ARTICLE

Relationship Between Vertical Drop Height and Passive Bloodstain Diameter Using Fresh Human Blood: An Experimental Study

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ABSTRACT

Background: Bloodstain Pattern Analysis (BPA) plays a vital role in forensic science by assisting in crime scene reconstruction through the interpretation of bloodstain characteristics. Vertical drop height is one of the major factors influencing passive bloodstain morphology; however, standardized quantitative data using fresh human blood remain limited.

Materials and Methods: A laboratory-based experimental study was conducted using fresh human venous blood. Passive bloodstains were produced from four predetermined heights (1 ft, 3 ft, 5 ft, and 7 ft) on a smooth, non-porous ceramic tile at 90° impact angle. Thirty bloodstains were produced at each height (n = 120). Bloodstain diameters were measured using a millimetre scale and analysed using one-way analysis of variance (ANOVA).

Results: The mean bloodstain diameter increased progressively with increasing drop height, measuring 1.41 ± 0.15 mm at 1 ft, 1.79 ± 0.15 mm at 3 ft, 1.93 ± 0.11 mm at 5 ft, and 2.01 ± 0.09 mm at 7 ft. A statistically significant difference was observed among the four groups ($F(3,116) = 145.04$, $p < 0.001$).

Conclusion: Vertical drop height has a significant influence on passive bloodstain diameter. The findings provide baseline quantitative data that may support the scientific interpretation of bloodstain evidence and contribute to crime scene reconstruction in forensic investigations. These findings may assist forensic experts in India under the BNSS, 2023 and BSA, 2023.

Keywords: Bloodstain Pattern Analysis, Passive Bloodstains, Drop Height, Fresh Human Blood, Bloodstain Morphology, Crime Scene Reconstruction.

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INTRODUCTION

Blood is one of the most commonly encountered forms of biological evidence at crime scenes. It is frequently associated with homicides, suicides, assaults, hit-and-run incidents, burglaries, sexual offences, and other violent crimes. In addition to providing biological material for DNA profiling and other forensic examinations, bloodstains serve as valuable physical evidence that can assist in reconstructing the events surrounding a crime. [1]

Blood evidence not only aids in individual identification through DNA analysis but also provides critical information regarding the sequence of events, and its proper detection and interpretation remain essential components of forensic crime scene investigation. [14]

Blood is a complex biological fluid composed of plasma and cellular components, including erythrocytes, leukocytes, and platelets. Once exposed outside the body, blood undergoes coagulation and progressive physicochemical changes that influence its rheological properties and behaviour during bloodstain formation. [2]

Bloodstain Pattern Analysis (BPA) is a specialized discipline within forensic science that involves the systematic examination and interpretation of the size, shape, distribution, and location of bloodstains to reconstruct the sequence of events associated with bloodshed. Bloodstain patterns provide valuable information regarding the mechanism of bloodshed, the direction of blood travel, the area of origin, the relative positions and movements of the individuals involved, and the type of force responsible for blood deposition. [3]

The interpretation of bloodstain patterns is based on established principles of fluid dynamics, physics, mathematics, and biology, which collectively explain the behaviour of blood droplets during flight and upon impact with a target surface. Blood exhibits non-Newtonian behaviour, and its physical properties significantly influence the characteristics of the resulting bloodstains. When a blood drop separates from its source and falls under the influence of gravity, it accelerates until impact, producing a stain whose morphology is determined by several interacting physical factors. [4,5]

Among the various factors influencing bloodstain formation, vertical drop height is one of the most important determinants of bloodstain size, shape, edge characteristics, and satellite spatter formation. As the release height increases, the velocity of the blood drop increases under the influence of gravity, thereby influencing the morphology of the resulting bloodstain upon impact. [4,6,7,12]

The size, shape, and morphological characteristics of passive bloodstains are fundamental parameters evaluated during Bloodstain Pattern Analysis and provide important information for the interpretation of bloodshed events.[5] Consequently, standardized experimental investigations are essential for generating reliable reference data that improve the scientific validity and practical applicability of Bloodstain Pattern Analysis in forensic casework. [4–7]

Previous experimental studies have demonstrated that drop height significantly influences bloodstain diameter and stain morphology under controlled laboratory conditions. However, variations in experimental design, blood source, and methodology have limited the availability of standardized quantitative reference data for forensic applications, particularly using fresh human blood under controlled conditions. [4–7]

Therefore, the present study was undertaken to evaluate the effect of different vertical drop heights on passive bloodstain diameter using fresh human venous blood under standardized laboratory conditions, with the aim of generating baseline quantitative data to support forensic crime scene reconstruction.

