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Article

Defining Patterns and Behaviours of Forward Spatter Gunshot Misting

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Abstract: The purpose of this research was to study forward-spatter misting patterns by shooting a firearm through a chamber of blood encased in ballistic gel to determine if there is a relationship between bloodstain pattern size as a function of distance and orientation. There is a lack of research on forward spatter, blood travelling in the direction of a bullet, as most studies focus on back spatter, blood travelling in the opposite direction of a bullet. A bullet was fired through ballistic gel containing a blood chamber, depositing bloodstains onto a large sheet of butcher paper as the target surface. In total, there were 34 trials. The distances observed were 10, 20, 40, and 80 cm, the angles tested were 30°, 60°, and 90°. The orientation between the ballistic gel and paper target varied. A criterion was established to observe the overall area and symmetry of the bloodstain patterns. Statistical analyses indicated a negative linear relation relationship between the bloodstain pattern size and the paper's angle and distance (R^2 = 0.78) and the vertical symmetry of the bloodstain (R^2 = 0.87). The orientation between the ballistic gel and paper target can impact the bloodstain pattern's symmetry and size.

Keywords: misting patterns; bloodstain pattern analysis; forward spatter; forensic sciences; firearms; ballistic gel; crime scene reconstruction

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1. Introduction

Gunshot misting is commonly described as a bloodstain pattern created at a velocity greater than 35 m per second and is produced by a high amount of kinetic energy upon impacting the target [1]. Bloodstains are usually less than 1 mm in diameter from a high-energy impact misting pattern [1]. There are two types of misting patterns when considering gunshots through the body, back spatter and forward spatter. Back spatter examines blood travelling in the opposite direction of the bullet, and forward spatter focuses on blood travelling in the same direction of the bullet [2]. Blood is one of the most common forms of evidence used during crime scene reconstructions, as it provides insight into the mechanism that created the bloodstain pattern, and at times, it can help interpret the victim and suspect's location [3,4].

Blood is a non-Newtonian fluid; it is a shear-thinning aqueous solution, the viscosity changes as a function of shear; thus, the less viscous the blood is, the more shear is present [5]. When an object travels through an individual's body, the object's velocity creates an intensive amount of shear on the blood, creating a small spatter misting pattern [5]. The higher the impact energy, such as a gunshot, the higher pressure and stress the blood is under, creating a small spatter misting pattern.

In crime scenes, bloodstain pattern analysts will categorize a bloodstain pattern as misting but will not always discuss if the bloodstain pattern is forward spatter or back spatter as it is difficult to determine at a crime scene. In the literature, most studies focus on qualitative and quantitative analysis on back spatter [6]. Previously in the literature, there was little information directly focusing on forward spatter, some articles define forward spatter, but there has been little to no quantitative information associated with forward

spatter [6]. Attinger and Comiskey [7] in 2017 did research observing high-speed videos of forward and back spatter; they concluded that forward and back spatter can create different bloodstain patterns in certain situations. This means that back and forward spatter should be treated independently when observing misting patterns. Although this statement has been understood by bloodstain pattern analysts, there has been no quantitative analysis performed on forward-spatter misting patterns.

The purpose of this research is to analyze misting patterns associated with forward-spatter gunshots by shooting a bullet through ballistic gel with a blood chamber to determine if there is a relationship between bloodstain pattern size and symmetry as a function of distance and orientation. This research is significant as it provides a better understanding of misting patterns, which can further help bloodstain pattern analysts when performing crime scene reconstructions. Understanding forward-spatter misting patterns may help to explain how the bullet impacted an individual or how the victim was positioned or oriented. Studying forward misting patterns will provide new quantitative and qualitative information about a topic that has not been studied previously in the literature. Although Attinger and Comiskey [7] state that forward spatter yields different patterns than back spatter, there has been no developed methodology to interpret forward spatter. Thus, there is a need for a standardized method and analysis procedure to interpret forward-spatter misting patterns.

2. Materials and Methods

2.1. Sample Subjects

Sheep's blood was used for the experiment since it has been found in previous literature to have similar physical properties to human blood in the context of creating bloodstain patterns [8]. The blood was sourced from the Canadian Food Inspection Agency, where they ensure the sheep are treated ethically and ensure the sheep's blood is pathogen-free [9].

2.2. Published Methods and Selection for Technique

In the literature, the current standard use for misting patterns is blood-soaked sponges [10]. Since sponges are porous, the blood-soaked within the sponge can be absorbed differently depending on the sponge's porosity. Secondly, the sponge is not contained in anything resembling human tissue; thus, different types of bloodstains can also be deposited on the paper, which can impact the bloodstain pattern size and shape. Mahoney et al. [11] published a method that observed back spatter on a synthetic skull; this methodology used ballistic gel and a surrogate skin layer to yield similar results that would be found in real-life situations. This study was used as an aid to develop the methodology to observe forward spatter as it implied the importance of using ballistic gel as a substitute for human tissue. However, our methodology is different as we use ballistic gel to simulate human tissue with an internal blood chamber instead of a skin layer.

Clear ballistic gel was used from Clear Ballistics. Each ballistic gel block was made from 100% synthetic gel and was calibrated to ensure it could withstand gunshots [12]. Ballistic gel was used for the experiment because it has been used previously in the literature to represent tissue in the body, and its translucency helps observe how the bullet reacts in the ballistic gel [13]. For instance, the translucency can provide insight into the depth at which the bullet expanded and the angle the bullet travelled through the gel. The ballistic gel is primarily used as a more controlled method to reproduce experiments. The ballistic gel was used to shoot the bullet through, and the internal blood chamber operated as a pocket to hold the blood within a fixed location, ensuring the gun would penetrate through a similar amount of blood at the same location for each trial of the experiment. Although the ballistic gel is used to simulate human tissue, it has to be noted that it is not a perfect replica of the human body. The human body has many different variabilities between people, and the ballistic gel cannot account for all these variabilities; therefore, the ballistic gel was used as a repeatable simulant, not a replicate. This research consisted of

two main sections: The equipment preparation consisting of equipment preparation and data collection.

