What is bloodstain pattern analysis? What is it used for?

Bloodstain pattern analysis (also called BPA) refers to the forensic specialty of analyzing blood traces found in a crime scene. The results are highly descriptive, but not absolute, and it is used as evidence that corroborates testimony by witnesses, suspects, and/or victims. Blood evidence or lack of blood evidence can be used to bolster or contradict a witness statement or statements the suspect may make.

Bloodstain pattern analysis can offer information about aspects of the violent act, such as:

- The type of weapon used
- The velocity of blood
- The number of blows
- The position and movements of the victim and assailant during and after the attack
- Which wounds were inflicted first
- The type of injuries
- How long ago the crime took place, and
- Whether death was immediate or delayed.

Bloodstain pattern analysis has a long history in forensics, with the first methodical study of blood spatters published in Poland in 1895 by Dr. Eduard Piotrowski. It has a history of subjectivity, often based in experiences, anecdotes, and empirical observation. The 1970s saw the expansion and modernization of the field, and the 1990s saw significant developments in blood analysis with the addition of DNA testing. Recent development involves comparing the physics of blood to fluid dynamics. Bloodstain pattern analysis is based on math, physics, biology, and chemistry.

Today, bloodstain pattern analysis has two parts: pattern analysis and reconstruction.

The mechanics of blood Pattern analysis

Blood travels in spherical drops because of surface tension, which is the tendency of liquids to minimize their surface area because their molecules are attracted to one another. Blood is viscoelastic with elastic behavior and brittle fractures, meaning it drips slow, sprays fast, and gets runnier if more force is applied to it. Blood is also complex, as it teems with living cells and active enzymes, and its properties shift under the influence of minute fluctuations of temperature or the presence of drugs.

Bloodstain patterns change shape depending on the height and velocity at which it falls, as well as the surface on which it lands. As height increases, so does the diameter of the blood drop. Droplets on hard surfaces will retain their circular shape, while droplets on carpets and fabrics are absorbed and the edges will spread.

These patterns of shape, size, and distribution can leave evidence of what happened at the crime scene. During documentation and analysis, the terminology of bloodstain pattern analysis is derived both from the physical appearance of the pattern and the mechanism in which patterns are created. Bloodstain types are divided into passive gravity, spatter, or altered categories to describe the mechanisms that created them.

- Drips and large volume bloodstains are both passive gravity patterns that show slow moving blood that occurs after an injury (4 mm or more).
- Transfer patterns are passive gravity impressions left by bloody objects, and sometimes retain the shape of the object that made it, such as handprints or footprints.
- Back-spatter refers to blood from the wound's entrance (behind the impacting object).
- Forward spatter refers to blood from the wound's exit (ahead of the impacting object) and will form smaller droplets over a wider area.
- Impact spatter is when the object comes into contact with the blood, such as in gunshots, beating/stabbing, or industrial events.
- Secondary spatter is when multiple drops hit the same spot.
- Projected or projectile patterns are spatters from fast bleeding or spurting blood.
- Voids or blockages are from altered mechanisms resulting in gaps in the pattern that indicate something was in the way of the blood's blowback.
- Clotted, diluted, diffused, dried, insects, and sequenced patterns also result from altered mechanisms which affect the determination of the order of events.

Distribution of blood spatter can determine the weapon used. Siu et. al determined that the mean drop size in gun shot spatter is up to 30% smaller than the mean drop size in blunt instrument patterns. Additionally, they found that spatial distribution of droplets are as much as 400% larger for gunshot impacts than blunt instruments.

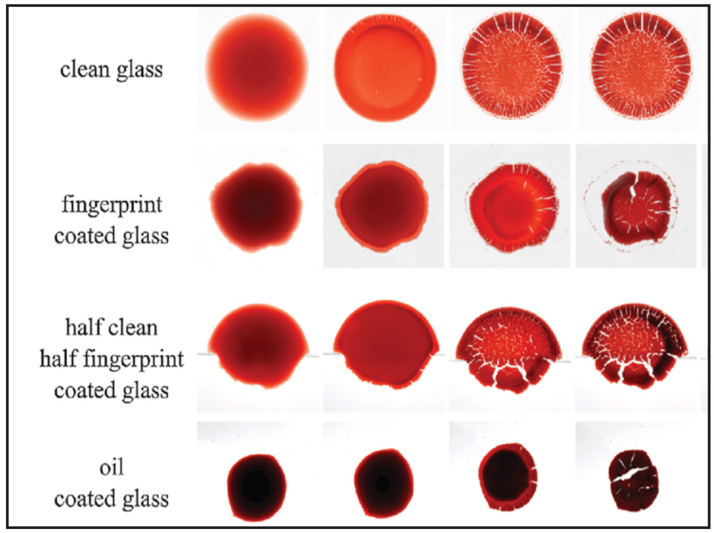
Analysts can determine approximate angles, including height, by looking at the shape of blood spatter and using the angles to determine a convergence point. Drops landing at a 10 degree angle create elongated stains, while drops landing at a 90 degree angle leave a round stain. The greater the difference between the width and length of the drop, the sharper the angle of impact. These calculations can determine whether the victim was seated, standing, or lying down when the event occurred.

