Journal of
Forensic Research and Criminal Studies

Research | Open Access

An Experimental Study to Quantify Error Rates Resulting from Measurement Deviation in Area of Origin Reconstructions of Blunt Force Impact Patterns

Mark W. Davison[1]*, Timothy M. Palmbach[2]

[1]University of New Haven, West Haven, CT
[2]University of New Haven, Chair, Forensic Science Dept., West Haven, CT

***Corresponding author:** Mark W. Davison, University of New Haven, West Haven, CT, USA, E-mail: davison169@comcast.net

Received Date: February 22, 2014, **Accepted Date:** April 14, 2014, **Published Date: April 04, 2014**

Citation: Mark W. Davison (2014) An Experimental Study to Quantify Error Rates Resulting from Measurement Deviation in Area of Origin Reconstructions of Blunt Force Impact Patterns. J Forensic Res Crime Stud 1: 1-12

Abstract

The intent of this study was to attempt to quantify error associated with the measurements required in area of origin reconstructions resulting from the analysis of blunt force impact patterns. Mathematical tables were constructed in order to examine trends associated with changing width and length ratios and the influence of impact angle change and area of convergence deviations. The analysis of the trends enabled informed stain selection, mitigating potential error. The analysis of the influence of stain measurement error and gamma angle error was conducted by reconstructing experimentally created blunt force impact patterns using the Tangent Method, comparing the resulting area of origin determinations to reconstructions generated using HemoSpat, a bloodstain pattern analysis software, and then isolating each variable in order to examine its effect on precision and accuracy.

A total of 10 blunt force impact patterns were created and initially analyzed utilizing the Tangent Method. The stains selected for the analysis of each pattern were input into HemoSpat software which generated separate and independent results, enabling a comparison of the absolute and relative error rates between the known area of origin and the two methodologies. This also provided a foundation for the examination of each variable's contribution to absolute and relative error. Finally, artificially induced measurement error was generated by uniformly increasing and decreasing the length, width, and gamma angle values of the selected stains based on an absolute analysis of error. The deviation from the compared values was examined in order to determine if the resulting area of origin determination would adversely affect inferences related to scene analysis. The results indicate that the incorporation of measurement error into a reconstruction creates an error rate that would not substantively affect an area of origin determination or inferences which would typically be rendered based on that determination.

Introduction

Bloodstain pattern analysis is the examination of the size, shape, location, and arrangement of bloodstains in order to determine their manner of deposition, source, sequencing, or area of origin. The classification of a bloodstain or bloodstain pattern enables an analyst, through the application of inductive reasoning, to narrow the range of circumstances or events that potentially contributed to its creation. Further contextual information derived from the crime scene or other factually objective sources contribute to the analyst's ability to then deduce the most probable determination of the events or actions which created the bloodstain or pattern. Experimentation has shown that the blood's behavior in accordance with the laws of physics makes the creation of bloodstain patterns predictable and reproducible. Spatter patterns are predominantly regular shaped stains that are circular or elliptical in shape [1]. Impact stains are classified as bloodstains that are arranged as "a radiating pattern of small individual drops created when a blood source is broken up at a source by some force [1]." Impact patterns are unique in that they allow the analyst to determine, through proper documentation and reconstruction, the approximate location of the area of origin of the pattern. The variable nature of the events which create the pattern and the potential error associated with reconstruction techniques yield a determination of area and not a distinct data point. An area limited to the size of a tennis ball to the size of a soccer ball is typical, and further refinement does not necessarily enhance the probative nature of the result [1]. As an example, the analyst's inference regarding the area of origin of a blood source is often associated with a victim's potential body position, specifically, standing, kneeling, or prone/supine. Based on the spacial variations between these positions, the area result retains value in the scene reconstruction, in assisting the investigator with determining accuracy of testimony, and in answering other questions which may arise. The expansion of an area of origin result that encroaches on this spacial variation may present challenges. As a result, the quantification of error due to measurement is important in the evaluation and to the understanding of area of origin reconstructions.

The determination of the area of origin of an impact pattern begins with a selection of stains that completely represent the area of the pattern. In order to minimize potential error, the selection of stains utilized for analysis should be small, clearly elliptical, oriented in an upward moving direction, contain clearly defined edges, and reside close to the perceived area of convergence. Stains closer to the perceived area of convergence and oriented in an upward moving direction are assumed to retain flight paths closer to straight line trajectory which are not significantly affected by air resistance and gravity [2].

The measurement of the selected stains involves the actual or imagined superimposition of an ellipse surrounding the edges of the stain. The measurements of the minor and major axis of this ellipse constitute the measurements utilized for the impact angle calculation [3]. The leading edge of the impact stain and the sides are generally defined and distinguishable on a surface that is relatively smooth and nonporous; other surfaces present challenges. The trailing edge of the ellipse is typically less defined, especially with stains that impact at acute angles. In field reconstructions, a visual estimation of the termination point of the major axis of the ellipse must be rendered by the analyst. The defined shape of the ellipse is potentially masked in these instances by spines, scalloped edges, or tails which should not be included in the measurement of the major axis. The subsequent estimation of the terminating point becomes a source of subjectivity which potentially results in an inaccurate distance.

In a comparative study using Excel AutoShapes and Collaborative Testing Systems Bloodstain Proficiency Testing results, the measurement of stains with the AutoShape process demonstrated a higher degree of accuracy and returned average impact angles within 2 degrees of the known impact angle, and in 60% of the cases, the impact angles were within 1 degree of the known [3]. It should be noted that these deviations do not necessarily represent error in measurement associated with the computer generated ellipse. The physical aspects of a theoretical spherical blood droplet transitioning to a theoretical ellipse upon impact with a surface are also incorporated in the known and measured differences [4]. Drop dispersion, oscillation, increased surface area due to air resistance, or receiving surface characteristics are contributing factors to the calculated deviations in impact angle. The existence of these physical and contextual factors contributes to the potential negligible effect of the measurements of computer generated ellipses on impact angle deviation. Reliance on computer fitted ellipses as source references for stain measurement is fortified by these results.

The orientation of the stain in the vertical plane is determined by extending the line constituting the major axis of the ellipse and measuring its angle relative to a vertical. This angle is commonly referred to as the gamma angle [2]. On-scene reconstructions utilizing stringing or the Tangent Method require lines drawn or placed from the leading edge of the stain opposite the direction of travel aligned with the major axis of the stain. The perceived or calculated area of convergence of these lines constitutes the approximate position of the blood source in a two dimensional plane.

In the Tangent Method, a calculated area of convergence can be determined by averaging the intersections of the converging lines. The distances of the stains from this averaged point are then measured. The assumed straight line flight path of the drop constitutes the hypotenuse of an imagined right triangle formed by the area of convergence point, the distance of the origin of the stain at a right angle from the vertical surface, and the stain. The distance of the leading edge of the stain from the area of convergence point constitutes the adjacent leg of this triangle, with the impact angle intervening between these two legs. The product of the tangent of the impact angle and the distance of the leading edge of the stain from the area of convergence result in the determination of the distance of the blood source from the vertical plane. The average of these distances defines the magnitude of this value [2].

