A Comparative Study of Bloodstain Patterns on Different Porous and Non – Porous Surfaces

Harshini Sundarapandian[1], Joemon K J[2], Anup Kudtarkar[3]
[1,2]*Department of Forensic Science, Garden City University, Bangalore, Karnataka.*
[3]*Phoenix Screening Services, Bangalore, Karnataka.*

***Abstract*—Bloodstain pattern analysis is an essential aspect of forensic science, providing valuable information for reconstructing events at crime scenes. The size, shape, and distribution of bloodstains are influenced by several factors, among which surface characteristics play a significant role. Variations in texture, porosity, and absorbency can alter stain morphology, potentially affecting forensic interpretation. This study aims to comparatively examine bloodstain patterns formed on selected porous and non-porous surfaces under controlled experimental conditions. Fresh animal blood was used to simulate passive bloodstain formation in a laboratory environment. Uniform droplets of predetermined volume were released from a fixed height onto various commonly encountered surfaces, including textile and rigid substrates. All experimental conditions, such as drop height and volume, were standardized to ensure consistency. After complete drying, the stains were documented using controlled photography. Quantitative image analysis was performed using digital software to measure morphometric parameters such as stain diameter, area, circularity, and edge characteristics. The collected data were subjected to statistical analysis to evaluate the influence of surface properties on stain spread and overall morphology. This study aims to establish a clearer understanding of how different surface types influence bloodstain formation. The findings are expected to strengthen the scientific foundation of bloodstain pattern interpretation, enhance reliability during crime scene reconstruction, and contribute to improved accuracy in forensic case analysis and courtroom presentations.**

***Index Terms*—Bloodstain Diameter and Area Measurement, Blood Droplet Morphology, Bloodstain Pattern Analysis, Forensic Crime Scene Reconstruction, Surface Absorbency**

I. INTRODUCTION

Bloodstain Pattern Analysis (BPA) is an important component of forensic science that assists investigators in reconstructing events at a crime scene. By examining the size, shape, distribution, and location of bloodstains, forensic experts can infer the mechanisms of bloodshed, the direction of force, and the sequence of events that occurred during violent incidents. The interpretation of bloodstain patterns provides valuable insights into crime scene dynamics and has become a widely accepted forensic tool in criminal investigations and judicial proceedings.

The formation and morphology of bloodstains are influenced by multiple physical and environmental factors. These include the height and angle of blood drop impact, the volume of the droplet, gravitational forces, and the physical characteristics of the surface on which the blood lands. Among these variables, the nature of the target surface plays a particularly significant role in determining the final appearance of a bloodstain. Surface texture, porosity, roughness, and absorbency can influence the spread, edge characteristics, and overall morphology of the resulting stain.

The Surfaces encountered at crime scenes can broadly be categorized as porous and non-porous. Porous surfaces, such as fabrics, paper, cardboard, and wood, tend to absorb blood into their structure, often resulting in irregular stain edges and limited outward spreading. In contrast, non-porous surfaces such as glass, metal, tiles, and polished plastics generally do not absorb blood, allowing the droplet to spread across the surface and often producing smoother and more circular stain patterns. These differences in stain formation can significantly affect the interpretation of blood evidence.

The Accurate interpretation of bloodstain patterns requires a clear understanding of how the surface characteristics influence stain morphology. Misinterpretation may occur if the influence of the target surface is not properly considered during analysis. Therefore, controlled Experimental studies examining bloodstain formation on various materials are essential for strengthening the scientific reliability of BPA. This study aims to comparatively analyze bloodstain patterns formed on selected porous and non-porous surfaces under standardized laboratory conditions. By maintaining consistent droplet volume, drop height, and environmental conditions, this research evaluates variations in stain diameter, area, and morphological characteristics across different surfaces. Digital image analysis techniques are employed to obtain quantitative measurements of stain parameters. The findings of this research are expected to contribute to a better understanding of surface effects on bloodstain formation. This can improve the accuracy of bloodstain pattern interpretation during crime scene reconstruction and enhance the evidentiary value of bloodstain analysis in forensic investigations and courtroom testimony.