2.3. Equipment Preparation

Four FBI blocks 40.64 × 15.24 × 6 × 15.24 cm in length, and one gel air rifle block 10.16 × 10.16 × 22.86 cm from the manufacturer Clear Ballistics were used. Using a Swanson turkey oven, the ballistic gel blocks were melted to a viscous liquid at 275 F°. Wooden blocks were made as the mould to hold the ballistic gel. Figure 1 displays the wooden mould used to make the ballistic gel. The mould was 12 × 12 cm and 5 cm in depth. The wooden blocks were sprayed with heat enamel spray paint, ensuring no gel would absorb within the wood. Strips of parchment paper of 11 × 5 cm were placed inside the wooden mould to make it easier to remove the solidified ballistic gel from the wooden block.

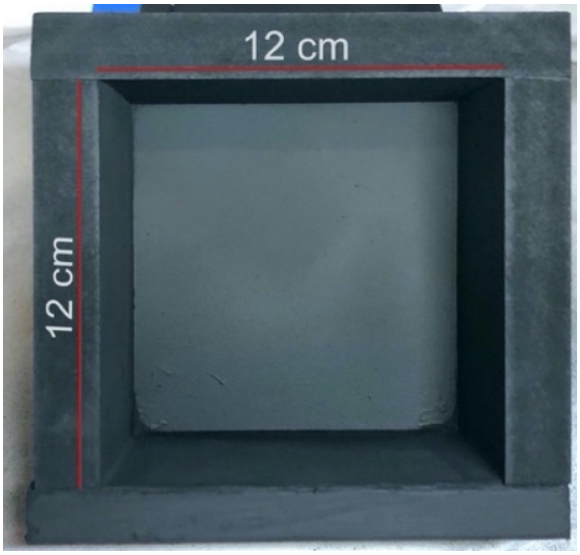


Figure 1. A 12 × 12 cm wooden frame sprayed with heat enamel spray paint to make ballistic gel mould.

Once the ballistic gel was melted to a liquid form, it was poured into the wooden mould 2.5 cm in depth. After approximately 10–20 min, depending on the environment's ambient temperature (the cooler the environment, the faster the gel solidifies), a 5 cm × 5 cm × 2 mm thick wood piece was placed directly in the centre of the wooden block using an L-shaped measurement jig. The jig was placed onto the gel, and the wooden piece would go into the corner of the jig; this procedure was performed for each mould. Figure 2 displays the measurement jig and the wooden chamber in the centre of the ballistic gel moulds. Once removed, this small wooden piece created a void that became the internal chamber to hold the blood in a fixed position.

After placing the chamber piece into the centre, 1 cm of the liquid gel was poured over the wooden piece to ensure it was held in the centre position. Once the layer cooled, more liquid ballistic gel was poured, making the gel mould's depth 5 cm. In total, the ballistic gel took about 3–6 h to cool down and solidify to its gel form. Once cooled, the ballistic gel was taken out of the mould, and the parchment paper was peeled off. Using a lighter, a knife was heated to make a 5 cm long incision onto the 12 cm side of the mould; the incision had to be deep enough to touch the wood chamber piece. Once cut, needle-nose pliers were used to pull the wood chamber out of the mould, creating the internal blood chamber pocket. A heat gun was used to close the incision, allowing both sides of the incision to fuse together, to make an enclosed, complete mould. Figure 3 provides an example of a complete ballistic gel mould with the wooden chamber piece removed.

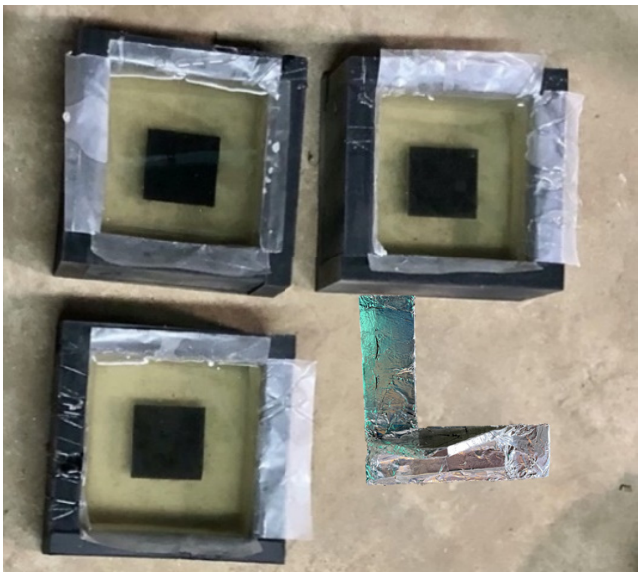


Figure 2. The liquid ballistic gel in the wooden frame showing the 5 × 5 cm wood chamber piece and the parchment paper underneath the ballistic gel. The bottom right shows a picture of the L-shaped jig used to find the centre of each mould.

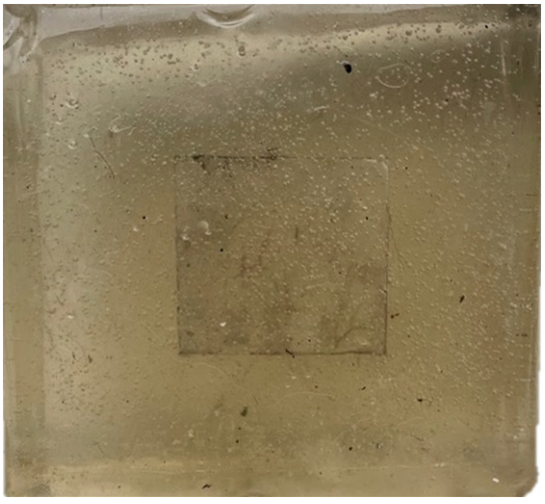


Figure 3. An enclosed ballistic gel mould with the closed chamber pocket (centre darker square).

2.4. Description of the Stands Used for Data Collection

The bloodstain pattern area and symmetry were examined by varying the distance and the angle of the paper target to the ballistic gel. To hold the ballistic gel in place, a wooden platform was made; the platform had a slot for the ballistic gel to sit in and a lid to secure the gel in its place, Figure 4 displays a close up of the slot to hold the ballistic gel. This platform had adjustable knobs to vary the height of the stand accordingly to the handgun. A second stand was required to hold the butcher paper target. This stand had adjustable knobs to change its angle and height relative to the gel block. The paper target stand had a main frame that was 91.4 × 91.4 cm; in preparation for data collection, sheets of butcher paper were cut to the same size for efficiency. Please refer to Figure 5 to see the stands used for data collection and an image of the overall methodology.

