RESEARCH ARTICLE

Evaluation of Blood Saturation as a Mechanism of Change in Stabbing Defects in Clothing

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Introduction

The analysis of evidence relating to stabbing events, like many forensic analyses, can be complex. The analysis of clothing is but one factor to consider within the totality of the evidence comprising the commission of a crime. Other relevant factors are the analyses relating to the wound and the weapon. These three elements comprise a kind of forensic triad with symbiotic relationships which, when viewed in isolation, provide less information than when viewed as a whole. This analysis typically becomes more complicated with the presence of multiple weapons, especially when these weapons have similar dimensions. Several authors have commented to various degrees on this phenomenon (1-6). Through several investigative articles, both Taupin and Sitiene et. al. discuss the variations in wound and damage morphology created by changes in clothing type, position, body movement, weapon type, decomposition and other relevant factors (2,3, 4,7). Additionally, these authors observe that it may be impossible to unequivocally choose between alternating possibilities if this data is missing or incomplete. Daenid et. al. observed that clothing damage defects were affected by the weapon type, fabric type, and whether the fabric was stretched or loose over the body (1). Furthermore, Monahan and Harding observed that depending upon volume applied, blood saturation of clothing tended to alter the appearance of defects in fabric by binding fibers to one another (8).

Our purpose is not to discuss the linking of a weapon with a wound or defect. Nor are we proposing any systematic approach to the examination of wounds, weapons, and defects in clothing in an effort to create a viable nexus. The purpose of this study is merely to determine if blood soaking, and subsequent drying, can influence or change the size of said defect, thus adding an additional consideration for examiners in their evaluations. This study was initiated following a request by defense experts to examine bloodstained clothing in a homicide case.

Case Overview

In October 2006 a homicide occurred in the City of Westminster, Colorado (USA). The adult male victim was a roommate of the reporting party. The resident had become annoyed with the victim "mooching" from him and complained to two friends. One evening the suspects responded to the apartment to forcibly evict the victim. According to the resident, the two suspects entered the apartment, each having a knife in hand. The suspects then reportedly attacked the victim, who sustained two stab wounds as well as defensive cuts to

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the fingers and/or palm of each hand. One stab wound was in the muscle tissue of the left buttock. The wound, which was not life threatening, measured approximately 16mm in length and 50mm in depth. The wound morphology indicated a single edged knife.

The second wound measured approximately 22mm in length. The morphology of the wound indicated a single edged knife. The weapon cut through the top of the third rib on the left side and penetrated the heart. The victim was wearing a short sleeve cotton T-shirt at the time of the stabbing. The victim eventually stumbled out of the apartment and onto a second floor landing where he died. During blood loss the victim's shirt was saturated in blood.

The reporting party (resident) was an eye witness to the stabbing and gave a description of the knives wielded by each suspect. This information was corroborated by DNA testing performed on the handles of each knife. One of the knives was a "butterfly" style knife with a blade dimension of 16mm in width and 89mm in length. The other knife was a folding style knife measuring approximately 25mm in width and 77mm in length. Both knives were single edged. Both blades also yielded DNA from the victim indicating that both knives were used in this attack.

Prior to trial experts retained by the defense made arrangements to examine the bloodstained clothing but did not request to examine the knives. This prompted one of the authors (Adair) to question how reliable an examination of the knife defect could be in a blood saturated garment without corresponding weapon examination. The T-shirt had not been examined since the day of the homicide. The garment was dried and then packaged in a paper evidence bag for several months. It was theorized that the defense experts were trying to determine if one or both of the knives could be eliminated as having been involved in the fatal wound. This theory could not be confirmed since the results of their garment examination were never offered in court. Nonetheless, the question remained as to whether blood soaking and subsequent drying could affect the size of stabbing defects in clothing.

Experiment Design

The garments selected for this study were a pair of denim blue jeans, a mid-weight cotton T-shirt with iron-on Bronco logo and a waffle-weave cotton polo T-shirt. The authors strongly suggest subsequent studies evaluating the effects of blood drying on different fabric types. For the purposes of this study, however the authors limited the evaluation to these three variations of cotton garments. Two knife types were chosen for this study, one measuring 17mm at the widest point, and the second measuring 25mm at the widest point.

