Determination of the robustness of the identification criteria of bloodstains patterns

Alicia PETIT[a], Corentin SABAUT[b], Géraud DÉCHANET[c], Philippe ESPERANÇA[c, d]

Summary

The analysis of morphological criteria (at least size, shape, distribution) is the base of Bloodstain Pattern Analysis. Therefore, this work was carried out to determine the robustness of these criteria allowing the classification of bloodstain. For 18 of the 24 bloodstain patterns referenced, we made a hundred traces on four supports, paper, as a reference, tiles, wood, and linoleum, considered as the most common supports found at a crime scene. The analysis of the characteristics found allowed us to highlight the criteria sufficient to classify each of the 18 patterns studied. The comparison with those commonly admitted, allowed to confirm the previous classifications.

Keywords: Morphoanalysis, bloodstain pattern, morphological criteria, blood stain.

Introduction

Bloodstain Pattern Analysis allows to determine the events at the origin of the presence of blood at crime scenes [1]. It has been based for several years now on morphological criteria (at least size, shape, distribution) commonly accepted by the BPA community. These criteria allow the classification of a bloodstain into a pattern to determine the mechanism that caused the stain. Older publications describe the mechanisms of pattern formation, the interpretation of these patterns or the terminology (common vocabulary, reference atlas, ...). However, today, no scientific article has demonstrated experimentally the robustness of the morphological criteria useful for the classification of these patterns. Therefore, the objectives of our work have been to establish sufficient and robust criteria for each of the bloodstain pattern as well as to validate those currently accepted, and to complete them if necessary.

[a] : Polytech Angers, Université d'Angers, France
[b] : Université du Québec à Trois-Rivières, Canada
[c] : Laboratoire d'Analyses Criminalistiques, Marseille, France
[d] : Correspondance : expert.morpho@l-a-c.expert

Material and methods :

Material :

Several types of blood were used in this study :

- Human blood (blood sample taken in a medical analysis laboratory on 4 volunteers (2 men and 2 women aged between 22 and 54 years)
- Artificial blood (Maqpro Paris, reference 2005/N, lot N°22084), with a dilution of 1.4 (5 ml of blood for 7 ml of city water) to obtain a viscosity close to that of human blood
- Dehydrated pig blood (La Bovida, lot N° PR19040210, 100g of blood for 500ml of city water), with an addition of 20% of artificial blood to obtain a reddish color.

The amount of human blood available was not sufficient to perform all the stains. Therefore, a mixture of pig blood and artificial blood was used. No macroscopic differences between the stains with human blood and with the mixture were observed.

The bloodstains have been realized on different types of supports:

- Paper was used as a reference support.
  Paper type Cathedrale (reference: FBWHTA310), A3 board (30x42x0,5cm / 600g) rigid in foam of 5mm laminated on both sides by paper coated with smooth white color.
- For the model of impregnation, the fabric used is from a comforter cover 100% cotton with white and clear blue color of the brand Carré blanc
- Linoleum stratified of light brown color
- The tile is beige and size 40x40 cm
- The wood painted comes from a piece of house furniture

The last three materials were chosen to represent as faithfully as possible the materials commonly found inside a house.

The availability of the supports is not unlimited (except for the paper), so they have been cleaned with a sponge humidified with water and then dried.

Several small materials were used during the different experimentations:

- The pipette used is a transfer pipette (SAMCO, reference 231, lot n° H56823130).
- The syringe used is a 3 pieces syringe BD EMERALD 5 ml
- The hammer used is a carpenter type hammer
- The shoe used is a Newfeel Essensole left shoe size 42
- The piece of wood used measures 6.5 cm large and 70 cm high
- A standard teaspoon
- A stick in wood measures 8mm in diameter and 43 cm in length
- Nitrile gloves (Nitrilex model from Mercator Medical, lot N°NB000015926)
- standard protractor and meter.