MATERIALS AND METHODS

Study Design and Setting

A laboratory-based experimental study was conducted in the Department of Forensic Medicine research laboratory, AIMS. Ethical approval for the study was obtained from the Institutional Ethics committee of Adichunchanagiri institute of Medical Sciences prior to the commencement of the study. Written informed consent was obtained from all participants prior to blood sample collection.

Blood Sample Collection

Fresh venous blood samples were collected from healthy adult male and female volunteers aged 18–60 years into sterile EDTA vacutainer tubes under aseptic precautions. Individuals with known haematological disorders were excluded from the study. One healthy volunteer donated approximately 5 mL of venous blood on each experimental day, with a different volunteer participating for each of the four experimental sessions corresponding to the four drop heights. All experiments were completed within 6 hours of blood collection to minimize alterations in blood properties. Any remaining blood was discarded according to standard biomedical waste disposal guidelines.

Experimental Procedure

Four predetermined vertical drop heights (1 ft, 3 ft, 5 ft, and 7 ft) were evaluated. Each height was tested on a separate day using freshly collected blood from one healthy volunteer. The release height was measured using a standardized measuring tape. Fresh blood was transferred into a standardized 0.5 mL dropper with a 2.8 mm tip diameter, which was held vertically at an angle of 90° throughout the experiment. Individual passive blood drops were allowed to fall freely onto a smooth, clean, non-porous ceramic tile. The tile was cleaned and dried after each trial to avoid contamination. A total of 30 passive bloodstains were produced at each height, resulting in 120 bloodstains for analysis.

Bloodstain Measurement

Each bloodstain was allowed to stabilize immediately after formation before measurement. The maximum length and width of each passive bloodstain were measured directly using a transparent millimetre ruler. The mean bloodstain diameter was calculated as the average of the length and width of each stain and recorded in millimetres (mm) for statistical analysis.

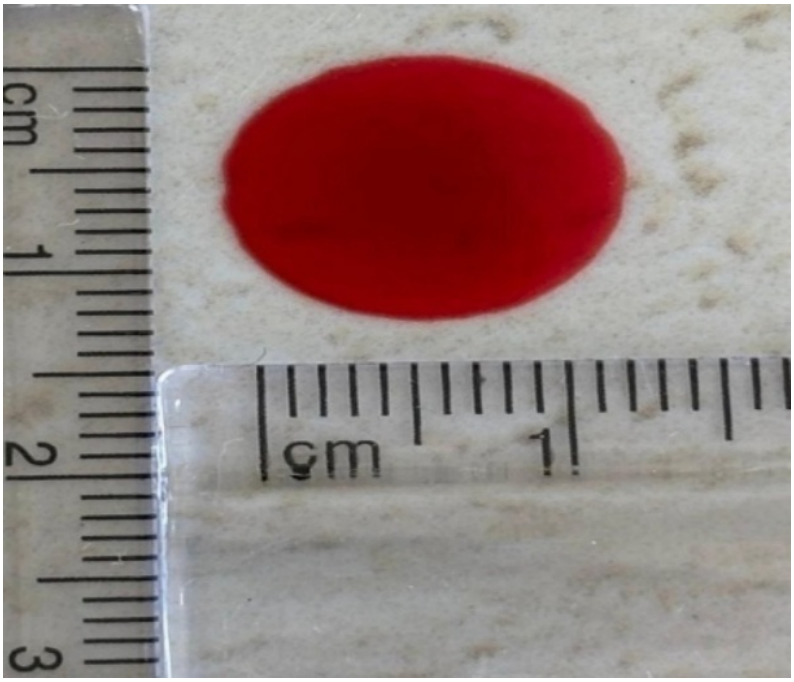

Figure 1: Passive bloodstain generated from a height of 1 ft showing length and width measurements.