The garments were draped over an open barrel and stabbed in a grid pattern. Each garment has two sets of stab wounds (A and B) using one knife type for set A only (17mm) and the second for set B only (25mm). Eight cuts were made in a rectangular grid pattern on one half of the garment with each knife. After each cut was created in the garment, measurements in millimeters were taken by the authors Adair and Brown prior to saturation with blood. Measurements were taken with six inch rulers without magnification, and measurements were rounded to the nearest full millimeter. Each garment was then laid on a flat surface and evenly saturated with approximately 250mL of equine blood. After saturation, the garments were allowed to dry on the flat surface for approximately 10 days. A second set of measurements were taken by the authors Brown and Boltman of each defect on each garment in a similar manner as before. Table 1 shows the results for the denim blue jeans, Table 2 shows the results for the Bronco T-shirt, and Table 3 shows the results for the polo T-shirt.

All measurements are in millimeters. The results at this stage of the study are focused on changes between pre- and post-saturation measurements that show a change greater than ±2mm. Below is a list of the notable results:

- The Bronco T-shirt and the tan polo shirt results had an equal number of measurements (six) that varied more than ±2mm within each respective set.
- Of the Bronco T-shirt results with change greater than ±2mm, the average difference was -4.6mm. The blue jean results had only one instance of change in measurement greater than ±2mm, which was stab B4 with a difference of -2.5mm.
- The blue jean results had the greatest number of post-saturation measurements that were larger than the pre-saturation measurements (nine with an average of +1.05mm).
- The knife showing the greatest amount of variation in measurements was the 25mm knife blade used for set B (average change in measurement through all three garments was 4.94mm).

Stab	Pre-blood	Post-blood	Pre - Post delta
A 1	13.50	14.00	0.50
A 2	12.50	14.50	2.00
A 3	15.00	15.00	0.00
A 4	15.00	13.00	-2.00
A 5	16.00	14.00	-2.00
A 6	12.00	13.00	1.00
A 7	13.50	14.00	0.50
A 8	10.00	9.00	-1.00

Stab	Pre-blood	Post-blood	Pre - Post delta
B 1	20.00	20.50	0.50
B 2	20.50	22.00	1.50
B 3	22.00	23.00	1.00
B 4	20.50	18.00	-2.50
B 5	21.00	19.00	-2.00
B 6	25.00	24.00	-1.00
B 7	22.50	23.50	1.00
B 8	24.00	25.50	1.50

Table 1: Authors' pre- and post-blood saturation raw data and calculated change in measured defect size in jeans (all measurements in millimeters).

Stab	Pre-blood	Post-blood	Pre - Post delta
A 1	20.50	17.00	-3.50
A 2	16.00	15.00	-1.00
A 3	16.50	15.00	-1.50
A 4	22.00	21.00	-1.00
A 5	14.50	13.00	-1.50
A 6	14.00	13.50	-0.50
A 7	22.00	15.00	-7.00
A 8	21.50	19.50	-2.00

Stab	Pre-blood	Post-blood	Pre - Post delta
B 1	31.00	24.00	-7.00
B 2	32.00	32.00	0.00
B 3	33.00	31.50	-1.50
B 4	30.00	29.00	-1.00
B 5	25.50	23.50	-2.00
B 6	25.00	21.00	-4.00
B 7	28.00	24.50	-3.50
B 8	29.50	26.50	-3.00

Table 2: Authors' pre- and post-blood saturation raw data and calculated change in measured defect size in Bronco shirt (all measurements in millimeters.

Stab	Pre-blood	Post-blood	Pre - Post delta
A 1	17.00	17.00	0.00
A 2	15.00	14.00	-1.00
A 3	14.50	14.00	-0.50
A 4	20.00	20.00	0.00
A 5	17.00	18.00	1.00
A 6	10.50	10.50	0.00
A 7	13.50	10.00	-3.50
A 8	14.50	12.00	-2.50

Stab	Pre-blood	Post-blood	Pre - Post delta
B 1	30.00	24.00	-6.00
B 2	30.00	27.00	-3.00
B 3	31.00	28.00	-3.00
B 4	26.50	25.50	-1.00
B 5	36.00	34.00	-2.00
B 6	24.00	25.50	1.50
B 7	25.50	21.00	-4.50
B 8	23.50	24.00	0.50

Table 3: Authors' pre- and post-blood saturation raw data and calculated change in measured defect size in polo shirt (all measurements in millimeters).