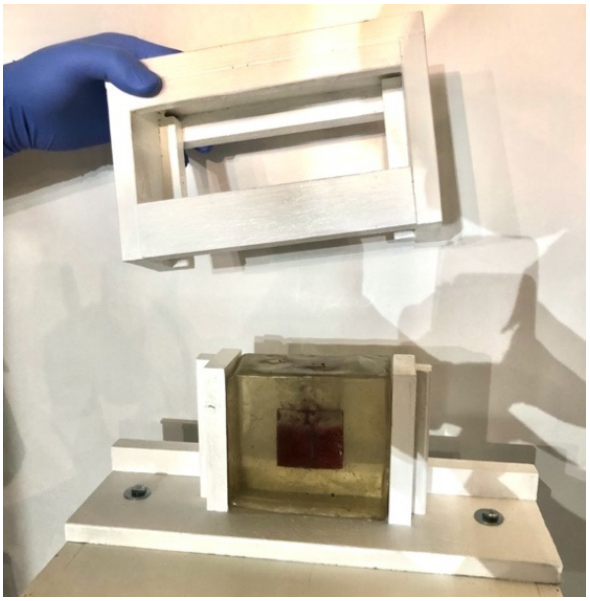


Figure 4. Ballistic gel mould with blood placed in its securing gel block.

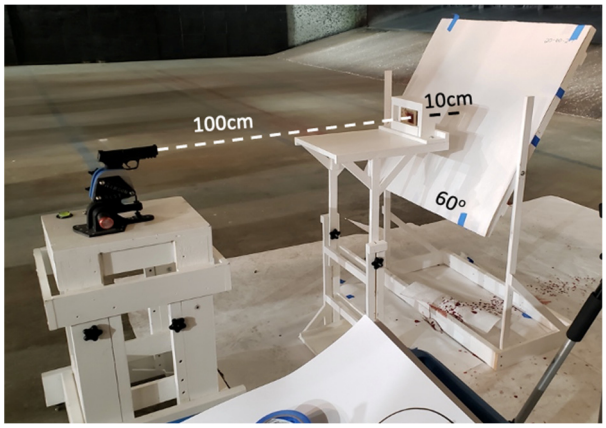


Figure 5. Overall methodology in situ from trial 10 cm at 60°, paper target rig (**far right**), gel block stand (**middle**), and ransom rest (**left**).

2.5. Data Collection

Data collection occurred at Peel Regional Police Emily V. Kolk Centre in Mississauga, Ontario. A Smith and Wesson M&P M2.0 9mm handgun was used, as handguns are the most common type of gun used in homicide cases in Canada [14]. Nine-millimetre Hornady Critical Duty bullets were used throughout the entire experiment for consistency. Butcher paper was used rather than regular white paper because it is sturdy and has been used as the surface to deposit bloodstain patterns previously in the literature [10]. In total, four distances were examined between the gel block and the target sheet: 10, 20, 40, and 80 cm. At each of the distances, three angles were examined and tested, 30°, 60°, and 90°. Each angle had at least three trials at each distance, except for 10 cm at 30°, which had no data collected due to interference between the lower part of the paper and the gel stand, resulting in a total of 34 trials.

A ransom rest displayed in Figure 6, held the gun in a fixed position and was used throughout the experiment. The ransom rest is a metal-like stand situated on a large wooden block to hold the firearm in a fixed position when fired. The ransom rest was used because it ensures stability and consistency throughout each trial in the experiment, this reduced human error and variability when considering a fixed position. Once the gun was secured in the ransom rest, it was levelled to 0° using a digital scale after each trial to

ensure an accurate shooting angle between the bullet path and the target sheet. This was a controlled variable in the experiment because the firearm's height and angle were at a fixed position.

Figure 6. Ransom rest mechanism used to hold the gun at a controlled height and level.

Using a medical syringe, 6 mL of sheep's blood was injected into the gel block chamber, creating a centralized pocket of blood within the mould. Figure 7 displays the medical syringe injecting the sheep's blood into the ballistic gel mould. A narrow medical syringe was used because the needlepoint is small and would create a narrow opening within the gel mould. This ensured that the path of least resistance would be the bullet hole and not the incision made by the needle. Preliminary testing proved this to be a reliable and repeatable method.

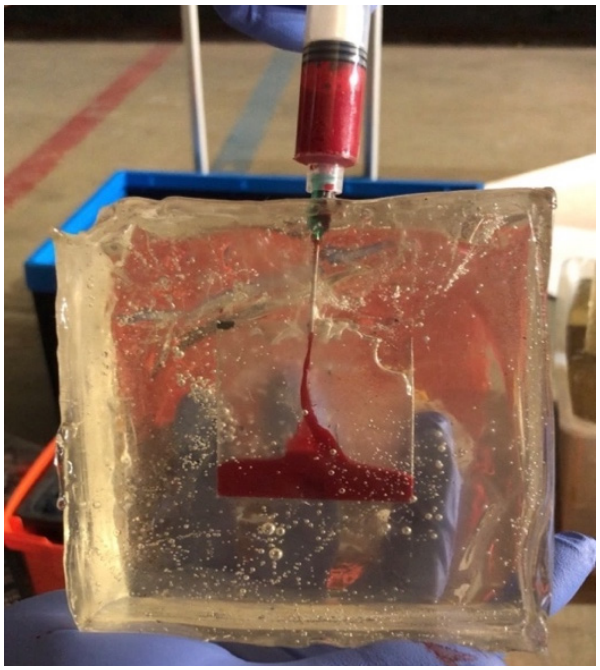


Figure 7. Syringe injecting the 6 mL of blood into the enclosed chamber of the ballistic gel.

The ballistic gel mould was then placed on the gel block stand, and a piece of butcher paper was placed on the paper target stand; one ballistic gel mould and one piece of paper were used. For each trial, the trial number, distance, and angle were all written in

the top right corner of the target paper. Initial setup and testing before data collection determined that a 100 cm distance between the muzzle of the gun and the ballistic gel yields the best results to observe the bloodstain pattern with minimal influence from the exiting muzzle gases. The angle of the butcher paper was measured using a digital level rather than a mechanical level near the location where the bullet was to provide a more precise reading. Once the distance between the ballistic gel and the firearm's muzzle was measured to 100 cm, and the paper target stand was at its appropriate distance and angle, a laser boresight was placed into the muzzle to ensure that we targeted the blood chamber in the gel block at the same relative location for each trial. From there, the firearm was shot from the ransom rest, and the bullet penetrated through the ballistic gel and blood chamber onto the large butcher paper where the misting pattern was deposited. After the bloodstain was created, the paper was taken down, and a new piece of paper and ballistic gel mould was used for the next trial.

