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A Comparative Analysis of Impact Spatter and Satellite Spatter on Fabric

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A Comparative Analysis of Impact Spatter and Satellite Spatter on Fabric

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Abstract

Bloodstain pattern analysis (BPA) is the practice reconstructing bloodletting events by interpreting the bloodstains left at the crime scene. In addition to the examination of well-formed bloodstains on non-porous surfaces, the bloodstain analyst is often asked to analyze bloodstained clothing. These types of analyses present challenges to the analyst because of the distorted nature of bloodstains on fabric. Although the evaluation of bloodstained fabric is both difficult and common, the research concerning bloodstain development on textiles is limited. A strong understanding of bloodstain mechanisms on fabric is imperative because an analyst's conclusion may implicate or exclude the wearer as an assailant based on their interpretation. As an effort to contribute to the limited research, the current research comparatively analyzed two types of spatter, impact spatter and satellite spatter, on 100% cotton jersey knit t-shirt fabric and 100% cotton bed sheet fabric.

Impact spatter was reproduced by a mousetrap apparatus and satellite spatter was simulated by dripping drops of blood into a volume stain. The two types of spatter were analyzed in a quantitative manner through the use of ImageJ. The bloodstains were qualitatively analyzed with and without macroscopic magnification. Descriptive attributes such as size, impact angle, shape, symmetrical properties, and weave saturation were recorded and a narrative analysis allowed the presentation of other unique features of each spatter.

The non-fabric control samples successfully reproduced unique characteristics of impact spatter and satellite spatter and were used as a standard for the comparison of the spattered fabrics. The t-shirt fabric proved to have the highest amount of bloodstain distortion. The spatters were comparative in the quantitative and qualitative analysis; however, the narrative analysis revealed the presence of fine, very small submillimeter stains on the satellite spattered fabric that was absent in the impact spatter samples. Additionally, the satellite spattered t-shirt fabric exhibited some signs of random directionality within the bloodstains. The bed sheet fabric yielded results that coincided more with the controls in terms of size. The descriptive stain analysis yielded similar results; however, the narrative analysis revealed the same results for the satellite spattered bed sheet fabric as the satellite spattered t-shirt fabric. Furthermore, the impact spattered bed sheets revealed distinguishing spines around the stains; spines were present in the controls, but not in the t-shirt fabric.

The conclusions of the current study revealed that impact spatter and satellite spatter may or may not have distinguishing characteristics depending on the type of fabric; however, the study also affirmed the previous claims that impact spatter and satellite spatter have many similar qualities. The characteristics of impact spatter on fabric have been investigated by previous research; however, because of satellite spatter's resemblance to impact spatter, more research ought to be conducted on satellite bloodstain development on an array of fabrics and also at different angles and distances from its source to its impact site. Experimentation of this nature will contribute to the knowledge of small bloodstain development on fabric and thus, assist in the advancement the discipline.

Keywords: Satellite Spatter, Impact Spatter, Fabric, Textile

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CHAPTER 1

INTRODUCTION

The criminal justice system, a structured entity whose ultimate goal is protecting and serving society, is a complex system comprised of various components whose entirety works towards justice through the revelation of facts. Although obtaining the facts about a past crime can be a difficult task, its acquisition ensures the most appropriate administration of justice. The procurement of truth involves many elements within the system; however, a valuable component that provides a considerable amount of insight into criminal action is the forensic sciences. The totality of the forensic science disciplines can assist in not only administering justice, but ensuring that justice is administered correctly. However, in order for forensic science to provide the most accurate information, the disciplines must continuously investigate their foundations, frameworks, and practices in an effort to continually validate and advance their discipline.

Bloodstain pattern analysis (BPA) is one of the many fields of forensic science. Bloodstain pattern analysis does not intend to identify who committed the crime, such as DNA analysis; rather, the practice can provide a reconstructed vision of past criminal events by investigating deposited bloodstains at the crime scene. An expertise in BPA methodology and an encompassing understanding of blood's morphological behavior during flight and after impact allows the analyst to use that information to reconstruct a blood-letting event. Although the ongoing research in the discipline continuously work to advance the practice and contribute additional knowledge of reconstruction, research inadequacies still remain much like other disciplines of the forensic sciences.

Calls for Research in BPA

In 2009, The National Academy of Sciences published *Strengthening Forensic Science in the United States: A Path Forward,* a report with a goal of identifying the previously mentioned gaps within the totality of forensic science; among the disciplines referenced was bloodstain pattern analysis (N.R. Council, 2009). The report contended that bloodstain pattern analysts relied too heavily on experience and subjective analysis rather than scientific principles (N.R. Council, 2009). The National Academy of Sciences recommended that extended experimentation ought to be conducted in order to further research the effects of bloodstains under various circumstantial factors (N.R. Council, 2009). Massed experimentation would serve to expand the scientific foundation of the discipline and would further supplement the experience that is also needed for a qualified bloodstain pattern analyst.

Two years after the report was published, the Scientific Working Group on Bloodstain Pattern Analysis (SWGSTAIN) released a written report describing the needs for BPA research that would further advance the discipline. Among the list provided by SWGSTAIN was a need for research on small stain analysis and the evaluation of bloodstains on fabric. Despite the recurrent presence of bloodied clothing encountered on crime scenes, the research on bloodstained textiles is limited. The literature concerning bloodstained clothing is growing in recent years; however, a number of phenomena have yet to be thoroughly and scientifically investigated.

Bloodied Fabric

An ongoing inquiry into BPA methods is essential to further validate and advance the discipline; however, an awareness of the surface on which the blood is found is also crucial due to the surface's influence on bloodstain formation. Unlike blood striking a smooth surface, such as a wall, and leaving an "ideal" bloodstain fit for calculated observation, blood strikes fabric in an irregular manner that yields a more cautious analysis (Karger et al., 1998). Bloodstains deposited on smooth, non-porous surfaces provide clear elements that are needed for analysis, such as stain classification, impact angle measurements and directionality; however, the details needed for a dependable and accurate analysis become lost in fabric. The interruption of a bloodstain's formation by its impact site warrants thorough research of bloodstains on a vast array of targets, including non-porous surfaces.

Furthermore, unlike bloodstains found on inanimate objects at a crime scene, bloodstains found on clothing are linked to the wearer. A specific individual wearing bloodstained clothing can be implicated as a suspect based on the stains deposited onto their own personal attire. Although an involved party may proclaim the events of the crime to law enforcement, the bloodstains found on his or her clothing may either confirm or refute those accounts (Slemko, 2003). Bloodstained clothing introduces an additional element of personal linkage to an individual. If done correctly, bloodstains have the potential to identify those individual roles in crimes.

The capacity for bloodstains to depict the events of the crime is a powerful asset; however, if interpreted incorrectly, it can also have an adverse effect. In order to accurately complete forensic examinations of bloodstained clothing, a full examination of the actual phenomena must be investigated and understood. Although the discipline has begun to investigate various areas of blood deposition on fabric, the research gaps in small stain analysis on fabric introduce an alarming level of difficulty accompanying an analyst's examination. Without a vast amount of knowledge about a particular bloodstain event, an examination of this caliber can result in inaccurate analyses and consequential injustice.

Impact Spatter and Satellite Spatter on Fabric

A reoccurring suggestion by bloodstain experts is to adopt a cautionary approach when examining impact spatter and satellite spatter on fabrics. Generally, impact stains, occurring as a result of force impacting a blood source, indicate proximity to a bloodletting event whereas satellite spatter, secondary spatter originating from a primary stain or pool, indicate proximity to the parent stain. In ideal circumstances, the impact spatter and satellite spatter can be differentiated with minimal issues; however, some less than ideal circumstances can render a difficult differentiation. Both of the aforementioned spatter types will be examined in the current research.

In occurrences where either impact spatter or satellite spatter are examined on smooth, non-porous surfaces, it is relatively easy to spot their respective identifying characteristics (Bevel & Gardner, 2008). Targets of this nature allow for the bloodstains' detailed characteristics to be visualized with minimal interruption from the surface's topography. Additionally, if the satellite spatter's parent stain is in sight, the satellite bloodstain's directionality can lead back to its parent stain, making it more easily identifiable. Impact spatter and satellite spatter possess distinct qualities as long as those characteristics are available for inspection.

However, the classification of spatter becomes more problematic if the impact target is fabric. Fabric's irregular contour and porous nature interrupts the morphological process of bloodstain formation. Once blood's formation on fabric is interrupted, the unique characteristics are also disrupted, rendering an identification more challenging. This phenomenon introduces difficulty in identifying bloodstain types in general; furthermore, it creates challenges in distinguishing impact spatter from satellite spatter. The unique characteristics of both spatters undergo disruption and the consequential disruptions of each are similar.

Bevel and Gardner (2008) address the circumstances in which satellite spatter is disassociated from the parent stain, which is described as a pooling volume stain. An accumulating stain, such as blood pooling from a bleeding individual, can be dripping on top of a shoe and therefore ejects spatter around the surrounding objects or people. The resulting satellite spatter may easily be identified with an associated parent stain nearby; however, the pooling parent stain located on an individual's shoe may or may not walk away from the scene. These cases remove the opportunity to trace satellite spatter back to its originating parent stain, one of the unique methods in the identification of satellite spatter.

As noted by White (1986), satellite stains can hold a strong resemblance to impact spatter on clothing and deserve caution. Laber et al. (2014) affirms that the presence of satellite stains is more obvious and easier to identify if a parent stain is present. The researchers state that the identification of drip stains originating from a blood pool in a classroom setting are more feasible because, often, the analyst has the parent stain in close proximity which allows for an easier correlation; however, the researchers continued, "In clothing examinations, the parent stain is most often not present because it is on some object the clothing was adjacent to and left at the scene" (Laber et al., 2014, p. 69). As previously mentioned, impact spatter indicates proximity to the actual blood-letting event whereas satellite spatter indicates proximity to a parent stain, resulting in opposing implications. While considering the error rates associated with the identification of satellite spatter (Laber et al., 2014), confusing the two bloodstains as one another creates the potential for stain misclassification and, consequently, the determination of an individual's involvement may become jeopardized.

Objective

Although experts have acknowledged the dangerous similarity between impact spatter and satellite stains, there is an absence of research investigating and comparing the characteristics of both. Scenarios have been discussed in which satellite spatter may be misidentified as impact spatter, but the dearth of research investigating unique spatter phenomena on fabric postpones a potential solution. The combination of a lack of research and the high error rates associated with the identification of satellite spatter requires extensive research. In order to bridge this particular gap in the BPA knowledge pool, the author conducted pilot research that reproduced impact spatter and satellite spatter on fabric and investigated the following research questions both quantitatively and qualitatively:

1: What are the distinguishing characteristics of impact spatter on fabric?

2: What are the distinguishing characteristics of satellite spatter on fabric?

3: What are the shared characteristics of impact spatter and satellite spatter on fabric?

At a glance, the two types of spatter on fabric appear similar, but the details found in focused research may provide further insight. The current study aimed to scientifically identify characteristics of both spatters and furthermore, identify the shared and possibly distinguishing characteristics that could serve as an informational base for analysts in the future. Before conducting research on methods of differentiation, the unique characteristics of satellite spatter on textiles must be known while simultaneously considering impact spatter.

CHAPTER 2

LITERATURE REVIEW

Distortion of Bloodstain Formation on Fabric

Physical Properties of blood

Although knowledge of post-impact bloodstain characteristics is required in terms of interpreting their investigative significance, it is also imperative that the bloodstain analyst has an understanding of blood's behavior in flight and during impact. As noted by early bloodstain experts such as James E. Macdonald and Dr. Alfred Carter, a droplet in flight aims to remain compact due to its inherent surface tension (Bevel & Gardner, 2008). While external forces influence a blood droplet's form dependent upon the force applied, the cohesive nature of blood remains intact in the form of a sphere.

The surface tension of a blood droplet is the force that causes molecules to constrain and decrease the droplet's surface area (Eckert & James, 1998). Surface tension is a crucial force to the manner in which it impacts surfaces (Attinger, et al., 2013); however, it is not the sole force that causes its compact, spherical shape. The viscosity, defined as the "measure of the resistance of a fluid to a change of shape or flow" (Attinger et al., 2013, p.377) of blood is the element that prevents droplets from oscillating excessively resulting in separation. The symmetrical features of an intact, spherical droplet allow bloodstain pattern analysts to calculate impact angle information (Baxter, 2015), which can be crucial to interpreting bloodletting events. Once a blood droplet impacts a surface, it will exhibit morphological stages. The manner in which the ultimate bloodstain appears is dependent upon the surface impacting those stages.

Phases of Bloodstain Morphology

The following description of impacting blood morphology is based upon the publications of prominent bloodstain analysts Tom Bevel and Ross Gardner (Bevel & Gardner, 2008). The termination of a droplet's flight is at first impact of a surface. Bevel & Gardner (2008) describe the collision of a blood droplet into a surface in four distinct phases: Contact/Collapse, Displacement, Dispersion, and Retraction (Bevel & Gardner, 2008). The analysts also describe the effect that surface characteristics have on bloodstain formation.

The Contact/Collapse phase begins when a blood droplet initially impacts a target. The initial impact forces the blood outward and creates a rim with a partial sphere of blood protruding out the center of the rim. Blood dropped at ninety degrees exhibits a fairly symmetrical rim due to blood flowing evenly throughout its area; however, blood dropped at a more acute angle causes an uneven blood flow favored towards one side, initiating an elliptical shape. In terms of surface characteristics of the impact site, if a blood droplet impacts a more topographically varying surface, the initial outflow of blood to the rim as described above occurs in an irregular fashion in comparison to impacting a smooth surface.

After the initial collapse of the droplet onto a surface, the majority of the blood will then laterally travel into the rim in the displacement phase. The stain's shape takes place during this phase. Due to the majority of the blood being forced into the rim, spines may also start to form. If the droplet deposits onto a textured surface, the blood that has flowed into the rim will do so irregularly, creating a distorted stain. A blood drop impacting a liquid surface will exhibit an increased amount of blood being forced into the rim. As a result, the increase in blood in these instances create an increased amount of spines and/or satellite spatter.

The dispersion phase initiates the rise of the rim of the blood droplet. The blood that was forced laterally into the rim in the previous phase is now forced upward. At ninety degree angles, the blood will equally rise around the perimeter of the drop, creating a blossoming effect. In acute angles, the volume of blood that flows into one side creates a wave-like appendage off of the parent stain. If the inertia is great enough, blood will separate from the parent drop, resulting in satellite spatter.

The final phase of a blood droplet impacting a surface is the retraction phase. The surface tension of the blood drop attempts to pull itself back together from the upward rising in the dispersion phase. There are two contending forces at play during this phase: inertia and surface tension. If the inertia overcomes the surface tension, a secondary drop, or satellite spatter, will separate from the parent stain. If the surface tension can sustain the inertia of impact, then the drop will remain as one mass. In regards to surface characteristics affecting this phase, absorbency of the target can produce asymmetrical stains.

Influence of Textile Impact Sites

It is apparent that the surface topography of the impact site plays a major role in the phases of stain morphology. The bloodstain that impacts a smooth, non-porous surface exhibits a "normal" transition throughout the phases of bloodstain morphology; however, a blood drop that impacts an irregular surface initiates a disruption beginning in the first phase. This consequently ensues a domino effect into the other three phases and ultimately creates an irregularly shaped bloodstain. Specifically, fabric impact sites exhibit their own type of distortions; not only is fabric a textured surface, but fabric also is absorbent.

The amount of distortion can vary depending upon the impact site. In terms of fabric surfaces, Miles et al. (2014) determined the influence of fabric type on satellite stains from a singular passive blood drop. They asserted, "As the surface roughness increases, the extent of disruption and splashing also increases," and continued affirming that a number of variables concerning fabrics will affect how a stain is formed (p. 263). Slemko (2003) investigated if the appearance of bloodstains on fabric is caused by fabric attributes or velocity. The researcher found that the resulting distorted appearance is dependent upon the fabric's absorbency and texture (Slemko, 2003). De Castro et. al (2013) concluded in their research investigating bloodstain formation on fabrics that fabric texture interrupts the normal impact dynamic. Furthermore, the research describes that the shape of the bloodstains was irregular because of its tendency to follow the grain of the fabric (de Castro et al., 2013). Bloodstain wicking, the process of blood traveling through the weave of the fabric due to capillary forces, is also responsible for irregular bloodstain formation (de Castro, et al., 2015).

Due to the distortion that fabric causes in bloodstain formation, impact angle calculations have either been cautioned or prohibited. Some experts claim that angle of impact calculations can cautiously be done on fabric (Raymond, 1997), while other analysts state that the irregularity of the stains causes calculations to be completely unreliable and should not be reported (White, 1986). While impact angle calculations are considered to be unreliable on irregular bloodstains, the mere process of classifying the bloodstain type may be compromised as well because the characteristics that are used to identify specific bloodstains are distorted.

As Bevel & Gardner (2008) affirm, "Classification . . . involves evaluating and identifying the physical characteristics of the questioned stain without consideration of additional data such as scene context or associated evidence" (p. 37). The distortion of the physical characteristics that define the stain pattern type, without the known context, may influence the ability to merely identify certain pattern types. Among the numerous bloodstain classifications, impact spatter and satellite spatter are two of the various pattern types found at crime scenes.

Attributes of Impact Spatter and Satellite Spatter

The categorization of bloodstain type can be identified through the recognition of unique stain attributes. Among the spatter stain classifications include impact spatter and satellite spatter. Generally, impact stains, occurring as a result of force impacting a blood source, indicate proximity to a bloodletting event whereas satellite spatter, secondary spatter originating from a primary stain or pool, indicate proximity to the parent stain (Raymond, 1997). In ideal circumstances, the impact spatter and satellite spatter can be differentiated with minimal issues; however, some less than ideal circumstances can render a difficult differentiation. Both of the aforementioned spatter types will be examined in the current research.