II. REVIEW OF LITERATURE

The Bloodstain pattern analysis has been widely studied as a scientific method for reconstructing events at crime scenes. Early foundational work by Herbert Leon MacDonell significantly contributed to the understanding of bloodstain classification and interpretation in forensic investigations. His research emphasized that the physical characteristics of bloodstains can provide valuable information regarding the direction of travel, point of origin, and mechanism of bloodshed.

Various researchers have examined the physical properties that influence bloodstain formation. Studies by Stuart H. James and William G. Eckert highlighted that droplet volume, height of fall, and angle of impact play important roles in determining stain morphology. Their work demonstrated that passive blood droplets falling vertically tend to form circular stains when deposited on smooth surfaces. Further research has explored the influence of surface characteristics on bloodstain patterns. Investigations by Tom Bevel and Ross M. Gardner indicated that surface texture and absorbency significantly affect the spread and edge characteristics of blood droplets. Rough or porous materials often produce irregular stain margins, while smooth non-porous surfaces generally allow greater spreading and produce more regular circular patterns.

Experimental studies have also shown that porous materials such as fabrics and paper tend to absorb blood rapidly, reducing the outward spread of the droplet. In contrast, non-porous materials such as glass, metal, and tiles allow blood to remain on the surface, resulting in wider stain diameters and smoother edges. Despite the availability of several studies on bloodstain pattern analysis, comparative experimental data examining single passive droplets across multiple commonly encountered porous and non-porous materials remain limited. Therefore, further controlled experimental studies are required to better understand the influence of surface characteristics on bloodstain morphology.

This study aims to address this need by conducting a comparative analysis of passive blood droplet stains on selected porous and non-porous surfaces under standardized laboratory conditions.

III. METHODOLOGY

3.1 Study Design

This study shows a controlled experimental design to examine the formation of passive blood droplets on different surface types. The experiment focused on observing and measuring the morphology of single blood droplets deposited on selected porous, semi-porous, and non-porous surfaces under standardized laboratory conditions. The objective was to evaluate how variations in surface characteristics influence the spread and morphology of bloodstains.

3.2 Blood Sample Collection

Fresh goat blood was used as the biological sample for the experiment. Goat blood is frequently used in experimental studies of Bloodstain Pattern Analysis due to its physical properties, which are considered comparable to human blood in terms of viscosity and fluid behavior. The blood was freshly collected and immediately transferred into sterile collection tubes containing Ethylenediaminetetraacetic Acid (EDTA) as an anticoagulant. The use of EDTA prevented clotting and ensured that the blood maintained consistent fluid properties throughout the experimental process.

3.3 Experimental Setup
All experiments were conducted in a controlled indoor laboratory environment to minimize environmental variables such as air movement and temperature fluctuations that could affect droplet behavior.
A syringe without a needle was used to release blood droplets. The syringe was held vertically to maintain a "90-degree angle" relative to the target surface. Blood was allowed to move slowly toward the syringe tip using very minimal pressure until a droplet formed at the tip. Once the droplet reached sufficient size, it was allowed to detach naturally under the influence of gravity, producing a "passive blood drop".
The droplet release height was standardized at "30 cm above the target surface" for all trials. This ensured consistency in droplet velocity and impact energy across all surface types.

3.4 Surface Samples
A total of "21 different surface samples" were selected for the experiment to represent materials commonly encountered at crime scenes. These surfaces included a mixture of porous, semi-porous, and non-porous substrates. Most samples were prepared in "10 × 10 cm dimensions" to maintain uniformity in experimental conditions. However, a few materials such as shoes and stones were used in their natural form due to practical limitations.

3.5 The surfaces used in the experiment included:
A4 Sheet, Leather Shoe, Thermocol, Tile, Steel Plate, Cardboard, Leaf, Cotton Fabric, Filter Paper, Aluminium Foil, Denim Fabric, Polythene, Tissue Paper, Glass, Plastic Paper, Jute, Mirror, Wood, Canvas Board, Stone, Brown Paper.
These surfaces were selected to represent different levels of surface roughness, porosity, and absorbency, which are known to influence bloodstain formation.