2.6. Criteria and Analysis to Determine Forward Misting Pattern

This research investigates how bloodstain pattern size is affected by distance and orientation; therefore, observing the densest part of the misting pattern was found to be the most efficient method. Density was defined as how many bloodstains (less than 1 mm in diameter) fit within a 1 cm square; the criteria for inclusion of a dense forward-spatter misting pattern was established as ten or more stains in a 1 cm square. Figure 8 displays an example of the photoshop analysis using the criteria of inclusion.

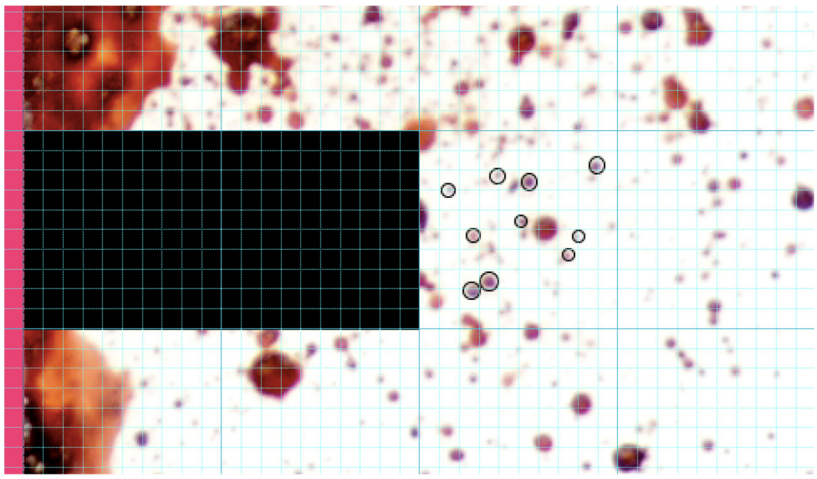
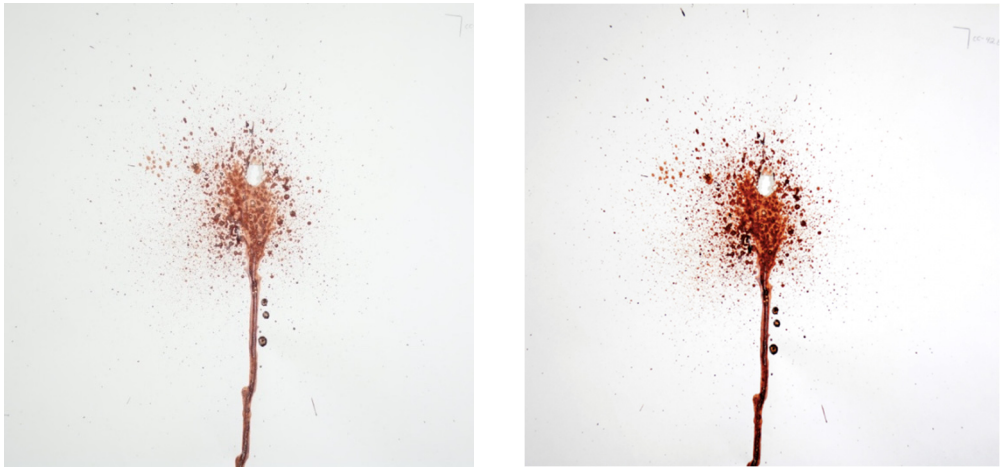


Figure 8. Example of the Photoshop analysis zoomed at 200%. There is evidence of 10 bloodstains less than 1 mm (black circles). That square was counted toward the total area.

Using a DSLR camera set perpendicular to the target sheet, photographs were taken of each bloodstain pattern. Each photograph was brought into Adobe Photoshop, where the levels were adjusted. Figure 9 provides a comparison of the same bloodstain image with and without the levels adjusted. The photographs' levels adjusted the brightness, tones, and contrast of each photograph, making the dense bloodstains more visible to the naked eye. Using the eyedropper tool, the white point levels were adjusted to the colour of the butcher paper, as it was the lightest point in the photograph. Similarly, the black point levels were adjusted by choosing the darkest colour on the bloodstain pattern.

Once levelled, the photographs were scaled; this allowed for accurate measurements when taking the bloodstain pattern's area and symmetry. Two guides were made and crossed over in the centre of the entry hole in each photograph; one guide ran vertically, and one guide ran horizontally. These guides separated the bloodstain into four zones. Once guides were placed, a 1 × 1 cm grid was displayed over the entire bloodstain, still with the guides showing to know the difference between each zone. In the grid system,

10 subdivisions were made, thus in each 1 cm^2 square, 100 squares are 1 mm. Figure 10 provides an example of a bloodstain image with the 1 cm grid displaying the four zones.



(**a**) (**b**)

Figure 9. (**a**) Bloodstain image without levels adjusted; (**b**) bloodstain image with levels adjusted.