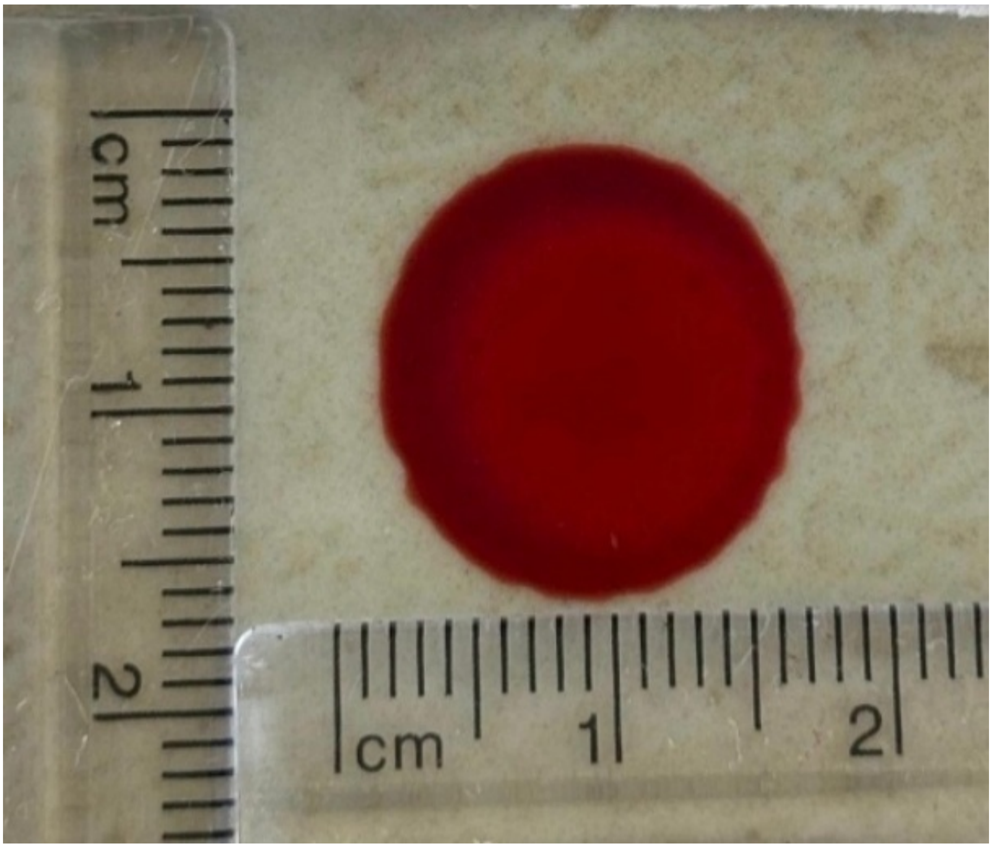

Figure 2: Passive bloodstain generated from a height of 3 ft showing length and width measurements.