Impact Spatter

The bloodstain pattern analysis community recognizes three variations of impact spatter: low, medium, and high velocity (Bevel & Gardner, 2008). Low velocity spatter is typical of spatter that impacts a surface caused by gravity. Medium velocity impact spatter typically occurs as a result of blunt force trauma. High velocity impact spatter is typical of gunshot wounds due to the high amount of force associated with firearms. Medium velocity type impact spatter will be the focus of the current research and will be referred to as "impact spatter" henceforward.

As mentioned previously, impact spatter is a series of small spatter stains that are a product of some force, such as a weapon, striking a blood source, such as an individual. Impact stains will typically be one to four millimeters in diameter. The blood will generally disperse from the blood source in a radiating, non-linear fashion from the impact site (Bevel & Gardner, 2008). Impact spatter is a reliable indicator that the bloodletting event occurred in close proximity to that location (Raymond, 1997). Generally, impact bloodstains can be used to make calculations that determine an area from which the blood was dispersed.

Although it is unlikely, it is possible that an assailant involved in a bloodletting event can lack the presence of impact spatter on his or her clothing when specific circumstances are conducive to the absence of spatter (Raymond, 1997; Baxter, 2015). Consequently, the amount of impact spatter that can be found on an assailant can range from complete absence to an indefinite amount. Identifying impact spatter based solely on the total quantity of spatter may be considered unreliable.

Satellite Spatter

Satellite spatter can appear in the form of attached, semi-detached, or detached from its original parent stain (Bevel & Gardner, 2008); however, for the purposes of the current research, detached satellite spatter will be the area of focus due to its potentially misleading nature. The secondary spatter that detaches from its parent droplet occurs as a result of velocity overcoming blood's inherent surface tension. Blood naturally attempts to remain cohesive; however, due to velocity's overpowering force, blood will separate into smaller, secondary blood droplets as a result. Satellite spatter is also produced in a "splashing" fashion when blood deposits into a pool of blood. The latter form of satellite spatter will be the focus of the current research.

A manner in which satellite spatter may be identified is its opposite directionality as the primary spatter. While the directionality of impact spatter leads back to the impact site, i.e., the blood-letting act, satellite spatter will have a directionality leading back to its parent stain or blood pool. However, this occurrence can only be visualized if the satellite stain is not disassociated from the parent stain. In some instances, it may be difficult to link satellite spatter to its origin because satellite spatter has been known to travel several inches away from its origin (de Castro et al., 2013; White, 1986). Overall, satellite spatter will exhibit a random distribution from its origin.

Another unique quality of satellite spatter is the shape of the resulting bloodstains. As mentioned previously, satellite spatter typically points back to the parent stain, and does so in the shape of a tear-drop or a tadpole. The tail points back to the parent and the head of the stain is rounded. Stains of this shape are more typical of satellite spatter. Furthermore, the resulting bloodstains of satellite spatter may overlap due to its random ejection from its origin. An overlapping of deposited bloodstains will result in random, irregular shapes (Bevel & Gardner, 2008).

Complications with Impact and Satellite Spatter on Clothing

The unique characteristics that are associated with either impact or satellite spatter can be visualized and discerned on smooth, non-porous surfaces. However, the previous research has shown that fabric distorts those identifying characteristics and, thus, requires a cautious and complex analysis. Miles et al. (2014) conducted research concerning the morphology of satellite spatter detaching from a single primary drop at different heights and angles on two different fabrics. The research discussed the possible intermixing presence of primary spatter, originating from the blood source, and secondary spatter, stains that originate from the primary spatter. Due to the similarities of the separate spatter on fabric, the overlap of primary and secondary spatter can potentially be mistaken as only primary spatter.

Eckert and James (1998) affirm that satellite spatters on a vertical surface that are a product of blood dripping into blood can be mistaken as impact spatter. They continued that investigators often evaluate small blood spatter on pants, socks and shoes as impact spatter; however, the authors continue to caution that satellite spatter should be included as the possible source of the bloodstains due to its similar appearance. Lastly, the authors state that it should be acknowledged and considered that non-blunt force occurrences, including blood dripping into blood, can produce spatter one to three millimeters in diameter or less.

Perhaps the research executed by Laber et al. (2014) contains the most alarming findings concerning the interpretation of satellite spatter on fabric. The research that aimed to investigate the current methods used in bloodstain pattern analysis found that the highest rates of misclassification (59%) were the identification of satellite spatter on fabric. The researchers possibly attributed this finding to the absence of an associated parent stain. The error rate in identifying satellite spatter in this particular study highlights the possibility of misinterpreting satellite spatter as impact spatter or vice versa.

Previous Comparative Analyses on Fabric

Although the current research had not been attempted to the author's knowledge, other investigations with similar objectives served as an aid in the current research structure. Previous research has involved examining and comparing impact spatter and transfer stains. Transfer stains occur as a result of a bloodied object coming into direct contact with another object. The research investigating the dichotomy of primary stains (impact spatter) versus secondary stains (transfer stains) serves as a foundation for the proposed research.

Holbrook (2010) investigated transfer stains and impact spatter on fabric. The research advised that the physical characteristics of bloodstains and the overall distributions of each should be considered when cautiously evaluating both (Holbrook, 2010). The research further concluded that the distinction between transfer stains and impact spatter became more difficult as the stain size decreased (Holbrook, 2010). As a supplemental investigative tool, the researcher utilized photomicrographs to observe the weave penetration of the bloodstains. Transfer stains typically remained on the top weave while impact spatter penetrated further down into the weave.

The use of microscopic examination has been widely used in BPA research. Cho, et al. (2015) states that, “The spatter and transfer bloodstain patterns qualitatively look similar and are difficult to differentiate simply by visual inspection . . .,” and continued to add that the details and trends become more apparent as magnification increases (Cho et al., 2015, p. 235-36). Furthermore, Karger et al. (1998) asserts that as stain size decreases, the more difficult it becomes to analyze on fabric. This renders using microscopic examination necessary in order to capture additional information.

As a means to quantitatively examine bloodstains on textiles, previous research investigating passive bloodstain drops on fabric have utilized imaging software to obtain measurements of bloodstains such as the area, perimeter, circularity, and axes length (Michelson et al, 2015; Li, 2015; Williams et al, 2016; de Castro et al, 2015). Although the discipline of bloodstain pattern analysis has an inherently subjective component; quantitative measures of the bloodstains can be recorded for further objective classification. Additionally, observing bloodstains via imaging software provides precise data by utilizing pixels within an image to calibrate the measurements. The use of software may also assist in reducing subjective measurement errors while being more practically advantageous. While this tactic has been used to observe passive bloodstains on fabric, the same methodology was applied in examining whole patterns of impact spatter and satellite spatter.

CHAPTER III

MATERIALS AND METHODS

Introduction

In order to observe the defining characteristics of impact stains and satellite stains on fabric, simulations of each spatter were conducted. Both simulations produced the necessary data to provide a descriptive analysis of each bloodstain mechanism in this study. The research was conducted at the Forensic Science Institute at the University of Central Oklahoma in Edmond, Oklahoma. The researcher purchased materials for the simulations and the remaining utilized materials and tools were provided by the Forensic Science Institute.

For analysis, a bloodstain pattern examination may utilize both quantitative and qualitative data when investigating blood at a crime scene; therefore, the bloodstains created in this research were analyzed alike. A quantitative analysis was executed as a means to minimize some of the subjectivity associated with bloodstain pattern analysis. The qualitative analysis of the samples included bloodstain descriptors that are commonly exhibited in the discipline. Although examining individual bloodstains may prove to be imperative for comparing and contrasting impact and satellite spatter, an overall analysis of the entire fabric is important to execute (Holbrook, 2010); therefore, narrative descriptions of the fabric's entirety were also recorded. The qualitative data were visualized with and without macroscopic magnification.

Simulations

Simulation Materials

The fabrics were purchased online from Testfabrics, Inc. The selected fabrics were 100% cotton, optically brightened percale bed sheeting (Item Number: 439XW) and 100% cotton, bleached jersey knit t-shirt fabric (Item Number: 437W-60). This study will be limited to 100%

cotton; however, a constant fabric composition will allow for a more practical analysis by integrating a constant variable. Additionally, cotton accounts for seventy percent of daily clothing items and sixty percent of bedding (National Cotton Council for America); therefore, it is likely to be encountered in bloodied fabric at crime scenes.

A fabric of 100% cotton, blue denim dyed indigo (Item Number: 2550Y) was also purchased for the experiments; however, in terms of the analysis techniques for this particular research, future inspection would show that the dark blue color of the denim prevented the researcher from conducting an equal and reliable analysis of the fabric in comparison to the white sheet and t-shirt fabrics. As a result, the spattered denim could not be reliably analyzed. A detailed account will be provided later in this chapter.

The fabrics were washed in a conventional, top-loading washer before being used in the simulations. Tide Original Scent detergent was used as the soap agent and the clothes were washed at a "warm" temperature and a "cold" rinse temperature. The fabrics were dried for forty-five minutes in a conventional dryer. This process was repeated for a total of six cycles as previous research has recommended for the testing of stable fabrics (Gore et al., 2006; Slemko, 2003). Additionally, this provides a more realistic component due to the fact that fabrics encountered at crime scenes have more than likely been washed before. After the six cycles were completed, the fabrics were cut into 250 mm by 250 mm samples for this study.

Bovine whole blood with K2 EDTA anticoagulant, obtained through the Forensic Science Institute from Innovative Research, Inc. was utilized in the research. The blood was stored at the appropriate storage temperatures. Shortly before the simulations began, the blood was warmed to a human temperature of 98.6 degrees (37 degrees Celsius) in a warm water bath. The temperature was confirmed with a thermometer before experimentation. A number of small blood containers were kept in the warm water bath and exchanged throughout the experiments in order to use newly warmed blood for the ongoing trials. The temperature of the blood was monitored and maintained approximately at human temperature throughout the experiments.

A mounting surface was designed for the fabric samples with five foam boards and duct tape. The foam boards were constructed in a way that created a box-like shape without a top covering and one of the vertical "walls" of the box having the ability to flip up or fold down. This shifting wall was either suspended upwards or laid down horizontally depending on the simulation being executed. All of the foam boards were connected with the use of duct tape. Appropriate markings were made on the box to serve as a guide for measurements and placement of tools.

An additional, smaller foam board cut-out was used as a mobile mount for the fabric samples. The mount contained adhesive strips that were equally aligned with the corresponding adhesive strips located on the blood barricade. The fabrics were secured onto the removable mount with thumbtacks at each corner of the fabric, and then the mount was secured onto the blood barricade via the adhesive strips. This allowed for a practical method of mounting, removing, and remounting fabrics onto the blood barricade while using the minimal amount of time.

Impact spatter was produced by the use of a "mousetrap" apparatus that is designed for the purpose of mimicking impact spatter. This device is commonly used in bloodstain pattern analysis experimentation. An ErgoOne 100-1000µ pipette was utilized to deposit the bovine blood onto the platform of the mousetrap. Additionally, a protractor was used to gauge the angle at which the mousetrap was released. Satellite spatter was reproduced by releasing drops of bovine blood from an eye dropper suspended by a constructed "drip rig". The drip rig was loaned by Bevel, Gardner & Associates, which consisted of a wood base, a tent pole, and a securing device on the top to support a dripping mechanism.

Impact Spatter Simulation Methods

The mousetrap apparatus was placed twenty-four inches from the mounting surface of the blood barricade and was equidistant between the side boards. The outline of the mousetrap was traced at this position to ensure that the mousetrap was positioned consistently throughout the trials. A 250 mm x 250 mm fabric sample was thumbtacked onto the removable foam board mount and then the mount was secured onto the corresponding adhesive strips located on the blood barricade. The shifting vertical board was folded down against the floor for the impact spatter simulation.

One milliliter of blood was deposited from the pipette onto the frontal-center area of the mousetrap platform. The placement towards the front of the platform maximized the amount of impact spatter that projected forward towards the fabric samples. Initially, aluminum foil was tautly placed around the platform of the mousetrap to provide a clean surface for each trial upon replacement of the foil; however, after inspection of the impact spatter simulation test run, the foil was causing the blood to run towards the backward portion of the mousetrap platform, inhibiting the amount of spatter produced (see Figure 1).

Figure 1: Blood running towards back of platform, creating insufficient spatter on vertical target

As an alternative, the blood on the mousetrap was simply wiped clean with a paper towel after each trial to provide a clean surface for the next. Additionally, the spatter was not adequately impacting the target; rather, it was depositing more so onto the horizontal base of the box-like blood barricade between the mousetrap and the fabric. This was occurring as a result of the mousetrap position being too low. In order to accommodate for this placement issue, the mousetrap was raised approximately five inches by placing the mousetrap onto a secured box. The mousetrap was secured and remained to be twenty-four inches away from the mounted fabric.

After the mounting of the fabric and the placement of one milliliter of blood onto the mousetrap platform, the arm of the mousetrap was raised to an angle of eighty degrees. The angle was confirmed with a protractor located adjacent and equally level to the mousetrap on an additional fingerprint kit box (see Figure 2). After the arm was raised to an eighty-degree angle, the researcher released the mousetrap arm with no additional force. The practice of elevating the mousetrap arm to a specific level and the release of the mousetrap with no additional force minimized drop variability from trial to trial.

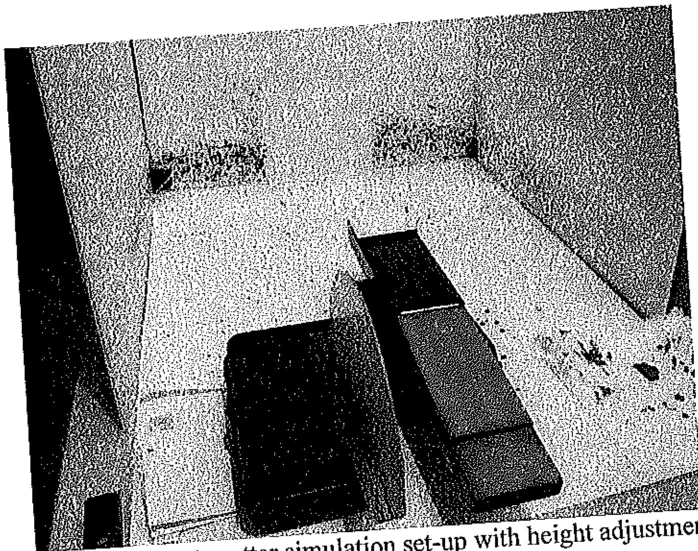


Figure 2: Impact spatter simulation set-up with height adjustment

The fabric samples were removed after one spatter event was produced on each. The fabrics were placed onto a table to dry with a note depicting its unique identifier, including spatter type, fabric, and sample number. The placement of the note above the fabric indicated the correct orientation. Five samples of the t-shirt fabric and five samples of the sheet fabric were created, yielding a total of ten fabric samples to be analyzed. The eventually excluded five denim samples were also treated in the same manner. Additionally, five impact spatter events were created onto five separate sheets of poster board (250 mm x 250 mm) to serve as control samples. Impact spatter on poster board reflects spatter on smooth, non-porous surfaces and will demonstrate pronounced unique differences in comparison to the spattered fabric samples.

The fabrics were stapled onto poster board to prevent the fabrics from folding. The identifiers were written on the top-center edge of the poster board with a permanent marker. The placement of the identifier at the top also indicated that the orientation was upright. After the fabrics were secured onto their corresponding poster board mounts, the fabrics were photographed with a Nikon D3300 camera with a 60mm micro lens and a flash attachment. The samples were photographed after a minimum of ten minutes of being dismounted due to previous research finding no significant change in bloodstain appearance after ten minutes (Chang &

Michielson, 2015). Included in the photograph frame was the entirety of the fabric, its identifier, and a scale. The samples were stored and transferred from locations in a paper bag for future analysis on a different date.

Satellite Spatter Simulation Methods

The moveable board that was laid horizontally on the floor in the impact spatter simulation was flipped vertically and secured with duct tape for the satellite spatter simulation. The board was flipped in an upright position due satellite spatter impacting around the entirety of the drop point rather than towards one particular direction. The 250 mm x 250 mm fabric and control samples were mounted, removed, and remounted in the same manner as discussed previously in the impact spatter experiments. After a test run of the satellite spatter simulation, some issues prompted some adjustments to be made.

In order to reproduce satellite spatter, blood drops would be released from the drip rig onto the horizontal base of the blood barricade below. This particular event mimics the act of an individual bleeding into an accumulating volume stain, which consequently produces secondary satellite spatter. The rig has the capacity to suspend an eye dropper above the intended target approximately forty inches above the drop point (see Figure 3). The drip rig was originally positioned where the blood drops would impact approximately eight inches away from the target samples; however, a minimal amount of spatter was depositing onto the mounted targets at this distance. The drop point was relocated to approximately four inches away from the target samples to allow for a greater amount of satellite spatter to impact the targets.