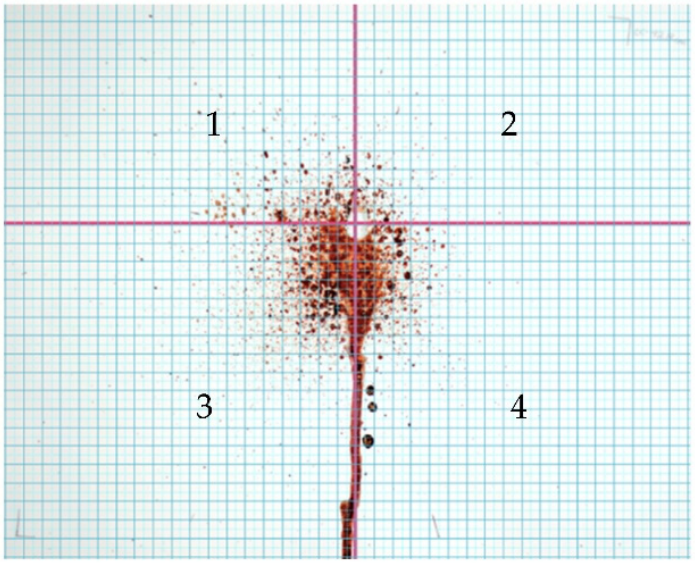
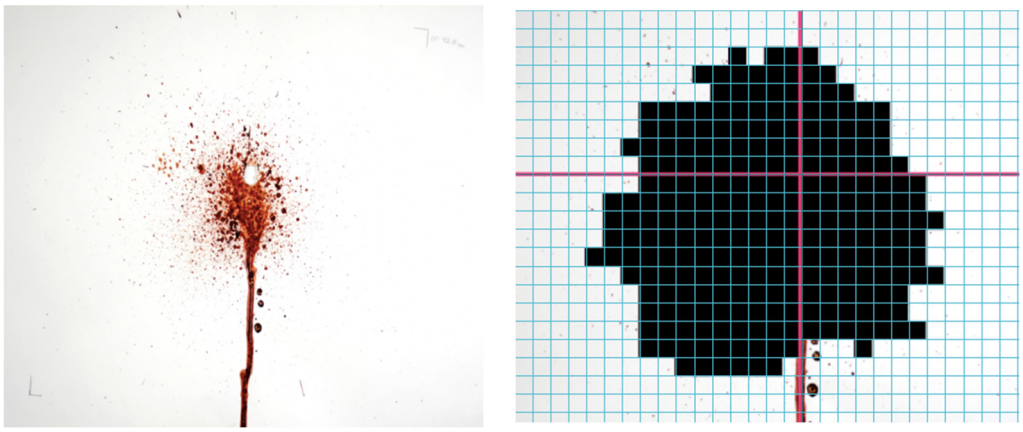


Figure 10. Image of a bloodstain pattern (20 cm at 60°), scaled with the guides (pink) and 1 cm grid displaying the four zones.

Each trial's dense misting pattern and vertical symmetry were calculated using the previously stated criteria. Each trial started at the fourth zone's vertical guide and moved upwards toward the second zone, then the first zone and ending at the third zone; each photograph was magnified to 200% for each photograph for consistency and to remove bias as to what was considered dense and not dense. The perimeter of the dense misting pattern was established, and everything inside the perimeter was included for the area measurement. The area and symmetry of each zone were calculated by counting the total number of 1 cm squares. In certain trials, there was excess blood that ran down the sheet of paper. In these cases, we excluded any flowing blood from the total dense pattern estimation. Figure 11 displays the complete process of the photoshop analysis and an example of flowing blood that was excluded from the dense misting pattern.



(**a**) (**b**)

Figure 11. (**a**) Example of the beginning result; (**b**) end result of the same bloodstain pattern (20 cm at 60°) to calculate the total area. There is an example of excess blood that was not used for the dense pattern estimation (bottom left).

3. Results

Bloodstain Pattern Area

To perform parametric statistical analysis, a normality test was conducted on the total area of the bloodstain pattern. A Kolmogorov–Smirnov test for normality in smaller samples showed that the data were normally distributed ($\alpha = 0.05$, $p = 0.79$), and parametric tests can be conducted [15]. Figures 12–14 display the raw data of the bloodstain pattern's total area for each trial.

Figure 15 was created to observe how distance affected pattern size when the target sheet was at 90° to the bullet path. The average bloodstain area at each distance was graphed. There was a general trend that as the distance increases, the dense forward-spatter area decreases.

Table 1 documents the average area of forward spatter at all three trials at each distance and angle. Using these values, Figure 16 represents the average area of the forward-spatter misting patterns at each distance and grouped by angle.

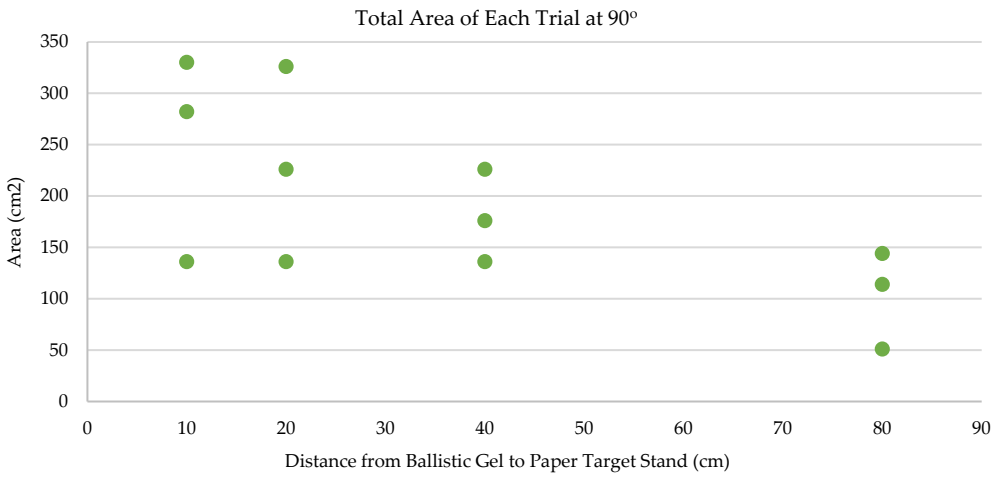


Figure 12. Total area of each trial at 90°; in total, there were three trials at each distance.

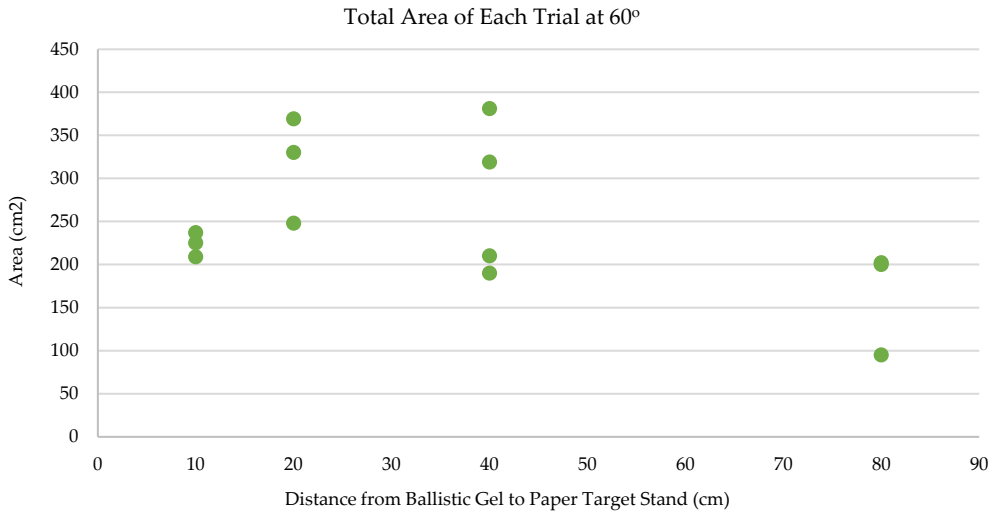


Figure 13. Total area of each trial at 60°; in total, there were three trials at each distance, except there were 4 trials at 60°.