3.6 Blood Droplet Deposition
For each and every surface sample, individual blood droplets were deposited from the fixed height of 30 cm. The droplet was allowed to fall vertically under gravitational force to ensure the formation of passive bloodstains.
Each droplet impacted the surface at approximately a "90-degree angle", minimizing directional distortion in the resulting stain pattern. Only one droplet was deposited at a time and the droplets were not affected by external disturbances.
After deposition, the stains were allowed to dry naturally at room temperature.

3.7 Documentation of Bloodstains
Once the bloodstains were completely dried, each sample was documented using controlled digital photography. Photographs were taken perpendicular to the surface to avoid distortion and to ensure accurate measurement of stain morphology.
The images were captured using Iphone 15 camera, under consistent lighting conditions to maintain clarity and uniformity for further analysis.

3.8 Image Analysis
The captured images were analyzed using "ImageJ", digital software to obtain quantitative measurements of bloodstain morphology. Morphometric parameters measured during the analysis included Area, Perimeter, Major (cm), Minor (cm), Diameter, Circularity

IV. RESULT

Table 1: Measurements of Bloodstains

S.no	Samples	Surface	Area	Perimeter	Major(cm)	Minor(cm)	Diameter	Circularity
1	A4 sheet	Porous	2.913	6.051	1.927	1.925	1.927	1.000
2	Leather shoe	Semi-porous	3.041	6.182	1.977	1.959	1.976	1.000
3	Thermocol	Porous	0.833	3.595	1.130	0.939	1.247	0.810
4	Tile	Non-porous	3.446	6.580	2.108	2.081	2.108	1.000
5	Steel plate	Non-porous	2.748	5.826	1.831	1.723	1.944	0.917
6	Cardboard	Porous	2.525	5.944	1.876	1.713	1.943	0.898
7	Leaf	Semi-porous	1.451	4.748	1.657	1.115	1.756	0.809
8	Cotton fabric	Porous	1.851	5.432	2.157	1.093	2.311	0.788
9	Filter paper	Porous	4.135	7.596	2.340	2.250	2.385	0.901
10	Aluminium foil	Non-porous	2.815	5.989	2.086	1.719	2.085	0.986
11	Denim fabric	Porous	2.176	6.351	1.753	1.581	1.961	0.678

12	Polythene	Non-porous	1.865	4.847	1.606	1.478	1.606	0.997
13	Tissue paper	Porous	3.977	10.993	2.549	1.987	2.847	0.414
14	Glass	Non-porous	2.881	6.020	1.963	1.869	1.963	0.999
15	Plastic paper	Non-porous	1.650	4.892	1.633	1.287	1.703	0.866
16	Jute	Porous	1.983	5.953	1.613	1.566	1.837	0.703
17	Mirror	Non-porous	3.535	6.668	2.174	2.070	2.174	0.999
18	Wood	Semi-porous	1.271	3.997	1.278	1.266	1.278	1.000
19	Canvas board	Porous	1.426	4.242	1.423	1.276	1.422	0.996
20	Stone	Semi-porous	2.447	5.552	1.836	1.697	1.836	0.998
21	Brown paper	Porous	2.335	5.947	1.830	1.625	1.895	0.830

This table shows the surface and raw measurements of bloodstain area, perimeter, major (cm), minor (cm), diameter and circularity obtained from passive drops on different surfaces under controlled experimental conditions.

Table 2: Mean Diameter Table

S. No	Samples	Mean Diameter
1	A4 Sheet	1.926
2	Leather Shoe	1.968
3	Thermocol	1.034
4	Tile	2.094
5	Steel Plate	1.777
6	Cardboard	1.794
7	Leaf	1.386
8	Cotton Fabric	1.625
9	Filter Paper	2.295
10	Aluminium Foil	1.902
11	Denim Fabric	1.667
12	Polythene	1.542
13	Tissue Paper	2.268
14	Glass	1.916
15	Plastic Paper	1.460
16	Jute	1.589
17	Mirror	2.122
18	Wood	1.272
19	Canvas Board	1.349
20	Stone	1.766
21	Brown Paper	1.727

This table shows the calculated mean diameter values of bloodstains for each surface based on the recorded measurements using ImageJ, digital software.

Table 3: Comparison of Porous, Non- Porous and Semi-Porous

S.no	Surface type	Mean diameter
1	Porous	1.727
2	Non-porous	1.830
3	Semi-porous	1.598

This table shows the Comparison of mean diameter across porous, semi-porous, and non-porous surfaces.