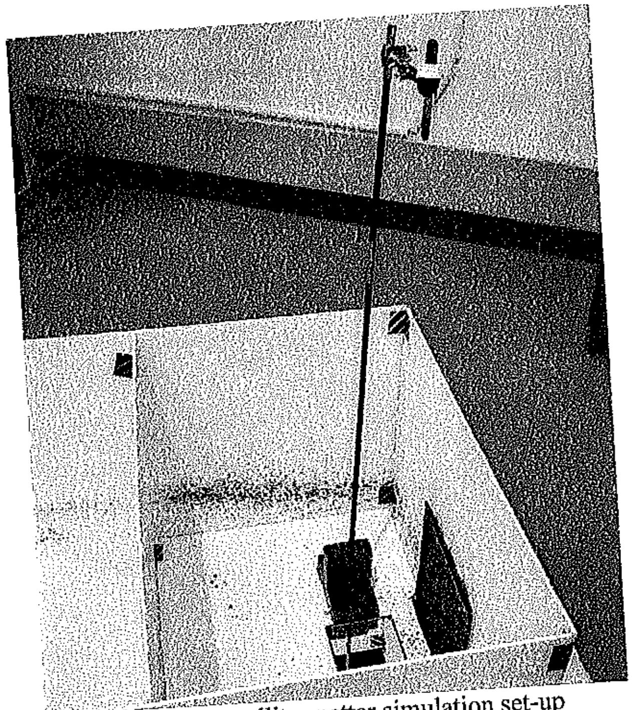


Figure 3: Satellite spatter simulation set-up

From the suspended eye dropper, one drop of blood would be released every two to three seconds until a total of twelve drops had fallen onto the drop point. As a result, satellite spatter would "splash" onto the fabric samples four inches adjacent. After the initial test trial, an additional problem was discovered. Satellite spatter was not being fully produced until a volume stain had formed, which occurred approximately after six to seven drops had been released. Consequently, only five to six drops worth of satellite spatter was ultimately impacting the target. In order for the totality of the drops to produce sufficient satellite spatter for analysis, a pre-existing volume stain (two mL in volume) was added to the drop point and then proceeded to release twelve blood drops from the suspended eye dropper every two to three seconds. This event is comparable to an individual bleeding in one position for a prolonged amount of time. A flat mirror served as the drop point on which the drops would be deposited. The mirror was selected because it is smooth, non-porous, and could easily be removed and cleaned for each trial of the simulations (see Figure 4).

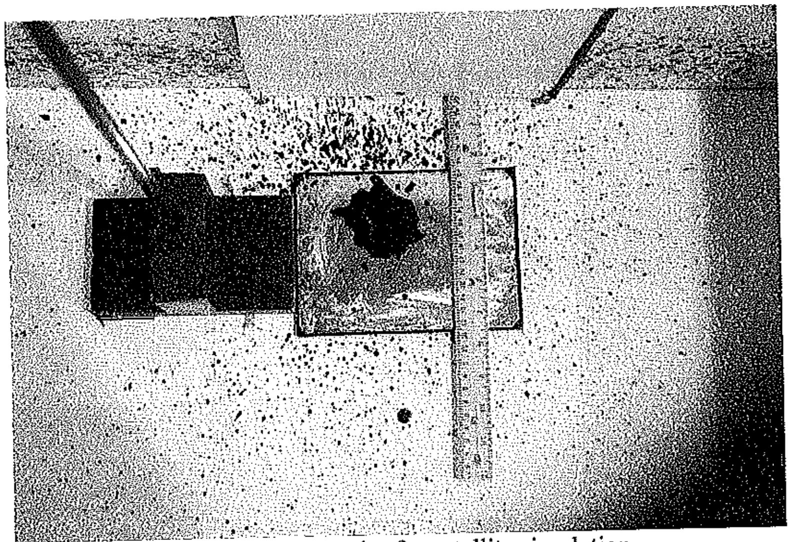


Figure 4: Drop point for satellite simulation

The same number of fabric samples and control samples were made for the satellite spatter simulation as the impact spatter simulation. Photographs were taken of all of the samples which included the fabric, identifier, and scale in each of the photographs. The drying time and storage of the fabric samples were also treated as described previously.

Quantitative Analysis

Quantitative Analysis Materials

As a means to quantify the data within the samples, a free imaging software program titled "ImageJ" (Abramoff, et al., 2004) was utilized in a similar manner as previous BPA research (Michelson et al, 2015; Li, 2015; Williams et al, 2016; de Castro et al, 2015). The program has the capability to analyze distinct particles in an image (bloodstains) by assigning pixel values to a known distance (scale) located within the image and ultimately provide the measurements of those particles. When photo editing or photo cropping was necessary, Paint.net and Irfanview, digital photo editing computer programs, were utilized. The results produced by ImageJ were then imported into Microsoft Excel for the statistical evaluation of the data.

Quantitative Preliminary Analysis

Before the analysis began, a fabric photo underwent a test evaluation to ensure the initial methods would be sufficient. Upon loading the photograph into ImageJ, the researcher searched for potential issues that could arise during the analysis. First, the photo had to be converted to a binary image in ImageJ. A binary image consists of two colors: black and white. The program assigns darker pixels to be black (bloodstains), and the lighter pixels to be white (unstained fabric). The black portions, or the bloodstains, of the photo would then be measured by the program. At this stage is when the researcher encountered the issues associated with the analysis of the denim fabrics. The dark color of the denim was causing the program to assign a significant portion of the unstained, background denim as a black color, the color reserved for bloodstains. The incapability of ImageJ to distinguish the denim from the bloodstains caused a great deal of contamination and, consequently, skewed the results. The denim images were uploaded into the available photo software programs in an attempt to decipher the bloodstains within the denim fabric; however, the attempts were unsuccessful due to further distortion and contamination of the photograph (see Figure 5). The problem could have potentially been resolved by retaking the photographs of the denim with an infra-red camera; however, due to unforeseen circumstances, the researcher was unable to gain access to such a device.

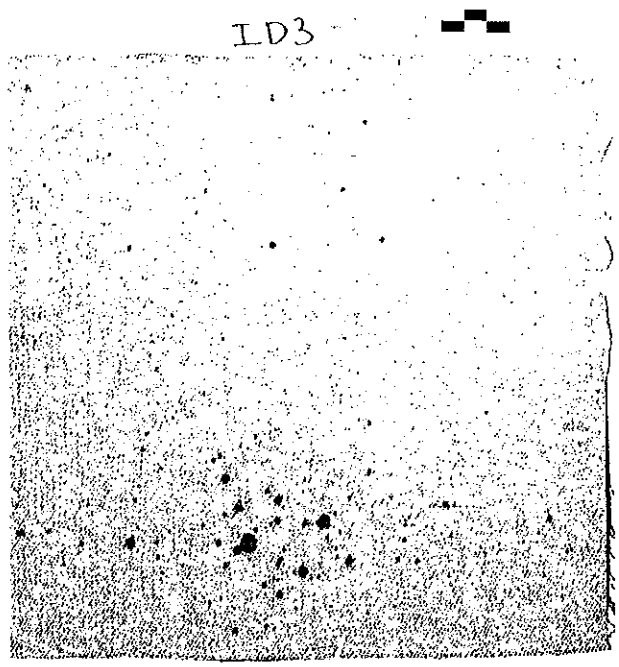


Figure 5: Photo correction and binary conversion of denim sample with uncorrectable background noise

The photographs of the white t-shirt and sheet fabrics were analyzed by ImageJ with minimal issues. However, a problem was encountered with the photographs that contained a background of a white color. When the image was ultimately converted to binary, it was difficult for the researcher to distinguish where the white fabric ended and the white background began. In order to resolve this issue, Paint.net was used to add a distinct boundary perimeter that would encompass the intended area of analysis. Before binary conversion, the photo was uploaded into Paint.net and zoomed in by twenty-five percent along the fabric borders. A stylus was used to draw a distinct, pink line on a touchscreen laptop along the border of the fabric. Elements that were excluded from the perimeter of analysis were staples that secured the fabric onto the poster board, the background, the fabric identifier, and partial stains on the very edge of the fabric, all of which would skew the results. After assuring that the line did not interfere with relevant data, the photo was saved as a separate file and then uploaded into ImageJ. This process allowed the area of analysis to be easily visualized after a binary conversion (see Figure 6).

Figure 6: Before and after the addition of a visual boundary

Lastly, the flash attachment of the camera was causing the poster board control bloodstains to appear heavily reflective in the photographs. In order to reduce the reflective nature of these specific samples, the photographs were retaken without the flash attachment; rather, the camera's built in flash was utilized. Although it helped significantly, some of the photographs had to be mildly edited via Irfanview. The only process needed to correct the issue fully was to replace the bloodstain color (and variations of that color) of the bloodstains with a black color. As a result of this change, the photograph was suitable for analysis in ImageJ and the process did not negatively affect the analysis.

Analysis via ImageJ

Analysis of the photographs began with uploading a photograph (including the added pink boundary) and setting the pixel-to-millimeter scale. This process was achieved by zooming into the scale located within the photo by 600 times, selecting the straight line tool and beginning the straight-line at any millimeter line on the scale and ending the straight-line at the next millimeter line. To assign the values, the "Set Scale" command in ImageJ was selected, "1 mm" was entered as the corresponding measurement, and the scale was set to "Global" to lock in the scale for the rest of the image analysis. Afterwards, another one-millimeter length line was created along the scale to validate that the scale was set.

A duplicate of the original uploaded photo was created within ImageJ. The original photo was renamed "(ID)Overlay" and the duplicate was renamed "(ID)Binary", following a binary conversion of that assigned image. A select number of bloodstains within the fabric had overlapped, causing the program to analyze the particle as one bloodstain. To avoid producing skewed results, the issue was resolved by using the "watershed" command, which recognizes and separates two overlapping stains (see Figure 7). The command was successful in separating some stains, but was not successful in separating every single set of overlapping stains. The watershed command emerged an observable issue in the satellite spatter control samples. A minimal amount of parent stains produced semi-detached secondary tail stains that the watershed command would separate from each other. Since the watershed command was recognizing these occurrences as separate events, when the two particles were actually from the same blood drop, the watershed command was not used for the satellite spatter control samples.

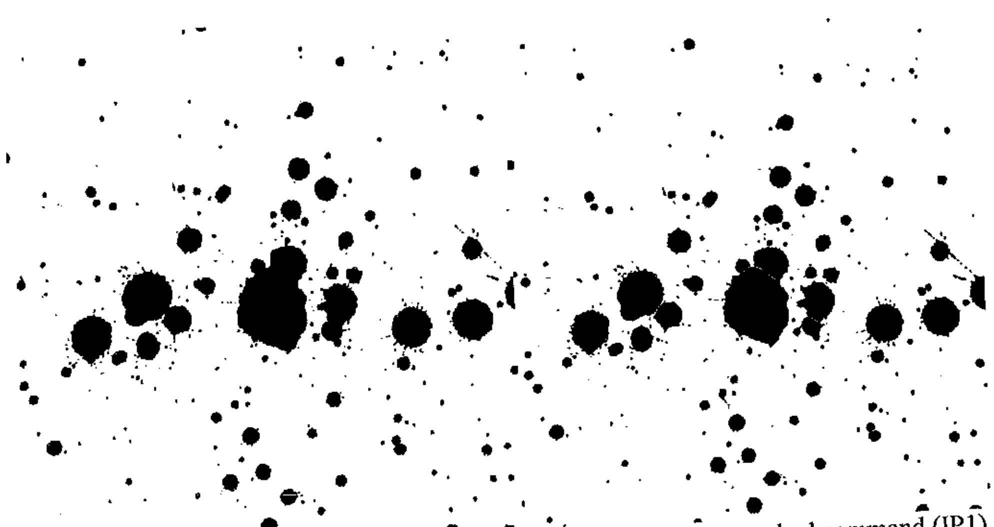
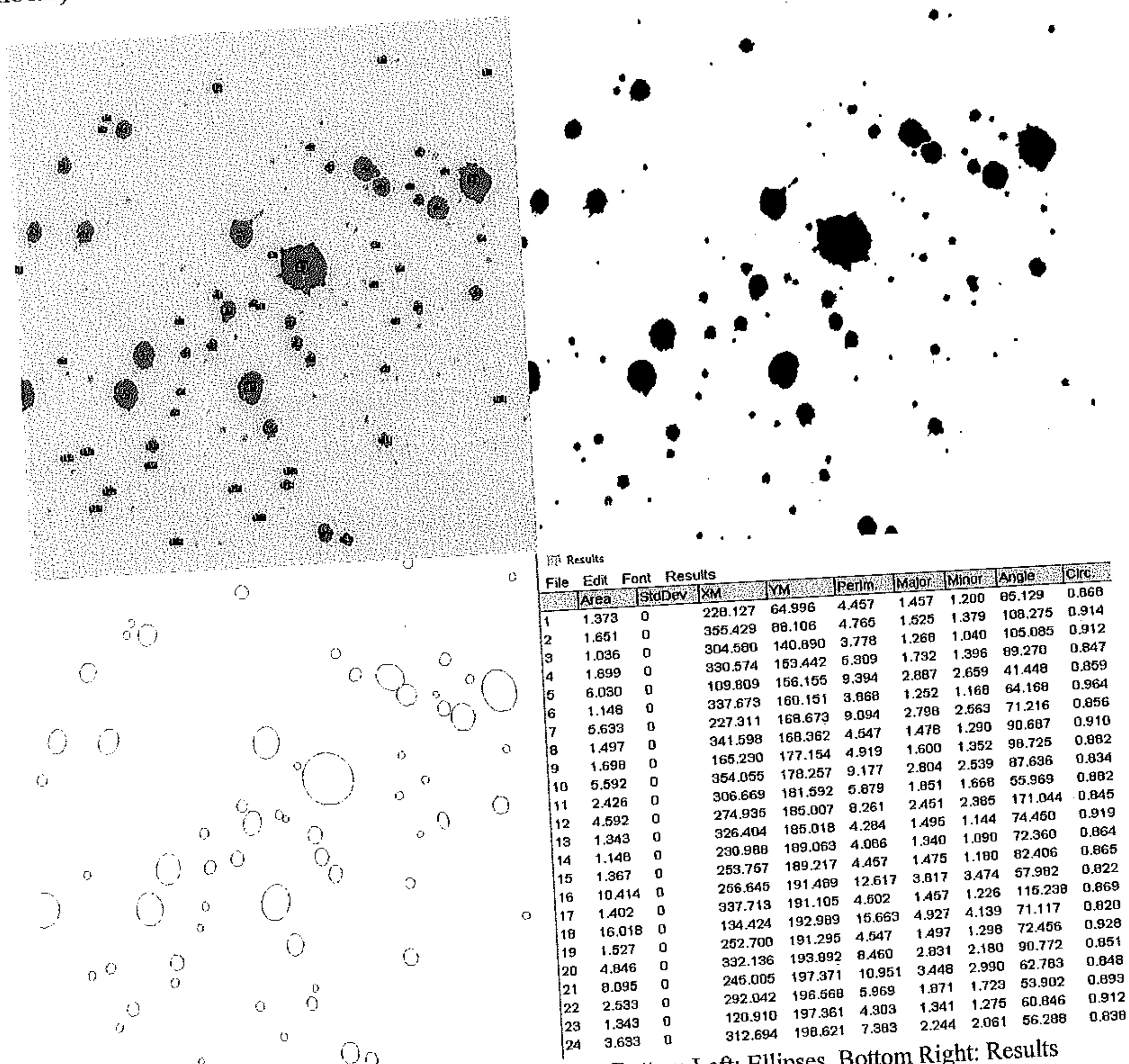


Figure 7: Before and after the separation of stains via ImageJ's watershed command (IP1)

The area of analysis was selected using the "Polygon Selections" tool. This tool allowed for an irregular border to be created along the boundary created in Paint.net. After validating that the area of selection included all relevant data, the analysis variables were selected: area, perimeter, circularity, and the fit ellipse. Area measures the area, in mm^2, that a bloodstain occupies. The perimeter measures the length of the outside boundary of a bloodstain. Circularity is a set value ranging from 0 to 1; a value of "1" indicates a perfect circle and as the value approaches "0", the bloodstain is increasingly elongated. Lastly, the major and minor axes will be measured using the "Fit Ellipse" option within ImageJ. This involves the program fitting an ellipse to a bloodstain and providing the lengths of its major and minor axes. Finding a best fitting ellipse is a process executed in bloodstain pattern analysis usually by the researcher rather than an imaging program.

The bloodstains within the area of selection were analyzed by initializing the "Analyze Particles" demand. The typical measured stain in the field has a one to four millimeter diameter (Bevel & Gardner, 2008); therefore, the quantitative analysis was restricted to bloodstains with a minimum area of 1 mm^2. Additionally, a number of smaller, submillimeter stains were not detected by the software due to the stain's extremely small nature; however, the program was able to detect stains with an area of 1 mm^2 without observable problems. The software was prompted to show the fit ellipse map with the produced results, to exclude bloodstains on edges, and to include any "holes" within the bloodstains as relevant data.

After the results are provided, any stain on the physical fabric was selected to validate that the software was correctly measuring the bloodstains. A stain was selected and physically measured with a ruler scale and the digital macroscope and lastly compared the researcher's measured value to the measurement value given in ImageJ. After confirming the stain's measurement in ImageJ, the data provided by ImageJ was saved. The process was executed for every sample. The bloodstain results spreadsheet was saved as an Excel file and the ellipse map image, the binary image (including stain numbers), and the overlay image (including stain numbers) were saved as TIFF files (see Figure 8).