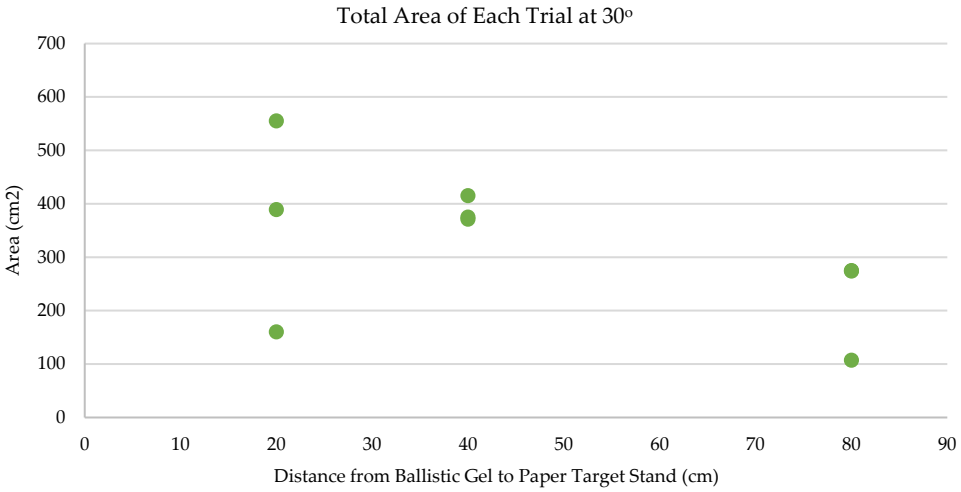


Figure 14. Total area of each trial at 30°; in total, there were three trials at each distance, except there are no values at 10 cm due to equipment restrictions.

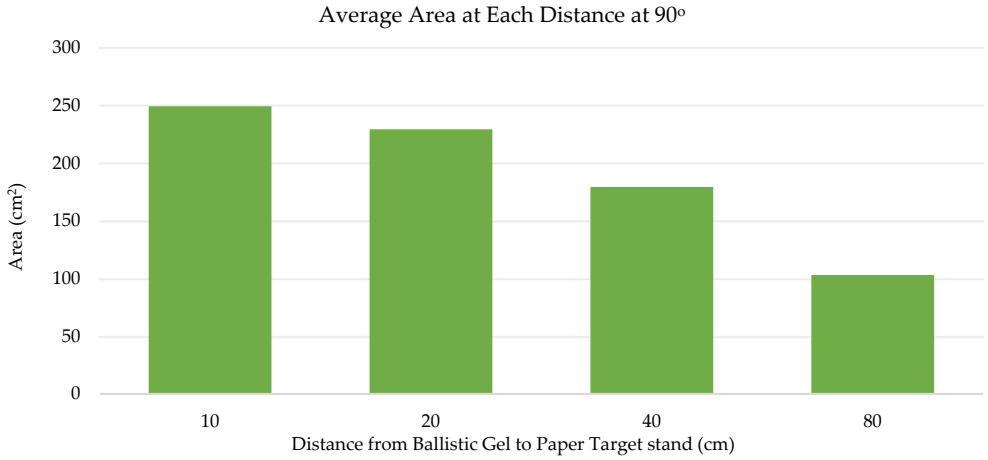


Figure 15. The average area at each distance from a perpendicular angle to the floor (90°).

Table 1. Average area of each bloodstain.

Angle (°)	Distance (cm)	Zone (cm^2)				Total (cm^2)
		1	2	3	4	
90	10	52.83	40.33	89.67	66.33	249.17
	20	49.67	33.67	83.33	62.67	229.33
	40	31.00	15.00	81.33	52.00	179.33
	80	5.00	3.67	50.33	44.00	103.00
60	10	52.67	55.67	62.67	52.67	223.67
	20	48.33	45.0	125.0	97.3	315.7
	40	25.00	30.75	98.25	121.00	275.00
	80	5.00	2.33	83.67	74.67	165.67
30	20	104.67	63.33	126.00	74.00	368.00
	40	43.67	43.33	143.33	156.67	387.00
	80	0.00	0.00	105.00	113.67	218.67

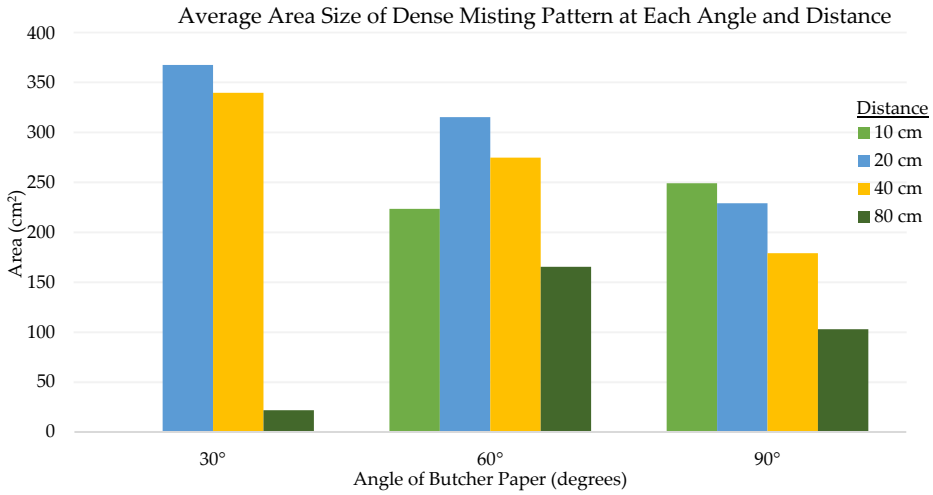


Figure 16. Average total area at all three angles (30°, 60°, and 90°) at all four distances (10, 20, 40, and 80 cm). Note that 10 cm distance at 30° was not able to be tested due to physical limitations.