Further Inquiries

In addition to the information gained from the analysis of the pre- and post-saturation defects, this study offered the authors an opportunity to test the influence of the examiner on the resulting data collected. Namely, we wanted to see how multiple examiners with various levels of training would measure these defects and if any significant differences would exist within that recorded data set. In order to test this effect the authors presented the clothing items to members of the Rocky Mountain Association of Bloodstain Pattern Analysts (RMABPA). This analysis was conducted after this case was adjudicated. RMABPA members are primarily law enforcement personnel from Colorado who must have completed at least a 40 hour school in bloodstain pattern analysis from an approved instructor. Many of

the analysts have had advanced training and years of experience as bloodstain pattern analysts, however it is unknown how many examiners had training specifically in clothing examination.

The clothing items were presented to the members with instruction to measure the length of each defect. The same lot of 6 inch rulers was supplied to the members so that each measurement was made by the same brand and lot of ruler. All of the measurements were taken of defects following blood soaking and subsequent drying. Each RMABPA member was provided an anonymous worksheet on which to record each measurement. RMABPA members did not measure these defects prior to blood staining. Several factors should be considered when evaluating the results of this experiment. Only eight RMABPA members were present to take part in the experiment. The members had limited time, limited equipment to perform the measuring, and knowledge that this was simply an exercise. Despite the RMABPA members knowing this was simply an exercise; the authors do not have reason to believe that the amount of variance is necessarily exclusive to this study, and could occur in examinations of real evidence.

Tables 4-6 show the RMABPA set of results. All measurements are in millimeters. Some of the results showed an unexpectedly large range of defect measurements. Some degree of measurement variation was expected by the authors. More specifically, it was hypothesized that a measurement range of no more than 3mm would be seen. The results of this experiment, however, showed a much greater range of measurement. The range of measurement variation seen of each defect by RMABPA experts was between 1mm and 24mm, with an average variation of 6.1mm. When the authors evaluated the RMABPA data set, there appeared to be outlier points that were notably beyond the data grouping. Due to this, the authors investigated the data sets with the single highest and single lowest values dropped. With the highest and lowest values for each defect measured dropped the average measurement range changes to 2.7mm. There could be any number of reasons for the original recorded degree of variation. To the authors this indicates that most likely either one or more members were misreading the rulers, they did not clearly see the edges of the defects, or their results were inaccurately recorded. The greatest range of measurements for any particular defect was 24mm found on the Bronco shirt for defect B2, a range of nearly a full inch. This is a notably large discrepancy. Even if one were to disregard the largest and smallest measurements for this same defect, the range is still 8mm, which is a significant variation when measuring items of evidence.

Jeans A 1	Jeans A 2	Jeans A 3	Jeans A 4	Jeans A 5	Jeans A 6	Jeans A 7	Jeans A 8
12.00	12.00	14.00	13.00	14.00	10.00	11.00	9.00
15.00	12.00	10.00	12.00	15.00	15.00	15.00	14.00
13.00		17.00	12.00	17.00		14.00	10.00
14.00	13.00	15.00	16.00	15.00	13.00	14.00	10.00
16.00	14.00	18.00	17.00	19.00	13.00	14.00	13.00
16.00	14.00	18.00	17.00	19.00	13.00	14.00	13.00
13.00	12.00	14.00	12.00	16.00	17.00	10.00	9.00
8.00	12.00	13.00	12.00	14.00	13.00	14.00	13.00
13.38	**12.71**	**14.88**	**13.88**	**16.13**	**13.43**	**13.25**	**11.38**