	Area	StdDev	XM	YM	Perim.	Major	Minor	Angle	Circ.
1	1.373	0	228.127	64.996	4.457	1.457	1.200	85.129	0.868
2	1.651	0	355.429	88.106	4.765	1.525	1.379	108.275	0.914
3	1.036	0	304.580	140.890	3.778	1.268	1.040	105.085	0.912
4	1.899	0	330.574	153.442	6.309	1.732	1.396	89.270	0.847
5	6.030	0	109.809	156.155	9.394	2.887	2.659	41.448	0.859
6	1.148	0	337.673	160.151	3.868	1.252	1.168	64.168	0.964
7	5.633	0	227.311	168.673	9.094	2.798	2.663	71.216	0.856
8	1.497	0	341.598	168.362	4.547	1.478	1.290	90.687	0.910
9	1.698	0	165.290	177.154	4.919	1.600	1.352	98.725	0.882
10	5.592	0	354.055	178.257	9.177	2.804	2.539	87.636	0.834
11	2.426	0	306.669	181.592	5.879	1.851	1.668	55.969	0.882
12	4.592	0	274.935	185.007	8.261	2.451	2.385	171.044	0.845
13	1.343	0	326.404	185.018	4.284	1.496	1.144	74.460	0.919
14	1.148	0	230.988	189.063	4.086	1.340	1.090	72.360	0.864
15	1.367	0	253.767	189.217	4.457	1.475	1.180	82.406	0.865
16	10.414	0	266.645	191.489	12.617	3.817	3.474	57.982	0.822
17	1.402	0	337.713	191.105	4.602	1.457	1.226	116.238	0.869
18	16.018	0	134.424	192.989	15.663	4.927	4.139	71.117	0.820
19	1.527	0	252.700	191.295	4.547	1.497	1.298	72.456	0.928
20	4.846	0	332.136	193.892	8.460	2.831	2.180	90.772	0.851
21	8.095	0	246.005	197.371	10.951	3.448	2.990	62.783	0.848
22	2.533	0	292.042	196.568	5.969	1.871	1.723	53.902	0.899
23	1.343	0	120.910	197.361	4.303	1.341	1.275	60.846	0.912
24	3.633	0	312.694	198.621	7.383	2.244	2.061	56.288	0.838

Figure 8: Top Left: Overlay, Top Right: Binary, Bottom Left: Ellipses, Bottom Right: Results

The results were opened in Microsoft Excel for statistical analyses. Bloodstains with a minimum area of 1 mm^2 were analyzed based on area, perimeter, circularity, major and minor axes, and the impact angle was calculated based on the values of the axes. Although impact angle calculations have been cautioned, the results can potentially reveal valuable information. ImageJ provided all of the data except for the impact angle. The impact angle (θ) was calculated in Microsoft Excel by entering the inverse sine formula (θ=arcsin(width/length)). The "width" of the bloodstain was assigned as the value in the minor axis cell and the "length" was assigned as the value in the major axis cell, yielding the appropriate formula for calculating the impact angle of each stain ("=DEGREES(ARCSIN(MINOR/MAJOR))"). Measures of central tendency were used to analyze the data. Means and percentages were used to demonstrate and describe the data. The total amount of stains analyzed for each sample was also recorded. This process was repeated for every impact and satellite spattered sample.

Qualitative Analysis

Qualitative Analysis Materials

The qualitative analysis involved the detailed examination of particular bloodstains within the spattered samples. Computer-generated random number tables, a computer-generated grid transparency overlay, dry-erase and permanent markers were used during the stain selection process. A great portion of the analysis was visualized through the use of a Celestron Handheld Digital Microscope. Using magnification allowed for a detailed examination of the bloodstains at the yarn level of the fabric.

Qualitative Preliminary Analysis

A preliminary examination was conducted on a fabric to determine if any complications would emerge during the qualitative analysis. The examination of a few bloodstains revealed a dilemma with a shape descriptor variable. Originally, the researcher proposed examining the edges of the bloodstains to discover if specific bloodstains would exhibit jagged or smooth perimeter edges; however, due to the overall wicking behavior of bloodstains on fabric, all of the bloodstains naturally had jagged edges in some manner; this occurrence caused the determination to be excessively subjective and a threshold between the determinations could not be clearly established. Alternatively, the researcher replaced the category with an assessment of whether the stain was of submillimeter size. This quality was investigated to determine if either satellite spatter or impact spatter contained more sampled submillimeter spatter than the other. Furthermore, the physical search of submillimeter spatter in the samples compensated for the inability of ImageJ to detect spatter of that small size.

Stain Selection Methods

The manual examination of hundreds of bloodstains on each of the thirty samples would be both impractical and excessively time consuming; rather, the researcher took a representative sample of each spattered target. This was achieved through the use of stratified random sampling without replacement. A 20x20 gridded, transparent overlay of the same size of the spattered targets was placed over each spattered sample and secured with binder clips to prevent movement. The grid was divided into four separate quadrants, listed from the top-right going counter-clockwise: I, II, III, and IV. Additionally, the horizontal edge (x-axis) below the last row of squares of the overlay and vertical edge (y-axis) on the left was numbered 1 through 20 to allow a coordinate system to be utilized. The division of quadrants yielded a total of four 10x10 quadrants containing unique coordinates: Quadrant I: (X: 11-20, Y: 11-20), Quadrant II: (X: 1-10, Y: 1-10), Quadrant III: (X: 1-10, Y: 1-10), and Quadrant IV: (X: 11-20, Y: 1-10). To select bloodstains, a random number table was created on Excel to randomly generate square coordinates within specific quadrants. For example, if bloodstains were selected in Quadrant 1, a random number generator with random values of 11-20 for the X grid coordinate and random values of 11-20 for the Y grid coordinate would be produced. The stains from that particular coordinate location would be chosen for selection. If there were no stains present at that particular location, it was skipped. Four stain-present locations would ultimately be produced from each quadrant, yielding a total of 16 stain coordinate locations from each spattered target (see Figure 9).

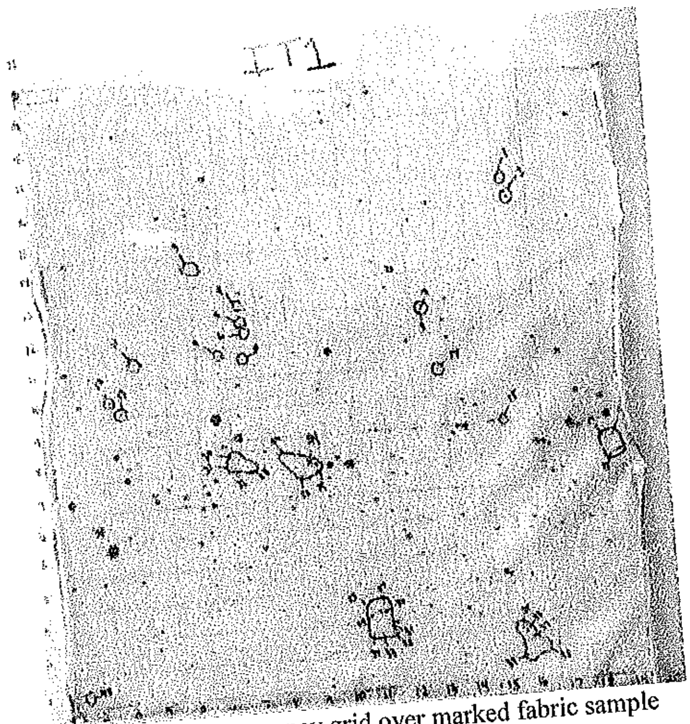


Figure 9: Transparency grid over marked fabric sample

During the progression of the random selection of bloodstains, a dry-erase marker was used to circle the stains within the square locations on the transparency overlay. The number of stains produced from each quadrant were recorded (Appendix A). After the stains had been temporarily identified on the secured transparency, a permanent marker was used to circle and individually number the selected stains on the physical sample. Once all of the stains were permanently identified, the transparency was wiped clean, and the entire process would start for the next spattered sample.

Descriptive Stain Analysis

The descriptive analysis of the randomly selected bloodstains was conducted through the use of the macroscope for visualization purposes (approximately 20x). This allowed the researcher to observe the maximum amount of detail in the fabric as possible. Four variables were investigated: shape, symmetrical properties, saturation, and whether the stain was of submillimeter size. Although qualitative analysis inherently contains a level of subjectivity, the operationalization of the above mentioned variables were determined to objectify the analysis procedure.

The shape was categorized as either round, polygonal, or irregular. The round category contained stains that were either circular or oval. If the overall shape of the bloodstain was round, but contained some irregularities and/or straight edges due to wicking behavior, the stain was not identified as round. In order to be classified as round, the bloodstain had to contain only round edges without the presence of irregular extremities. A polygonal stain was recorded if the stain contained straight edges with corners. These shapes resembled squares, rectangles, and diamonds. If a stain did not meet the criteria for either the round or polygonal category, the stain was classified as irregular. Irregular stains could exhibit both round and polygonal characteristics, but not strictly one or the other. If the stain resembled some other recognizable shape, it was documented in the miscellaneous notes. The shapes can be seen in Figure 10.

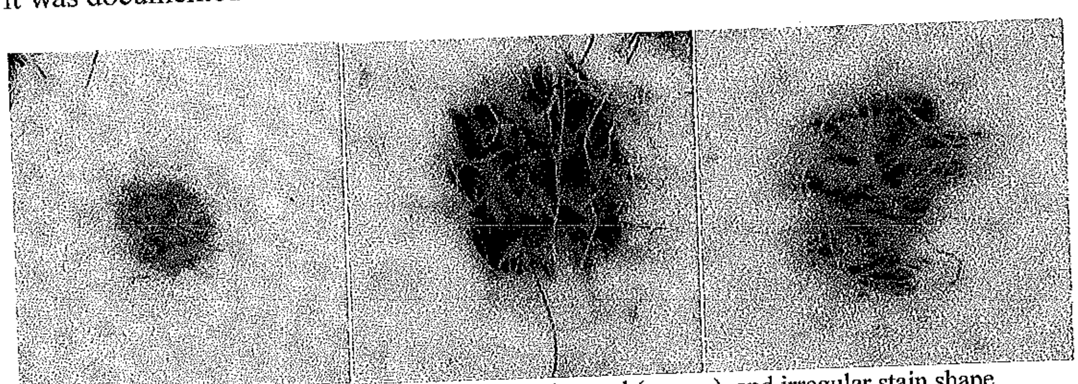


Figure 10: (From left to right) A round, polygonal (square), and irregular stain shape

Symmetrical properties of the stain were documented. The stain could be documented as either symmetrical or asymmetrical. A stain was symmetrical if the stain contained mirrored characteristics about any axis. An asymmetrical stain was a stain that did not have any mirrored characteristics about an axis.

Following previous research (Holbrook 2010), the current research examined the saturation behavior of the simulated spatter. The stains were documented as either being saturated into the fabric or remaining on the upper levels of the yarn. Saturated stains exhibited full blood permeation into the yarns. If the stain was of larger size, the stain completely saturated the fabric due to its high volume of blood. The stains of smaller size were classified as a saturated stain if the blood soaked completely into the yarn(s). Stains of this size could be contained to one individual yarn or span across a number of yarns in the weave. If a stain remained on the upper levels of the yarn, meaning that the stain never penetrated the subsequent levels of the weave under the top level, it was documented as a top-weave only stain (see Figure 11).

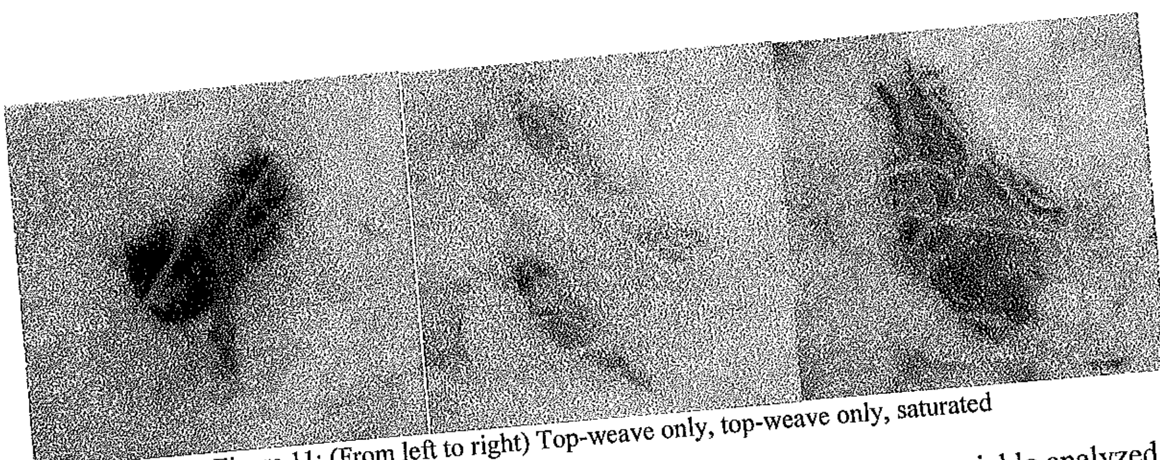


Figure 11: (From left to right) Top-weave only, top-weave only, saturated

The documentation of the stain's submillimeter nature was the last variable analyzed in the descriptive analysis. A stain was identified as submillimeter if the stain had a major axis of less than one millimeter and, conversely, a stain with a major axis of one millimeter or larger was excluded as being submillimeter. Size determination was determined with a ruler scale and a macroscope. As previously mentioned, the documentation of the submillimeter qualities of the sampled stains can reveal quantities that ImageJ was not capable of detecting. Although it is difficult, and not recommended, to obtain specific measurements of stains of this minute size, simply quantifying the amount of submillimeter stains in both impact spatter and satellite spatter can be beneficial in their respective characterizations.

Each analyzed stain had a reserved space for unique notes. Unique qualities such as secondary spatter, spines, pooling, and other recognizable shapes were documented if discovered. The results of the above-mentioned variables were documented by hand then imported into an Excel spreadsheet. The program was prompted to count of the amount of each variable detected for that particular sample and the necessary statistics were calculated.

Narratives

A narrative description was produced for each spatter sample to identify unique characteristics that were not detected in the stain microanalysis. The samples were generally examined and analyzed based on overall directionality of the spatter, the dispersion of spatter, stain shapes without macroscopic aid, and any other unique attributes including, but not limited to, the overlapping of bloodstains, presence of spines or secondary spatter, and weighted spatter areas. The control samples were also analyzed in the same manner as the fabric samples.

CHAPTER 4

RESULTS AND ANALYSIS

Introduction

The spattered samples were analyzed both quantitatively and qualitatively. ImageJ was able to produce bloodstain measurements for spatter with an area of 1 mm^2 or larger. The measurements taken include the bloodstain area, perimeter, major axis, minor axis, impact angle, and circularity. The quantitative results will be presented in table form. The qualitative analysis included an individual stain analysis and a narrative description of the entire sample. The stains were randomly selected for the individual stain evaluation. The analysis included the evaluation of stain size, weave permeation, symmetrical properties, the submillimeter nature of the stain, and any unique and consistent characteristics. A detailed analysis of the data in table form can be found in Appendix B. The narrative description allowed the researcher to depict themes within the samples that the above analyses were not able to provide such as overall dispersion, directionality, and other identifying attributes that could potentially be unique to the corresponding spatter type. The results will be provided by sample type: poster board controls, t-shirt samples, and finally sheet samples.

Control Samples

Impact Spatter

Quantitative Results

Table 1: Measurement Means for Control Sample – Impact Spatter

Total Stains Analyzed (>1mm^2)	782
Area (mm^2)	7.18
Perimeter (mm)	9.05
Major Axis (mm)	2.61
Minor Axis (mm)	2.37
Impact Angle (degrees)	68.44
Circularity	0.81

Qualitative Stain Analysis

The qualitative stain analysis was based on randomly selected bloodstains (N=161). The most prominent stain shape was a round shape (73%) which includes elliptical shapes and circular shapes. Twenty-four percent of the selected stains were classified as irregular. Irregular stains may have an overall round shape; however, any extremities that deviate from the roundness will render the shape to be classified as irregular. The remaining three percent exhibited a polygonal shape. Furthermore, ninety-three percent of the stains were symmetrical about an axis within the bloodstain. A weave analysis was not conducted because the control samples were poster board. Of the 161 stains qualitatively analyzed, seventy-one percent were of submillimeter nature (major axis is less than 1mm). The remaining twenty-nine percent had a major axis of one millimeter or larger.

Narrative Analysis

The evaluation of the control samples, without macroscopic magnification, concluded that the majority of the stains appeared circular with no acute directionality. This is to be expected due to the known ninety-degree impact angle. Spines were visible throughout the plane of the sample, some of which were completely detached from the parent stain. The impact spatter control samples yielded some areas of centralized spatter where a higher number of spatter was confined to a certain area. Furthermore, some stain overlap was present within the samples which is most likely attributed to the occurrence of bloodstains wicking together (see Figure 12).

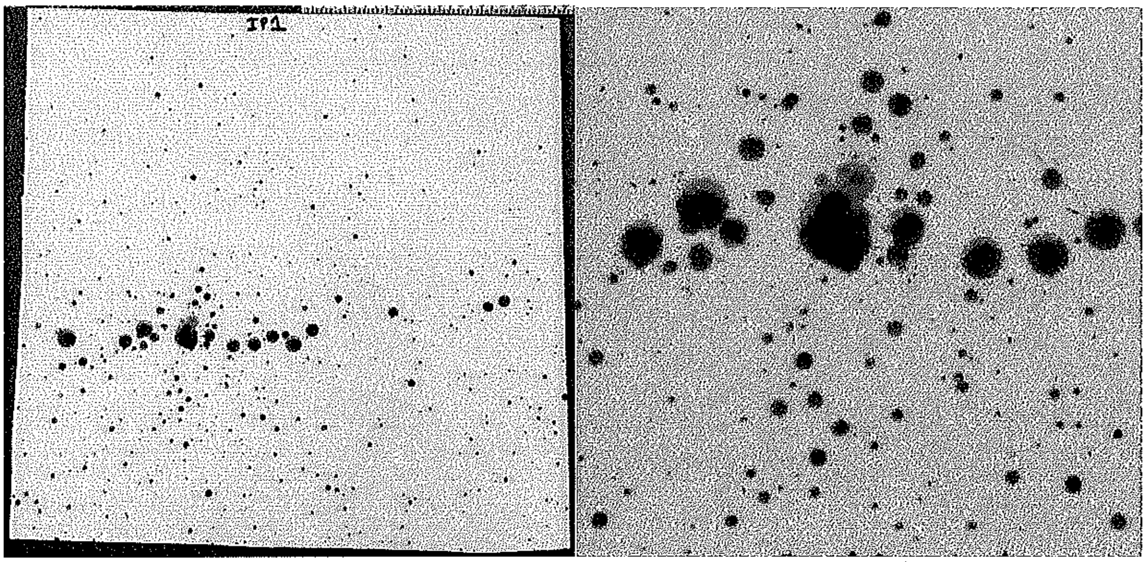


Figure 12: Left: Overall perspective of centralized spatter on a control impact sample; Right: Close-up view of the spines

Satellite Spatter

Quantitative Results

Table 2: Measurement Means for Control Sample – Satellite Spatter

Total Stains Analyzed (>1mm^2)	187
Area (mm^2)	2.18
Perimeter (mm)	5.9
Major Axis (mm)	2.2
Minor Axis (mm)	1.18
Impact Angle (degrees)	39.46
Circularity	0.77

Qualitative Stain Analysis

A random selection of 224 bloodstains yielded the following results. Fifty-six percent of the bloodstains were classified as round while forty-two percent were irregular and two percent were polygonal. Ninety-two percent maintained a symmetrical shape. Again, a weave analysis was not conducted due to poster board face. Eighty percent of the analyzed bloodstains were classified as submillimeter with a major axis of less than one millimeter in length.