4. Discussion

4.1. Bloodstain Pattern Dense Area

A general pattern was observed at all three angles: as distance increases, the pattern area appears to decrease; 10 cm at 60° is an outlier as it is the only value that does not follow the trend. A linear regression analysis was computed using *Microsoft Excel* and *SPSS statistics* to determine if there was a relationship between the independent variable (distance) and the dependent variable (average area) at each angle. The multiple R-values were used to determine how many data points fit within the regression line; this determined the overall "goodness of fit" [16]. The R^2 value is known as the coefficient of determination; this evaluates the strength of the relationship between the distance and average bloodstain pattern size [17]. The standard estimate of error was also calculated at each angle to determine how accurate our calculations were by observing accuracy predictions along the regression line. Table 2 is the summary of the results. At angles 30° and 90°, the values are close to 1, implying a strong relationship between the paper's angle and bloodstain pattern size.

The average multiple R-values were 0.87 and 0.78 for the R^2. The outlier in the data is 60°, which has lower R-values in comparison to the other angles. Overall, the linear regression analyses values implied a significant linear relationship between forward-spatter blood pattern size and the distance between the firearm and location of the bloodstain pattern. The standard estimate error value is lower at 90° in comparison to 30° and 60°

with a value greater than 11. The high value is a result of the sample size and the unknown variabilities in bloodstain pattern analysis.

Table 2. Linear regression analysis results for the average area at each angle.

	Regression Statistics		
	90°	**60°**	**30°**
Multiple R	0.99	0.65	0.97
R Square	0.99	0.43	0.93
Standard Error of Estimate	2.21	28.66	11.13
Observations	4	4	3

4.2. Vertical Symmetry

A key focus in this research was to observe the vertical symmetry of the bloodstains through a horizontal line of symmetry. The bloodstain patterns symmetry was analyzed by observing the ratio between the top zones (1 and 2) and bottom zones (3 and 4) of the forward-spatter misting patterns. The pattern of symmetry was first tested at 90° to see how symmetry changes at a perpendicular angle (90°) to the floor. Figure 17 displays the trend that the top zones decrease as the bottom zones increase in size, stating a more considerable difference in perpendicular zones as distance increases.

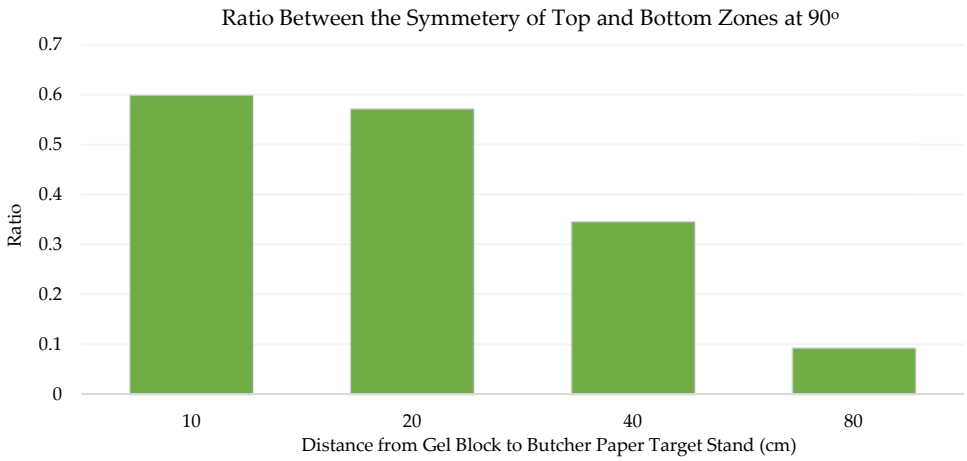


Figure 17. The ratio between the top and bottom zones (1 and 2) from a perpendicular angle to the floor (90°).

Table 3 documents the summary of the ratios at each angle and distance to compare the symmetry of all the data. Figure 18 displays the symmetry ratio at each angle and distance except for 10 cm at 30°, as no information was obtained.

As seen, there is a trend that at each angle, as the distance gets larger, the symmetry ratio gets smaller. Secondly, as the angle gets closer to 0, the ratio between the top and bottom zones increases, with 30° having the most significant ratio difference at each distance. Linear regression analysis was performed at each angle using Microsoft Excel. Table 4 documents the summary of the regression analysis.

All three angles show that there is a strong negative linear relationship. The 90° and 30° statistics have values greater than 0.95, while 60° has a lower coefficient of 0.86. This, however, is a high value for a small sample size, concluding that there is a significant relationship between the symmetry of the perpendicular zones and the angle and distance of the butcher paper from the ballistic gel. The standard estimate error is a low value for 90°; however, at 60° and 30°, the value is high due to the previously stated limitations in the study. Our research goal was to interpret forward-spatter misting patterns to determine if there is a relationship between bloodstain pattern size and symmetry as a function of

distance and orientation. Interpreting the results achieved in this study, we reject the null hypothesis as there is clear significance between the bloodstain pattern size and symmetry as a function of distance and orientation.

Table 3. Ratio difference between top and bottom zone of each bloodstain.

Angle (°)	Distance (cm)			
	10	**20**	**40**	**80**
90°	0.60	0.57	0.35	0.09
60°	0.94	0.42	0.25	0.04
30°	N/A [1]	0.93	0.36	0.0

[1] No data were collected due to equipment interferences between the ballistic gel and paper target.

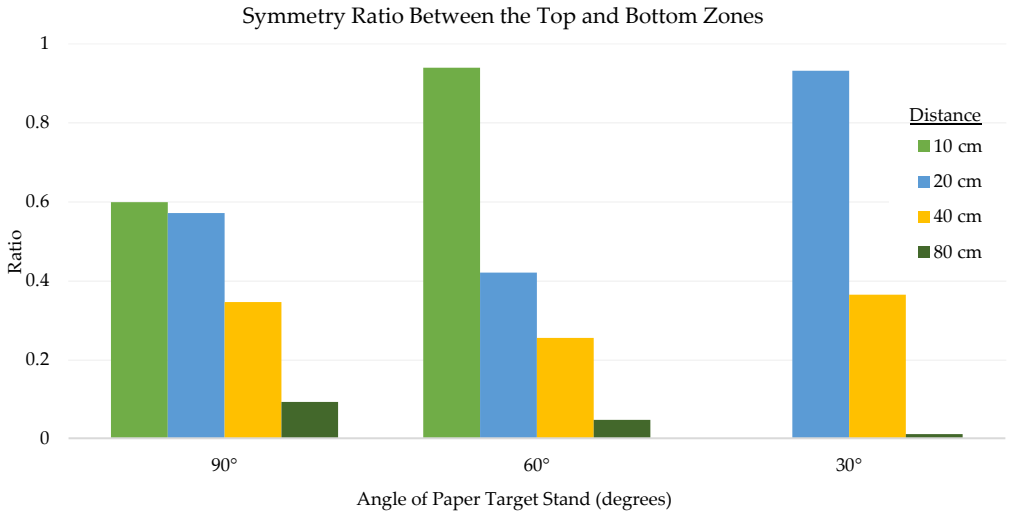


Figure 18. Graph of the ratio between the top and bottom zones at each distance and angle.