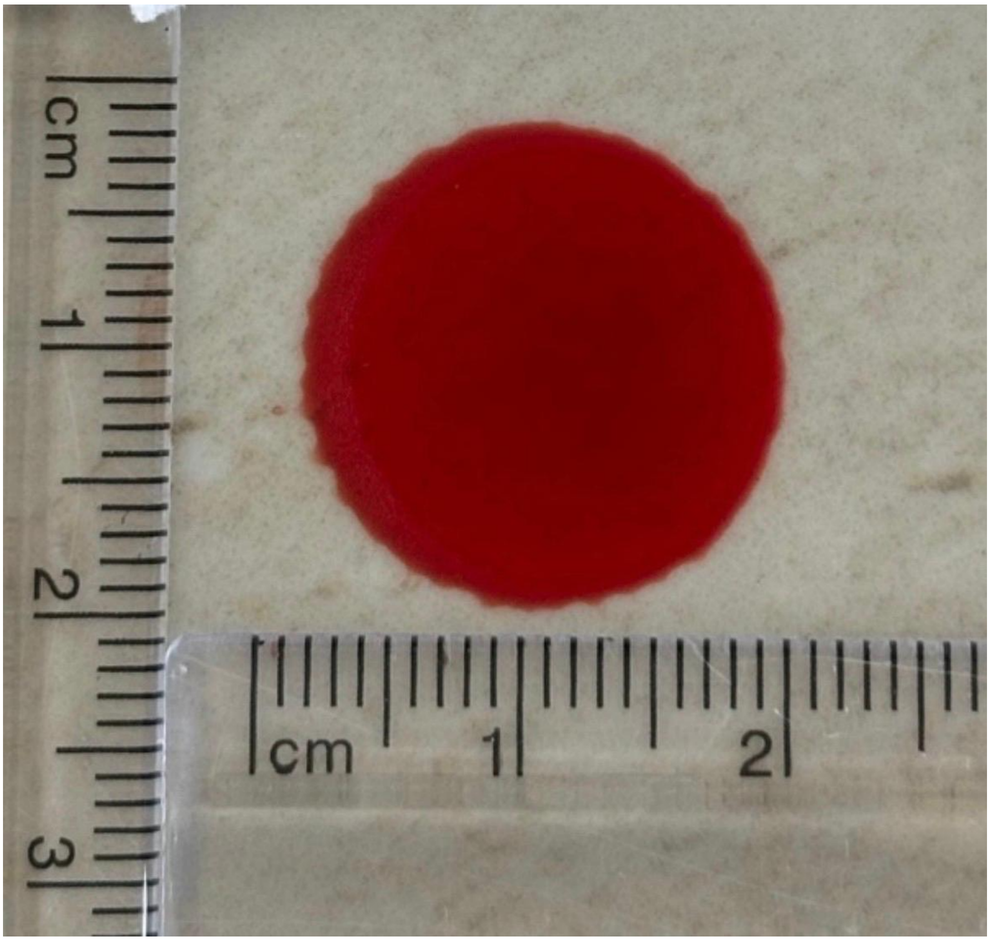

Figure 3: Passive bloodstain generated from a height of 5 ft showing length and width measurements.

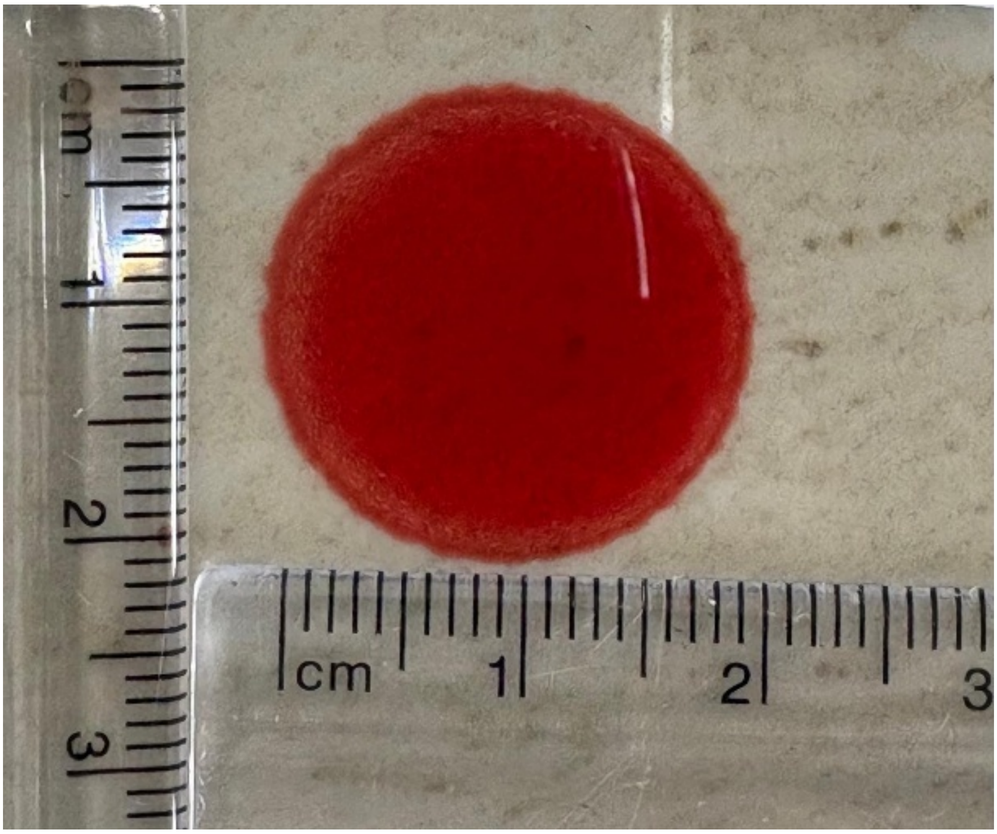

Figure 4: Passive bloodstain generated from a height of 7 ft showing length and width measurements.

Statistical Analysis

Data were entered into Microsoft Excel. Descriptive statistics including mean and standard deviation (SD) were calculated. Differences in mean bloodstain diameter among the four drop height groups were analyzed using One-way analysis of variance (ANOVA). A p-value <0.05 was considered statistically significant.

RESULTS

A total of 120 passive bloodstains were analysed in the present study, with 30 bloodstains produced at each of the four predetermined vertical drop heights (1 ft, 3 ft, 5 ft, and 7 ft).