Computer based software, such as HemoSpat and BackTrack, similarly utilize impact angle and gamma angle calculations as the basis for determining the three dimensional distances constituting the area of origin of a pattern. These angles are used to determine the value of a third angle, beta, which represents the angle formed in the horizontal plane between the area of origin of the blood source and the vertical plane. Lines drawn from points on this axis at the beta angle represent the top view of the flight paths of the droplets constituting the impact pattern. The subsequent averaging of the intersections of these lines represents their area of convergence projected onto the horizontal plane. The average of the heights of the points where lines extended from the stains at the impact angle cross a line perpendicular to the area of convergence point allows for the estimation of the height of the blood source above the horizontal plane [2].

The measurements of the width and length of a stain directly influence the value of the calculated impact angle and subsequently the values which constitute the area of origin in computer generated reconstructions and the distance from the vertical plane in Tangent Method reconstructions. Gamma angle measurement directly influences the values of the components in the vertical plane utilizing the Tangent Method and all three variables utilizing computer generated software. The intent of this study is to attempt to quantify the error associated with stain and gamma angle measurement and to determine the individual and collective effects of the variables on area of origin calculations, results not previously encountered in a review of the literature. Accuracy and precision in measurement are vital to reducing error in impact stain reconstructions. Conversely, quantification of this error and its influence on the final area of origin determination is critical to understanding the limits of analysis. This understanding allows the analyst to make logical inferences, withstand legal challenges, and explain the limits of procedure.

Materials and Methods

The experimentation was conducted in three parts. The first part involved the construction of mathematical tables in order to evaluate the effect of changing independent variables. This was conducted in order to establish an understanding of the interrelationship between changes in width and length measurements and their subsequent effects on impact angles. The second part required the physical creation of impact patterns and the mechanical reconstruction of their areas of origin utilizing the Tangent Method. The third part was accomplished by reconstructing the areas of origin utilizing HemoSpat software and then isolating and incorporating the measured independent variables into HemoSpat in order to analyze and evaluate their effects on area of origin values through the comparison of results.

The impact patterns were created by impacting a blood source with a varnished, wooden spindle. The blood source consisted of room temperature pig's blood with 2% EDTA. A regulation hockey puck was centered at the forward edge of a level platform resting on a concrete surface. The top of the platform measured 30 inches from the floor. A section of white colored Elmer's foam board, measuring 30 inches by 40 inches, was taped to a concrete wall (front wall) with the long axis parallel to the floor and centered on the hockey puck. The plane representing the front wall was designated YZ, with the Y axis vertical and the Z axis horizontal. The plane representing the floor was designated XZ, with the X axis representing the distance from the front wall and the Z axis representing the distance from the left wall. The known area of origin for the experiment, the center of the hockey puck, was represented by the following measurements: X: 24 inches; Y: 31 inches; Z: 42 inches. Twenty four inches was selected as the distance from the wall because at this distance the flight paths of the droplets formed as a result of impact would be minimally inhibited by gravity and air resistance and fairly representative of straight line distances. Further, the majority of the pattern would be captured on the surface area of the receiving surface. Figure 1 depicts a photograph of the initial set up.

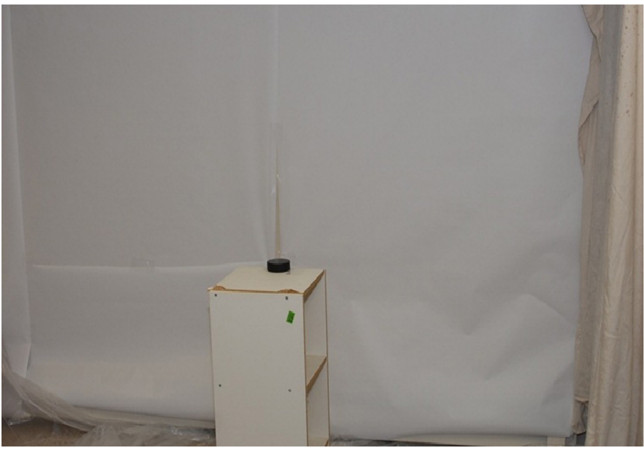


Figure 1 depicts the initial set up

Blood was dispensed from a dropper onto the surface of the hockey puck. The volume of blood per drop was measured at approximately .064 milliliters. Ten drops of blood were deposited onto the center of the hockey puck for each strike. The resulting pool was generally circular and measured approximately one inch in diameter. The impact patterns were created from a single strike to the blood source by the cylindrical portion of the spindle.

The impact patterns were first analyzed using the Tangent Method. The board was divided into 30 degree sectors so stains could be selected in order to uniformly represent the entire pattern. The stains were measured using a 2X loupe with a clear, plastic Westcott ruler graduated in millimeters, and Pittsburgh 6 inch digital caliper which resolved to 1/10 millimeter. Measurements were recorded to the nearest 1/10 millimeter. Ideal stain selection for each pattern yielded three stains per sector, for a total of 18 stains. Due to the dynamic nature of the creation of the impact patterns, this was not achievable for each pattern. The absence of stains in a sector occurred in one pattern, which was represented by 12 selected stains and considered suitable for inclusion in the analysis.

The area of convergence utilized for the Tangent Method calculations was determined by identifying intersecting focal points, which consisted of three or more lines intersecting at a point or in close proximity. Where three or more lines intersected in close proximity, the approximate center of the intersection was used as a measuring point. The locations of the focal points were measured, and the distances from the left and bottom of the board were averaged. The resulting point was plotted back onto the board and labeled as the AOC (area of convergence). The angle of each line relative to the horizontal was measured and recorded. This angle represents the gamma angle, and orients the stain with respect to the impacted vertical surface, the YZ plane. No downward moving stains were analyzed in this portion of the experiment. The calculated values of X for each stain were averaged in order to determine the value of X returned by the analysis. The area of convergence values provided the final Y and Z values. The values representing X, Y, and Z represent the area of origin for the pattern. Figure 2 depicts a close up of the area of convergence intersections, selected focal points, and the plotting of a calculated AOC point. Figure 3 depicts an example of a stain used for analysis.

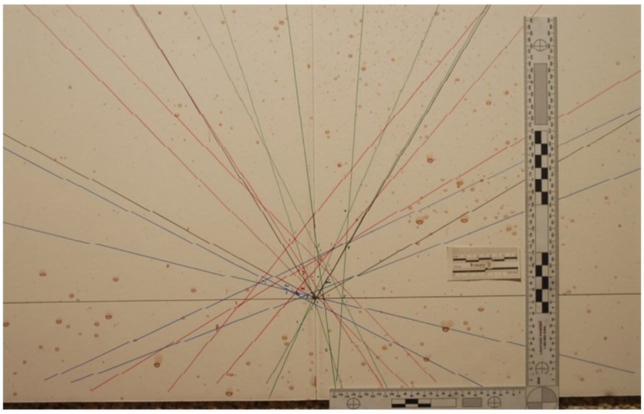


Figure 2 depicts an example of AOC intersections, selected focal points, and the AOC average.

