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REVIEW ARTICLE

ADVANCEMENT IN BLOODSTAIN PATTERN ANALYSIS: BENEFITS AND OBSTACLES

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ABSTRACT

Different types of blood patternare found at the scene of violent crimes. Within the discipline of forensic science, bloodstain pattern analysis uses blood evidence to draw conclusions about criminal activity. Bloodstains' form and convergence can be used to determine the homicide. Identifying the weapon and the attack's place of origin is essential when examining witness accounts. On the other hand, analyst error can occasionally lead to incorrect findings. This review will cover the methods used to identify and categorize blood as well as several variables that could influence how blood looks. We will talk about both new and developing classification techniques. The examination of blood patterns may become a more trustworthy field of forensic science with further research into analytical techniques.

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INTRODUCTION

One of the bodily fluids that forensic scientists come across the most frequently is blood, especially when it comes to violent crimes. (4). Because evidence of blood can confirm or deny a witness's account of events, it is crucial in criminal investigation. Blood can also be used to build a DNA profile that matches the victim or suspect because it contains a lot of DNAs because of this, blood detection methods that preserve genetic information are essential. Forensic science is based on physical evidence, which is the most important component (1). Any of the various physical evidence types that may be found at a crime scene could play a significant role in the investigation. The most common type of evidence is blood, especially in severe crimes like murder and assault. Documents, glass, fibers, hair, paint, fingerprints, blood, tool marks, etc. are other kinds of evidence that are commonly found. Blood can appear as stains, pools, prints, spatter, and other forms. Finding blood on light-colored objects is frequently a fairly simple procedure. However, because blood darkens over time, it is much more difficult to see bloodstains on dark objects because of the lack of contrast, especially with older stains (1).

Advances in Blood Detection and Forensic Testing methods: Blood detection and analysis is used to identify bloodstains at crime scenes and examine them. Among the methods are chemical, luminol, and fluorescence tests, among others. Luminol reacts with hemoglobin and glows blue in dim light (1). Fluorescein fluoresces in ultraviolet light. The Kastle-Meyer and Leucomalachite Green tests are presumptive tests showing the presence of blood by color change. More advanced techniques can confirm its presence, such as DNA analysis and immunological tests. Effective methods are plagued by false positives and degradation over time, so the forensic expert must carefully interpret results in criminal investigations.

Classification of Bloodstain in Crime Scene Investigation: BPA is a useful investigative method in the determination of bloodshed events at crime scenes which is of great importance to the forensic experts. Bloodstains are identified based on the way they are deposited and the forces that are acting on them. The leading groups of bloodstains include passive stains, transfer stains, and projected (impact) stains. And the peculiar thing about each type is that it can do two things - regarding the type of the crime, it can give us clear indications of itand the interaction of people.

Key factors Influencing Bloodstain Patterns in Forensic Analysis: In reconstructing crime scenes, blood stains can be useful to forensic investigators. Often, blood is used to establish when a crime was committed. However, interpretations can be challenging due to a variety of factors.

Table 1. Different Blood Detection Method.

Chemical-Based Tests	Luminol and Fluorescein-based Tests	Confirmatory Blood Tests
Kastle-Meyer Tests(phenolphthalein Test) • Uses phenolphthalein and hydrogen peroxide. • If there is a blood, the teststurnspink. • May react with other substances(e.g. vegetables) to give false positive results.	**Luminol Tests** • Sprayed on suspect area glows blue when blood present. • Detects very diluted blood, but can be affected by bleach or other chemicals.	**Teichmann and Takayama Crystal Tests** • Chemical reagents that form microscopic heme crystals if blood is present. • Effective but not commonly used in modern forensics.
Leucomalachite Green (LMG) Test • Like Kastle-Meyer test, LMG becomes green in presence of blood. • More sensitive but also suspectable to false positive.	**Fluorescein Test** • Reacts with hemoglobin and fluoresces under UV light. • Less sensitive to environmental factors compared to luminol.	**Immunological Tests** (serological Tests) • RSID:(Rapid stain identification tests)-identifies human hemoglobin.