Jeans B 1	Jeans B 2	Jeans B 3	Jeans B 4	Jeans B 5	Jeans B 6	Jeans B 7	Jeans B 8
20.00	20.00	22.00	15.00	18.00	18.00	14.00	20.00
20.00	23.00	20.00	20.00	20.00	21.00	20.00	24.00
20.00		20.00		22.00	24.00	27.00	27.00
20.00	22.00	21.00	19.00	24.00	20.00	22.00	25.00
21.50	25.00	22.00	21.50	22.00	24.00	24.00	26.00
21.50	25.00	22.00	21.50	22.00	24.00	24.00	26.00
21.00	26.00	22.00	19.00	24.00	21.00	25.00	24.00
20.00		20.00	20.00	20.00	20.00	20.00	20.00
20.50	**23.50**	**21.13**	**19.43**	**21.50**	**21.50**	**22.00**	**24.00**

Table 4: RMAPBA members' post-blood saturation raw measurements of defect size in jeans (all measurements in millimeters).

Bronco A 1	Bronco A 2	Bronco A 3	Bronco A 4	Bronco A 5	Bronco A 6	Bronco A 7	Bronco A 8
14.00	14.00	15.00	20.00	16.00	13.00	19.00	19.00
18.00	15.00	16.00	20.00	15.00	15.00	16.00	20.00
19.00	14.00	15.00	22.00	13.00	14.00	15.00	19.00
19.00	15.00	15.00	22.00	14.00	13.00	21.00	20.00
20.00	13.00	15.00	22.00	15.00	14.00	20.00	21.00
16.00	16.00	15.00	22.00	10.00	13.00	19.00	20.00
16.00	15.00	15.00	21.00	13.00	15.00	19.00	20.00
17.43	**14.57**	**15.14**	**21.29**	**13.71**	**13.86**	**18.43**	**19.86**

Bronco B 1	Bronco B 2	Bronco B 3	Bronco B 4	Bronco B 5	Bronco B 6	Bronco B 7	Bronco B 8
29.00	32.00	30.00	29.00	25.00	24.00	25.00	25.00
29.00	34.00	30.00	30.00	25.00	24.00	25.00	29.00
30.00	37.00	35.00	29.00	24.00	25.00	25.00	27.00
29.00	30.00	33.00	28.00	27.00	24.00	25.00	26.00
27.00	35.00	32.00	29.00	27.00	22.00	27.00	21.00
16.00	16.00	15.00	22.00	10.00	13.00	19.00	20.00
28.00	40.00	30.00	29.00	25.00	23.00	23.00	25.00
26.00	29.00	32.00	27.00	25.00	18.00	23.00	22.00
26.75	**31.63**	**29.63**	**27.88**	**23.50**	**21.63**	**24.00**	**24.38**

Table 5: RMABPA members' post-blood saturation raw measurements of defect size in Bronco shirt (all measurements in millimeters).

Polo A 1	Polo A 2	Polo A 3	Polo A 4	Polo A 5	Polo A 6	Polo A 7	Polo A 8
15.00	14.00	14.00	18.00	16.00	8.00	7.00	12.00
17.00	15.00	14.00	16.00	17.00	9.00	10.00	14.00
20.00	19.00	15.00	15.00	17.00	10.00	9.00	14.00
15.00	14.00	14.00	15.00	16.00	9.00	10.00	13.00
16.00	14.00	15.00	17.00	16.00	10.00	10.00	12.00
17.00	14.00	15.00	18.00	17.00	9.00	9.00	13.00
18.00	14.50	15.00	17.00	17.00	7.00	7.00	8.00
21.00	14.00	15.00	17.00	16.00	8.00	7.00	12.00
17.38	**14.81**	**14.63**	**16.63**	**16.50**	**8.75**	**8.63**	**12.25**

Polo B 1	Polo B 2	Polo B 3	Polo B 4	Polo B 5	Polo B 6	Polo B 7	Polo B 8
25.00	28.00	27.00	26.00	33.00	22.00	22.00	24.00
25.00	28.00	27.00	25.00	24.00	24.00	20.00	24.00
29.00	26.00	27.00	26.00	32.00	23.00	22.00	24.00
26.00	29.00	26.00	25.00	34.00	23.00	21.00	24.00
25.00	28.00	31.00	26.00	34.00	23.00	22.00	25.00
26.00	28.00	27.00	27.00	33.00	23.00	22.00	24.00
27.00	28.00	28.00	26.00	34.00	20.00	21.00	23.00
26.14	**27.86**	**27.57**	**25.86**	**32.00**	**22.57**	**21.43**	**24.00**

Table 6: RMABPA members' post-blood saturation raw measurements of defect size in polo shirt (all measurements in millimeters).