The first project created in HemoSpat was named HemoSpat Area of Origin. The intent of this project was to allow the HemoSpat software to generate an area of origin with minimal user input in order to achieve a nearly mathematical result.

The HemoSpat Area of Origin project consisted of the 10 previously analyzed patterns, labeled Pattern 1 to Pattern 10.

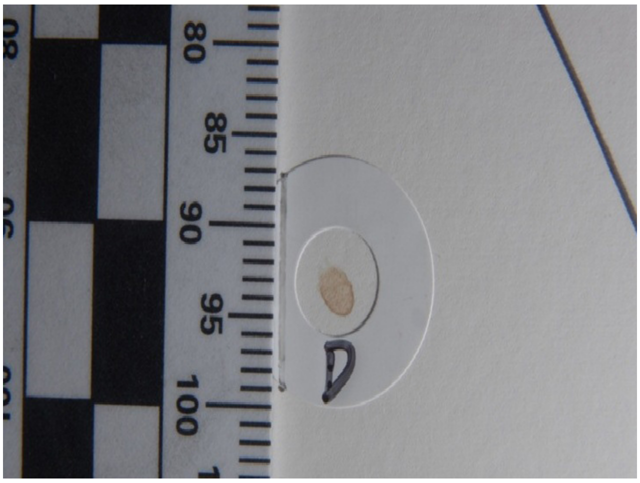
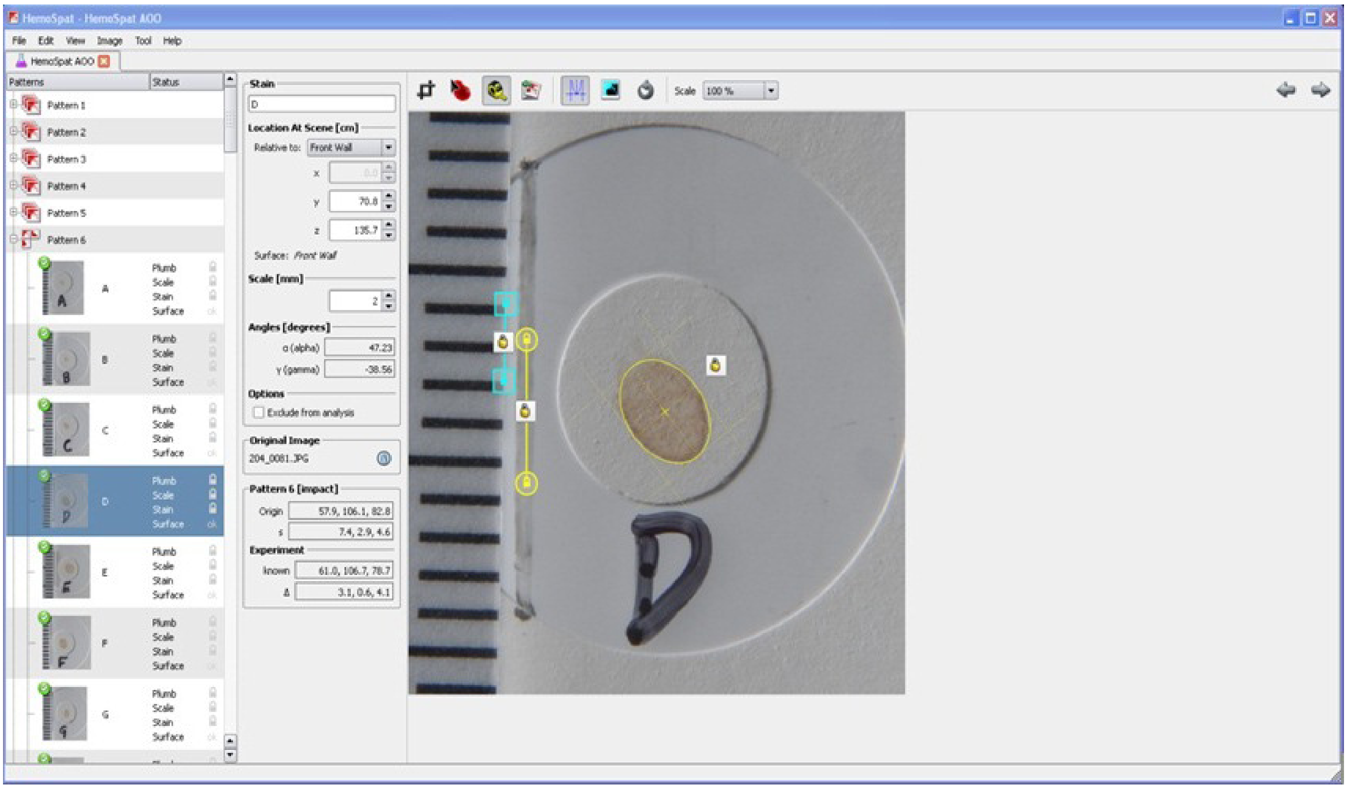


Figure 3 depicts an example of a stain used for analysis.

A photograph of each stain in the pattern was uploaded into the software and into the appropriate pattern. Using the stain selection tool, a computer generated ellipse was placed around the perceived area of the stain by clicking on the stain or an edge of the stain. The ellipses are placed by the program through the detection of the edges of the stain in the image. The shape of the ellipse could be changed by extending or contracting either end of the major and minor axes. Additionally, both ends of either axis could be contracted or extended simultaneously. The orientation of the ellipse in its plane could also be manipulated by maneuvering another graphic user interface point. In total, 164 stains were utilized during this portion of the experiment. Of these, 39, or 23.8% required some minor user input in order to properly fit the ellipse around the stain. The majority of these instances resulted from stains that had edges which were scalloped or poorly defined, edges that contrasted poorly with the light colored background, or stains which contained different tones of color. A poorly focused photograph contributed to two of these adjustments. Thirty six stains, representing 21.9%, required total fit by the user. These almost exclusively were derived from poor contrast, inhibiting the computer's ability to detect the stain's edges. Eighty nine stains, representing 54.3%, required no user input in order to fit the stain. The input allows the software to calculate the impact angle (alpha angle), the gamma angle, and the beta angle, which enables the determination of the values of the X, Y, and Z axes and subsequently, the area of origin for the pattern. The comparison of these results against the known area of origin and the Tangent Method results provides a comparison between the methods related to accuracy and precision, respectively. Figure 4 depicts an example of an analyzed stain in HemoSpat.

