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PHYSICS OF BLOODSTAIN PATTERN ANALYSIS

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Abstract

Bloodstain patterns are one of the pieces of evidence that can be found at the scene. Bloodstain pattern analysis is carried out to help reconstruct the events or occurrences that caused the formation of the pattern. Analysis is based on a combination of physics, biology and mathematics. Factors that influence the formation of bloodstain patterns are: surface tension and viscosity, drag and gravity and their influence on speed, and the shape of bloodstains when falling. In addition, surface conditions can affect the pattern of blood produced. Determining the area of origin of the bloodstain is carried out based on the impact angle calculated from the length and width of the bloodstain pattern. The analysis carried out in the experiment shows that there is closure in the bloodstain pattern analysis due to the assumption of a linear trajectory and determining the angle of the bloodstain. Different impact speeds will produce different bloodstain patterns

Keywords: Fluid dynamic, bloodstain patterns

Abstrak

Pola bercak darah merupakan salah satu barang bukti yang dapat ditemukan di tempat kejadian perkara. Analisis pola bercak darah dilakukan untuk membantu merekonstruksi kejadian atau peristiwa yang menyebabkan terbentuknya pola tersebut. Analisis didasarkan pada gabungan ilmu fisika, biologi dan matematika. Faktor yang mempengaruhi pembentukan pola bercak darah yaitu : tegangan permukaan dan viskositas, gaya hambat dan gravitasi serta pengaruhnya terhadap kecepatan, dan bentuk bercak darah saat jatuh. Selain itu, kondisi permukaan dapat mempengaruhi pola bercak darah yang dihasilkan. Penentuan daerah asal noda darah dilakukan berdasarkan sudut tumbukan yang dihitung dari panjang dan lebar pola bercak darah. Analisis yang dilakukan pada percobaan menunjukkan bahwa terdapat ketidakpastian dalam analisis pola bercak darah dikarenakan asumsi lintasan linier serta penentuan sudut pada bercak darah. Kecepatan tumbukan yang berbeda akan menghasilkan pola bercak darah yang berbeda.

***Kata Kunci**: Dinamika fluida, pola bercak darah*

1. INTRODUCTION

Blood is the most common biological evidence found and secured from crime scenes during crimes. Bloodstains are generally used as evidence to identify victims or suspects by DNA examination. However, in some cases, the bloodstains found have certain patterns that can be analyzed to provide information about the events that occurred and how the patterns were formed. Bloodstain pattern analysis is an examination of the shape and categorization and distribution of bloodstain patterns to provide an interpretation of the physical events of a crime that occurred (Peschel, 2011).

Blood stain patterns can be formed by several factors such as force, gravity, speed caused by direct physical attacks as a result of impact, discharge patterns or active splashes of blood. Bloodstain pattern analysis in the forensic subdiscipline is based on the combined principles of biology, physics and mathematics. Most bloodstain pattern analyzes are carried out based on fluid dynamics applied to blood (Adam, 2012).

Fluid dynamics in bloodstain pattern analysis describes events that cover a wide range of time and length scales. In addition, fluid dynamics analyzes all forces acting on the fluid which are evaluated based on the strength of the forces that are most relevant in the formation of the bloodstain pattern. Fluid dynamicists know that two liquids will behave the same as long as they are in the same physical conditions and experience the same force ratios. The force and speed acting at the time of impact, as well as the type of target surface can influence the bloodstain pattern that forms (Attinger, 2013)

Bloodstain pattern analysis is a complex analysis because many factors influence it and must be considered in concluding the evaluation results. The bloodstain pattern that forms requires analysis of the source of the blood, estimation of the speed and force of the impact, as well as the tool or cause of the bloodstain formation. Next, this pattern is compared with existing patterns and analyzed so that it can be concluded about the events that occurred to help the forensic investigation process.

2. METHOD

The method in this writing is a review of several journals on the topic of physical phenomena in the analysis of bloodstain patterns. The article review carried out was articles related to bloodstain pattern analysis as well as other supporting articles.