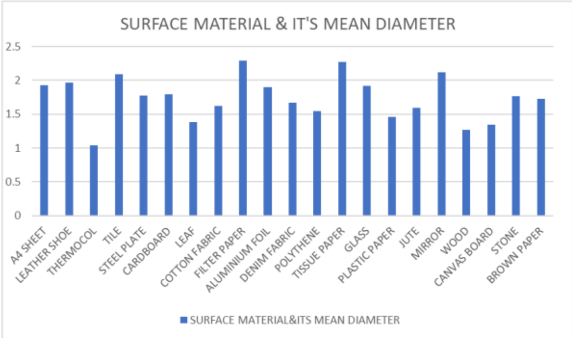


Fig 1: Bar Graph 1; Surface Material & It's Mean Diameter

Bar graph showing the measured bloodstain diameters obtained on different surfaces under controlled experimental conditions.

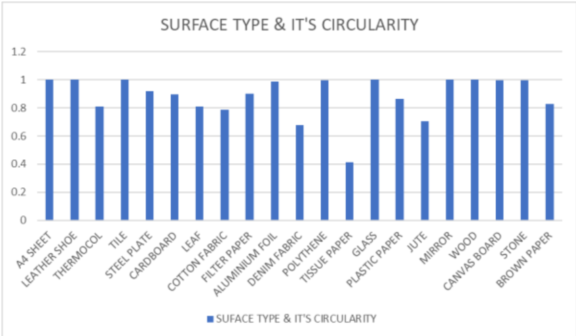


Fig 2: Bar Graph 2; Surface Type & It's Circularity

Bar graph showing the mean diameter of bloodstains formed on the tested surfaces based on the recorded measurements.

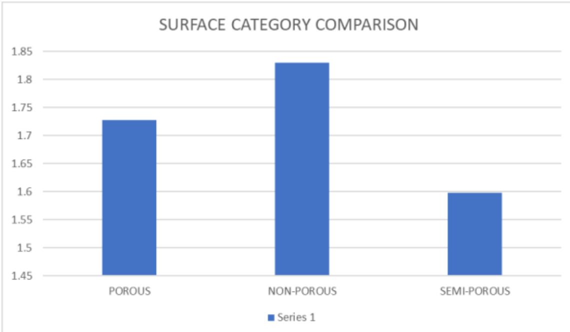
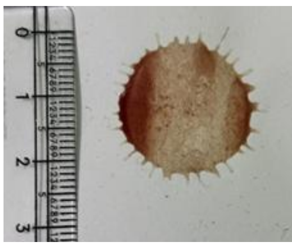
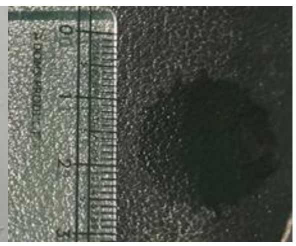
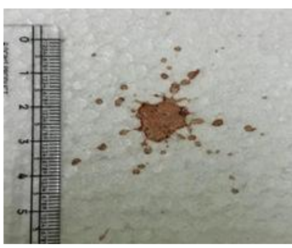
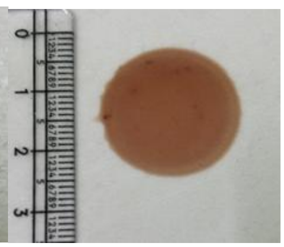


Fig 3: Bar Graph 3; Surface Category Comparison

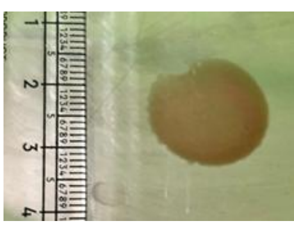
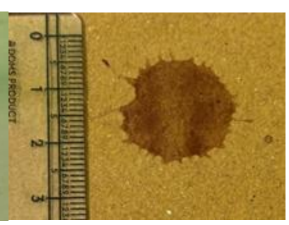
Bar graph showing the comparison of average bloodstain diameter across porous, semi-porous, and non-porous surfaces.