Table 4. Linear regression analysis results on the vertical symmetry at each angle.

	Regression Statistics		
	90°	**60°**	**30°**
Multiple R	0.99	0.86	0.95
R Square	0.98	0.74	0.90
Standard Error of Estimate	0.04	19.16	13.42
Observations	4	4	3

4.3. Elliptical Bloodstain Observations

While performing the Photoshop analysis, an observation was made about the angle at which the pattern was deposited onto the paper. It was evident that as the angle decreases, most of the bloodstain pattern was below the bullet entry point; this was evident through the ratios of symmetry. Toward the top of the bloodstain pattern, the overall pattern had a fan shape. This was most evident on the smaller angles. The bloodstains were elliptical, and as the angle got closer to zero and the distance increased, the elliptical tail was longer. This observation implies that the angle of impact affects the elongation of the bloodstain droplet. Although this elongated elliptical stain concept is not new, there is no research discussing any observations of elliptical misting patterns on forward spatter.

The paper target stand was positioned so that the lower part was closer to the gel block stand than the top. Thus, only angles in one direction were tested and changing the target to lean forward, (i.e., paper target stands top closer to the gel block rig), may have produced an inverse effect on what was found in this study.

4.4. Implication of the Findings

We emphasize that research of forward-spatter misting patterns is essential, and they provide implications for the forensic science community by developing an understanding of how forward-spatter misting patterns alter at various orientations. This research establishes a new methodology to test forward-spatter misting patterns. The methodology we developed is considered successful because the bloodstains made using the ballistic gel method were largely reproducible; the same distances and angles yielded similar area size and symmetry. This study established a new assessment to observe misting patterns, in specific, forward-spatter gunshot misting patterns. We intend for this criterion and the ballistic gel and chamber method to be used by bloodstain pattern analysts as a valuable method to assess forward-spatter misting patterns. The Photoshop analysis could be used to calculate distance from the exit wound and possibly orientation.

A better understanding of misting patterns can help the forensic sciences understand how forward spatter changes as a function of the victim's position to a wall or other surface. Our results imply that as the distance increases, the bloodstain pattern density decreases, showing an inverse relationship. This concept is important because knowing the bloodstain pattern's location can provide information on how the victim was positioned at the time of the incident. For instance, if the victim was moved, the bloodstain pattern can provide insight into where the victim was standing or how they may have been oriented. Our research results can provide a guideline to be used by members of the medicolegal system at a crime scene with an unknown misting pattern. A bloodstain pattern analyst can perform the Photoshop analysis on an unknown forward-spatter misting pattern and use the results presented in our data to compare the results and estimate the distance the victim was standing once the firearm was fired. By providing an understanding of how forward spatter is affected by a function of distance and orientation, it can potentially aid in the understanding of the victim's position to the location of the bloodstain pattern. It must be noted that at this point in the research, our results may not yet have a forensic applicational value as our research provides a beginning start on a novel research topic.

4.5. Future Recommendations

The concepts studied in this research need further study as there were serval limitations. Our research presents information on how the distance between ballistic gel blocks and a paper target area by distance and angle. In total, there were only 34 trials. For that reason, the normality test conducted had to be specific toward a small sample, and the standard estimate error is relatively high in Tables 2 and 4. This is most likely a result of the sample size and the nature of bloodstain patterns. When performing a linear regression analysis, the recommended sample size is at least 10; however, each angle tested had an observation number less than 4. Therefore, the smaller sample size increases the standard error estimation. In bloodstain pattern analyses, statistical tests typically produce high error values. This is because many variabilities can affect the overall bloodstain pattern. Our research is exploratory; therefore, many of these variables are still unknown and require future work using a high-speed camera to observe how the misting pattern is deposited. The high-speed camera will be used to observe detail that cannot be seen by the naked eye. Another limitation in the study was the lack of calculations for 10 cm at 30°. This affected the results because it is difficult to interpret how 30° truly affects the symmetry if one of the distances were not obtained. A future recommendation to fix this problem is making the stand to hold the ballistic gel mould smaller on the bottom, so there is more space to move the paper target stand closer to the mould. The last main limitation of this research is the limited variability; because this study was novel, a limited selection of distances and angles were chosen. In the future, more incremented distances should be tested to see how far forward spatter can spread and still be reproducible. Although our research's predominant focus was to focus on forward spatter, further tests should be performed to see if the methodology and Photoshop analysis can be used on back spatter. Lastly, our

research was performed only using a handgun; further research can test other firearms to see how the results differ from our research.

5. Conclusions

A new method and analysis to quantify forward spatter was established. Firing through a ballistic gel mould that contained an internal blood chamber to simulate humans yielded generally reproducible results. The ballistic gel method is thought to be a more controlled method to reproduce misting patterns than the current literature that most commonly uses blood-soaked sponges [10]. Through this process, we tested four distances, 10, 20, 40, and 80 cm, at three angles, 30°, 60°, and 90°, to see how these variables would affect pattern size and symmetry. After conducting multiple linear regression analyses and interpreting multiple graphs, parameters and patterns were found. As the distance and angle increase, the density of the bloodstain pattern size decreases; furthermore, as the distance increases and the angle decreases, the bloodstain pattern's symmetry increases. Thus, concluding that bloodstain pattern area and vertical symmetry are affected by distance and orientation.

Our research provides a beginning start on forward spatter that can be used by other bloodstain pattern analysts for crime scene reconstruction. As a result of this new exploratory research, it is recommended that future research is conducted. It is important to see how forward spatter is affected by smaller increments and use a high-speed camera to observe in finer detail how misting pattern is deposited and how it varied depending on the orientation.

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