The speed of drying blood also depends on the surface on which it lands, the amount of blood, as well as the heat and humidity at the crime scene. Blood pools do not dry in a uniform manner, and the shape of the pool can affect the dynamics of evaporation. The outer edges of a blood pool will dry first, and dry blood spatter can skeletonize and leave a ring similar to a

There are several stages of drying blood:
1. Coagulation
2. Gelation
3. Rim desiccation
4. Center desiccation
5. Final desiccation

These stages show changes in color from red to black, as well as cracking as the blood transitions from wet to dry. Clotting patterns in blood can help nail down the time factor if analysts arrive before the blood can fully dry. Clotting begins within 3-15 minutes, but actual times vary by amount, surface type, and environment.

Smith, Nicloux, and Brutin conducted a study in 2020 to find reliable patterns of drying blood pools, and found good results by comparing the physics of blood to the physics of sol-gel .They found before blood coagulation the evaporation rate is similar to water, after which dynamics are closer to a gel, and that as the blood pools dry, there is a shift in temperature from a very fast increase followed by a rapid decrease in temperature before plateauing in about 25 minutes, which is stable over time until the pool starts cracking. Based on "the drying front", they devised a mathematical formula that (in a controlled environment) could calculate the mass of blood and its drying time. This could potentially offer a tool in forensics for determining the time at which blood was spilled.



The patterns of drying blood help analysts determine how long an assault went on, whether it took place all at once or in stages, and to nail down possible crime scene contamination.

The mechanics of blood: Reconstruction

Documentation is necessary to record the condition of the crime scene and its related evidence as closely as possible to their original condition at the time of the crime. This documentation, along with bloodstain pattern analysis, aids the investigation in reconstruction. Using the laws of motion and gravity, physics, and chemistry, investigators can offer contextual explanations to bloodstain patterns during reconstruction of the scene. Bloodstain pattern analysis is particularly helpful in reconstructing cases when the manner of death is in question, and can support or refute assumptions in regard to the case.

Reconstruction involves analyzing the patterns found at the scene (bloodstain size, angles, distribution, altered mechanics, drying times) to determine positions and actions of the victim and the perpetrator. Analysis of the blood can determine whose blood is whose with some margin for error. By analyzing the directions of impact and the drying times of bloodstains, investigators can infer areas of convergence and origin. Reconstruction can be done using projections, strings and protractors, mathematical calculations, and/or computer models.

What else can blood tell us?

Bloodstain evidence can be used to type blood or run DNA analysis. DNA profiling is especially useful in cases involving multiple victims.

In the early 1970s, most crime labs relied on an ABO blood grouping system (ie. blood types A, B, O, or AB) to characterize bloodstains. Since the 1990s, most crime labs have used DNA analysis to characterize bloodstains and to narrow down possible blood sources. In particular with DNA analysis, the forensics community switched to STRs in the 1990s, which are a shorter type of repeat unit and allows for more sensitivity and more automation of analysis.

If DNA analysis is utilized, blood evidence falls into the category of evidence that can be linked to an individual with high probability. Current analysis is sensitive enough that a single sample analysis is likely to lead to multiple DNA profiles because methods may pick up DNA that may have been in the background. Once a DNA profile has been created, it is added to a DNA profile archive or database, which is what has really allowed forensic DNA profiling to take off in the last 30 years. Today's forensic scientists also use mathematical methods to incorporate all the data in their analysis, a process called probabilistic genotyping.

There are different methods of analyzing bloodstain evidence in the laboratory, and a crime lab may use more than one method. Reference samples will need to be studied to determine if it is human blood and to develop a DNA profile.

Conventional Serological analysis involves the analysis of proteins, enzymes, and antigens present in the blood. A large sample is needed for this method, and it rarely offers individual statistics.

Restriction Fragment Length Polymorphism (RFLP) analysis is a method of DNA analysis that involves analysis of certain DNA sequences present in white blood cells. DNA is less susceptible to degradation than proteins, enzymes, and antigens, and commonly results in individual statistics. It also requires a large sample size for significant results.

Polymerase Chain Reaction (PCR) analysis is another method of DNA analysis of certain DNA sequences that have been copied multiple times to a detectable level. This method works well on degraded samples and on small samples (pinhead size).

Dried Blood Spot (DBS) analysis is used for forensic and medico-legal applications. It can be used to detect metabolic diseases or drugs from small samples, particularly when seeking to explain a sudden and unexplained death.