The mean passive bloodstain diameter increased with increasing vertical drop height. The mean ± standard deviation (SD) bloodstain diameters were 1.41 ± 0.15 mm at 1 ft, 1.79 ± 0.15 mm at 3 ft, 1.93 ± 0.11 mm at 5 ft, and 2.01 ± 0.09 mm at 7 ft (Table 1), demonstrating a consistent increase in bloodstain diameter with increasing drop height.

One-way analysis of variance (ANOVA) demonstrated a highly statistically significant difference in the mean bloodstain diameter among the four experimental groups ($F(3,116) = 145.04$, $p < 0.001$) (Table 2). These findings indicate that vertical drop height has a significant influence on passive bloodstain diameter under the controlled laboratory conditions of the present study.

Figure 5 illustrates the increase in mean passive bloodstain diameter with increasing vertical drop height. The error bars (±1 SD) represent the variability within each experimental group and demonstrate good consistency of the measurements across all four height groups.

Table 1: Mean passive bloodstain diameter at different vertical drop heights using fresh human blood (n = 120)

Drop Height (ft)	Number of Bloodstains (n)	Mean Diameter (mm)	Standard Deviation (SD)
1	30	1.41	0.15
3	30	1.79	0.15
5	30	1.93	0.11
7	30	2.01	0.09

Table 2: One-way analysis of variance (ANOVA) comparing mean passive bloodstain diameter at different vertical drop heights

Source of Variation	SS	df	MS	F	p-value
Between Groups	6.311	3	2.104	145.039	<0.001
Within Groups	1.683	116	0.015	—	—
Total	7.994	119	—	—	—

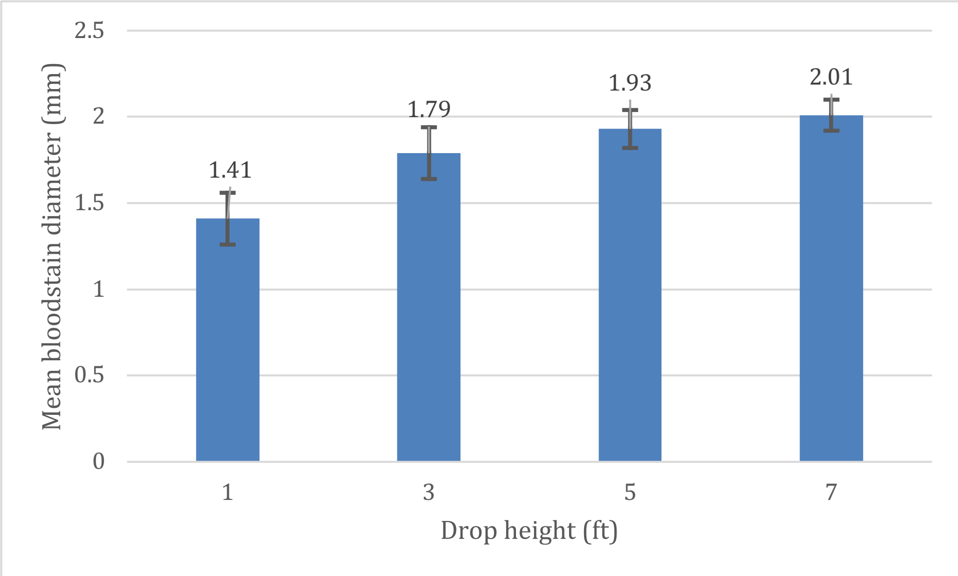

Figure 5: Effect of vertical drop height on the mean passive bloodstain diameter of fresh human blood

Figure 5. Bar diagram depicting the mean passive bloodstain diameter (mm) produced from blood drops released from vertical heights of 1 ft, 3 ft, 5 ft, and 7 ft. Error bars represent ±1 standard deviation. A progressive increase in diameter with height was observed.

DISCUSSION

Key findings

The present experimental study evaluated the effect of vertical drop height on the diameter of passive bloodstains produced using fresh human venous blood under controlled laboratory conditions. The findings demonstrated a progressive increase in mean bloodstain diameter with increasing drop height. The mean bloodstain diameter increased from 1.41 ± 0.15 mm at 1 ft to 2.01 ± 0.09 mm at 7 ft. One-way ANOVA demonstrated a highly statistically significant difference among the four height groups ($F_{(3,116)} = 145.04$, $p < 0.001$), confirming that vertical drop height significantly influences passive bloodstain diameter.