In this experiment, photography was realized with a Nikon camera model D850, coupled with an AF-S NIKKOR 24-120mm 1:4 G lens.

To determine the experimental conditions, a hygrometer (TEMTOP, model P20/20C) was used in the room where the experiments were done. We obtained the following data: temperature between 18 and 26 °C, humidity between 49 and 56%, and for information, suspended particles between 8.79 and 27.4 ug/m3 and CO2 between 686 and 1302 ppm.

Methods :

The bloodstain pattern names used are those accepted by the community and are available at www.iabpa.org.

2.1 Making the bloodstains patterns

- **Drip stain :**

  A quantity of blood has been taken with the pipette. By simple pressure, a drip falls by itself from a height of 1.5 m[1] above the support.

- **Drip pattern :**

  A quantity of blood has been taken with the pipette. By simple pressure, three drips fall by themselves successively, from the same position of a height of 1,5m[1] above the support.

- **Transfer stain :**

  The bottom of the shoe was put in contact with liquid blood. Then, it was put in contact with the support in a heel-to-toe movement imitating the step.

- **Swipe pattern :**

  One hand covered with the glove was put in contact with liquid blood and then 3 fingers came in motion on the support.

- **Alteration contact :**

  A drip of blood was put on the support with the syringe. After 1 hour, a pressure was exerted on the drip of blood using a shoe's bottom.

- **Wipe pattern :**

  A drip of blood was put on the support with the syringe. After 1 hour, a movement was exerted on the drip of blood using a gloved finger.

- **Pool :**

  With the help of the syringe, 3 ml of blood was put on the support, point of the syringe right on the support.

- **Flow pattern :**

  A drip of blood was put on the support with the syringe. The support was then put in a non-horizontal position.

[1] The drop height was defined at 1.5 m, a height at which the diameter of the stains does not change significantly [2]. Moreover, this height is ergonomic for the realization of the different bloodstains.

- **Splash pattern :**

  With the help of the syringe, 2ml of blood was put into a teaspoon. An abrupt reversal was then realized at a height of 1.5m[2] above the support.

- **Projected pattern :**

  With the help of the syringe, 2ml was ejected perpendicular to the ground from a height of 50cm above the horizontal and non-horizontal supports.

- **Cast-off pattern :**

  The end of the wood stick was plunged into liquid blood. It was then executed with this a fast, curvilinear movement going down from a height of 35cm above the horizontal support.

- **Impact stain :**

  With the help of the syringe, 2ml of blood was put on the horizontal support. A piece of wood falling from its own height impacted the volume of liquid blood.

- **Saturation stain :**

  With the help of the syringe, 3ml of blood was put on the fabric, point of the syringe in contact with the horizontal support.

- **Void pattern :**

  With the help of the syringe, 2ml of blood was put on the lying piece of wood. The liquid blood was then hit with the help of a hammer. Various objects were randomly fixed on the support and then removed before the photography.

- **Focus of the impact pattern / Impact pattern :**

  With the help of the syringe, 2ml of blood was put on the lying piece of wood. The blood was then hit with the help of the hammer.

- **Expiration pattern :**

  With the help of the syringe, 2ml of liquid blood was put into a mouth. A strong exhalation was then realized at 10cm with an angle of approximately 45° in the direction of the support.

- **Gravitational stain :**

  No experiments were dedicated to this pattern. These stains were observed on the paper support from the spatter pattern.

All the patterns of bloodstains were realized 100 times by supports, except for :

- Void pattern because the criteria for this pattern (area with an absence of blood) are systematically related to the obstructing object and not to the support. For this reason, only 50 stains were made per support;

[2] The drop height was defined at 1.5 m, a height at which the diameter of the stains does not change significantly [2]. Moreover, this height is ergonomic for the realization of the different bloodstains.