The HemoSpat generated results were the product of impact angles calculated from width and length measurements rounded to the nearest 1/100 millimeter, a degree of precision not compatible with field acquired measurements. It was realized that in order to evaluate the effect of measurement error on area of origin calculations, the HemoSpat results would have to be scaled to the precisional limits of field measurements, or 1/10 millimeter. The HemoSpat Area of Origin project was copied and renamed HemoSpat Scaled. Impact angles were calculated using the HemoSpat Area of Origin stains rounded to the nearest 1/10 millimeter. The gamma



Stain: D

Location At Scene [cm]

Relative to: Front Wall

x: 0.0

y: 70.8

z: 135.7

Surface: Front Wall

Scale [mm]: 2

Angles [degrees]

α (alpha): 47.23

γ (gamma): -38.56

Options

☐ Exclude from analysis

Original Image: 204_0081.JPG

Pattern 6 [impact]

Origin: 57.9, 106.1, 82.8

s: 7.4, 2.9, 4.6

Experiment

known: 61.0, 106.7, 78.7

Δ: 3.1, 0.6, 4.1

Figure 4 depicts an example of the same stain, analyzed in HemoSpat.

Method	Impact Pattern	X Value (In)	Y Value (In)	Z Value (In)	Method	Impact Pattern	X Value (In)	Y Value (In)	Z Value (In)
Tangent	1	20.52	31.79	41.17	Tangent	6	23.92	31.97	42.53
HemoSpat	1	23.23	32.4	41.85	HemoSpat	6	22.8	32.6	41.77
HemoSpat Scaled	1	23.19	32.09	41.69	HemoSpat Scaled	6	23.46	32.28	41.61
HemoSpat w. Measured Stains	1	19.84	32.09	41.65	HemoSpat w. Measured Stains	6	23.03	32.72	41.5
Tangent w. HemoSpat Stains	1	23.89	31.79	41.17	Tangent w. HemoSpat Stains	6	23.22	31.97	42.53
Tangent w. HemoSpat Scaled Stains	1	23.84	31.79	41.17	Tangent w. HemoSpat Scaled Stains	6	23.82	31.97	42.53
HemoSpat w. Measured Gamma	1	23.78	31.77	41.65	HemoSpat w. Measured Gamma	6	22.91	32.28	41.77
HemoSpat w. Meas Stains, Gamma	1	20.28	31.61	41.46	HemoSpat w. Meas Stains, Gamma	6	23.15	32.4	41.5
Tangent	2	18.29	31.29	41.84	Tangent	7	21.85	31.72	41.34
HemoSpat	2	21.81	32.48	41.38	HemoSpat	7	21.93	31.5	41.02
HemoSpat Scaled	2	21.97	32.24	41.26	HemoSpat Scaled	7	21.69	31.73	41.06
HemoSpat w. Measured Stains	2	16.93	33.23	41.61	HemoSpat w. Measured Stains	7	21.46	31.26	41.38
Tangent w. HemoSpat Stains	2	22.62	31.29	41.84	Tangent w. HemoSpat Stains	7	22.07	31.72	41.34
Tangent w. HemoSpat Scaled Stains	2	22.78	31.29	41.84	Tangent w. HemoSpat Scaled Stains	7	21.88	31.72	41.34
HemoSpat w. Measured Gamma	2	22.76	31.06	41.38	HemoSpat w. Measured Gamma	7	22.6	30.94	41.1
HemoSpat w. Meas Stains, Gamma	2	17.72	31.69	41.57	HemoSpat w. Meas Stains, Gamma	7	22.09	30.67	41.42
Tangent	3	23.2	31.6	41.92	Tangent	8	24.38	32.02	41.74
HemoSpat	3	21.26	32.72	42.05	HemoSpat	8	23.66	32.83	40.75
HemoSpat Scaled	3	21.1	32.76	41.93	HemoSpat Scaled	8	23.82	32.8	40.87
HemoSpat w. Measured Stains	3	22.6	32.52	42.32	HemoSpat w. Measured Stains	8	23.74	32.72	41.46
Tangent w. HemoSpat Stains	3	22.02	31.6	41.92	Tangent w. HemoSpat Stains	8	24.55	32.02	41.74
Tangent w. HemoSpat Scaled Stains	3	21.89	31.6	41.92	Tangent w. HemoSpat Scaled Stains	8	24.67	32.02	41.74
HemoSpat w. Measured Gamma	3	22.05	31.73	42.13	HemoSpat w. Measured Gamma	8	25.28	31.26	40.94
HemoSpat w. Meas Stains, Gamma	3	23.43	31.57	42.44	HemoSpat w. Meas Stains, Gamma	8	25.31	31.1	41.61
Tangent	4	22.67	31.9	42.67	Tangent	9	23.09	31.98	42.2
HemoSpat	4	21.46	31.81	42.28	HemoSpat	9	22.36	32.36	41.46
HemoSpat Scaled	4	20.71	32.09	42.09	HemoSpat Scaled	9	22.68	32.48	41.54
HemoSpat w. Measured Stains	4	22.09	31.93	41.38	HemoSpat w. Measured Stains	9	22.95	32.24	42.17
Tangent w. HemoSpat Stains	4	21.51	31.9	42.67	Tangent w. HemoSpat Stains	9	22.52	31.98	42.2
Tangent w. HemoSpat Scaled Stains	4	20.88	31.9	42.67	Tangent w. HemoSpat Scaled Stains	9	22.91	31.98	42.2
HemoSpat w. Measured Gamma	4	21.65	31.5	42.48	HemoSpat w. Measured Gamma	9	23.03	31.81	42.13
HemoSpat w. Meas Stains, Gamma	4	21.85	31.93	41.57	HemoSpat w. Meas Stains, Gamma	9	23.66	31.65	42.76
Tangent	5	23.4	31.73	42.25	Tangent	10	24.71	30.81	42.74
HemoSpat	5	22.48	32.99	41.89	HemoSpat	10	22.91	31.26	41.69
HemoSpat Scaled	5	22.52	33.11	41.89	HemoSpat Scaled	10	24.29	30.79	41.5
HemoSpat w. Measured Stains	5	22.6	32.6	42.83	HemoSpat w. Measured Stains	10	25.12	30.55	41.18
Tangent w. HemoSpat Stains	5	23.29	31.73	42.25	Tangent w. HemoSpat Stains	10	23.09	30.81	42.74
Tangent w. HemoSpat Scaled Stains	5	23.52	31.73	42.25	Tangent w. HemoSpat Scaled Stains	10	24.04	30.81	42.74
HemoSpat w. Measured Gamma	5	23.03	32.24	42.13	HemoSpat w. Measured Gamma	10	23.46	30.71	42.64
HemoSpat w. Meas Stains, Gamma	5	23.43	31.73	43.07	HemoSpat w. Meas Stains, Gamma	10	25.35	30.31	42.2

Table 1 displays the results of each method for the ten impact patterns

angles did not change. The areas of origin results generated by the HemoSpat Scaled project were used as the basis for stain measurement error and total measurement error.

The HemoSpat Scaled project was copied and renamed HemoSpat with Measured Stains. The results of this iteration represented the area of origin generated by the HemoSpat methodology utilizing physically measured stains. The comparison of these results with the HemoSpat Scaled results is representative of the effect of measurement error generated by visual ellipse estimation and measurement compared to mathematically created ellipses and computer measurement.