The progressive increase in bloodstain diameter observed with increasing drop height is consistent with the established principles of fluid dynamics governing blood drop impact. As the release height increases, gravitational potential energy is converted into kinetic energy, resulting in a higher impact velocity when the blood droplet strikes the target surface. The increased impact energy promotes greater radial spreading of the blood droplet, producing larger stain diameters. These findings are consistent with the fluid dynamic mechanisms of bloodstain formation described by Attinger et al. and Laan et al., who demonstrated that impact velocity is a major determinant of bloodstain size and morphology. [4,12]

Comparison with Previous Studies

The findings of the present study are in agreement with those reported by White, who demonstrated that increasing drop height produces progressively larger passive bloodstains under controlled laboratory conditions. [6] Similarly, Leonova et al. reported that bloodstain diameter increases with increasing fall height and suggested that stain dimensions may assist in estimating the height of blood drop origin during forensic reconstruction. [7]

The present findings are further supported by Attinger et al., who explained that bloodstain morphology is influenced by several interacting factors, including impact velocity, blood viscosity, surface tension, and fluid dynamic behaviour.[4] Likewise, Laan et al. demonstrated that impact velocity plays a critical role in determining bloodstain spreading characteristics, providing a scientific explanation for the progressive increase in stain diameter observed in the present investigation. [12]

A notable strength of the present study is the use of fresh human venous blood collected under standardized laboratory conditions. Several previous experimental investigations have employed animal blood or stored anticoagulated blood, which may not completely reproduce the rheological behaviour of fresh human blood. Since blood viscosity and surface tension directly influence bloodstain formation and spreading, the use of fresh human blood in the present study provides quantitative reference data that may better represent actual forensic casework, [9,11,13]

Forensic and Legal Implications

Passive bloodstain diameter is an important parameter in Bloodstain Pattern Analysis because it contributes to the estimation of the area of convergence, area of origin, and interpretation of bloodshed events during crime scene reconstruction. [3,8] The quantitative reference data generated in the present study may therefore assist forensic experts in interpreting passive bloodstain evidence more objectively under standardized conditions. In the Indian context, the increasing emphasis on scientific investigation under the Bharatiya Nagarik Suraksha Sanhita (BNSS), 2023 and the admissibility of expert opinion under the Bharatiya Sakshya Adhiniyam (BSA), 2023 further highlight the importance of reliable experimental reference data for forensic practice. [16,17]

Limitations and Future Scope

The present study has certain limitations. Bloodstains were produced only on a smooth, non-porous ceramic tile using a single blood drop volume at a 90° impact angle under controlled laboratory conditions. Consequently, the findings should not be directly extrapolated to porous or textured surfaces, different impact angles, or varying environmental conditions, all of which may alter bloodstain morphology through absorption, surface roughness, evaporation, and capillary effects. [10,15] In addition, thirty bloodstains were analysed at each height. Although fresh human blood was used during every experimental session, blood samples were collected from different healthy volunteers on different days, and minor inter-individual variations in blood rheological properties could not be completely eliminated.

Future studies should investigate the combined effects of different surface types, blood volumes, impact angles, environmental conditions, and haematological variables using advanced imaging techniques such as high-speed videography and three-dimensional bloodstain reconstruction. Such investigations would contribute to the development of comprehensive experimental reference databases and further strengthen the scientific reliability and forensic applicability of Bloodstain Pattern Analysis. [18–20]

CONCLUSION

The present study demonstrated that vertical drop height significantly influences the diameter of passive bloodstains produced from fresh human venous blood under controlled laboratory conditions. A progressive increase in bloodstain diameter with increasing drop height confirms the direct relationship between release height and bloodstain morphology and provides quantitative baseline data for bloodstain pattern analysis. [8]

The findings of this study may assist forensic practitioners in the objective interpretation of passive bloodstain evidence and contribute to more reliable crime scene reconstruction. In the Indian context, such experimental evidence supports scientific forensic investigation as envisaged under the Bharatiya Nagarik Suraksha Sanhita (BNSS), 2023 and the admissibility of expert opinion under the Bharatiya Sakshya Adhiniyam (BSA), 2023. [16,17]

Although the findings are limited to controlled laboratory conditions using a smooth, non-porous surface, they provide a valuable reference for forensic practice. Further studies involving different substrates, blood volumes, impact angles, environmental conditions, and advanced imaging techniques are recommended to enhance the applicability of Bloodstain Pattern Analysis in forensic investigations.

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CONFLICT OF INTEREST

There are no conflicts of interest regarding the publication of this manuscript.

Ethical Approval

Ethical approval for this study was granted by the Institutional Ethics Committee (IEC)

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