Narrative Analysis

The overall stain shape appeared to be a mixture of oval/elongated, irregular, and teardrop shaped bloodstains. The satellite control samples exhibited a "v-shaped" dispersion of spatter. The v-shape was present, but not as prominent, on one of the five samples. This type of dispersion is expected in blood-into-blood satellite spatter on vertical impact sites. The individual spatters appeared to have random directionality. Some spatter would exhibit one directionality while other spatter close in proximity would exhibit opposing directionality. Additionally, the spatters appeared more voluminous due to its darker red color. Lastly, there was a presence of extremely small spatters on all of the satellite control samples. These spatters were not detected by ImageJ; however, the stains could be seen with the unaided eye upon close inspection. A number of satellite spatter exhibited teardrop shapes; a minute number of stains had semi-detached tails.

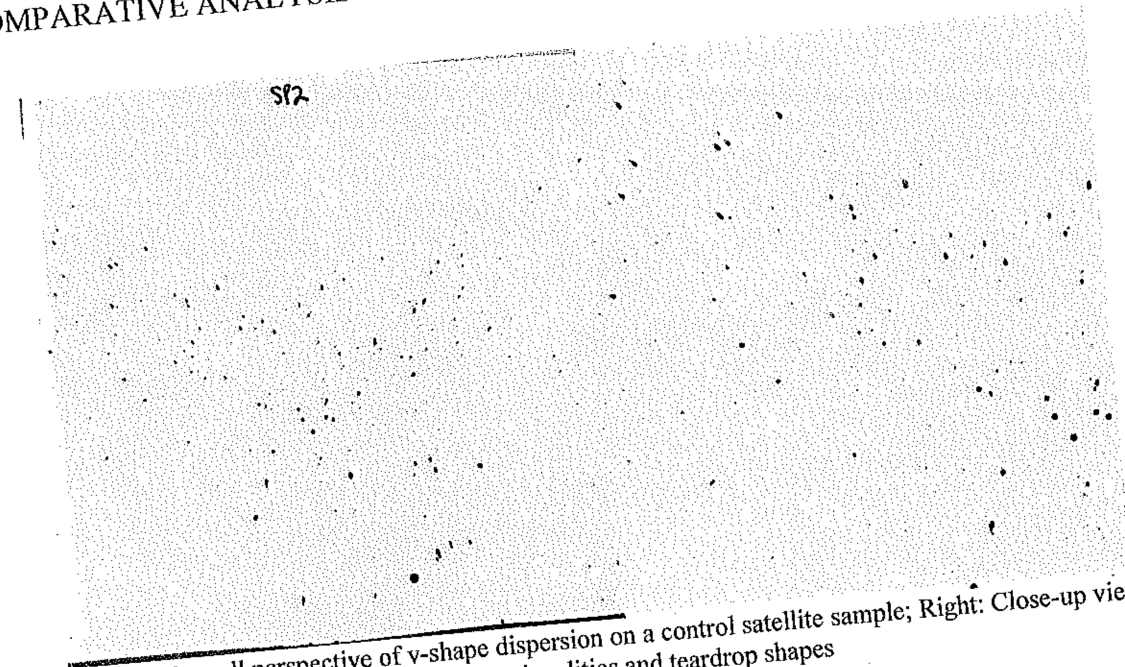


Figure 13: Left: Overall perspective of v-shape dispersion on a control satellite sample; Right: Close-up view of the random directionalities and teardrop shapes

T-Shirt Samples

Impact Spatter

Quantitative Results

Table 3: Measurement Means for T-Shirt Sample – Impact Spatter

Total Stains Analyzed (>1mm^2)	396
Area (mm^2)	4.03
Perimeter (mm)	7.1
Major Axis (mm)	2.18
Minor Axis (mm)	1.79
Impact Angle (degrees)	56.16
Circularity	0.78

Qualitative Stain Analysis

A total of 176 bloodstains were randomly selected for qualitative analysis. Eighty-eight percent of the bloodstains were classified as irregularly shaped. Eight percent were classified as polygonal and four percent were round. In the t-shirt samples, other shapes were noted that were consistent throughout the analysis. A hexagonal shape was detected throughout the samples along with arrow shaped bloodstains. Sixty-nine percent of the stains were symmetrical about an axis within the bloodstain. The weave penetration analysis yielded that ninety-nine percent of the bloodstains saturated the weave; whereas, one percent of stains remained on the top weave. Sixty-three percent of the stains were of submillimeter nature.

Narrative Analysis

The overall stain shapes appeared to be elongated and irregular in comparison to the control samples (circular). The stain overlap exhibited in the controls were visualized in the t-shirt samples also but in smaller numbers. In general, the spatter appeared to be more evenly dispersed throughout the plane of the fabric without centralized areas; however, two samples exhibited some condensed areas of spatter.

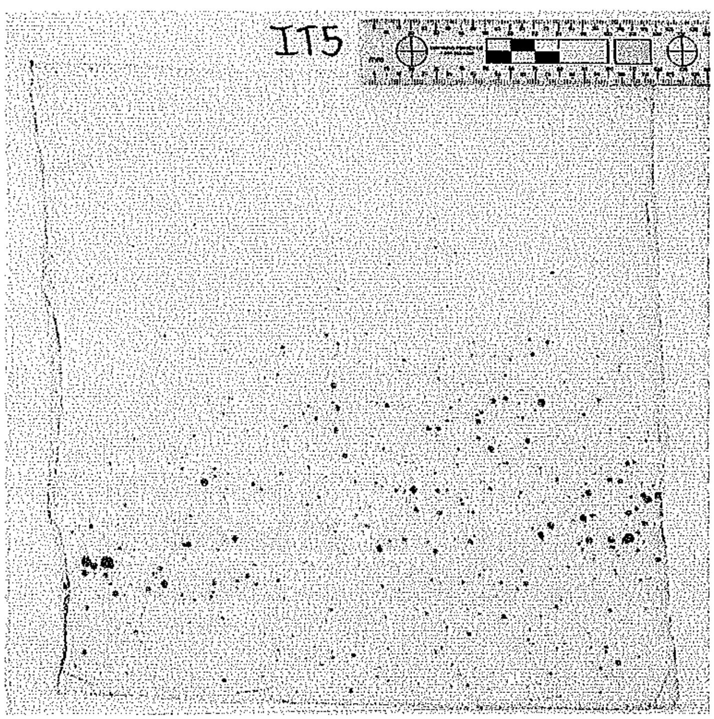


Figure 14: Overall photo of a t-shirt fabric impact spatter sample

Satellite Spatter

Quantitative Results

Table 4: Measurement Means for T-Shirt Sample – Satellite Spatter

Total Stains Analyzed (>1mm^2)	239
Area (mm^2)	2.86
Perimeter (mm)	6.7
Major Axis (mm)	2.13
Minor Axis (mm)	1.52
Impact Angle (degrees)	46.74
Circularity	0.72

Qualitative Stain Analysis

The qualitative analysis was conducted on 174 bloodstains. Ninety-five percent, an overwhelming majority, of the bloodstains were irregularly shaped, three percent exhibited a polygonal shape, and two percent maintained a round shape. As seen in the impact t-shirt samples, the hexagonal and arrow shapes were also present in the satellite samples. Seventy-one percent of the bloodstains appeared symmetrical. Ninety-four percent of the bloodstains saturated the fabric while six percent remained on the top yarns of the weave. Sixty-four percent of the spatter was of submillimeter size while thirty-six percent had a major axis of one millimeter or larger.

Narrative Analysis

All of the samples exhibited oval and irregular shaped bloodstains without magnification. As seen in the control samples, extremely small spatters were present in the fabric. Three of the five samples exhibited random directionality in the bloodstains; this was more evident in the lateral areas of the fabric. Although only one sample exhibited somewhat of a v-shape dispersion, the majority of the samples lacked spatter towards the top portion of the fabric. Additionally, there was an even distribution of spatter with a lack of centrality.

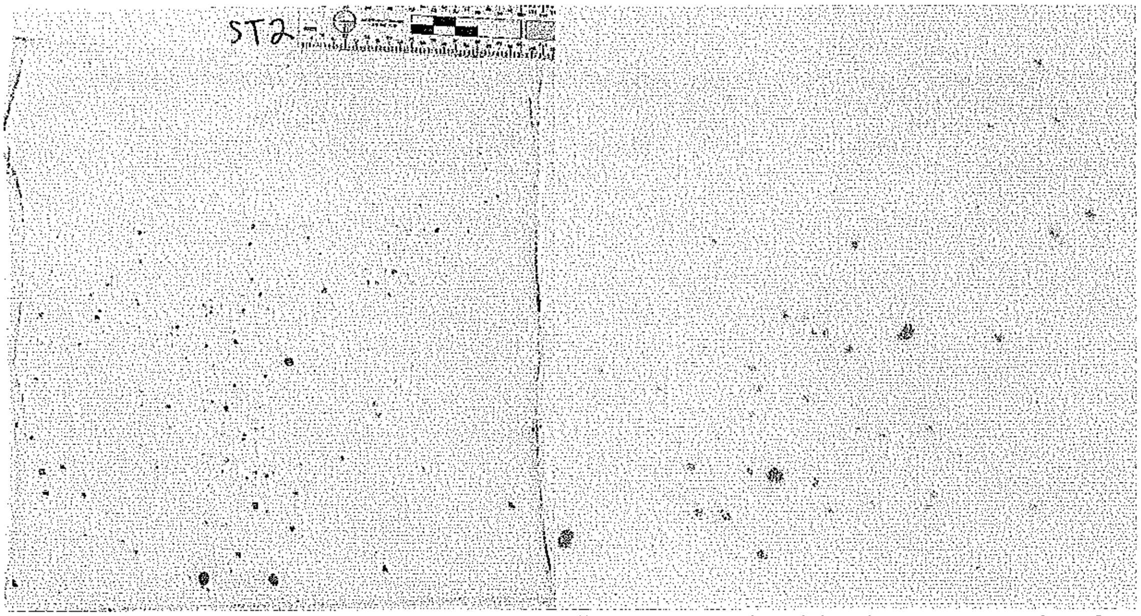


Figure 15: Left: Overall perspective of a t-shirt fabric satellite spatter sample; Right: close-up perspective of random directionalities

Sheet Samples

Impact Spatter

Quantitative Results

Table 5: Measurement Means for Bed Sheets Sample – Impact Spatter

Total Stains Analyzed (>1mm^2)	769
Area (mm^2)	5.49
Perimeter (mm)	8.45
Major Axis (mm)	2.49
Minor Axis (mm)	2.1
Impact Angle (degrees)	58.8
Circularity	0.75

Qualitative Stain Analysis

Eighty-eight percent of the 176 bloodstains that were analyzed were identified as irregular. Seven percent were classified as polygonal and five percent as round. A star shape in the bloodstains was also noted throughout this stage of analysis. Sixty-eight percent appeared symmetrical. Every stain analyzed (100%) saturated the weave of the sheet samples and none remained on the top weave only. Of the 176, fifty-five percent were submillimeter in size.

Narrative Analysis

As a whole, the stains appeared to be oval/elongated and irregularly shaped; however, three of the five samples appeared to have some circular stains throughout the plane. The spines that were visible in the control samples were also visible on all five samples of this particular fabric (see Figure 16). Additionally, there was a presence of fused bloodstains in every sample. Areas of centralized spatter could be detected in all five samples.

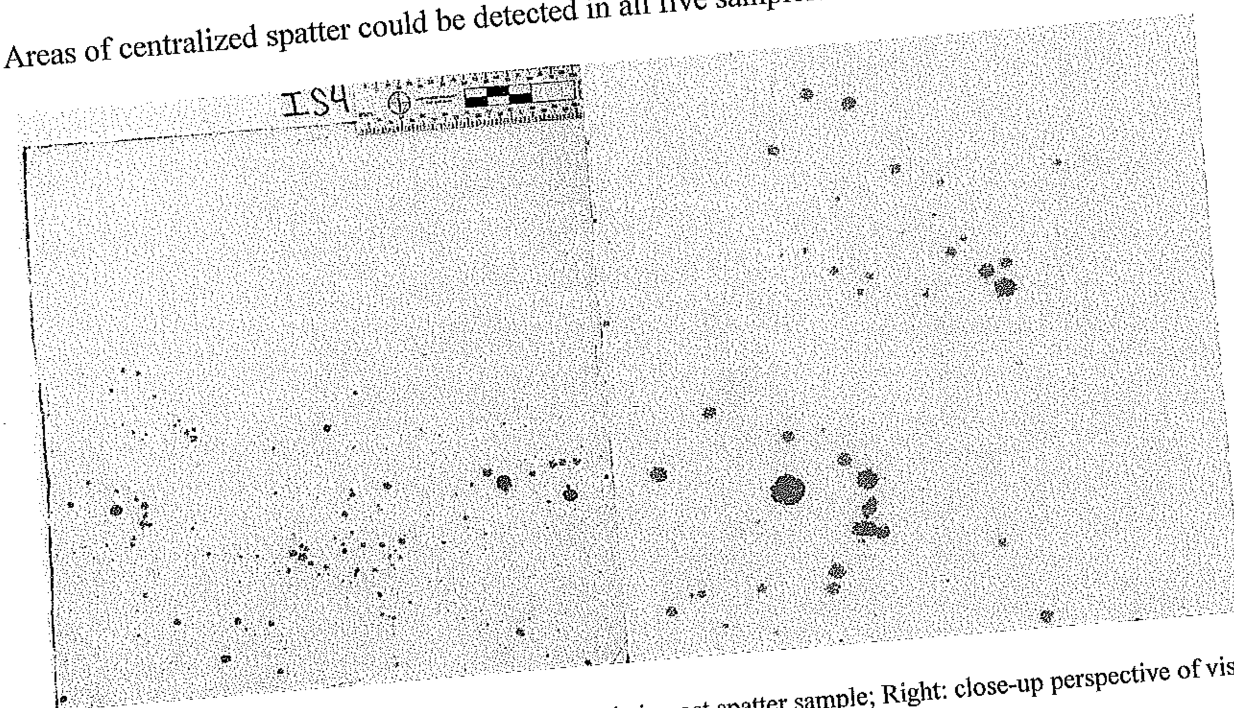


Figure 16: Left: Overall perspective of a sheet fabric impact spatter sample; Right: close-up perspective of visible spines

Satellite Spatter

Quantitative Results

Table 6: Measurement Means for Bed Sheets Sample – Satellite Spatter

Total Stains Analyzed (>1mm^2)	329
Area (mm^2)	3.55
Perimeter (mm)	6.62
Major Axis (mm)	2.16
Minor Axis (mm)	1.68
Impact Angle (degrees)	52.08
Circularity	0.83

Qualitative Stain Analysis

One-hundred and sixty-six bloodstains were qualitatively analyzed. Eighty-nine percent of the stains were classified as irregular, six percent as round, and five percent as polygonal. Symmetrical stains accounted for fifty-three percent of the sampled bloodstains. As noted with the impact spatter samples, all sampled bloodstains (100%) for satellite spatter saturated the fabric as well. Fifty-eight percent of the bloodstains had a major axis of less than one millimeter.

Narrative Analysis

Every satellite spatter sample for this particular fabric exhibited oval/elongated and irregular bloodstains overall. Some circular stains were noted on two of the five samples. A more even distribution was also noted with a lack of areas of centralized spatter. As noted with the previous satellite spatter samples, extremely small stains were detected on the fabric. Two the five samples exhibited some random directionality.