The HemoSpat project was copied and renamed HemoSpat with Measured Gamma. The measured gamma angles from the Tangent Method analysis were incorporated into the HemoSpat analysis. The results of this iteration represented the area of origin generated by the HemoSpat methodology utilizing physically measured gamma angles. The comparison of these results with the HemoSpat area of origin results is representative of the effect of measurement error generated by visual gamma angle estimation compared to mathematically measured gamma angles.

The HemoSpat Scaled project was copied and renamed HemoSpat with Measured Stains, Gamma Angle. The calculated impact angles and measured gamma angles from the Tangent Method analysis were incorporated into the HemoSpat analysis. The results of this iteration represented the area of origin generated by the HemoSpat methodology utilizing physically measured stains and gamma angles. The combination of the input of the measured stains and the measured gamma angles compared to the HemoSpat Scaled results is representative of the total measurement error related to the physical analysis of an impact pattern. The area of origin results from each method for the ten impact patterns are displayed in Table 1.

Results and Discussion

An examination of the mathematical results provided valuable information pertinent to stain selection and established an understanding of the implications of potential measurement error on impact angle calculations, both beneficial additions to the impact pattern analysis framework for the crime scene investigator to utilize during practical application. The initial mathematical analysis examined the asymptotic curves represented by plotting the ratios of constant width and incremental length increase (impact angle) against length and the ratios of incremental width decrease and constant length (impact angle) against width. Figure 5 and Figure 6 depict graphs of these curves. At points representing approximately 48 and 61 degrees, the differences between the changes in impact angles became essentially constant. This analysis suggests that stains with length and width ratios that produce obtuse impact angles, between 90 and approximately 48-61 degrees, should be avoided or treated sensitively in analysis because of the potential for increased impact angle error. The data also indicates that in stains producing obtuse impact angles, error in the length measurement produces a more significant error: the initial 2/10 millimeter of width changes accounted for 36.9 degrees while the same length changes accounted for 44.4 degrees.

The information derived from the mathematical analysis was applied during the examination and selection of the impact stains utilized for the reconstructions. A review of the initial reconstruction results created several interesting observations. Particular focus was placed on the X value results, as this variable is the only variable affected by width and length measurements in the Tangent Method. The accuracy of the results produced by both the Tangent Method and HemoSpat were within limits endorsed by the literature. The 10 patterns created in this study were represented by 164 selected stains. Based on the consistency of the results generated by this sample, the analysis of additional patterns was not necessary.

The average absolute difference between the known area of origin and the results for the Tangent Method for variables X, Y, and Z were 1.62, .72, and .44 inches, respectively. These values produced deviations of 6.73% in X, 2.32% in Y, and 1.04% in Z. The HemoSpat results yielded average absolute differences of 1.61, 1.3, and .45 inches. These values produced absolute deviations of 6.71% in X, 4.18% in Y, and 1.08% in Z.

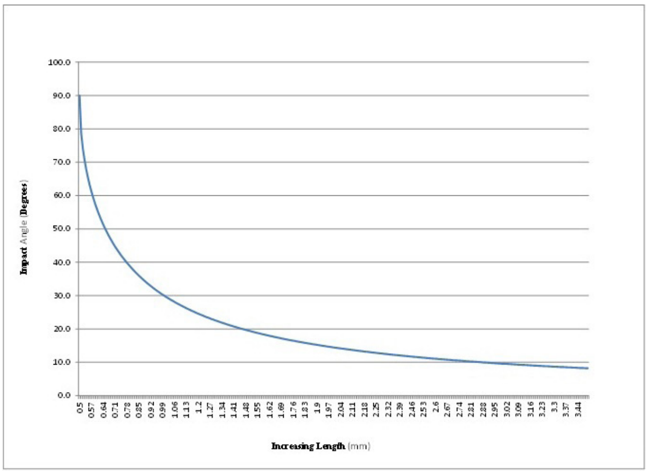


Figure 5 depicts a graph of Impact Angle and Increasing Length with constant Width

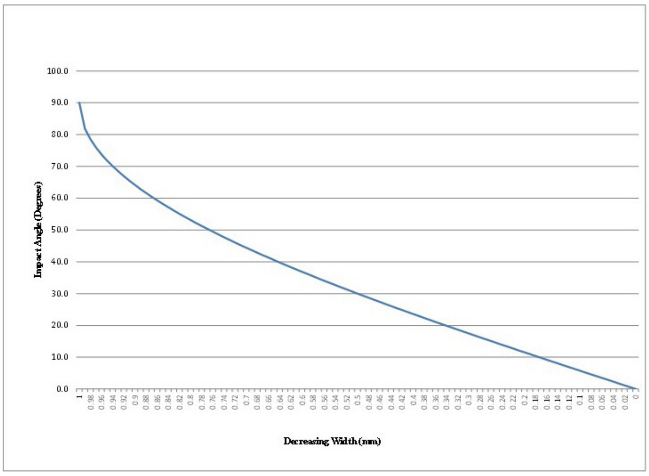


Figure 6 depicts a graph of Impact Angle and Decreasing Width with constant Length

In an unexpected result, the Tangent Method produced more accurate results in 50% of the reconstructions for the X variable, and similar results for the Y and Z variables; it was expected that the Tangent Method would produce results that were less accurate, based on the comparative measurement accuracy demonstrated by the computer generated results reviewed in the literature. Similar results also occurred when the HemoSpat stains were scaled from 1/100 millimeter to 1/10 millimeter. The HemoSpat Scaled average absolute differences were 1.52, 1.28, and .47 inches. These values produced absolute deviations of 6.31% in X, 4.13% in Y, and 1.13% in Z.

The initial evaluation of the absolute results appears to indicate that measurement error was negligible or imparted a minimal influence on results. Subsequent analysis revealed that although the differences between the averages of the X value results in the Tangent Method and HemoSpat were

Std Deviations: Methods		X Value (In)	Y Value (In)	Z Value (In)
Tangent		1.85	0.36	0.51
HemoSpat		0.74	0.55	0.44
HemoSpat Scaled		1.12	0.62	0.37
HemoSpat w. Measured Stains		2.15	0.75	0.49
HemoSpat w. Measured Gamma		0.95	0.51	0.54
HemoSpat w. Meas Stains, Gamma		2.18	0.58	0.58

Std Deviations: Manipulated measurements		X Value (In)	Y Value (In)	Z Value (In)
Width + .12mm		2.27	0.36	0.51
Width -.12mm		1.74	0.36	0.51
Length +.14mm		1.64	0.36	0.51
Length -.14mm		2.57	0.36	0.51
Width+ Length-		3.52	0.36	0.51
Width- Length+		2.08	0.36	0.51
Gamma +2.5		0.74	0.46	0.47
Gamma -2.5		1.36	1.22	0.41