In addition to the opportunity to examine measurement variation between examiners with similarly high levels of training when measuring the same defect, this study created an opportunity to examine the measurement variation due to expertise of examiners. Authors Boltman and Brown at the time of the examinations had only basic evidence examination training and no formal bloodstain pattern analysis training, whereas the RMABPA members had greater levels of expertise in both. As discussed later in the analysis, the post-saturation data set recorded by these authors did not show a great deal of variation from that of the RMABPA data set. The post-saturation data set collected by authors Boltman and Brown was verified by author Adair upon a separate examination of the defects. Mr. Adair is a board certified bloodstain pattern examiner with the International Association for Identification and a past president of the RMABPA. The separate verification measurements obtained by author Adair show that the data set recorded by authors Boltman and Brown is validated for use in this study. Additionally, this verification by an experienced examiner lends itself to being an additional data point, which can be used for comparison of examiner training level. However due to the level of observed scatter in collected data discussed earlier in this paper, the additional data set provided by author Adair did not provide additional clarification on measurement variation due to expertise of examiners.

When the mean RMABPA values for each measured defect are examined, it is seen that the author's post-saturation measurements were within 1.5mm of the RMABPA mean for each defect. (See tables 7-9) This result was closer to our expectations for this portion of the study, and notably presents a much smaller range of measurement variation than within the RMABPA member raw data set. Ultimately, this portion of the research tends to support the conclusion that some level of variation will occur between examiners of all skill levels and that the degree of variation can vary widely, as suggested by Boland et. al. (10). Despite the smaller variation seen between the two data sets, the authors suggest that the examiner skill level may be yet another important factor to consider when evaluating evidence of this manner. Tables 7-9 show both the authors' and calculated average RMABPA members' post-saturation measurements, and they illustrate any difference between these measurements of each defect.

Stab	Authors Post-blood	RMABPA Average	Delta
A 1	14.00	13.38	-0.62
A 2	14.50	12.71	-1.79
A 3	15.00	14.88	-0.12
A 4	13.00	13.88	0.88
A 5	14.00	16.13	2.13
A 6	13.00	13.43	0.43
A 7	14.00	13.25	-0.75
A 8	9.00	11.38	2.38

Stab	Authors Post-blood	RMABPA Average	Delta
B 1	20.50	20.50	0.00
B 2	22.00	23.50	1.50
B 3	23.00	21.13	-1.87
B 4	18.00	19.43	1.43
B 5	19.00	21.50	2.50
B 6	24.00	21.50	-2.50
B 7	23.50	22.00	-1.50
B 8	25.50	24.00	-1.50

Table 7: Authors' and average of RMABPA members' post-blood saturation measurements and calculated difference between measured defect size in jeans (all measurements in millimeters).

Stab	Authors Post-blood	RMABPA Average	Delta
A 1	17.00	17.43	0.43
A 2	15.00	14.57	-0.43
A 3	15.00	15.14	0.14
A 4	21.00	21.29	0.29
A 5	13.00	13.71	0.71
A 6	13.50	13.86	0.36
A 7	15.00	18.43	3.43
A 8	19.50	19.86	0.36

Stab	Authors Post-blood	RMABPA Average	Delta
B 1	24.00	26.75	2.75
B 2	32.00	31.63	-0.37
B 3	31.50	29.63	-1.87
B 4	29.00	27.88	-1.12
B 5	23.50	23.50	0.00
B 6	21.00	21.63	0.63
B 7	24.50	24.00	-0.50
B 8	26.50	24.38	-2.12

Table 8: Authors' and average of RMABPA members' post-blood saturation measurements, and calculated difference between measured defect size in Bronco shirt (all measurements in millimeters).

