



Application of bloodstain pattern analysis (BPA) to reconstruct a staged crime scene in a complex forensic case

Matteo Antonio Sacco, Saverio Gualtieri, Aurora Princi, Roberto Raffaele, Isabella Aquila ^{*} 

Institute of Legal Medicine, Department of Medical and Surgical Sciences, "Magna Graecia" University of Catanzaro, 88100, Catanzaro, Italy

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ABSTRACT

Bloodstain Pattern Analysis (BPA) constitutes a critical component of modern forensic science, particularly in complex crime scenes where the physical evidence may be manipulated or misinterpreted. This manuscript presents a detailed reconstruction of a residential scene initially suspected to be the site of a violent homicide. Despite extensive blood distribution across multiple rooms, forensic investigation revealed that the injuries sustained were superficial and incompatible with the volume and morphology of the bloodstains observed. A systematic application of BPA, revealed patterns predominantly consistent with passive and transfer mechanisms. Specific attention was given to void patterns—unstained areas interrupting otherwise continuous blood distributions—which were geometrically consistent with object repositioning and indicative of post-event manipulation. Integration of BPA with clinical wound assessment, genetic profiling, and contextual behavioral analysis allowed investigators to identify the scene as staged. High-resolution photographic documentation played a pivotal role in the accurate characterization of the bloodstains, enabling precise evaluation of stain edges, distribution, and mechanisms of deposition. This case underscores the necessity of interdisciplinary collaboration and adherence to updated forensic standards to avoid investigative misdirection and ensure the integrity of crime scene interpretation.

1. Introduction

Bloodstain Pattern Analysis (BPA) is increasingly recognized as a cornerstone in forensic scene reconstruction. It involves a meticulous examination of bloodstains to determine the physical events that generated them. These patterns provide insight not only into the nature and force of the actions involved but also into the sequence and spatial relationships of the individuals present. BPA has evolved with contributions from fluid dynamics, biomechanics, and forensic pathology, resulting in a refined toolset capable of resolving highly ambiguous cases [1–6].

From a methodological standpoint, BPA integrates elements of physics, biology, and materials science, offering a scientific basis for interpreting bloodstain morphology. This integration allows forensic analysts to reconstruct scenarios with an impressive degree of accuracy, particularly when stains vary in size, directionality, and distribution. However, the reliability of such reconstructions depends on multiple factors, including surface texture, blood viscosity, deposition mechanism, and environmental conditions at the time of stain formation.

These considerations highlight the importance of standardized protocols, updated terminological frameworks, and advanced training for analysts involved in scene interpretation.

The potential for misinterpretation of blood evidence is particularly pronounced in cases where the crime scene spans multiple rooms, or where misleading elements such as object displacement and inconsistent testimonies are present. Complications further arise in the absence of a victim or when observable injuries do not correspond to the volume or nature of blood deposition. A further confounding factor is the possibility of behavioral staging, in which individuals intentionally manipulate the environment to mislead investigators. In such scenarios, the presence of specific spatial features—such as voids interrupting otherwise continuous blood patterns—can provide critical indicators of post-event manipulation and scene tampering. Even highly trained professionals may be vulnerable to cognitive biases that cloud objective interpretation if such features are overlooked.

Recent advancements in digital forensics and three-dimensional scene reconstruction tools have enhanced BPA's capacity to accurately map blood distribution and trajectory. These tools, when combined with

^{*} Corresponding author.

E-mail address: isabella.aquila@unicz.it (I. Aquila).

traditional methods, enable more comprehensive and nuanced analyses of complex scenes. Additionally, the integration of BPA with other forensic disciplines—such as DNA profiling, toxicology, clinical assessment, and behavioral psychology—can yield a multidimensional understanding of the events leading to bloodshed. Such a holistic approach is essential in ensuring that conclusions drawn from BPA are both scientifically valid and judicially defensible [7–18].

This paper details a case in which a seemingly violent domestic event, initially presumed to be a homicide, was proven to be staged. The investigation benefited from systematic BPA application, strategic sampling for DNA analysis, high-resolution photographic documentation, and a multidisciplinary interpretative framework. Particular emphasis was placed on the identification of void patterns and the integration of findings across clinical, genetic, and spatial domains. Through this case study, we propose best-practice guidelines for similar forensic evaluations, advocating for a meticulous, evidence-based, and interdisciplinary approach to bloodstain interpretation.

2. Materials and methods

A multidisciplinary and protocol-driven approach was employed to ensure the integrity, repeatability, and scientific rigor of the forensic investigation. Following the emergency call and subsequent hospital admission of the subject, a forensic medical team conducted a detailed physical examination. This included wound morphology documentation using high-resolution macro photography and measurement tools to accurately determine wound depth, length, and orientation. Any signs of coagulation, wound age, and signs of manipulation or re-opening were also recorded.