Pattern	# of Stains	Net Sum: Width Differences(mm) (Measured Stains-HSS Stains)	Net Sum: Length Differences(mm) (Measured Stains-HSS Stains)	Absolute Avg: Width Differences(mm) (Measured Stains-HSS Stains)	Absolute Avg: Length Differences (mm)(Measured Stains-HSS Stains)	Std Dev Width (mm)	Std Dev Length (mm)
Impact Pattern 1	17	-1.2	0.1	0.12	0.12	0.14	0.14
Impact Pattern 2	17	-1.4	1.5	0.12	0.12	0.13	0.17
Impact Pattern 3	16	-1.6	-3.2	0.13	0.13	0.11	0.15
Impact Pattern 4	17	-1.3	-2.9	0.12	0.12	0.12	0.14
Impact Pattern 5	19	-0.7	-0.5	0.11	0.11	0.20	0.22
Impact Pattern 6	16	-1.1	-1.5	0.13	0.13	0.10	0.11
Impact Pattern 7	19	-1.3	-1.7	0.11	0.11	0.11	0.19
Impact Pattern 8	16	-0.1	0.4	0.13	0.13	0.12	0.18
Impact Pattern 9	14	-0.3	-0.3	0.14	0.15	0.11	0.17
Impact Pattern 10	12	-0.5	-0.9	0.17	0.18	0.14	0.15

		Avg Net Width Diff.	Avg Net Length Diff.	Avg Absolute Width Diff.	Avg Absolute Length Diff.	Std Dev Width - All	Std Dev Width - All
All Patterns	163	-0.06	-0.06	0.12	0.14	0.13	0.19

Table 2 displays the standard deviations for each methodology, the comparative differences between the Measured Stains and HemoSpat Scaled stains for each pattern, and standard deviations for width and length within 1/100 inch, the range of the HemoSpat and HemoSpat Scaled X values resulted in a narrower range of absolute deviations, an indication of greater precision within the methodology. The absolute differences in the X values produced by the Tangent Method ranged from .08 to 5.71 inches; HemoSpat ranged from .34 to 2.74 inches, while HemoSpat Scaled ranged from .18 to 3.29 inches. The standard deviations of the X values for each method provide another data point regarding precision. The standard deviation for the X values produced by the Tangent Method was 1.85 inches as compared to 1.12 inches for HemoSpat Scaled and .74 inches for HemoSpat. The values for the standard deviations for each method are displayed in Table 2. Because the valuation calculations in both methods are based on mathematics, deviations in precision are subsequently related to input values resulting from the measurements of stain size and orientation. Further, the average relative differences between the Tangent Method X, Y, and Z values and the HemoSpat values were 1.47, .68, and .59 inches, respectively. A relative comparison of the Tangent Method and HemoSpat Scaled results produced differences of 1.33, .56, and .6 inches. The existence of these differences juxtaposed with the minimal absolute differences reveal that input into the respective methodologies results in more significant changes.

The Tangent Method, HemoSpat, HemoSpat Scaled results, and their initial evaluation established the foundation for the generation of additional data and analysis. Since the methodology utilized to calculate each area of origin variable differs between the Tangent Method and HemoSpat, the measured stains were incorporated into HemoSpat and compared against the HemoSpat Scaled results in order to examine the effect of width and length differences while maintaining other variables. The average relative difference between the HemoSpat Scaled results and HemoSpat with Measured Stains for the X, Y, and Z variables was 1.32, .34, and .44 inches, respectively. These values represent the net effect of stain measurement error utilizing the HemoSpat methodology and produced deviations of 5.94% in X, 1.04% in Y, and 1.06% in Z. The values represented by these deviations would not affect an area of origin interpretation or inferences related to scene analysis.

The measured gamma angles were incorporated into the HemoSpat analysis and compared against the original HemoSpat results in order to examine the effect of gamma angle error while maintaining the other variables. The average relative difference between the HemoSpat results and HemoSpat with Measured Gamma for the X, Y, and Z variables was .67, .76, and .26 inches, respectively. These values represent the net effect of gamma angle measurement error utilizing the HemoSpat methodology and represent deviations of 2.96% in X, 2.36% in Y, and .63% in Z. These results would not affect an area of origin interpretation or inferences related to scene analysis. The differences in the X values resulting from gamma angle error are 45 to 50% less than the differences in X values resulting from measurement error.

The measured stains and the measured gamma angles were incorporated into the HemoSpat analysis and compared against the original HemoSpat results in order to examine the total net effect of measurement error utilizing a consistent methodology. The average relative difference between the HemoSpat results and HemoSpat with Measured Stains, Gamma Angle for the X, Y, and Z variables was 1.58, .8, and .59 inches, respectively. These values represent the net combined effect of measurement error and gamma angle error utilizing the HemoSpat methodology and represent deviations of 7.06% in X, 2.45% in Y, and 1.41% in Z. The values represented by these deviations would not affect an area of origin interpretation or inferences related to scene analysis.

The absolute results representing measurement error revealed that measurement deviations did not consistently have a deleterious effect on accuracy, a counterintuitive result. However, since two measurements are involved in the determination of the impact angle of the stain, and each measurement has three possible outcomes, nine possible combinations exist which result in the final measurement value of the stain. A measurement can be equal to the true value, or it can be overestimated or underestimated. Eight of these combinations involve a degree of error; one results in the true measurement value of the stain. The application of these combinations is not necessarily uniform, consistent, or predictable. The result of the combination of the magnitude and direction of the measurement errors determine the final magnitude and direction of the result. With direction taken into account, as in straight averaging, equal error in opposite directions will indicate no deviation from the source value, which is an inaccurate result when attempting to determine the existence and effect of the magnitude of the deviation. In order to examine the error generated by measurement in this study, it was necessary to compare the absolute values of the differences in the measurement of each stain. The absolute differences in the width and length of each measured stain and each HemoSpat Scaled stain were compared in order to determine the total measurement error associated with stain measurement. The totals of these values and their averages provided the average absolute error for each measured component. In order to examine the effect of this average error, it was applied in each of the eight possible error combinations utilizing the Tangent Method spreadsheet.

The decision to use the Tangent Method for this analysis was based on an evaluation of HemoSpat and HemoSpat Scaled stains utilized in the Tangent Methodology versus the HemoSpat and HemoSpat Scaled results compared to HemoSpat results with Measured Stains. The whole number changes and percentage changes in the values of X were congruous with the changes of the value of X in the HemoSpat Scaled and HemoSpat with Measured Stains comparison. As a result of the precision of these results, the Tangent Method was used to examine the effect of artificially induced measurement error.

A total of 163 stains were used for the analysis of the differences between the measured stains and the HemoSpat Scaled stains. The results are summarized in Table 2. The averages of the absolute totals are representative of the average measurement error associated with these stains. The average absolute width difference was .12 millimeters and the average absolute length difference was .14 millimeters. The standard deviations of the width measurements and the length measurements for all stains were .13 millimeters and .19 millimeters, respectively. The average impact angle difference was 4.4 degrees. It was hypothesized that the length measurement would retain a larger difference based on the potential for complexity associated with the interpretation of the tail end of the major axis of the ellipse. Width error, while expected, was larger than anticipated.