- Gravitational stains because this pattern corresponds to spatters, only the distribution is typical. For this reason, only a baseline of 100 stains on the paper has been realized.
- Expired blood because this pattern was not pleasant to realize (blood in the mouth).
  A baseline of 100 stains on paper was made, then 10 stains on the other three supports. As no differences were observed between the supports, it was decided not to follow the protocol to reach 100 stains per support.

The following pattern of bloodstains are not realized:

- Aspirated blood because the criterion of location in the barrel of a firearm is sufficient for its identification.
- Drip trail because it is enough to observe a linear distribution of stain gathering the criteria of Drip stain on horizontal target.
- Serum stain because the change of coloring is sufficient for its classification.
  It results from the physiological phenomenon of separation of the figurative elements of the blood compared to the plasma.
- Accompanying stain, resulting from the rupture of the capillary link between the drop forming the drip stain and the blood source, because its presence is too random to be studied scientifically.
- Insect stain due to an external cause that did not allow us to complete the experiment.
- Sprayed blood due to an external cause that did not allow us to complete the experimentation.

The bloodstains patterns made are studied:

- on a horizontal support (support at 0° to the horizontal i.e. an impact at 90°) ;
- on a non-horizontal support, for the models Drip stain, projected pattern, impact stain and Flow pattern (support at 70° with respect to the horizontal, i.e. an impact at 30°).

2.2 Documentation of the bloodstain patterns produced

A forensic picture of each bloodstain pattern produced is taken: full trace, non-blurred, at 90°, in the presence of a scale and a reference.

2.3 Description of the bloodstain patterns made

The morphological criteria observed are described according to the terms defined in Appendix 1 and documented in a spreadsheet (Google Sheet).

2.4 Morphological criteria of the bloodstain patterns made

An average of the presence of each morphological criterion by bloodstain pattern is then calculated for each support but also whatever the support. A standard deviation is also calculated.

Results

Table 1 : Statistics of morphological criteria depending on the supports for Drip stain horizontal target.

Drip stain horizontal target								
			Paper	Tiling	Wood	Lino	Average (%)	Standard deviation (%)
Number of traces			100	100	100	100	-	-
Size	Centimetric		100%	100%	100%	100%	100%	0,00
Shape	Irregular edge		0%	6%	0%	0%	1,50%	3,00
	Circular		100%	94%	100%	100%	98,50%	3,00
Satellites	Yes		100%	100%	81%	93%	93,50%	8,96
	No		0%	0%	19%	7%	6,50%	8,96
Distribution	Central		100%	74%	5%	9%	47%	47,42
	None		0%	26%	95%	91%	53%	47,42
Satellites' Shape	Ovoid		64%	68,00%	93,83%	95,70%	79,41%	14,47
	Circular		10%	20,00%	6,17%	0%	9,36%	7,37
	Circular-Ovoid		26%	12,00%	0%	4,30%	11,23%	9,89
	Majority	Circular	0%	41,67%	-	50%	16,90%	21,47
		Ovoid	100%	58,33%	-	50%	83,10%	21,47
Satellites' Size	Millimetric		100%	100%	100%	100%	100%	0,00
Satellites' Location	Peripheral		100%	100%	100%	100%	100%	0,00
Other	Spines		79%	25%	1%	32%	34,25%	32,65
	Teeth		0%	2%	97%	19%	29,50%	45,80
	Irregular edge		0%	40%	0%	100%	35,00%	47,26
	No particularity		21%	45%	3%	0%	17,25%	20,69

Table 2 : Statistics of morphological criteria depending on the supports for Drip stain no-horizontal target.

Drip stain no-horizontal target							
		Paper	Tiling	Wood	Lino	Average (%)	Standard deviation (%)
Number of traces		100	100	100	100	-	-
Size	Centimetric	100%	100%	100%	100%	100	0,00
Shape	Ovoid	100%	100%	100%	100%	100	0,00
Satellites	No	100%	100%	100%	100%	100	0,00
Distribution	None	100%	100%	100%	100%	100	0,00
Other	Trail	56%	66%	18%	4%	36,00	29,71
	Discontinuous trail	37%	5%	9%	0%	12,75	16,58
	Flow	10%	54%	100%	52%	54,00	36,77
	Discontinuous flow	0%	0%	0%	37%	9,25	18,50
	No particularity	0%	0%	0%	1%	0,25	0,50

Table 3 : Statistics of morphological criteria depending on the supports for Drip pattern.