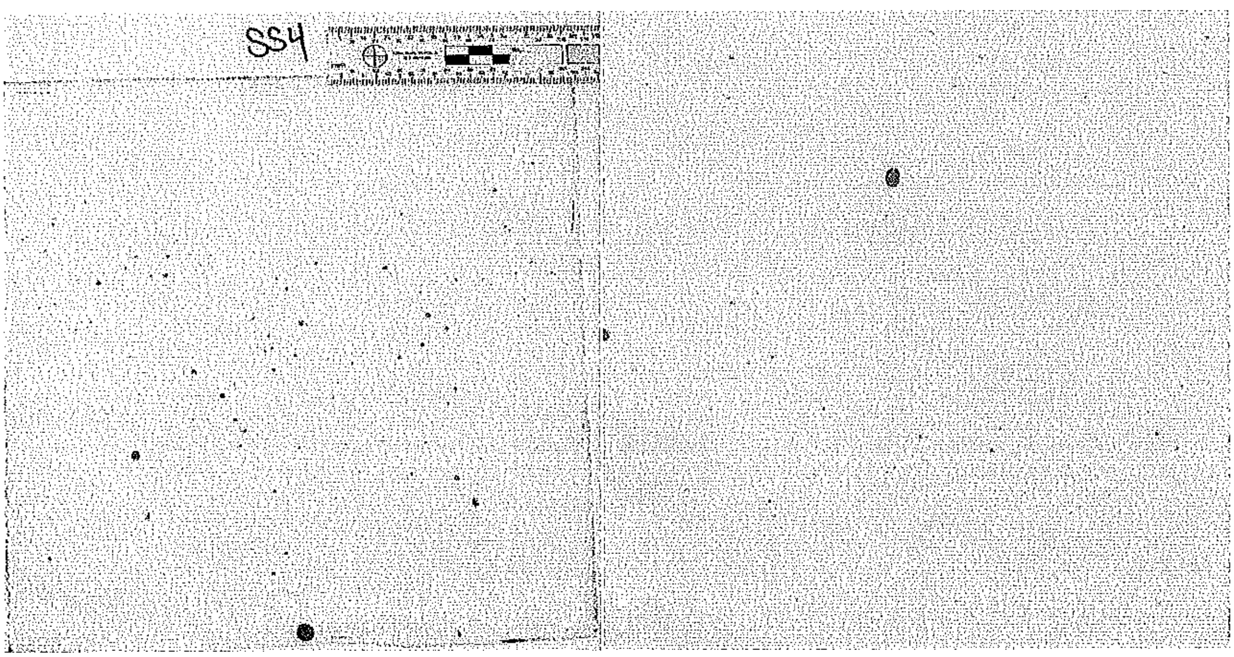


Figure 17: Left: Overall perspective of a sheet fabric satellite spatter sample; Right: close-up perspective of extremely small submillimeter spatter

CHAPTER 5

DISCUSSION & CONCLUSION

Control Samples

The impact and satellite spatter simulations on the control samples were able to reproduce their respective known characteristics. As to be expected, the unique attributes of both types of spatter could be visualized and identified on smooth, non-porous poster board. This type of impact site allowed the blood droplets to collapse with a minimal amount of disruption from the surface. Consequently, the spatter was able to form with minimal interuption, making identification more apparent. The control samples verified that the spatters were successfully reproduced and more easily distinguishable on smooth surfaces.

Impact Spatter

Impact spatter on the poster board control samples produced several details that aid in identification. Quantitatively, the size of the impact spatter is within the range of expected sizes of impact spatter (1-4 mm major axis), and, consequently, resulted in its associated area of 7.18 mm^2. The amount of impact stains analyzed (N=782) indicates that a vast number of the bloodstains were greater than the restricted area in the analysis (1 mm^2). The average circularity value, which assigns a value based upon the elongated nature of a stain, indicated a value of 0.81. Although it is not a perfect circle, as to be expected with ninety-degree impact stains, it was the second highest average circularity value of all of the samples.

Furthermore, the calculated impact angle was 68.44°. Although it was significantly higher than any other sample in the research, it is not the approximately ninety-degree value that was expected. However, Bevel & Gardner (2008) argue that stains with an impact angle larger than sixty degrees are associated with elevated error rates in their calculations. Additionally, the impact angle calculations (computed with the inverse sine function) are highly sensitive. Very small numerical disparities, such as one-tenth of a millimeter, have the potential to influence the resulting impact angle. Although the bloodstains appear to have ninety-degree impact angles from an overall perspective, the precise calculated impact angles by ImageJ using pixels within the images indicated the angles to be approximately seventy-degrees. ImageJ possibly captured a smaller impact angle because the blood slightly ran down the poster board immediately post-impact. The disparity in the impact angle may also be attributed to the parabolic arc associated with a bloodstain's flight. The use of straight-line geometry and trigonometry assumes that the blood's flight path is a straight line; however, this is not true due to influences of air resistance and gravity (Bevel & Gardner, 2008). The blood droplet could have potentially impacted at a very slight angle (as a result of a parabolic shape) at the end of the twenty-four inches that it traveled from the mousetrap to the target sample and, consequently, resulting in a reduced angle calculation. While considering the factors that influence impact angles, ImageJ may have captured the consequential stain dimensions on a pixel level; therefore, yielding a smaller impact angle than was expected.

The qualitative stain analysis yielded that the overwhelming majority of the bloodstains under macroscopic examination appeared round. Thirty-four percent appeared irregular; however, round stains that contained slight extremities from its shape were included within this classification. Additionally, ninety-three percent of the stains appeared symmetrical, which is another attribute of a "well-formed" bloodstain fit for evaluation.

The narrative analysis provides some of the most distinctive qualities. In addition to the overall circular appearing bloodstains as mentioned previously, the control samples exhibited spines originating from the individual spatters, and in some cases, the spines were detached from its parent stain (see Figure 18). The control samples also exhibited areas of centralized spatter with bloodstains that wicked together. Areas of centralized spatter can be expected due to impact spatter's radiating dispersion out from the blood source; however, the centralized nature of the spatter can occur as a function of distance from the target. Due to the ninety-degree impact onto the vertical surface, no apparent directionality could be identified.

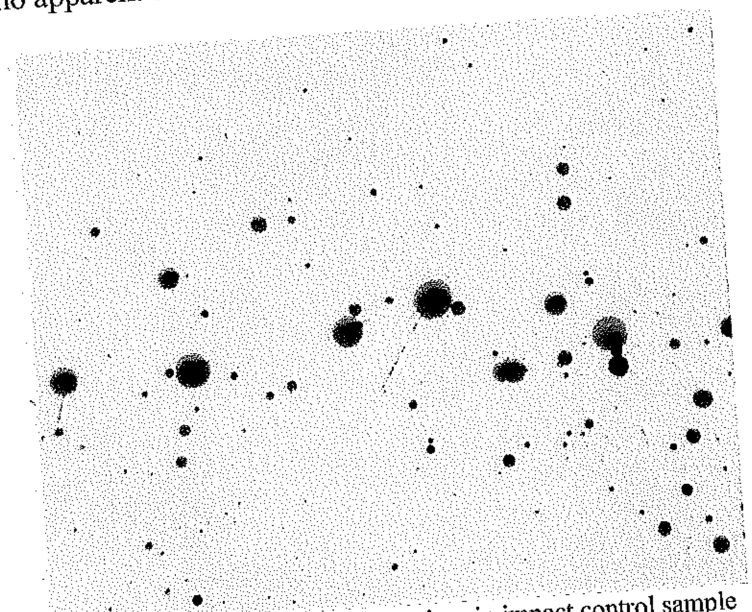


Figure 18: Close-up of detached spines in impact control sample

Satellite Spatter

The average size of the satellite spatter bloodstains (area, perimeter, major/minor axes) were much smaller in comparison to the impact spatter bloodstains. Another important finding is that the number of satellite stains analyzed was smaller (N=187) than the impact spatter samples. Due to ImageJ's analysis being restricted to stains with an area of 1mm^2 or larger, this can be indicative that the satellite spatter, overall, was either smaller or less spatter had gathered onto the samples. The circularity value was 0.77, which is comparable to the impact spatter value.

The calculated impact angle for the satellite control samples (36.46°) was approximately thirty degrees less than the calculated impact angle for impact spatter (68.44°). This particular disparity is another distinguishing characteristic of satellite spatter. The impact angle is smaller due to the blood impacting at a more acute angle from the floor. In the stain analysis, only fifty-six percent of the stains were identified as round whereas forty-two percent were classified as irregularly shaped. In addition to the entirety of the bloodstains appearing either elongated or tear drop shaped, these factors will influence the impact angle calculations.

The teardrop bloodstain shapes were a unique feature of the satellite spatter controls. Satellite spatter will typically exhibit bloodstains with tails pointing back to the parent pool; however, some of the spatter was characterized with random directionalities. A number of the spatter exhibited one directionality while other spatter in close proximity was pointing in opposite direction. This phenomenon is typical of blood-into-blood satellite spatter due to the random "splashing" effect of the blood droplets from the blood pool.

Unlike impact spatter, which exhibited no directionality and areas of centralized spatter, the satellite spatter had random directionalities and also exhibited a v-shape dispersion pattern. As previously mentioned, this is typical of blood-into-blood satellite spatter on nearby vertical surfaces and distinguishingly unique. One of the spatter samples did not exhibit a v-shape dispersion pattern that was as prominent as the other samples, but the shape was still detected. Some of the spatters had semi-detached tails from the primary bloodstain. This occurred as a result of the inertia of impact overcoming the blood's surface tension. The satellite spatter samples also contained extremely small submillimeter bloodstains that can be visualized upon close inspection. ImageJ was not able to detect these spatters, but their presence was noted in the narrative analyses.

Many distinguishing qualities of both impact spatter and satellite spatter on poster board impact sites were discovered during analysis. Impact spatter tended to be more circular, larger, centralized in some areas, and contained spines; whereas, satellite spatter was more irregular or elongated in shape, smaller, uncentralized with random directionalities, and contained extremely small submillimeter spatters that were not visible in the impact spatter samples. The unique characteristics of each leads to a more feasible identification; however, the fabric spatter samples distorted many of those identifying attributes.

T-Shirt Fabric

Quantitative Observations

The smaller amount of impact spatter analyzed (N=396) in comparison to its control samples indicated that the fabric potentially has size-reducing influences on bloodstain formation. This lead to a smaller disparity in size between impact spatter (area: 4.03 mm^2 and perimeter: 7.10 mm) and satellite spatter (area: 2.86 mm^2 and perimeter: 6.70 mm); thus, making the distinction between the two spatter types more difficult in terms of size. Furthermore, the size of the major and minor axes was also less distinguishable; as a result, the gap between calculated impact angles for impact spatter (56.26°) and satellite spatter (46.74°) was smaller. The reduced discrepancy between the two spatters on t-shirt material can make a distinction more difficult if impact angle calculations are evaluated. The circularity values remain comparable in the t-shirt samples. The quantitative analysis of the t-shirt fabric demonstrated a much smaller disparity between the two spatters than the control samples.

Qualitative Stain Observations

The random selection process yielded analogous sample sizes for the stain analysis (Impact: N=176; Satellite: N=174). The evaluation of the control samples found that the impact spatter had a significant amount of round spatter (73%); however, the t-shirt samples yielded a mere four percent of stains being classified as round with a majority of the bloodstains being irregular (88%). Similarly, ninety-five percent of the bloodstains in the satellite samples were classified as irregular. The author noted the presence of both a hexagonal shape and an arrow shape in several bloodstains with both spatter mechanisms; however, due to the shape presence on both types of spatter, the shapes can most likely be attributed to the fabric composition rather than the manner by which the bloodstain originated. As to be expected with fabric impact sites, the symmetry of both spatters were almost identically affected.

The weave permeation of the two spatters had similar behaviors. A vast majority of both spatters ultimately saturated the fabric. The amount of submillimeter stains analyzed in the random selection of both spatters yielded very similar results (Impact: 63%; Satellite: 64%). This was unexpected due to the increased amount of extremely small spatter seen on the satellite samples. Overall, the qualitative stain analysis yielded resembling results for the two types of spatter on t-shirt material.

Narrative Analysis

Both spatters, from an overall perspective, appeared to have either elongated or irregular bloodstains. Bloodstains that wicked together were visible in the impact samples, but not in the satellite samples. The v-shape dispersion pattern that was apparent in the control satellite samples was not prominent in the t-shirt fabric samples; however, there was an absence of spatter towards the upper-center area of the fabric whereas impact samples had a presence of spatter throughout the plane of the fabric. The absence of spatter towards the top of the satellite sample demonstrates the attempt of a v-shape pattern to form, but the fabric's distorting influence prevents the pattern to be apparent.

It was not as noticeable, but some random directionality could be seen in three of the five satellite samples. Furthermore, the randomness could be visualized the most in the lateral areas of the samples. Although hard to visualize in photographs, the presence of the very small spatter that was originally found in the satellite control samples was also found on the t-shirt samples (see Figure 19). The two latter findings could potentially be the only distinguishing characteristics between the two spatters on t-shirt fabric

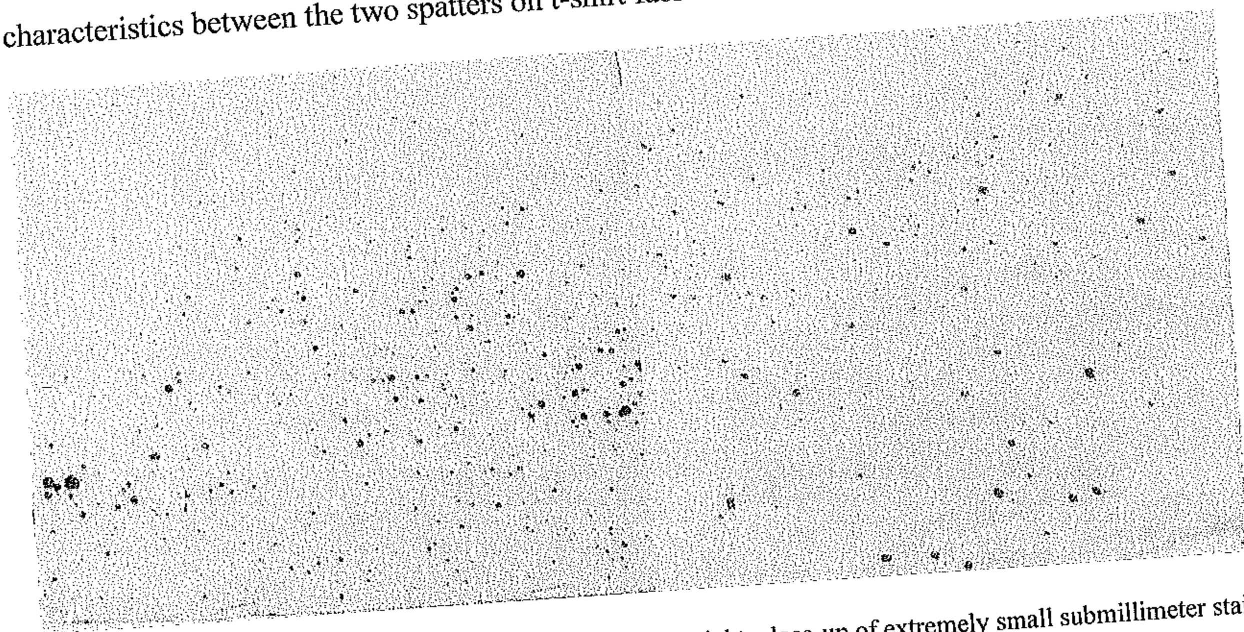


Figure 19: Left: Close-up of an impact spatter t-shirt fabric; Right: close-up of extremely small submillimeter stains on a satellite spatter t-shirt fabric sample

Sheet Fabric

Quantitative Observations

The sheet fabric generated bloodstains more similar in nature to the bloodstains present on the control samples. Primarily, the amount of spatter analyzed by ImageJ (N=769) was much closer to the control samples (N=782). This is indicative of a presence of larger spatter. An average area of 5.49 mm^2 and perimeter of 8.45 mm confirms that the size is closer to that of the control samples. Comparatively, the average area (3.55 mm^2) and perimeter (6.62 mm) of the satellite spatter was still larger than their control sample counterparts, but more comparable. Although the size of the two spatters were slightly differentiable, the impact angles were similar (Impact: 58.80°; Satellite: 52.08°). Up until this point, the impact spatter had maintained a higher circularity value than satellite; however, the sheet fabric samples indicated that the satellite spatter circularity value (0.83) was higher than the impact spatter's (0.75).

Qualitative Stain Observations

Regardless of the satellite spatter maintaining a higher circularity value, both impact spatter and satellite spatter exhibited almost the same percentage of irregular bloodstains, which were the overwhelming majority. The symmetry of impact spatter bloodstains was slightly higher than satellite spatter, but the percentages were not vastly different. The bed sheet bloodstain sample yielded one-hundred percent saturation of the weave for both spatter types. Along with the finding that blood permeation into the weave is very prominent, this particular determination was difficult at times due to the subjectivity associated with a decision of this nature. Lastly, the proportion of submillimeter spatter in both samples was almost identical; again, this finding was not expected due to the presence of very small submillimeter spatter on the satellite samples.

Narrative Analysis

The narrative analysis of the sheet samples provided, perhaps, the most distinguishing results. Both general stain shapes appeared to be elongated/oval or irregular, which is consistent with the findings of the t-shirt samples. However, unlike the impact spattered t-shirt samples, the spines that were visible in the control samples were visible in the sheet samples. This is potentially due to the contrasting absorbency of the bed sheet material and the force associated with impact spatter. The impact spatter on bed sheet material exhibited areas of centralized spatter; this is consistent with the findings in the control samples; however, this can potentially be due to the set distance from the mousetrap to the target. The oval/elongated and irregular shapes were the most prominent; however, from an overall perspective, three of the five samples exhibited bloodstains that appeared more circular in nature. The blood spatter exhibited on the bed sheet samples was more aligned with the control samples than the t-shirt fabric.

The satellite spatter also contained irregular and oval/elongated bloodstains; however, two of the five samples exhibited some circular bloodstains. Therefore, impact and satellite spatter are less likely to be distinguished based on bloodstain shape. Areas of centralized spatter were not detected in the satellite samples; rather, the distribution tended to be even throughout the fabric plane. Random directionality could be detected on only two samples towards the edgeways of the fabric. Extremely small submillimeter spatters could be seen in the sheet samples; whereas, these spatters remained to be absent in the impact samples.