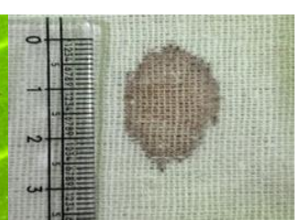
A4 Sheet Leather Shoe

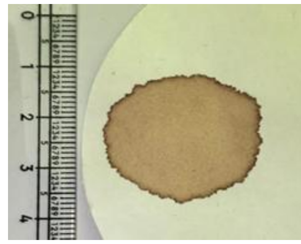
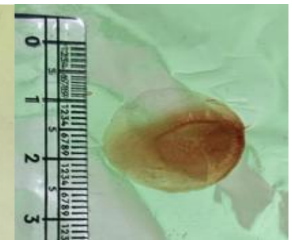
Thermocol Tile

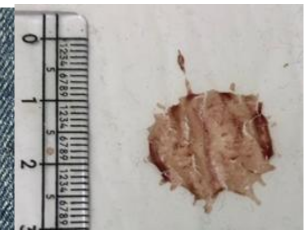
Steel Plate Cardboard

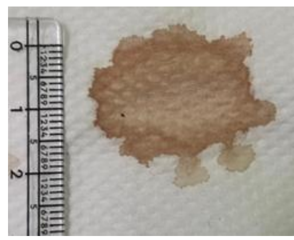
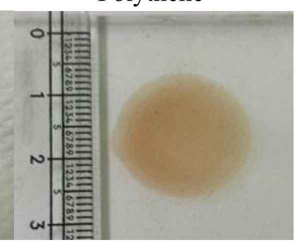
Leaf Cotton Fabric

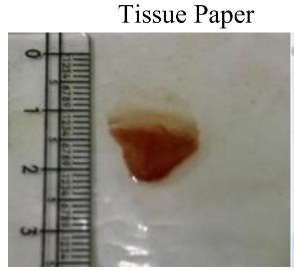
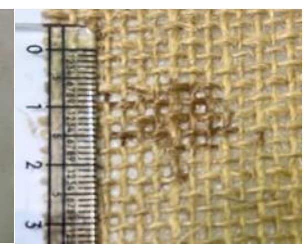
Filter Paper Aluminium Foil

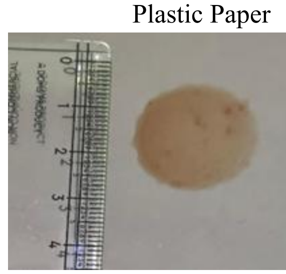
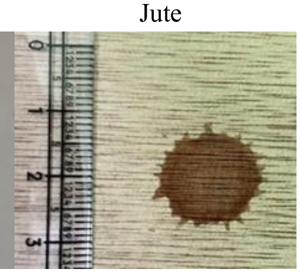
Denim Fabric Polythene

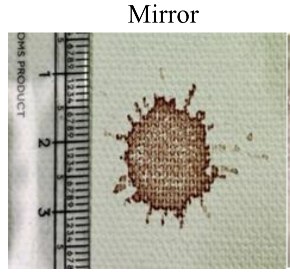
Tissue Paper Glass

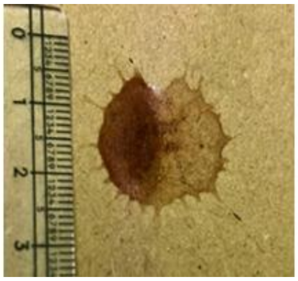
Plastic Paper Jute

Mirror Wood




Canvas Board Stone



Brown Cover

Fig 4: Goat Bloodstain Patterns on Different Surfaces

V. DATA INTERPRETATION

This experiment demonstrates the type of surface significantly influences the morphology of passive bloodstains. The diameter, circularity, and edge characteristics of the stains varied depending on the porosity, texture, and absorbency of the substrate.

On non-porous surfaces such as aluminium foil, steel plate, tile, and mirror, the blood droplets retained a more circular and well-defined shape. Since these surfaces do not absorb liquid, the blood remained on the surface and spread outward uniformly due to surface tension and gravity. This resulted in stains with larger diameters and smoother edges. Minimal absorption allowed the droplet to flatten slightly after impact, producing wider stains.