Drip pattern							
			Paper	Tiling	Wood	Lino	Average (%)	Standard deviation (%)
Number of traces			100	100	100	100	-	-
Size	Centimetric		100%	100%	100%	100%	100	0,00
Shape	Irregular edge		0%	0%	0%	11%	2,75	5,50
	Circular		19%	13%	14%	10%	14,00	3,74
	Rounded edge		81%	87%	86%	79%	83,25	3,86
Satellites	Yes		100%	100%	100%	100%	100	0,00
Distribution	Central		100%	100%	100%	100%	100	0,00
Satellites' shape	Circular		59%	72%	89,00%	78%	74,50	12,50
	Circular -Ovoid		41%	28%	11%	22%	25,50	12,50
	Majority	Circular	100%	92,86%	100%	100%	98,04	3,19
		Ovoid	0%	7,14%	0%	0%	1,96	3,19
Satellites' size	Millimetric		100%	100%	100%	100%	100	0,00
Satellites' location	Peripheral		100%	100%	100%	100%	100	0,00
Other	Spines		23%	0%	0%	3%	6,50	11,09
	Teeth		35%	2%	4%	4%	11,25	15,86
	Irregular edge		4%	40%	42%	29%	28,75	17,46
	No particularity		49%	58%	54%	66%	56,75	7,18

Table 4 : Statistics of morphological criteria depending on the supports for Transfer stain.

Transfer stain							
		Paper	Tiling	Wood	Lino	Average (%)	Standard deviation (%)
Number of traces		100	100	100	100	-	-
Size	Centimetric	100%	100%	100%	100%	100	0,00
Shape	Specific	100%	100%	100%	100%	100	0,00
Satellites	No	41%	47%	41%	54%	45,75	6,18
	Yes	59%	53%	59%	46%	54,25	6,18
Distribution	None	100%	100%	100%	100%	100	0,00
Satellites' shape	Circular	100%	100%	100%	100%	100	0,00
Satellites' size	Millimetric	100%	100%	100%	100%	100	0,00
Satellite' location	Axial	64,41%	90,57%	88,14%	73,91%	79,27	10,89
	Lateral	62,71%	13,21%	23,73%	52,17%	37,79	20,35
Other	Trail	16%	0%	3%	2%	5,25	7,27
	No particularity	84%	100%	97%	98%	94,75	7,27

Table 5 : Statistics of morphological criteria depending on the supports for Swipe pattern.

Swipe pattern							
		Paper	Tiling	Wood	Lino	Average (%)	Standard deviation (%)
Number of traces		100	100	100	100	-	-
Size	Centimetric	100%	100%	100%	100%	100	0,00
Shape	Specific	100%	100%	100%	100%	100	0,00
Satellites	No	57%	36%	34%	59%	46,50	13,33
	Yes	43%	64%	66%	41%	53,50	13,33
Distribution	None	100%	100%	100%	100%	100	0,00
Satellites' shape	Circular	100%	100%	100,00%	100%	100	0,00
Satellites' size	Millimetric	100%	100%	100%	100%	100	0,00
Satellites' location	Axial	76,74%	64,06%	72,73%	58,54%	68,22	6,63
	Lateral	41,86%	78,13%	68,18%	63,41%	64,95	12,76
Other	Decrease	100%	100%	100%	100%	100	0,00
	Internal striation	100%	100%	100%	100%	100	0,00
	Discontinuous stain	14%	0%	0%	28%	10,50	13,40
	Trail	2%	0%	0%	0%	0,50	1,00
	No particularity	0%	0%	0%	0%	0,00	0,00

Table 6 : Statistics of morphological criteria depending on the supports for Alteration contact.

