from the face side of the fabric. Note that loop legs sit above the neighboring stitch, and that each row appears as a series of alternating loop leg with opposing orientation. Reproduced from reference [10]. (b) Photograph of the face side of 100% cotton plain fabric. Note that only the loop legs, of left or right orientation, are clearly visible. Red dashed lines are superimposed to guide the eye. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)