Therefore, porous materials such as filter paper, cotton fabric, tissue paper, cardboard, and jute showed smaller stain diameters but irregular edges. These materials absorbed blood immediately after impact through capillary action. Because part of the liquid penetrated into the material rather than spreading across the surface, the visible stain area remained comparatively smaller. Absorption also caused diffused edges and feathering patterns, making the stains less circular.

Semi-porous surfaces like wood, leather shoe material, and certain coated boards displayed intermediate characteristics. These surfaces allowed partial absorption, resulting in stains that were neither as sharply defined as non-porous surfaces nor as diffused as highly porous materials.

Circularity measurements further supported these observations. Stains on smooth non-porous surfaces exhibited higher circularity values, indicating symmetrical stain formation due to minimal interference from surface texture. Porous surfaces showed lower circularity values, reflecting irregular spreading caused by uneven absorption and fibre structure. The experimental conditions such as constant height (30 cm), perpendicular angle (90°), and gravity-driven passive drops ensured that the observed variations were primarily due to surface characteristics rather than external factors.

Therefore, the data confirms that surface porosity plays a crucial role in determining bloodstain size, shape, and edge morphology, which is an important consideration in forensic bloodstain pattern analysis.

VI. FINDINGS

The study revealed that surface characteristics significantly influence bloodstain formation, including stain diameter, shape, and edge appearance.

Non-porous surfaces such as aluminium foil, mirror, steel plate, and tile produced larger and more circular bloodstains due to the absence of absorption and increased surface spreading.

The Porous materials including filter paper, cotton fabric, tissue paper, cardboard, and jute showed smaller stains with irregular and diffused edges, primarily due to rapid absorption through capillary action. The Semi-porous surfaces such as wood, leather shoe material, and certain coated boards exhibited intermediate stain characteristics, reflecting partial absorption and limited surface spreading.

The Stains formed on smooth surfaces demonstrated higher circularity values, whereas stains on fibrous or rough surfaces showed lower circularity due to irregular spreading. The controlled experimental setup (constant height of 30 cm and perpendicular impact angle) confirmed that substrate properties alone can produce noticeable variations in bloodstain morphology. The results highlight that surface porosity and texture are critical factors in bloodstain pattern interpretation.

VII. SUGGESTIONS

During crime scene investigations, the type and condition of the surface should be carefully documented, as it plays a significant role in bloodstain pattern formation. Forensic investigators should consider substrate porosity when analyzing bloodstain size and shape, as different materials may alter the appearance of stains.

Future research should explore different drop heights, angles of impact, and droplet volumes to better understand bloodstain behavior under varied conditions. Additional studies may include environmental factors such as temperature, humidity, and airflow, which can influence bloodstain formation. Expanding the study to include more commonly encountered crime scene surfaces such as glass, plastic, painted walls, and concrete would provide more comprehensive forensic reference data. The use of digital image analysis software such as ImageJ is recommended for accurate measurement of bloodstain parameters including diameter, area, and circularity. Developing reference databases of bloodstain patterns on different substrates could assist forensic experts in more accurate crime scene reconstruction.

VIII.CONCLUSION

This study investigated the influence of different surface types on the formation of passive bloodstain patterns under controlled laboratory conditions. Blood droplets released from a constant height of 30 cm at a perpendicular angle produced varying stain characteristics depending on the nature of the substrate. The results clearly demonstrate that surface properties such as porosity, texture, and absorbency significantly influence bloodstain morphology. On-porous surfaces produced larger and more circular stains with well-defined edges due to the absence of absorption, allowing the blood to spread across the surface. In contrast, porous materials exhibited smaller stains with irregular and diffused edges because of rapid absorption through capillary action. Semi-porous surfaces showed intermediate characteristics between these two extremes.

The findings highlight that even under identical experimental conditions, the nature of the surface can lead to considerable variations in bloodstain appearance. Therefore, substrate characteristics must be carefully considered during bloodstain pattern interpretation and crime scene reconstruction. The study contributes to forensic bloodstain pattern analysis by providing comparative observations of stain formation on commonly encountered surfaces. Further research incorporating additional substrates, varying drop heights, and environmental factors may enhance the understanding of bloodstain behavior and strengthen forensic interpretation in real case scenarios.

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