Alteration contact							
		Paper	Tiling	Wood	Lino	Average (%)	Standard deviation (%)
Number of traces		100	100	100	100	-	-
Size	Centimetric	100%	100%	100%	100%	100	0,00
Shape	Specific	100%	100%	100%	100%	100	0,00
Satellites	No	62%	73%	68%	70%	68,25	4,65
	Yes	38%	27%	32%	30%	31,75	4,65
Distribution	None	100%	100%	100%	100%	100	0,00
Satellites' shape	Circular	100%	100%	100%	100%	100	0,00
Satellites' size	Millimetric	100%	100%	100%	100%	100	0,00
Satellites' location	Axial	97,37%	74,07%	62,50%	83,33%	80,31	13,32
	Lateral	15,79%	48,15%	46,88%	20,00%	31,50	14,95
Other	Skeleton	100%	100%	100%	100%	100	0,00
	Trail	0%	1%	1%	0%	0,50	0,58
	No particularity	100%	99%	99%	100%	99,50	0,58

Table 7 : Statistics of morphological criteria depending on the supports for Wipe pattern.

Wipe pattern							
		Paper	Tiling	Wood	Lino	Average (%)	Standard deviation (%)
Number of traces		100	100	100	100	-	-
Size	Centimetric	100%	100%	100%	100%	100	0,00
Shape	Specific	100%	100%	100%	100%	100	0,00
Satellites	No	100%	100%	100%	100%	100	0,00
Distribution	None	100%	100%	100%	100%	100	0,00
Other	Skeleton	100%	100%	100%	100%	100	0,00
	Decrease	100%	100%	100%	100%	100	0,00
	Internal striation	94%	92%	99%	0%	71,25	47,59
	Trail	6%	3%	0%	0%	2,25	2,87
	No particularity	0%	0%	0%	0%	0	0,00

Table 8 : Statistics of morphological criteria depending on the supports for Pool.

Pool							
		Paper	Tiling	Wood	Lino	Average (%)	Standard deviation (%)
Number of traces		100	100	100	100	-	-
Size	Centimetric	100%	100%	100%	100%	100	0,00
Shape	Regular edge	100%	100%	100%	100%	100	0,00
Satellites	No	100%	100%	100%	100%	100	0,00
Distribution	None	100%	100%	100%	100%	100	0,00
Other	Crown	90%	90%	90%	90%	90,00	0,00
	No particularity	10%	10%	10%	10%	10,00	0,00

Table 9 : Statistics of morphological criteria depending on the supports for Flow pattern.

Flow pattern							
		Paper	Tiling	Wood	Lino	Average (%)	Standard deviation (%)
Number of traces		100	100	100	100	-	-
Size	Centimetric	100%	100%	100%	100%	100	0,00
Shape	Parallel and regular sides	100%	100%	100%	100%	100	0,00
Satellites	No	100%	100%	100%	100%	100	0,00
Distribution	None	100%	100%	100%	100%	100	0,00
Other	Discontinuous start	0%	19%	0%	0%	4,75	9,50
	No particularity	100%	81%	100%	100%	95,25	9,50

Table 10 : Statistics of morphological criteria depending on the supports for Splash pattern.