Stab	Authors Post-blood	RMABPA Average	Delta
A 1	17.00	17.38	0.38
A 2	14.00	14.81	0.81
A 3	14.00	14.63	0.63
A 4	20.00	16.63	-3.37
A 5	18.00	16.50	-1.50
A 6	10.50	8.75	-1.75
A 7	10.00	8.63	-1.37
A 8	12.00	12.25	0.25

Stab	Authors Post-blood	RMABPA Average	Delta
B 1	24.00	26.14	2.14
B 2	27.00	27.86	0.86
B 3	28.00	27.57	-0.43
B 4	25.50	25.86	0.36
B 5	34.00	32.00	-2.00
B 6	25.50	22.57	-2.93
B 7	21.00	21.43	0.43
B 8	24.00	24.00	0.00

Table 9: Authors' and average of RMABPA members' post-blood saturation measurements and calculated difference between measured defect sizes in polo shirt (all measurements in millimeters).

Conclusions

The three sets of results of this study show many a variations. The variations seen from pre-saturation to both post-saturation measurement sets are not consistent enough to draw any conclusions other than that variations existed. In fact, with the changes from pre- to post-saturation measurements being both positive and negative (though tending more towards negative figures), the authors' hypothesis that blood drying may lead to significant shrinkage of the defect size in a soaked garment is not fully supported. However, the negative tendency within the observed variations supports that there is measurable distortion that occurs between the measurement of a defect in a garment and a measurement of the same defect after blood saturation and drying, of which examiners must be aware when making their examinations.

In addition to distortion possibly caused by blood drying and shrinking, the results showed that the type of fabric in which the defect is being measured may play a role in the magnitude of distortion observed. The manner in which the garment is dried and packaged may also influence any defect distortion, although this study did not examine variations in drying or packaging methods. The authors can only infer that fabrics which allow for more stretching in the weave (i.e. cotton Bronco T-shirt compared to thicker blue jean denim) may pose a greater challenge to even experienced examiners in the exact measurement of the defect. However, further investigation is necessary to understand the complexity of this factor as well.

Additionally, both data sets demonstrating variation within examiner measurements showed an unexpected set of results. The compiled post-blood saturation measurements (post-blood author vs. RMABPA) vary within a range of differences of less than 7mm (+3.43mm to -3.37mm). One would expect the variance between examiners of similar high skill level and training to have been smaller than that between examiners of greater skill level

difference; however the data contradicted that expectation. As examined earlier, the possible factors that influenced the measurement variance are unknown and innumerable at this level of analysis. The authors believe that there is enough data scatter observed in the comparison results as well as within the raw RMABPA data set that we encourage further investigation into contributing factors, especially user error rate in taking these measurements.

The authors highly recommend that examiners, regardless of experience level, exercise great care when analyzing such defects due to the number of factors that may influence measurements. The authors have only begun to highlight factors that can influence defects in a variety of ways. Monahan and Harding suggest that test cuts be made in the same fabric as evidence fabric when possible in order to get an accurate interpretation of the defect. However, their studies also outline several factors that can influence the edge appearance of separate defects in the same garment type, to include the extreme of stabbing incidents involving blunt objects that can penetrate skin and leave fabric undamaged (8). Considering the wide range of circumstances that can be seen within crime scene evidence, a great deal more investigation into contributing factors is strongly suggested.

Therefore, in addition to exercising care when performing an analysis of blood-saturated clothing with stab defects, the authors recommend that examiners present any findings with caution if the analysis is performed in absence of any of the three critical elements (wound, garment, or weapon) that the authors consider minimally necessary for a full understanding of the evidence, or if any other factors are present that may alter the appearance of defect edges. The results of this study indicate that some variation or deformation is likely to be encountered and examiners or other individuals interpreting evidence of this type should not expect an exact correlation between the blade width and defect size. Additionally, it is well understood that the manner in which the weapon is used, or which type of cutting instrument was used can greatly influence a defect regardless of blood soaking, as studied in depth by others (8, 9). Similar studies should be conducted to broaden our understanding of the various factors influencing this phenomenon.

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