The analysis of error utilizing the average absolute differences produced several interesting statistics. The uniform increase and decrease of width while holding length constant created similar impact angle changes, but in different directions. The larger average impact angle created a greater average change in X value than the smaller impact angle. As the math tables predict, larger impact angles will have a greater effect on the error associated with derived values. A similar circumstance occurred when the length measurement was uniformly modified and the width held constant. The uniform increase of both length and width expectedly created only minor changes in the values of X; a similar result occurred when the length and width were uniformly decreased. This was anticipated because the magnitude of the changes was relatively proportional and applied in the same direction, resulting in impact angle differences that were between .63 and .71 degrees.

The application of width and length changes in opposite directions produced significant changes to the impact angle calculations. The average impact angle increase from the width addition and the length subtraction was 9.39 degrees, which represented an 11.82 inch average increase in the value of X, a 52.84% deviation from the Tangent Method values. The average impact angle decrease from the width subtraction and the length addition was 7.48 degrees, which represented a 5.03 inch average increase in the value of X, a 16.11% deviation from the Tangent Method values. The greater error is experienced by the increase in impact angle.

The largest difference in the value of X between the HemoSpat Scaled results and HemoSpat with Measured Stains was 5.04 inches. An examination of these measurement differences showed a total average decrease in width of .08 millimeters and a total average increase in length of .09 millimeters. As the previous analysis indicates, and the actual results illustrate, the application of measurement error in this manner represents the lesser of the two scenarios which produce the greatest error. The net negative width and net positive length errors also occurred in Patterns 1 and 8. The net length increase in Pattern 1 was .02 millimeters, and the effect was minimized. The net width decrease in Pattern 8 was negligible. A scenario did not occur where the net width and length changes created a larger impact angle. Out of the 20 net averages analyzed, 17 resulted in the underestimation of length or width; all three of the overestimations occurred in length measurements. These statistics are referenced only in terms of supplying a data point, as further study is required to determine if underestimation in measurement is a predictable result.

The results analysis representative of gamma angle measurement error replicated the accuracy circumstance experienced with stain measurement analysis: gamma measurement changes did not consistently have a negative effect on accuracy. Gamma angle estimations have only three possible outcomes: true value, overestimation, or underestimation. The application of these combinations is similarly not uniform, consistent, or predictable, and the comparison of absolute results, without direction and magnitude taken into account, inhibit proper analysis. In order to examine the error generated by gamma measurement in this study, it was necessary to compare the absolute values of the differences in the gamma angles for each stain. The absolute differences in the measured gamma angles and the HemoSpat gamma angle were compared in order to determine the total measurement error associated with gamma angle measurement. The subsequent totals of these values and their averages are representative of the average absolute error for the gamma angle component. In order to examine the effect of this average error, it was applied in each of the two possible error combinations utilizing the original HemoSpat analysis.

All 164 stains were utilized in this analysis. The average gamma angle difference was 2.5 degrees. The uniform increase and decrease of gamma angles compared to the HemoSpat results created similar changes in all three variables; each variable is affected by change in HemoSpat. The differences were slightly higher in the uniform gamma angle decrease, the largest represented by a .08 inch difference in the Y value. The Z value experienced the least amount of change, a .02 inch difference. The X values experienced average changes of 1.58 inches with the gamma angle increase and 1.63 inches with the decrease. The average Y values were similarly affected: 1.6 inches with the increase and 1.68 inches with the decrease. The values represented by these deviations would not affect an area of origin interpretation or inferences related to scene analysis. The increases in differences and percent deviations with uniform gamma angle changes from the original HemoSpat values were expected results. Further study is required to examine the effect of gamma angle deviations on the Y and Z values utilizing the Tangent Method for comparison to the HemoSpat results and to determine the interrelationship between the angles and X, Y and Z values in the HemoSpat methodology. The comparative results described in this section are summarized in Table 3.

Conclusion

The intent of this research was to attempt to quantify the effects of measurement error on the reconstruction of impact patterns. Prior to the reconstructions, it was determined that the measurement variables influencing the overall results were the stain width and length measurements and the estimation of their orientation, or gamma angle, in the vertical plane. A mathematical analysis was conducted in order to analyze the effects of width and length changes on impact angle and the effect of impact angle changes on the calculated value of X, the distance from the impacted surface. The analyst's ability to minimize error subsequently created by measurement relies on the selection of stains with ratios under 48 – 61 degrees and close to the perceived area of convergence. Stains with greater impact angles should either be avoided or treated sensitively with a focus on the potential for increased error.

Ten impact patterns were created under similar conditions with a known area of origin, and the patterns were initially reconstructed utilizing the Tangent Method, a functional

HemoSpat, Tangent, Origin	**X Value (In)**	**Y Value (In)**	**Z Value (In)**
Avg X,Y,Z Relative Difference	1.47	0.68	0.59
Avg HemoSpat Absolute Difference	1.61	1.3	0.45
Avg Tangent Absolute Difference	1.62	0.72	0.44
Avg HemoSpat % Absolute Deviation	6.71	4.18	1.08
Avg Tangent % Absolute Deviation	6.73	2.32	1.04
HemoSpat Scaled, Tangent, Origin	**X Value (In)**	**Y Value (In)**	**Z Value (In)**
Avg X,Y,Z Relative Difference	1.33	0.56	0.6
Avg HemoSpat Absolute Difference	1.52	1.28	0.47
Avg Tangent Absolute Difference	1.62	0.72	0.44
Avg HemoSpat % Absolute Deviation	6.31	4.13	1.13
Avg Tangent % Absolute Deviation	6.73	2.32	1.04
% Relative Deviation	6.01	1.71	1.45
HemoSpat Scaled, HemoSpat w. Measured Stains	**X Value (In)**	**Y Value (In)**	**Z Value (In)**
Avg X,Y,Z Relative Difference	1.32	0.34	0.44
Avg % Relative Deviation	5.94	1.04	1.06
HemoSpat, HemoSpat w. Measured Gamma	**X Value (In)**	**Y Value (In)**	**Z Value (In)**
Avg X,Y,Z Relative Difference	0.67	0.76	0.26
Avg % Relative Deviation	2.96	2.36	0.63
HemoSpat Scaled, HemoSpat w. Measured Stains, Gamma	**X Value (In)**	**Y Value (In)**	**Z Value (In)**
Avg X,Y,Z Relative Difference	1.58	0.8	0.59
Avg % Relative Deviation	7.06	2.45	1.41
HemoSpat, Gamma +2.5	**X Value (In)**	**Y Value (In)**	**Z Value (In)**
Avg X,Y,Z Relative Difference	1.58	1.6	0.07
Avg % Relative Deviation	7.04	4.97	0.17
HemoSpat, Gamma -2.5	**X Value (In)**	**Y Value (In)**	**Z Value (In)**
Avg X,Y,Z Relative Difference	1.63	1.68	0.09
Avg % Relative Deviation	7.25	5.24	0.22
Avg X Value Difference (In) Increased Width (+.12mm) vs. Tangent	**4.64**	**Avg X Value Difference (In) Decreased Width (-.12mm) vs. Tangent**	**3.31**
Avg % Relative Deviation	20.59	Avg % Relative Deviation	14.71
Avg Impact Angle Difference	4.82	Avg Impact Angle Difference	4.45
Avg Impact Angle % Deviation	10.4	Avg Impact Angle % Deviation	9.62
Avg X Value Difference (In) Increased Length (+.14mm) vs. Tangent	**2.75**	**Avg X Value Difference (In) Decreased Length (+.14mm) vs. Tangent**	**4.47**