Splash pattern								
			Paper	Tiling	Wood	Lino	Average (%)	Standard deviation (%)
Number of traces			100	100	100	98	-	-
Size	Centimetric		100%	100%	100%	100%	100	0,00
Shape	Irregular edge		5%	2%	1%	0%	2,01	1,87
	Rounded edge		95%	98%	99%	100%	97,99	1,87
Satellites	Yes		100%	100%	100%	100%	100	0,00
Distribution	Central		100%	100%	100%	100%	100	0,00
Satellites' shape	Circular -Ovoid		100%	100%	100%	100%	100	0,00
	Majority	Circular	0%	0%	0%	0%	0	0,00
		Ovoid	100%	100%	100%	100%	100	0,00
Satellites' size	Millimetric		100%	100%	100%	100%	100	0,00
Satellites' location	Peripheral		100%	100%	100%	100%	100	0,00
Other	Spines		69%	24%	30%	18%	35,34	19,95
	Teeth		67%	65%	75%	75%	70,48	4,56
	Irregular edge		31%	37%	43%	37%	37,00	4,25
	Circular satellites close to the mother track / ovoid if far away		12%	0%	0%	0%	3,02	5,20
	Bubble ring		100%	100%	100%	100%	100	0,00
	Crown of spines		3%	1%	9%	5%	4,50	2,97
	Ovoid in V		0%	4%	9%	4%	4,25	3,20
	No particularity		0%	11%	2%	2%	3,76	4,27

Table 11 : Statistics of morphological criteria depending on the supports for Projected pattern on a horizontal target.

Projected pattern horizontal target								
			Paper	Tiling	Wood	Lino	Average (%)	Standard deviation (%)
Number of traces			100	100	99	100	-	-
Size	Centimetric		100%	100%	100%	100%	100	0,00
Shape	Irregular edge		2%	15%	8,08%	0%	6,27	6,76
	Spine shape		98%	85%	91,92%	100%	93,73	6,76
Satellites	Yes		100%	100%	100%	100%	100	0,00
Distribution	Central		100%	100%	100%	100%	100	0,00
Satellites' shape	Ovoid		0%	6%	69,70%	43%	29,57	32,77
	Circular -Ovoid		100%	94%	30,30%	57%	70,43	32,77
	Majority	Circular	0%	4,26%	0%	0%	1,42	2,01
		Ovoid	100%	95,74%	100%	100%	98,58	2,01
Satellites' size	Millimetric		100%	100%	100%	100%	100	0,00
Satellites' location	Peripheral		100%	100%	100%	100%	100	0,00
Other	V-ovoid		0%	1%	0%	0%	0,25	0,50
	Very elongated ovoid		100%	100%	100%	100%	100	0,00
	Teeth		0%	2%	0%	0%	0,50	1,00
	Bubble ring		100%	100%	100%	100%	100	0,00
	No particularity		100%	97%	100%	100%	99,25	1,50

Table 12 : Statistics of morphological criteria depending on the supports for projected pattern on a no-horizontal target.

Projected pattern no-horizontal target							
		Paper	Tiling	Wood	Lino	Average (%)	Standard deviation (%)
Number of traces		100	100	100	100	-	-
Size	Centimetric	100%	100%	100%	100%	100	0,00
Shape	Spine shape	100%	100%	100%	100%	100	0,00
Satellites	Yes	100%	100%	100%	100%	100	0,00
Distribution	None of those identified	100%	100%	100%	100%	100	0,00
Satellites' shape	Ovoid	100%	100%	100%	100%	100	0,00
Satellites' size	Millimetric	100%	100%	100%	100%	100	0,00
Satellites' location	Lateral	100%	100%	100%	100%	100	0,00
	Axial	100%	100%	100%	100%	100	0,00
Other	Flow	100%	100%	100%	100%	100	0,00
	Swarm	55%	31%	34%	8%	32,00	19,24
	Bubble ring	100%	100%	100%	100%	100	0,00
	No particularity	0%	0%	0%	0%	0	0,00

Table 13 : Statistics of morphological criteria depending on the supports for Cast-off pattern.