3. DISCUSSION

One way of analyzing bloodstain patterns is assessing where the bloodstain came from, so it must be determined how far a drop of blood can be found from the source. Several experiments on shot studies have been carried out to determine the location of the furthest blood stain that can be reached from the blood source. The blood stain pattern will show the diameter range, initial speed and impact angle, so that the source of the blood can be identified.

The physical parameters and forces that are relevant to BPA are surface tension and viscosity, drag and gravity and their influence on speed, and the shape of bloodstains when falling. In addition, surface conditions can influence the pattern of bloodstains produced (Attinger, 2013)

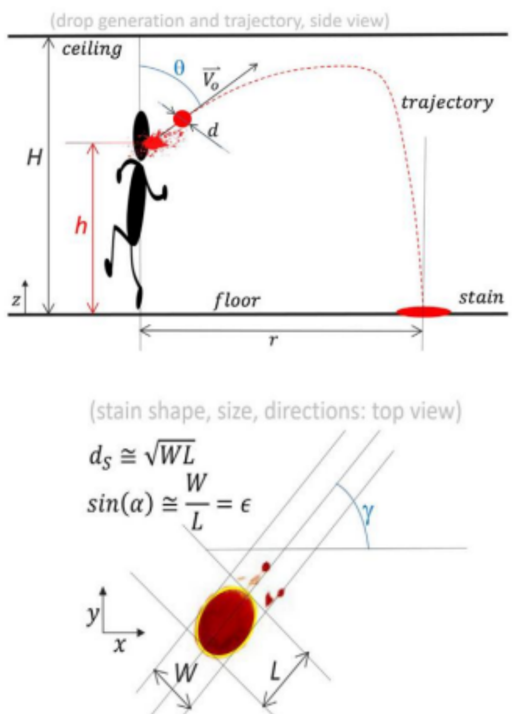

Figure 1. Describes the controlling variables: there are 2 heights (source and ceiling), initial velocity V0 and impact angle θ and fall diameter d. The top view shows how the main direction of the spot determines the direction angle g, and how the width W and length L of the ellipse mounted on the spot are used to determine the impact angle ÿ and equivalent diameter ds (Attinger et al, 2019)

Bloodstains are mostly elliptical in shape, so axial measurements (W/L) will produce an estimate of the impact angle which is usually measured from the surface with the formula:

$$\sin\theta = \frac{W}{L} \qquad (1)$$

According to Attinger et al 2019, in determining the impact conditions for certain spots, the impact speed does not depend on the droplet diameter. The relationship between normal impact velocity and droplet diameter can be determined from the fluid dynamics correlation between the amount of droplet spreading into the spot and the impact conditions.

In normal collisions, when the inertia force relative to surface tension is ignored, the edge of the blood stain will have a smooth circular shape. For collisions with higher inertia, the magnitude of which is proportional to surface tension, the edge of the spot will experience deformation like waves or spines. Figure 2 shows that the smaller the angle of impact, the maximum number of spines produced will decrease. This morphological transition is considered for trajectory reconstruction, but is hampered by many influencing factors such as impact angle, impact velocity, drop size and substrate roughness.

Bird et al describe the transition associated with a smooth drop boundary to a splash for the more complex case of oblique impacts with dimensionless impact numbers. The description of physical transitions with dimensionless numbers is a characteristic of fluid dynamics, and allows one to describe a phenomenon. A dimensionless number can be thought of as a measure of the ratio of the inertial force driving the collision, to the viscous force and surface tension resisting the collision.

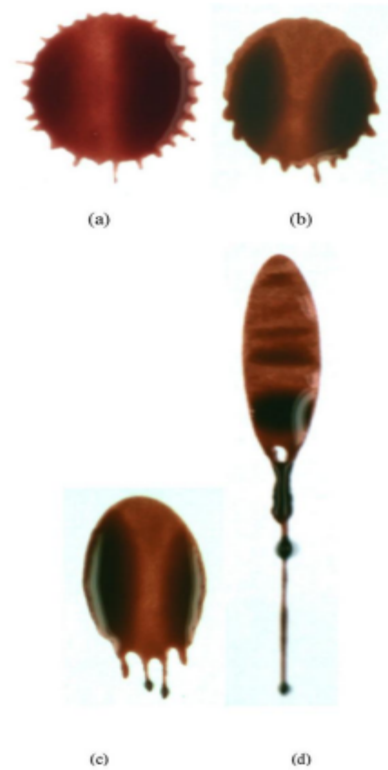

Figure 2. Example of a blood stain formed after a non-perpendicular impact from a height of 0.8 m at several angles, a) θ = 80o b) θ = 60o c) θ = 40o d) θ = 20o (Adam, 2012).