Simultaneously, a forensic scene team initiated a thorough judicial inspection of the residence. The entire premises were systematically segmented into zones using a predefined room grid reference system, and each zone was evaluated individually to ensure methodological consistency. All visible and enhanced bloodstains were categorized by mechanism of formation (e.g., passive drops, projected stains, swipe and wipe patterns), morphology, and spatial relationships, in accordance with the definitions provided in the literature [19]. Each stain was documented through high-resolution digital imaging, allowing precise analysis of stain boundaries, directionality, and droplet characteristics. Particular focus was placed on identifying void patterns—absence of stains indicating object removal or interference—and on cross-referencing these with furniture impressions and inventory placement.

Swab samples were collected from bloodstains in each room using sterile dual-tipped cotton swabs, stored in temperature-controlled evidence containers, and transported under strict chain-of-custody protocols to the molecular biology lab. DNA was extracted using silica-membrane technology and quantified using real-time PCR. Resulting DNA profiles were compared against the subject's reference buccal swab to confirm identity of the biological material.

Environmental data, including ambient temperature, humidity, and ventilation conditions, were recorded to account for potential degradation of blood evidence and to interpret drying times and fluid dynamics. This methodological framework ensured that the conclusions drawn from the scene investigation were grounded in reproducible, standardized scientific techniques suitable for presentation in judicial proceedings.

3. Case report

In the summer of the investigation year, emergency medical services were dispatched to a suburban residence following a distress call made by a young adult male reporting a suicide attempt. Upon arrival at the scene, the responders found the subject with a visible laceration on the dorsal aspect of his left hand. The wound was bleeding minimally at the time of intervention. The subject was fully conscious, cooperative, and

communicative. He informed the medical team that the injury was self-inflicted.

Upon entry into the residence, first responders observed an extensive presence of blood traces throughout the ground and upper floors. The upper floor comprised a master bedroom and a bathroom, both heavily contaminated with blood. The connecting stairwell also exhibited numerous blood patterns, including drips, smears, and apparent transfer marks consistent with foot traffic through blood-contaminated areas.

Emergency personnel noted that the scene appeared disproportionate to the single lesion observed on the subject's hand. The blood traces were numerous and distributed across multiple surfaces, including walls, floors, and furniture. A lack of additional physical trauma on the subject's body raised concerns regarding the origin and dynamics of the blood patterns.

Given the unusual presentation and the possibility of a violent event, the subject was transported to the emergency department for further clinical evaluation, and law enforcement was immediately notified. The subject's partner, who was reported to reside at the same address, was not present and could not be contacted at the time.

4. Results

4.1. Clinical examination

Clinical examinations confirmed that the subject presented with a single superficial wound located on the dorsal surface of the left hand. The lesion exhibited characteristics consistent with an incised wound, with sharp, clean edges, and partial epithelialization. No signs of coagulopathy, excessive bleeding, or secondary trauma were identified during the medical assessment. Vital parameters were within normal limits, and the subject's mental status was alert and stable.

4.2. Blood transfer patterns – stairwell

In the stairwell, investigators documented a sequence of blood transfer marks consistent with foot traffic. These patterns included heel-to-toe impressions and parallel smears consistent with bilateral gait (Fig. 1A and B). Additional vertical drip patterns were visible on the stair risers, exhibiting consistent roundness and angularity indicative of passive gravitational drops, rather than dynamic bloodshed resulting from a violent act. The stain edges were well defined, with no satellite spatter or radiating dispersion, supporting a low-energy deposition mechanism.

4.3. Bloodstain mapping – master bedroom

The forensic inspection of the residence yielded a comprehensive bloodstain map across the two floors. The master bedroom exhibited large surface areas covered in dried blood, including the bed, floor, wardrobe base, and surrounding walls. A particularly dense concentration of stains was observed on the floor in front of the bed, extending laterally toward the wall-mounted mirror and adjacent sofa (Fig. 2A, 2B, 2C and 2D). Notably, large voids—defined as unstained regions interrupting otherwise continuous blood patterns—were identified around the bases of several furniture items, suggesting their repositioning after the deposition of blood (Fig. 3A and B). These voids were geometrically coherent with known dimensions of objects found in the room, reinforcing the hypothesis of a staged rearrangement.

4.4. Stains in the bathroom

In the bathroom, blood was identified on the door frame, basin rim, faucet handles, and floor tiles. The stain morphology in this room was predominantly composed of swipe patterns and fine vertical drips (Fig. 3C and D). No stains consistent with projected mechanisms—such as atomized spatter from dynamic impact or arterial projection—were



Fig. 1A. Access door to the house; transfer pattern of unidentifiable origin.



Fig. 1B. Access staircase to the house; Multiple transfer patterns from shoe soles.

observed. Several containers recovered from a kitchen cupboard were found to contain dried blood residues. These included both glass and plastic bottles. The nature of the stains and the lack of directional features suggested controlled deposition rather than spontaneous dispersal.

4.5. Interpretation of scene findings

All findings collectively pointed to a single biological origin for the blood present at the scene. The distribution pattern lacked coherence with a scenario involving an active external aggressor or multiple injuries. The morphological features of the stains—characterized by passive drip trails, contact transfers, and void interruptions—combined with the preserved samples and blood-filled containers, suggested deliberate collection, storage, and dispersion of the subject's blood in a manner simulating a complex violent event.