Blood analysis is a comparison analysis, and reference blood samples should be collected from the victim and the suspect to provide more useful results. Blood from bloody clothing or items are unsuitable reference samples due to the presence of other factors that may give misleading results. Reference samples are collected in "Vacutainers", which are color coded to indicate the presence of additives for analysis. These samples should be stored in a refrigerator at about 4 degrees Celsius until it is transported to a crime lab.

What is the process of analysis like?

The crime scene investigator is the one who documents and collects blood evidence. When collecting evidence, they must recognize the value of the evidence and how it fits in with the overall event. The analysis of blood at a crime scene involves many people, including the crime scene's first responding officer, the case detective, the crime scene investigator, the forensic scientist, and the assistant district attorney handling the case. Knowledge of the lab resources and methods available are significant during documentation, as lab capabilities, methods of blood collection and preservation, and investigative information relevant to the forensic scientist are neither universal nor static.

Blood stains can be found by spraying luminol to make them glow in the dark, but luminol is not recommended as a first step as it can produce false reactions and cause the loss of several genetic markers. High intensity light, particularly when shone from an oblique (side) angle, is usually enough for investigation of bloodstains before removing, collecting, and submitting bloodstain evidence for confirmatory testing. Investigators will also need to consider possible alteration of the original scene by first responders such as EMS personnel, police officers, or fire fighters.

Documentation of evidence is important, and a slow and methodical approach is necessary. Documentation includes information from people, such as witness statements, suspect statements, victim statements, and information from first responding officers and detectives. Documentation of bloodstains and other evidence can consist of notes, videotape of the scene (aided with high intensity light), high resolution photography with rulers and slides for scale, infrared film for bloodstains on dark surfaces, and sketches to establish spatial relationships. The investigator will want to determine the "trail" of the crime (point of entry, location of body, clean up areas, point of exit) and to note locations of potential evidence.

After documentation, collection of evidence can begin. Collection methods depend on whether it is wet or dry, as well as what surface it is on. Most items of evidence will be collected in clean, unused paper containers such as packets, envelopes, and bags, but wet or biological evidence should be collected in clean, unused plastic containers and refrigerated at the scene. If bloodstains are is on a small item it can be stored in a paper bag or envelope, if it is on larger surfaces it may be cut out and wrapped in paper for transport and if it is not transportable samples may be photo documented and samples lifted. Investigators can use tape to lift bloodstains like a fingerprint onto vinyl acetate backing, or by scraping dried bloodstains into a paper package. Stains can also be absorbed onto white cotton threads or 1" x 1" squares of cotton muslin. Each sample must be closed, secured, and clearly labelled, and kept separated to avoid cross contamination.

Once at the lab, liquid samples are dried out at room temperature and transferred into paper storage. Time and documentation is of the essence, because after 2 hours microorganisms can destroy damp evidence, and after 48 hours a sample might be useless.

What are the limitations of bloodstain pattern analysis? What questions are still being studied?

Bloodstain pattern analysis information and results cannot be used alone. Additional information from an autopsy and DNA analysis is required to be useful. Even with correctly collected and documented bloodstain pattern analysis and the addition of DNA testing, bloodstain pattern analysis does not result in absolute certainty. In court, a forensic scientist cannot testify that a bloodstain came from a specific individual, but they can testify that based on population studies, only one person in several million or billion has that particular DNA profile and that the suspect or a victim has that DNA profile. Bloodstain pattern analysis is simply another tool and another source of evidence in understanding what happened in a particular crime.

There are still developments to be made regarding DNA profiling. Future forensic scientists may be able to establish key features of a perpetrator's physical evidence, which would be useful in cases with lots of DNA but no comparative profile and no suspect.

Perhaps surprisingly, scientists are still studying the physics of blood. There has been a recent shift in approach to research, and blood is now being compared to fluid dynamics. These studies involve mathematics and oversimplification to control known variables, and eventually will influence forensic practice. Currently there is still a scientific gap in disciplines between research papers in fluid dynamics and forensic experts, although this may be due to issues in communication and limitation of time resources. This research also needs to be evaluated for its impact on the criminal justice system and the ability to be ethically applied in the field.

How can I learn more?
Bloodstain pattern analysts are found at all levels of crime scene investigation. It is becoming more common for bloodstain pattern analysts to have a degree in math or a physical science. However, the field of bloodstain analysis is related to the field of criminology, criminal justice, and forensic science. Its study involves math, physics, biology, and chemistry. Training is available in formal studies from a degree or certificate in criminal justice or forensic science, as well as from individual courses, workshops, and seminars that occur throughout the bloodstain analyst's career. The International Association of Bloodstain Pattern Analysts has developed criteria for basic and advanced courses on the subject.

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