Based on Reinhart's experiments with droplets of different liquids in air, the Reynolds and Weber numbers are calculated using air as the fluid. When the droplet strikes the ceiling or floor, the angle between its velocity and the impacted surface is used to estimate the ellipticity of the stain, relying on the ratio between the length and width of the bloodstain. An oblique impact indicates a correlation between the normal component of impact velocity and the spread of the droplet fallout.

Reynold's Number Re = V.D. ρ/μ or Re = V.dv/v measures the ratio of the normal blood inertia at the impact surface to the viscous force inside the droplet and the Ohnesorge number. The inertial scale resists viscous forces and surface tension. Viscosity affects the liquid dripping process. If the flow rate causes the initial volume of liquid to become faster, inertial forces come into play. Inertia effects will influence droplet size, forming smaller "satellite" droplets.

The curve in the image below describes the maximum and minimum horizontal distance between the bloodstain and its source, with each colored line. For example, if blood is known to come from a standing person, and the ellipticity of the measured stain is 0.7, the red curve gives minimum and maximum horizontal distances of 3 m and 6 m. In assessing blood sources, there is an assumption of uncertainty in the main direction of the blood stain.

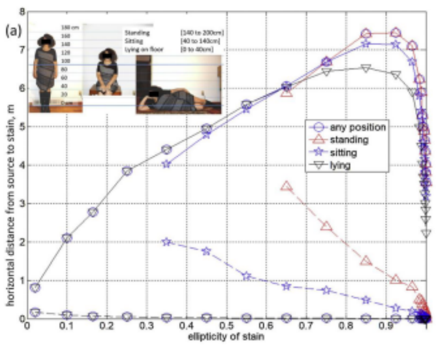

Figure 3. Distance in meters between the stain and its blood source as a function of droplet ellipticity and victim position. The minimum and maximum distance in positions (standing, sitting and lying on the floor) at a certain predetermined height.

There are two types of uncertainty in bloodstain pattern analysis, namely errors caused by assuming a linear trajectory and uncertainty in determining the angles g and a from the stain examination. Uncertainty in bloodstains is reported to stem from the asymmetric nature of bloodstains, and inappropriate use of a protractor. The uncertainty of this angle depends on several factors such as target material, spot size, and impact angle.

The problem in figure 1 can be better addressed by considering additional information regarding the size of the bloodstain. Additional information regarding the size of the bloodstain can reduce uncertainty about the location of the blood source in certain cases. In reality, at crime scenes it is not uncommon for the source of blood to move when blood spatter occurs, this fact will add uncertainty in determining the area of origin.

Determining the area of origin of the bloodstain or convergence area begins with determining the area in the horizontal plane as the area that best matches the projected trajectory (in the form of a straight line). Straight line projection is carried out based on the direction of the bloodstains attached to the surface, then for each point is discretized from the convergence area to determine the height range that corresponds to the physical trajectory. Each splash pattern is selected automatically and randomly for reconstruction purposes based on certain criteria. (Attinger et al, 2019).

When determining the source of blood, scars and the victim's height can be used to determine the height of the blood source. Height based on three positions (lying on the floor, sitting or standing) can be seen in figure 3, assuming a height range that only corresponds to one particular position.

Each trajectory in the bloodstain pattern is calculated by integration of Newton's second law for droplets moving through the air, moving forward in time until the droplets hit the ceiling, floor or break apart in the air. Information regarding the shape or ellipticity of the bloodstain is estimated from the numerically calculated impact angle and the estimated size of the stain.