Avg % Relative Deviation	12.15	Avg % Relative Deviation	19.73
Avg Impact Angle Difference	3.58	Avg Impact Angle Difference	4.44
Avg Impact Angle % Deviation	7.7	Avg Impact Angle % Deviation	9.55
Avg X Value Difference (In) Width (+), Length (+)	**0.46**	**Avg X Value Difference (In) Width (+), Length (+)**	**0.51**
Avg % Relative Deviation	2.1	Avg % Relative Deviation	2.31
Avg Impact Angle Difference	0.63	Avg Impact Angle Difference	0.71
Avg Impact Angle % Deviation	1.39	Avg Impact Angle % Deviation	1.58
Avg X Value Difference (In) Width (+), Length (-)	**11.82**	**Avg X Value Difference (In) Width (-), Length (+)**	**5.03**
Avg % Relative Deviation	52.84	Avg % Relative Deviation	22.39
Avg Impact Angle Difference	9.39	Avg Impact Angle Difference	7.48
Avg Impact Angle % Deviation	20.42	Avg Impact Angle % Deviation	16.11

Table 3 displays the Relative and Absolute Differences between the different methodologies

methodology for on-scene reconstruction. Similar accuracy results were obtained from the Tangent Method reconstructions and the HemoSpat reconstructions. Further analysis indicated that the accuracy ranges varied and that the existence of relative differences between the methodologies was a function of input. The measured stains utilized in the Tangent Method analysis were incorporated into the HemoSpat analysis while maintaining the gamma angles utilized in the initial reconstruction. The average results, indicative of the error created by stain measurement caused a 5.94% deviation in the X value, a 1.04% deviation on the Y value, and a 1.06% deviation in the Z value. These percentages represented distances of 1.32, .34, and .44 inches, respectively. The values represented by these distances would not alter the typical interpretation of the location of a blood source.

An analysis of the differences in the measurements of 163 stains determined that the average error created by measurement was .12 millimeters in width and .14 millimeters in length. These averages represented a 4.4 degree change in impact angle. It was expected that the error in length would emerge as the greater value, due to the interpretation challenges presented by the long axis of impact stains. Due to the relatively defined edges of the minor axis of impact stains, it was anticipated that the width measurements would retain a higher degree of accuracy than the results indicate. Further study is required in order to evaluate the consistency of these differences. The directions of the average errors were manipulated in order to evaluate the effects of error magnitude and direction. The worst case scenarios involved error magnitude applied in different directions. The most egregious scenario, width overestimation and length underestimation, produced results which created a 52.82% deviation in the value of X. This deviation represented an average 11.82 inch difference from the compared value and an average change in impact angle of 9.39 degrees. It is possible that an analyst's inferences could be altered based on this degree of error depending on scene context and the questions the analyst is attempting to answer. During this study, there were no occurrences of magnitude and direction error applied in this manner. The alternate negative scenario involved width underestimation and length overestimation. This scenario produced results which created a 22.39% deviation in the value of X. This deviation represented an average 5.03 inch difference from the compared value and an average change in impact angle of 7.48 degrees. It is unlikely that class characteristic type inferences, such as the differences between a standing, kneeling, or prone position absent other contextual factors, would be misinterpreted during analysis as a result of this degree of error. During this study, there was one occurrence of error applied in this direction.

The incorporation of measured gamma angles into HemoSpat and the subsequent comparison yielded an analysis of the net effect of gamma angle error. The averaged results, indicative of the error created by gamma angle measurement caused a 2.96% deviation in the X value, a 2.36% deviation on the Y value, and a .63% deviation in the Z value. These percentages represented distances of .67, .76, and .26 inches, respectively. The values represented by these distances would not alter the interpretation of the location of a blood source. Gamma angle error was approximately 50% of the error created by stain measurement. The net combined effect of measurement error and gamma angle error utilizing the HemoSpat methodology represented deviations of 7.06% in X, 2.45% in Y, and 1.41% in Z. These percentages represented distances of 1.58, .8, and .59 inches, respectively. The values represented by these deviations would not affect an area of origin interpretation or inferences related to scene analysis.An analysis of the differences in the gamma angle measurements of all 164 stains determined that the average error created by measurement was 2.5 degrees. The manipulation of the gamma angle in positive and negative directions produced similar results, with the largest relative difference represented by .08 inches. The values represented by these results, with 1.68 inches representing the largest, would not affect an area of origin interpretation or inferences related to scene analysis.

The quantification and examination of measurement error in this research contains limitations. First, the measured stains and gamma angles are the result of a relatively experienced analyst's measurements and interpretations. While this is a valid calibration for the analyst, further study is required in order to determine if the magnitude and direction of the error in this study presents a consistent outcome. Subsequent measurements of the stains by other analysts of varied experiences would validate the existing measurement results and potentially supply trends regarding over or underestimation. Secondly, the error rate for the X value in the Tangent Method, in addition to the stain's measurement, is a function of the distance of the stain from the area of convergence. The average in this study was approximately 21.3 inches. Areas of convergence with distances that differ from this average would experience a different error rate, predictable by an examination of the mathematical tables. Finally, although the majority of any physical manipulation of measurements of the stains in HemoSpat by the analyst was minimal, 36 stains required complete adjustments. Potential error induced by the inclusion of this subjectivity, although mitigated by the mathematical constraints imposed by computer software, could create minor deviations in the results. The results indicate that the incorporation of measurement error, either in width and length measurements or gamma angle estimation, into a reconstruction creates an error rate that would not substantively affect an area of origin determination or class type inferences which would typically be rendered based by that determination, although a potential exception exists with the greater error rate produced by a consistent overestimation of width and an underestimation of length.

References

1) Tom Bevel, Ross M. Gardner (2008) Bloodstain Pattern Analysis With an Introduction to Crime Scene Reconstruction Third Edition. Boca Raton FL: CRC Press Taylor and Francis Group, LLC.

2) Carter AL, Forsythe-Erman J, Hawkes V, Illes M, Laturnus P, et al. (2006) Validation of BackTrack Suite of Programs for Bloodstain Pattern Analysis Journal of Forensic Identification 56: 242-254.

3) Mark Reynolds, Raymond MA (2008) New Bloodstain Measurement Process Using Microsoft Office Excel 2003 AutoShapes. Journal of Forensic Identification 58: 453-468.

4) Reynolds, Franklin, Raymond MA, Dadour IR (2008) Bloodstain Measurement using Computer-Fitted Theoretical Ellipses: A Study in Accuracy and Precision. Journal of Forensic Identification 58: 469-484.