4.6. Genetic analysis

Buccal swabs collected from the subject were processed for DNA profiling and served as the reference standard in the comparison of biological samples gathered at the crime scene. Short Tandem Repeat (STR) profiling was performed on all bloodstains sampled from the various rooms within the residence. The results demonstrated a full match between the subject's DNA and all tested stains, with no evidence of mixed profiles or third-party contributors.



Fig. 2A. Double bedroom; dripping of drops of blood by gravity.



Fig. 2B. Void pattern corresponding to the photograph of the couple.



Fig. 2C. Double bedroom; voids at the sofa.



Fig. 2D. Double bedroom; voids near the wardrobe.



Fig. 3A. Wall of the room; fine mist-like pattern suggestive of dynamic dispersal.



Fig. 3B. Double bedroom; swab sampling of blood stains on the wardrobe.

5. Discussion

This case underscores the critical importance of a multidisciplinary approach in the forensic interpretation of complex bloodstained environments. The integration of clinical assessment, molecular genetics, and Bloodstain Pattern Analysis (BPA) revealed a highly controlled and intentional simulation of a violent event [20–25]. Among the most diagnostically significant features identified during the scene investigation were void patterns.

Void patterns—defined as unstained areas interrupting otherwise continuous bloodstains—suggest that an object or person was present during blood deposition but was subsequently removed. These patterns are essential in scene reconstruction, as they not only indicate obstruction during the deposition event but can also reveal staged manipulation when the void geometry corresponds precisely with displaced furniture or household objects. In the present case, voids observed around the bed,

wardrobe, and adjacent sofa were geometrically consistent with the dimensions of those items, suggesting their movement after blood had been deposited. The interpretation of voids must be considered alongside the morphology and spatial distribution of bloodstains.

The blood patterns across the bedroom, stairwell, and bathroom were predominantly consistent with passive and transfer mechanisms—gravitational drips, swipe marks, and foot impressions—without



Fig. 3C. Entrance door to the bathroom; swipe pattern.



Fig. 3D. Bathroom sink; bloodstains from vertical fall due to gravity.

any indications of projected or atomized mechanisms such as mist-like patterns from dynamic events or blood dispersed by arterial injury. According to ASB Technical Report 033 (1st Edition, 2017), bloodstain descriptors should reflect mechanisms of formation rather than velocity, and the present case did not exhibit any stain characteristics suggestive of forceful projection or high-energy events [19].

The absence of projected or radiating stains, combined with the uniformity and saturation of blood distribution, supports the hypothesis of blood being deliberately poured, transferred, or manipulated. The presence of well-defined transfer marks, drip trails consistent with low-angle deposition, and the lack of directional satellite patterns typically associated with dynamic events indicate that the stains were not the result of a sudden or forceful act of violence.

STR analysis confirmed the mono-origin of the blood, establishing conclusively that all samples matched the subject's DNA profile. The recovery of blood in household containers strongly suggests that the subject had collected and stored his own blood over time, later redistributing it to fabricate a traumatic event. These findings, when assessed in light of the clinical characteristics of the wound and the psychological context of the subject, support the conclusion that the event was staged.

This scenario demonstrates the dangers of relying solely on the apparent visual complexity of a scene without integrating scientific analysis. Blood saturation across multiple rooms may superficially suggest a brutal altercation, yet BPA—when applied rigorously and with adherence to current standards—can dismantle such illusions. The presence of voids in particular serves not only as a physical clue but also as a psychological fingerprint of the manipulator's interaction with the

environment.

It is imperative for forensic teams to be trained in the identification and interpretation of such patterns. Moreover, BPA must be performed in conjunction with high-quality photographic documentation, including high-resolution macro photography that allows for precise evaluation of stain edges, droplet characteristics, and distribution. Environmental conditions such as temperature, humidity, and air flow must also be recorded, as they influence drying times and blood behavior on various surfaces. Only through such a comprehensive and scientifically grounded strategy can investigators distinguish genuine scenes of violence from carefully crafted simulations designed to mislead authorities and provoke specific emotional or legal responses.

This case thus contributes to the growing recognition of voids as critical markers in forensic pattern analysis, particularly in staged scenarios. It reinforces the value of integrating behavioral context with physical evidence and affirms the necessity of multidisciplinary analysis in reaching valid forensic conclusions.

6. Conclusions

This case demonstrates the effectiveness of a multidisciplinary forensic approach in identifying staged crime scenes. The combined use of BPA, DNA profiling, and clinical evaluation was essential in revealing that the scene was fabricated. Void patterns were key in recognizing object displacement and post-event manipulation. Their presence, along with uniform bloodstains and stored blood matching the subject's DNA, supported the conclusion of a deliberate simulation. These findings highlight the importance of integrating technical BPA skills with contextual analysis to detect falsified scenarios. Proper training and cross-disciplinary collaboration remain crucial for accurate crime scene reconstruction and reliable forensic outcomes.

CRedit authorship contribution statement

Matteo Antonio Sacco: Investigation. **Saverio Gualtieri:** Data curation. **Aurora Princi:** Formal analysis. **Roberto Raffaele:** Writing – original draft. **Isabella Aquila:** Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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