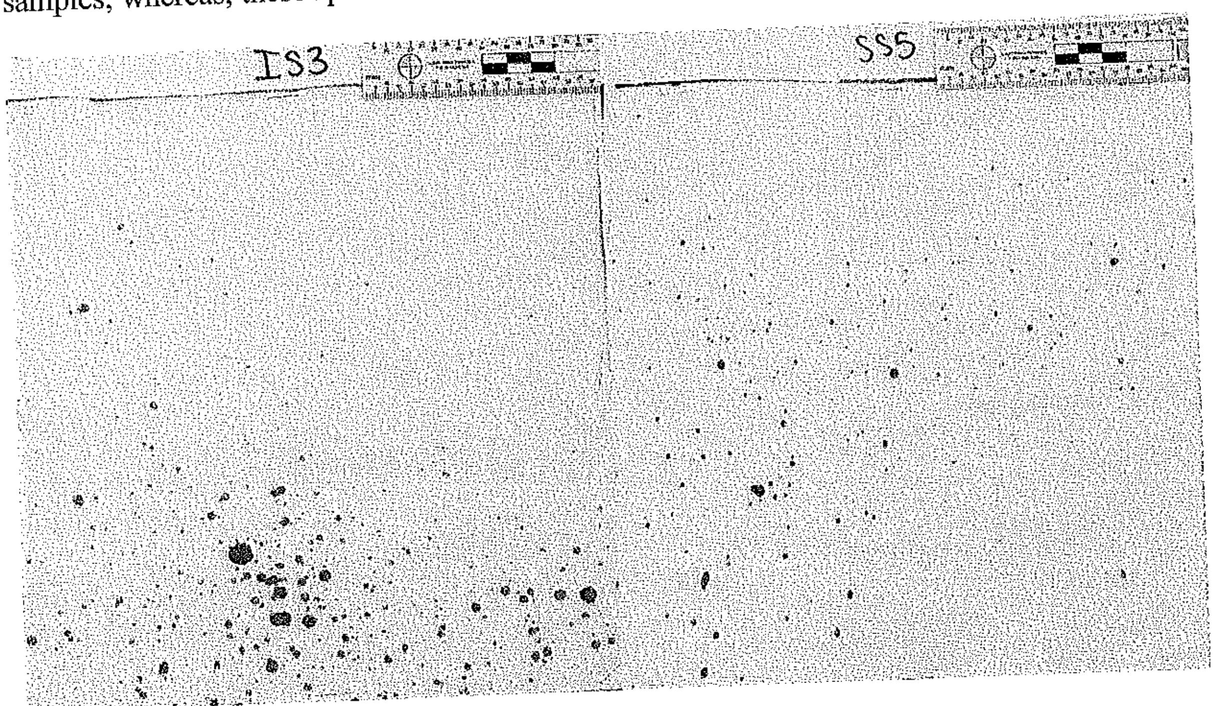


Figure 20: Left: Overall photograph of an impact spattered bed sheet sample with areas of centralized spatter; Right: Overall photograph of a satellite spattered bed sheet sample without areas of centralized spatter

Limitations

Preliminary Study

Laber et al. (2014) generated satellite spatter on fabric by releasing consecutive blood drops which ultimately ejected onto a pair of trousers; however, that particular research did not investigate the details of the resulting bloodstains; rather, the study focused on the error rates associated with the analyst's identification of different types of spatter. Although the bloodstains themselves were not the target of investigation, the resulting error rates were a crucial finding because it illuminated the fact that satellite spatter can be misleading. These findings served as a major motivation for the current research. The satellite simulations of the current research were inspired by the methods used in the study by Laber et al. (2014); however, the analysis of satellite bloodstains of that particular origin are unprecedented. As a result, the current study was structured in a basic manner to serve as a foundation for future, more detailed research.

The current research was limited to fabrics with a composition of one-hundred percent cotton in order to keep the variable constant. Additionally, the fabrics that were investigated were white. The original research included blue, cotton denim; however, the dark background of the fabric against the dark color of blood prevented the author from conducting a thorough and accurate analysis on a consistent basis. The introduction of an infra-red camera may aid in the photographing of bloodstains on dark fabrics, but the analyses that are executed on the physical fabric, without IR photography, may prove to be a difficult task due to visualization issues. The evaluation of the denim spatter samples required investigative methods beyond the scope of the current preliminary research and were ultimately withdrawn.

The angle at which the impact spatter deposited onto the target was also kept constant at approximately ninety-degrees. Blood impacting surfaces at different angles will result in varying bloodstains. Furthermore, satellite spatter was solely deposited onto surfaces that were vertical rather than horizontal, diagonal, etc. The resulting bloodstains of satellite spatter impacting a fabric surface at a different angle may prove to have different results. Lastly, the current research investigated impact spatter at a distance of twenty-four inches and satellite spatter at four inches. The reproduction of both types of spatter at various distances may potentially result in different bloodstains.

ImageJ

ImageJ was not able to recognize very small bloodstains on the fabric samples, but, in the field, the investigation of bloodstains of submillimeter size is not recommended. This recommendation, along with ImageJ not detecting very small bloodstains after a binary image conversion, prompted the restriction of analyzing stains with an area of less than 1 mm^2 (or major axis of 1 mm). However, the inclusion of these stains would have yielded lower size measurements. This fact needs to be taken into account when considering the quantitative results.

As mentioned previously, some of the stain overlap in the target samples was registering two separate bloodstains as one. To correct this, the watershed tool was used. Although the software did have the ability to detect and separate overlapping stains, the division resulted in bloodstain boundaries that were not exactly accurate. The number of overlapped bloodstains present was minimal, so the impact on the numerical analysis of hundreds of bloodstains was also minimal. As a consequence of the water shed command, the program was separating primary bloodstains from their subsequent tail stains in the satellite spattered control samples (the only target that created bloodstains with tails). Ultimately, the watershed tool was not used on the control samples because of this. Again, the amount of bloodstains with a tail were minimal in comparison to the totality of the bloodstains analyzed, so the impact was also minimal.

Subjectivity

One of the major criticisms of bloodstain pattern analysis is the subjective interpretations that are required within the discipline. In the current study, some of the qualitative analyses can be considered subjective; however, necessary. The classification of a "round" stain or an "irregular" stain may be determined based on a different criterion from individual to individual. To mitigate the subjective impact of this type of analysis, the qualitative analysis was done by one person, the author, and the same standards were applied in the evaluation of each individual stain. The determination of stain shape, symmetrical properties, and the saturation of the fabric weave is subjective due to its human interpretation done by the author, but, ultimately, the information found through qualitative analysis proved to be especially relevant.

Future Research

The current research was preliminary in nature and, therefore, tested the feasibility of the current methods, revealed unexpected inconsistencies, and discovered the areas that ought to be further explored. The analysis and results found characteristics consistent which each type of spatter; however, the presence and ability to visualize those characteristics were dependent upon the impact site. The control samples yielded the most identifying characteristics of each spatter while the t-shirt samples blurred the unique attributes the most. The spatter types, distances, and angles were kept consistent, but the results depended upon the surface characteristics. A vast amount of research has affirmed that bloodstains, in general, appear differently depending upon the fabric; furthermore, it is essential for future research to explore satellite spatter on a variety of fabric types and compositions. It is also important to investigate the influences and interactions of various impact angles and distances at which the blood travels.

The major dilemma encountered in the current research was the inability to analyze a fabric type: dark denim. Denim, being one of the most common pieces of clothing, would yield especially crucial results; however, the very dark color required an analysis that was beyond the scope and beyond the resources of this study. The use of an IR camera would benefit the quantitative evaluation via ImageJ, but future research ought to discover and utilize the most feasible methods of physical examination (visualizing the fabric at the macroscopic level). If the fabric is a lighter color, the current methods can be used in their evaluations.

The use of ImageJ to investigate bloodstains has been used in previous research (Michelson et al, 2015; Li, 2015; Williams et al, 2016; de Castro et al, 2015); however, the majority the above research investigated a single bloodstain instead of an entire group of bloodstains. The current study tested the feasibility of using ImageJ when analyzing an entire distribution of bloodstains. Although the author did not discover any major, uncorrectable dilemmas, the use of ImageJ in bloodstain pattern analysis ought to be tested and validated to empirically ensure its validity. The use of this free software program can provide precise measurements in a practical and speedy manner; its validation in terms of investigating bloodstains can be a valuable asset.

The investigation of impact spatter and satellite spatter on fabric was the main goal of the study; however, as a preliminary study, the feasibility of the research structure was also tested. As mentioned above, investigating dark fabrics, with the current methods, proved to be infeasible due to a lack of appropriate resources. Additionally, the circularity value, in terms of investigating bloodstains in this particular study with its associated parameters, did not prove to be a useful factor; however, it may be more useful in the evaluation of bloodstains at different angles. Acute angles tend to be more elongated, and the circularity value may be useful in their evaluation in comparison to bloodstains that are circular or close to circular.

The saturation of the fabric weave was investigated due to these methods leading to significant findings in research investigating impact spatter and transfer stains; however, the author argues that the weave saturation is not particularly useful when comparing satellite spatter and medium velocity impact spatter. The past literature has argued that blood remaining on top levels of the weave is typical of transfer spatter; whereas, the saturation into the weave is typical of impact spatter (Holbrook, 2010); the author of the current research found the latter to be true and, in addition, found that it is also typical of satellite spatter. Future research investigating satellite spatter and impact spatter on fabric should not use weave permeation as a method of measurement.

Conclusion

Ultimately, the ability to distinguish impact spatter and satellite spatter on fabric is crucial because of the implications of both types of spatter: impact spatter indicates proximity to a bloodletting event and satellite spatter indicates proximity to a parent stain or pool, which may or may not be present. This distinction is especially important if the fabric is a piece of clothing that is identified with a wearer. The study conducted by Laber et al. (2014) found that the error rates associated with the identification of satellite spatter originating from a blood pool were high while other experts have cautioned its misinterpretation as impact spatter. The goal of the current research was to serve as a catalyst for the vast amount of necessary research by investigating vital questions about both impact spatter and satellite spatter on fabric. The characteristics of both spatters will vary depending upon the surface typography and absorbency qualities of the fabric; therefore, the initial research questions will be answered as a function of fabric type.

The shared characteristics of impact spatter and satellite spatter on t-shirt fabric included irregularly shaped bloodstains macroscopically, elongated/oval and irregularly shaped bloodstains via the naked eye, reduced symmetry, comparable impact angles, weave saturation, and comparable bloodstain sizes. The t-shirt fabric distorted the unique characteristics of each spatter to a significant degree, yielding little to no absolutely distinguishing observations; however, the satellite spatter samples on t-shirt fabric yielded extremely fine submillimeter spatter on the targets; this phenomenon was not prominent in the t-shirt fabric. Additionally, it is possible to detect the random directionalities of bloodstains in the satellite samples. The latter observations can possibly serve as the only distinguishing features in terms of identifying satellite spatter over impact spatter.

The shared characteristics of impact spatter and satellite spatter on bed sheet fabric yielded similar results as the t-shirt analysis. The evaluation of the spattered bed sheet fabric yielded the same shape observations both macroscopically and without visual aid as the t-shirt fabric samples along with similar behaviors in terms of weave saturation and symmetrical properties. The stain dimensions and the calculated impact angles were comparable; however, the overall stain dimensions for both impact spatter and satellite spatter (area, perimeter, axes length) were aligned more with the control references, but still exhibited the same size-reducing effect for impact spatter and size-enlarging effect for satellite spatter. Although the aforementioned observations were noted, the attributes are not sufficiently distinctive, preventing a classification of being distinguishingly unique; rather, the size attributes ought to be considered corroborating clues.

Unlike the impact spattered t-shirt fabric, a potentially distinguishing feature was discovered on the impact spattered bed sheet fabric. As seen in the impact spatter control samples, spines were also observed around individual bloodstains on the bed sheet fabric. This is most likely due to the force associated with impact spatter and the less absorbent quality of the bed sheet fabric. The satellite spattered bed sheet samples did not exhibit spines; however, the satellite spattered bed sheet samples yielded the same potentially distinguishing attributes as the t-shirt samples: the presence of extremely fine submillimeter spatter throughout the plane of the fabric and the presence of random directionalities. The presence of fine spatter and random directionalities in the bloodstains in both satellite spattered fabrics ought to be further researched as it can be some potentially distinguishing attributes of satellite spatter on fabric in general.

Although some of the discovered features were similar between the two fabrics, the conclusions were not identical. The ability to identify distinguishing attributes of each type of spatter will be dependent upon the characteristics of the fabric. As an effort to provide as much information to the analyst as possible, a constructed database or reference would be beneficial to analysts who are examining any sort of conflicting spatter on particular fabric types. In order to accomplish a task of this magnitude, a high degree of experimentation is necessary.

Sufficient experimentation concerning bloodstain formation on fabric will narrow the gap between the current research and the phenomena that have yet to be thoroughly tested and investigated. An extensive amount of research could potentially serve as the foundation for a future database of blood behavior with certain fabrics and, furthermore, other porous and non-porous surfaces. A development of this sort would serve as a catalyst that challenges the criticisms that BPA is subjective in nature and relies too heavily on experience rather than scientific evidence. Consequently, a knowledge base of this magnitude would aid in reducing error rates associated with bloodstain identification on clothing. Although experimentation of this degree will require a substantial effort on the part of the BPA community, it would assist in an analyst's ability to correctly asses conflicting bloodstains by having access to information that can help in confirming or refuting the analyst's examination. Most importantly, an in-depth and detailed analysis with a strong informational foundation will serve as a major component for ensuring proper results.

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APPENDIX A

STAIN COUNTS BY QUADRANT

ID	QUAD 1	QUAD 2	QUAD 3	QUAD 4	TOTAL
IP1	5	5	18	10	38
IP2	4	4	13	5	26
IP3	4	2	8	13	27
IP4	5	4	18	10	37
IP5	5	5	12	11	33
SP1	18	15	19	12	64
SP2	9	12	13	13	47
SP3	7	4	18	12	41
SP4	5	4	12	11	32
SP5	8	5	12	15	40
IT1	5	7	10	18	40
IT2	5	5	10	10	30
IT3	7	11	19	4	41
IT4	5	5	10	13	33
IT5	4	4	8	16	32
ST1	5	13	15	11	44
ST2	9	5	18	7	39
ST3	7	10	8	11	36
ST4	4	5	5	11	25
ST5	6	8	6	11	31
IS1	6	6	10	7	29
IS2	7	5	17	18	47
IS3	4	4	12	20	40
IS4	4	6	10	12	32
IS5	4	5	9	10	28
SS1	8	7	12	6	33
SS2	5	8	19	8	40
SS3	5	6	8	6	25
SS4	6	6	10	8	30
SS5	6	10	10	9	35

APPENDIX B

QUALITATIVE NOMINAL DATA BY SAMPLE AND SPATTER

Impact Control (N=161)

Shape	#	%	Sym	#	%
Round	118	73%	Asym.	11	7%
Polygonal	3	3%	Sym.	150	93%
Irregular	40	24%			
Weave	#	%	SM	#	%
Saturated	N/A	N/A	Yes	115	71%
Top	N/A	N/A	No	46	29%

Satellite Control (N=224)

Shape	#	%	Sym	#	%
Round	126	56%	Asym.	19	8%
Polygonal	5	2%	Sym.	205	92%
Irregular	93	42%			
Weave	#	%	SM	#	%
Saturated	N/A	N/A	Yes	179	80%
Top	N/A	N/A	No	45	20%

Impact T-Shirt (N=176)

Shape	#	%	Sym	#	%
Round	7	4%	Asym.	55	31%
Polygonal	14	8%	Sym.	121	69%
Irregular	155	88%			
Weave	#	%	SM	#	%
Saturated	175	99%	Yes	110	63%
Top	1	1%	No	66	37%

Satellite T-Shirt (N=174)

Shape	#	%	Sym	#	%
Round	4	2%	Asym.	51	29%
Polygonal	5	3%	Sym.	123	71%
Irregular	165	95%			
Weave	#	%	SM	#	%
Saturated	164	94%	Yes	112	64%
Top	10	6%	No	62	36%

Impact Sheets (N=176)

Shape	#	%	Sym	#	%
Round	9	5%	Asym.	56	32%
Polygonal	13	7%	Sym.	120	68%
Irregular	154	88%			
Weave	#	%	SM	#	%
Saturated	176	100%	Yes	96	55%
Top	0	0%	No	80	45%

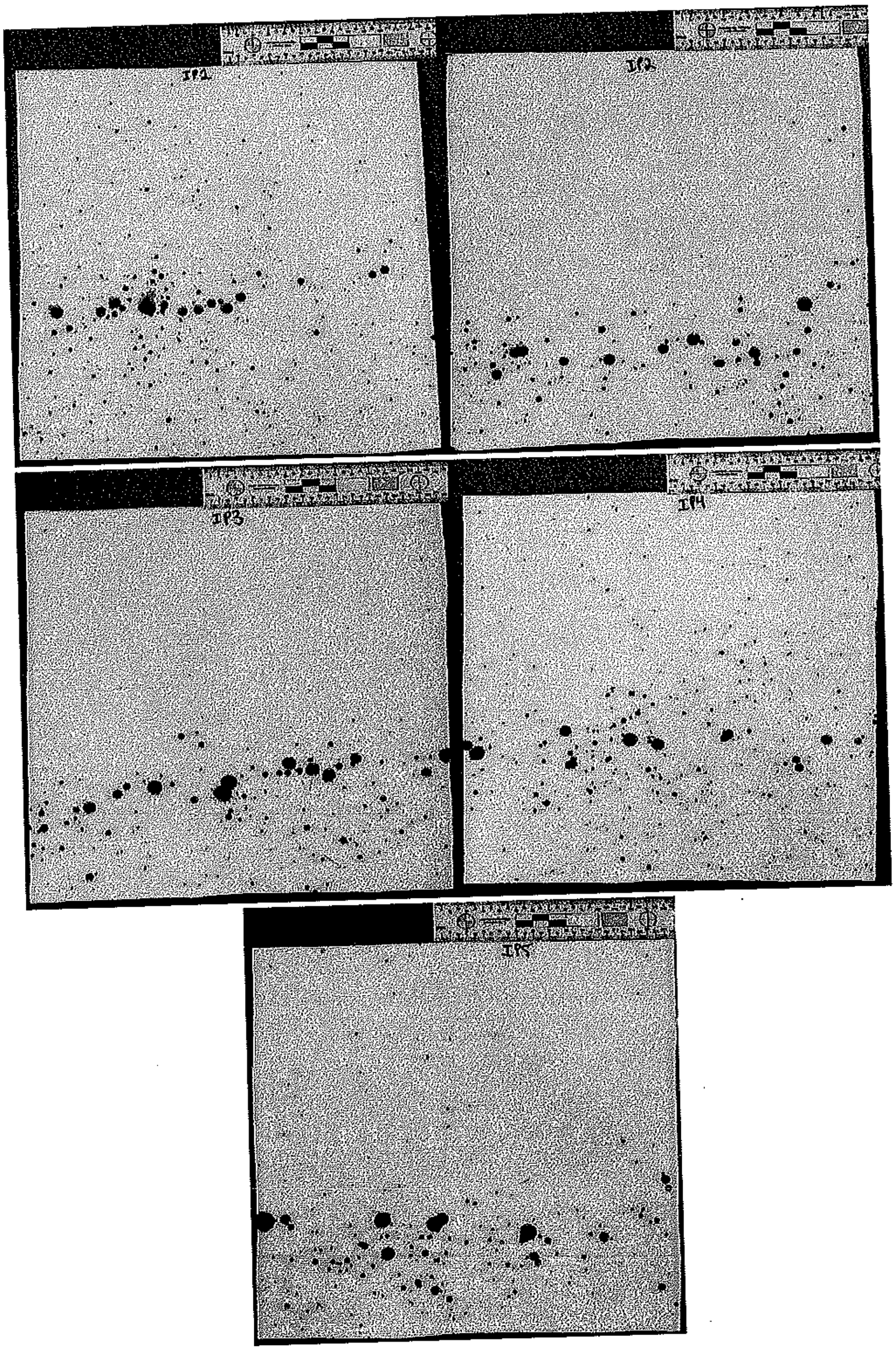
Satellite Sheets (N=166)