Table 2. Classification of Bloodstains

Passive Bloodstain	Transfer bloodstain	Miscellaneous Bloodstains
• Drip Stain: Produced when blood falls, gravity-driven, straight onto a surface. The surface's texture and impact angle determine the form. Long stains imply an angled impact, whereas a round form denotes a 90-degree descent. • Pooling Blood: Forms when a large quantity of blood accumulates in one location. Indicates prolonged bleeding from a stationary victim. • Saturation Stains: Form when blood soaks into absorbent materials like fabric, carpet, or bedding. It can indicate where the victim rested	• Contact Patterns: Created when a blood-covered object touches another surface. It can reveal the shape and texture of the object for e.g, fingerprints, handprints, shoe prints. • Swipe Patterns: It forms when a blood-covered object moves across a clean surface. It can indicate the movement direction based on the smear pattern. • Wipe patterns: Occur when an object moves through an existing bloodstain,	• Drip trails: A series of droplets indicating movement from a bleeding individual. It can help to track victim or suspect movements at the crime scene. • Insect stains: Bloodstains created by insects feeding on blood and then regurgitating or defecating. It can be mistaken for true spatter but show irregular patterns upon close examination. • Serum separation stains: It occurs when the liquid portion of blood separates from clotted

Environmental Factors: The drying times of blood droplets at humidity levels below 60% were not significantly impacted by changes in relative humidity from 16 to 93% in one study (8). At humidity levels exceeding 60%, the drying times were notably affected due to the challenges associated with evaporation in high humidity conditions (8). Furthermore, a separate study revealed that the evaporation rate of blood droplets decreased as the relative humidity increased from 12% to 66.5% (9). The report found that crack formation and bloodmorphology changed with relative humidity (9). It is clear from comparing the two studies that relative humidity has a direct effect on blood drying. Ramen spectroscopy was used in one study to accurately identify bloodstains that were up to a week old. It is difficult to estimate drying times due to several factors like temperature, humidity, how quickly blood spreads on various surfaces, and the size of the pool (10). Moreover, blood loss may become more complicated if it permeates your hair or carpet.

Health Factors: Ultimately, drying rates can also be affected by health-related issues (2). Anticoagulants can lead to blood cells accumulating in a pool by disrupting clotting processes, which prolongs drying times (2). Consequently, it is crucial for the forensic pathologist to inform blood spatter analysts about any medical conditions the victim may have experienced. Furthermore, due to the fine mist produced by expired blood, it is often confused with high-velocity impact spatter (3). When injuries occur to the mouth, throat, or lungs, blood is expelled (2)(3). These resemblances occasionally necessitate saliva testing to determine if the blood was exhaled (3).

Accuracy and Reliability in Bloodstain Pattern Analysis: The role of Computerized Methods: Precise scientists play a crucial role in forensic science, as their expertise is vital for producing reliable outcomes. But human error cannot be prevented (1). Consequently, forensic science is beginning to explore automated methods. In a particular study for example, 20% of blood pattern analysts failed to accurately identify a blood spatter (17). Nevertheless, most of the analysts who made errors were inexperienced and had insufficient training and practical experience in bloodstain pattern analysis (1). When there are overlapping stains at the crime scene that make it difficult to discern between them, mistakes are frequently made when recognizing blood spatter evidence. Blood spatter manifested in several distinct forms, such as low-velocity droplets and streaks resulting from dragging, arterial sprays caused by decapitation, and high-velocity impact splatter produced by gunfire. Blood spatter is separated into local and globular features using an image processing technique in one study, and these features are given quantitative data (11).

Statistics could be used to swiftly differentiate between bloodstain patterns in the future, but more blood spatter kinds need to be studied. Another technique for capturing precise and improved crime scene images for analysts to review is multi-resolution 3D scanning (11). This approach is expensive and takes a long time to process data. Bloodstains are not only hard to classify, but they can also be hard to trace back to their source. The traditional method is stringing, which involves putting a string and a marking in the middle of each bloodstain. The linked thread is then tilted in the direction where the blood originated using trigonometry (1). The laborious procedure of stringing presents issues with spurious areas of convergence. Another technique used by analysts to identify regions of bloodstain convergence is directional analysis. To improve the current method, one study used a method (trimmed) bloodstain mean and compared it with two others: the arithmetic means and the ransac mean. The results were not improved by analysts choosing the stains, but the modified mean was the best way to identify the region of convergence for random stains (12). One Because it demonstrated the accuracy of the directional analytic techniques now in use, this experiment was essential. Overall, the automation of many techniques is enhancing blood spatter analysis (6).

CONCLUSION

The accuracy and reliability in Bloodstain Pattern Analysis (BPA) have greatly increased because of recent developments. More modern technology, which includes machine learning, complex fluid dynamics modeling, and high-definition 3D imaging, enables explanations of blood patterns that are so much more scientific than they used to be. This means that crime scenes can be reconstructed, establishing a timeline of events and presenting critical evidence in court cases. The introduction of improved scientific techniques will ensure greater objectivity with respect to BPA, while minimizing human error that would legitimize the evidence in the eyes of the court. The area has also grown through interdisciplinary collaborations among forensic scientists, engineers, and physicians that have enhanced understanding on the behavior of blood in several conditions. Yet there are some challenges. Bloodstain patterns are still greatly variable on the one hand: namely, with respect to environmental variables.

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