The trajectory of a flying object is described by the equation of motion based on Newton's laws:

$$m_d \frac{dV}{dt} = m_d \rightarrow -\overrightarrow{F_D} \qquad (2)$$

Note: md, t, V, g, FD are the falling mass, time, falling speed, gravitational acceleration and drag force. In this experiment it is assumed that the air is calm. To calculate the equation of motion, it is necessary to estimate the drag force exerted by the air on the moving droplet.

The blood droplets that move furthest are the average sized droplets (d = 2 mm – 6 mm with an average speed of 14 m/s). The drag force overcomes the surface tension in the liquid and the droplets break apart in the air. Smaller droplets will experience very strong drag, due to their inertia and cannot move very far. Comiskey's (2017) experiment stated that smaller and faster droplets came from locations near the blunt object hit by the bullet. While the bigger and slower ones are further away.

Peschel (2011) states that smaller droplets have a lower surface-to-volume ratio than larger ones, making them more susceptible to air resistance. This applies when the motion is not purely vertical but includes a slight horizontal component. Since air resistance is inversely related to the size of the blood droplets, larger droplets are capable of traveling farther than smaller ones. This phenomenon becomes significant when the blood is dispersed into fine splatter or spray due to high-energy impact, such as that caused by a gunshot wound.

The speed associated with the emergence of blood spatter is referred to as "Low, Medium or High Speed Impact Splash" with the aim of knowing the best correlation between the size of the blood stain and the amount of speed or momentum applied to the static blood to produce a splash (Attinger, 2013)

Splash stains or blood spatter are formed due to pressure applied to the liquid source. There are two types of spatter that are formed, namely forward spatter which is caused by movement in the same direction as the force and backspatter. The higher the energy level, the smaller the splash stains produced, therefore bloodstain patterns can be differentiated based on the speed of impact (Peschel, 2011):

a) Low speed impact sparks: the resulting force or energy encounters gravity at an average speed of up to 1.5 m/s, the result is relatively large (> 4mm), often in the form of irregular splashes in a rather small area, can spine was found in the blood stain pattern.
b) Medium speed impact splash: a blood stain with a diameter between 1 – 4 mm, which is produced on a surface due to a medium speed force of 1.5 m/s – 7.5 m/s to the blood source. Hitting a solid object is an example of a medium speed impact. The patterns formed are irregular with sometimes larger volumes and overlapping patterns, and low speed patterns can also be found.
c) High speed impact splash: when the blood source is hit by a force with a speed of about 35 m/s or more. Most spatter produced is less than 1 mm in diameter, although larger spots may be found. Typically high impact splashes are associated with gunshot injuries, where large amounts of energy affect a fairly small area.

The bloodstain pattern that forms is also influenced by the condition of the target surface. The type of blood spatter on a surface influences the resulting spatter, including the size and appearance of the blood droplet. In general, it can be said that the smoother, harder and less porous a surface is, the smaller the distortion will be around or at the edge of the bloodstain. This occurs because high surface tension is easier to overcome than irregular and porous surfaces.

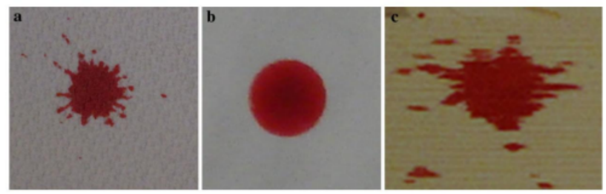

Figure 4. Differences in bloodstain patterns based on the target surface, falling from a height of 50 cm, a) on cotton, b) on tiles c) on wood (Peschel, 2011)

4. CONCLUSIONS

Based on the explanation above, it can be concluded that there are many physical factors or phenomena that can influence the analysis of bloodstain patterns found at the scene. Most analyzes are based on fluid dynamics which relate to liquid surface tension, air resistance, impact speed and surface shape. In gunshot wounds, air resistance plays a big role in creating splashes or small droplets due to surface tension which causes the blood to break apart in the air, resulting in splashes. Different impact speeds will produce different bloodstain patterns. Suggestions for the next review might be to discuss the bloodstain pattern analysis process in more detail regarding the analysis stages and patterns that might be found at the crime scene.

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