Shape	#	%	Sym	#	%
Round	10	6%	Asym.	78	47%
Polygonal	9	5%	Sym.	88	53%
Irregular	147	89%			
Weave	#	%	SM	#	%
Saturated	166	100%	Yes	97	58%
Top	0	0%	No	69	42%

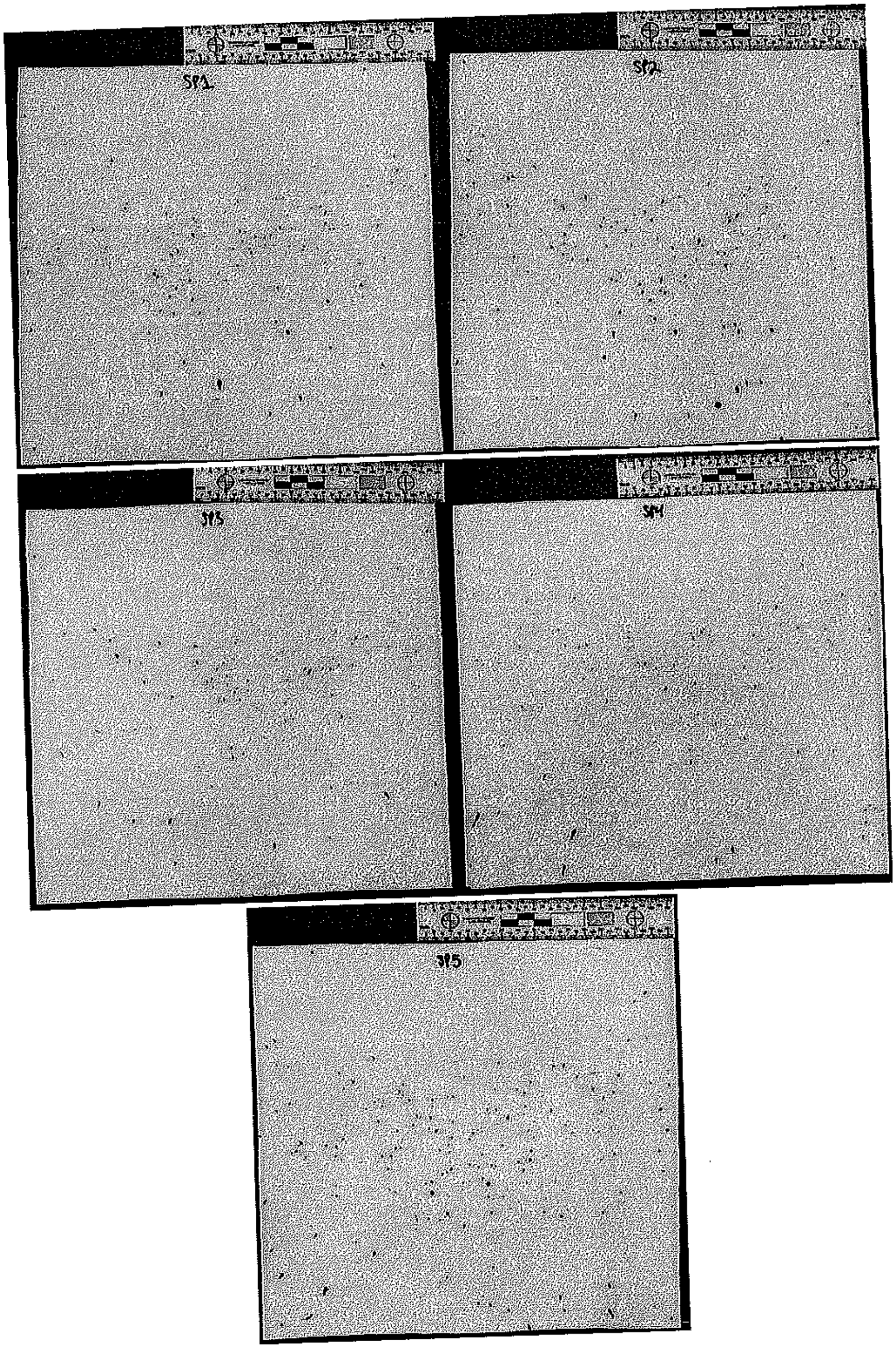
APPENDIX C

PHOTOGRAPHS OF SPATTERED SAMPLES

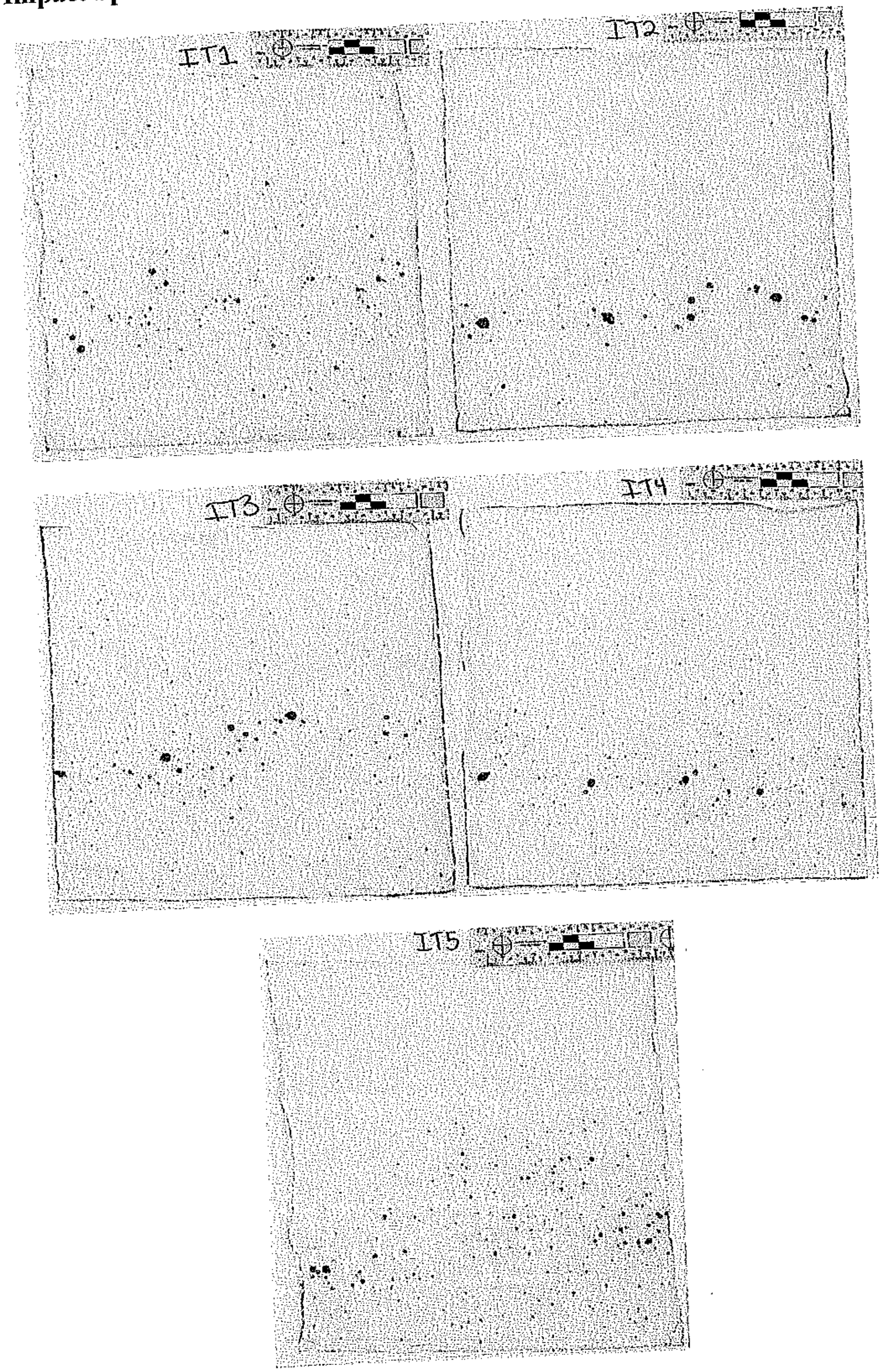
Control – Impact Spatter



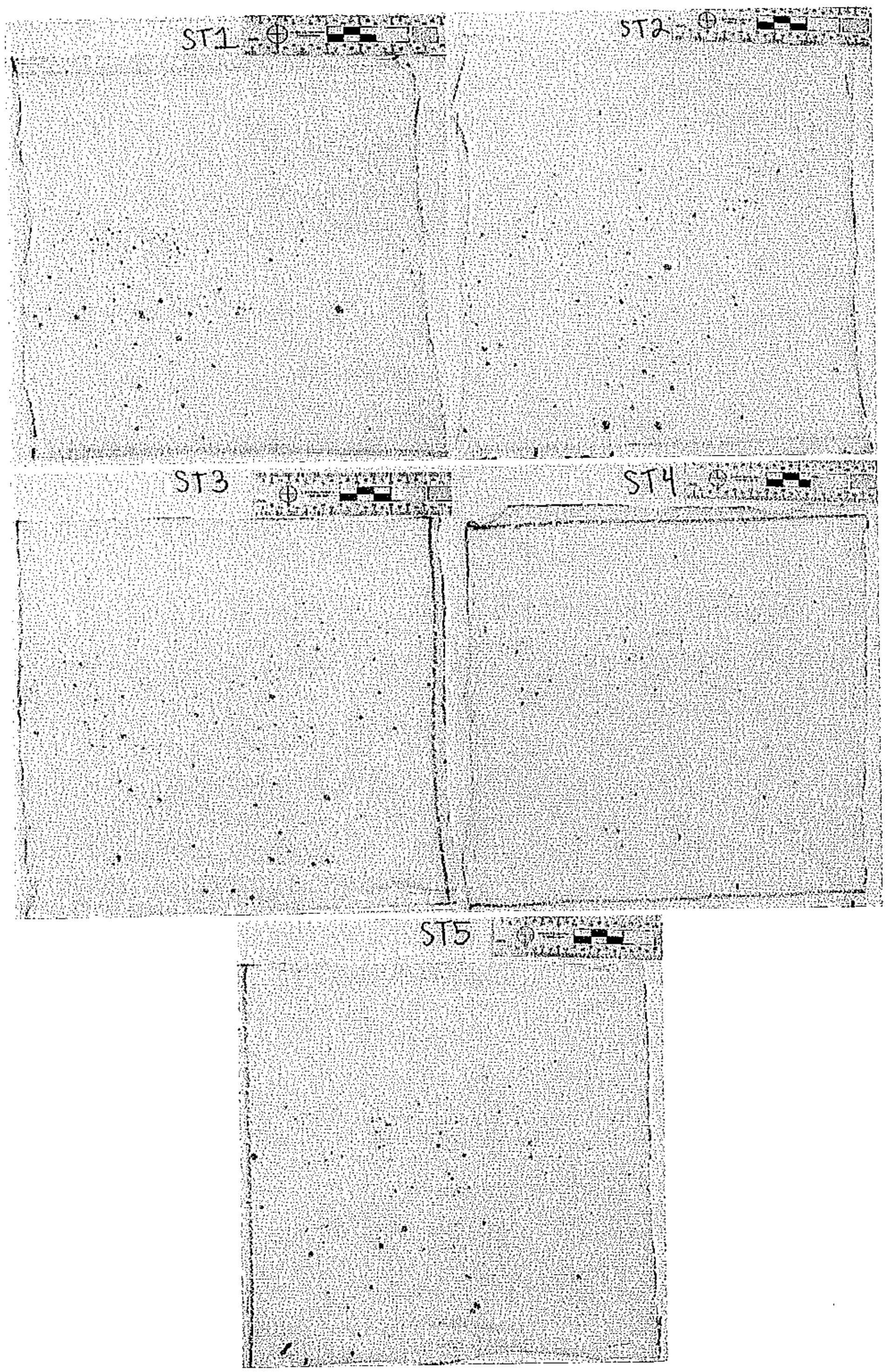
Control – Satellite Spatter



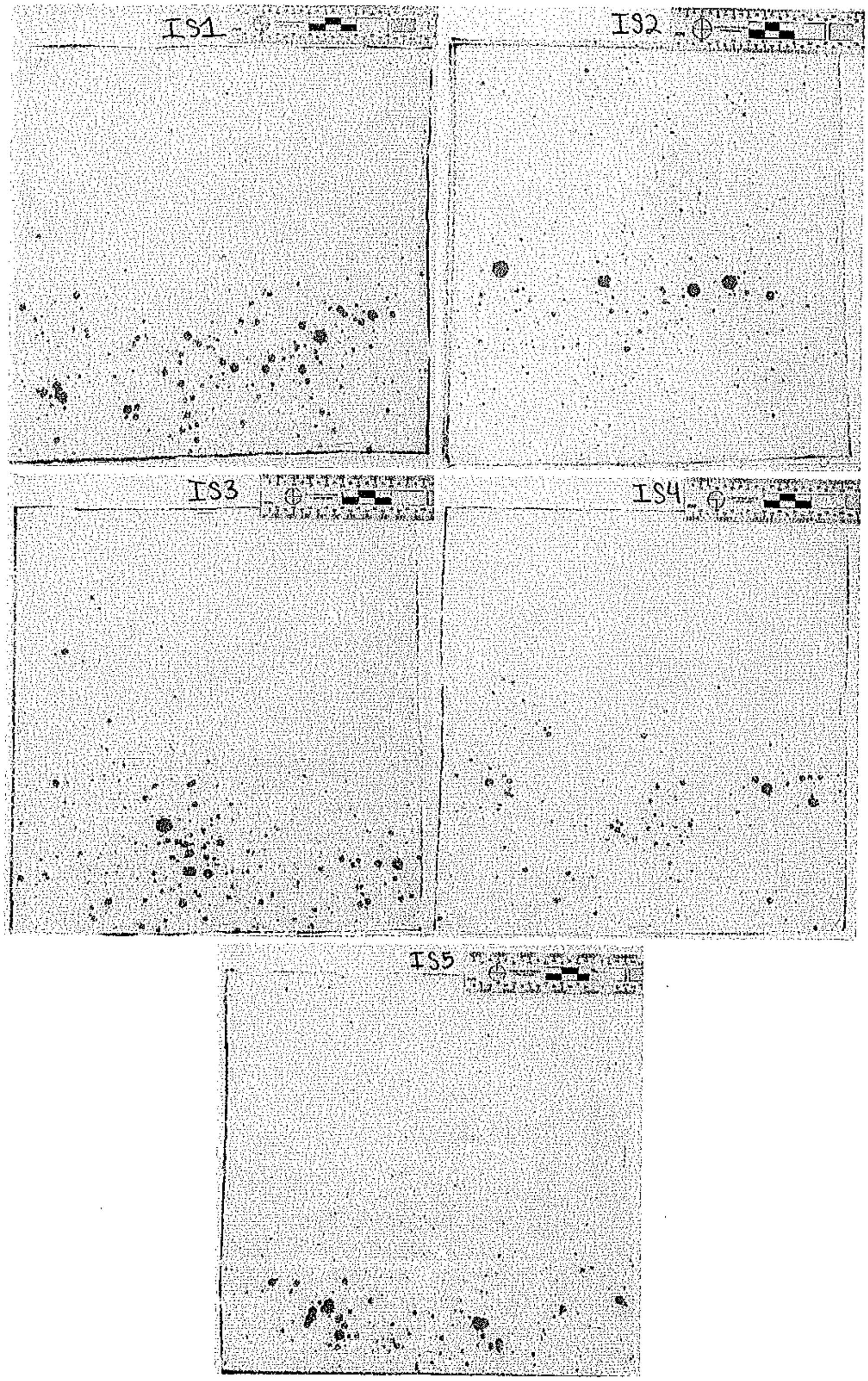
T-Shirt – Impact Spatter



T-Shirt – Satellite Spatter



Bed Sheet – Impact Spatter



Bed Sheet – Satellite Spatter