Cast-off pattern							
		Paper	Tiling	Wood	Lino	Average (%)	Standard deviation (%)
Number of traces		100	100	100	100	-	-
Size	Millimetric	81%	79%	84%	88%	83	3,92
	Millimetric - Centimetric	19%	21%	16%	12%	17	3,92
Shape	Circular -ovoid	99%	80%	100%	100%	94,75	9,84
	Circular	1%	20%	0%	0%	5,25	9,84
Satellites	No	100%	100%	100%	100%	100	0,00
Distribution	Curvilinear	24%	34%	36%	35%	32,25	5,56
	Linear	76%	66%	64%	65%	67,75	5,56
Other	Decreasing size	91%	54%	94%	100%	84,75	20,84
	Swarm	12%	12%	19%	13%	14,00	3,37
	Bifurcation	4%	4%	1%	1%	2,50	1,73
	No particularity	84%	84%	80%	86%	83,50	2,52

Table 14 : Statistics of morphological criteria depending on the supports for Impact stain on a primary horizontal target.

Impact stain on primary horizontal target								
			Paper	Tiling	Wood	Lino	Average (%)	Standard deviation (%)
Number of traces			99	100	100	100	-	-
Size	Centimetric		100%	100%	100%	100%	100	0,00
Shape	Altered edge		100%	19%	26%	46%	47,62	31,68
	Spine shape		0%	81%	74%	54%	52,38	31,68
Satellites	Yes		100%	100%	100%	100%	100	0,00
Distribution	None		2,02%	17%	28%	16%	15,79	9,21
	Central		97,98%	83%	72%	84%	84,21	9,21
Satellites' shape	Ovoid		3,03%	42,00%	49%	56%	37,59	20,46
	Circular		0,00%	2,00%	3%	0%	1,25	1,30
	Circular -Ovoid		96,97%	56,00%	48%	44%	61,15	21,03
	Majority	Circular	2,06%	11,11%	18,75%	2,27%	8,56	6,66
		Ovoid	97,94%	88,89%	81,25%	97,73%	91,44	6,66
Satellites' size	Millimetric		100%	100%	100%	100%	100	0,00
Satellites' location	Peripheral		100%	100%	100%	100%	100	0,00
Other	Bundles		100%	100%	100%	100%	100	0,00
	Spines		97,98%	17%	20%	30%	41,10	33,03
	Bubble ring		100%	100%	100%	100%	100	0,00
	V-ovoid		0%	0%	2%	1%	0,75	0,83
	No particularity		0,00%	0%	0%	0%	0	0,00

Table 15 : Statistics of morphological criteria depending on the supports for Impact stain on a secondary no-horizontal target.

Impact stain on secondary no-horizontal target								
			Paper	Tiling	Wood	Lino	Average (%)	Standard deviation (%)
Number of traces			98	100	99	100	-	-
Size	Millimetric		11,22%	8%	12,12%	11%	10,58	1,55
	Millimetric- Centimetric		88,78%	92%	87,88%	89%	89,42	1,55
Shape	Ovoid		5,10%	3,00%	2,02%	2%	3,02	1,26
	Circular		14,29%	19,00%	10,10%	28%	17,88	6,66
	Circular -Ovoid		80,61%	78,00%	87,88%	70%	79,09	6,40
	Majority	Circular	36,71%	33,33%	36,78%	40%	36,62	2,28
		Ovoid	63,29%	66,67%	63,22%	60%	63,38	2,28
Satellites	No		100%	100%	100%	100%	100	0,00
Distribution	None		100%	100%	100%	100%	100	0,00
Other	Bubble ring		96,94%	99,00%	97,98%	97,00%	97,73	0,84
	Spines		53,06%	58,00%	6,06%	16,00%	33,25	22,59
	Flow		62,24%	49,00%	52,52%	54,00%	54,41	4,84
	Bottom side accumulation		36,73%	1,00%	2,02%	39,00%	19,65	18,21
	No particularity		13,27%	9,00%	43,43%	29,00%	23,68	13,62

Table 16 : Statistics of morphological criteria depending on the supports for Saturation stain.

Saturation stain		
		Tissue
Number of traces		100
Size	Centimetric	100%
Shape	Regular, diffuse, rounded edge	100%
Satellites	No	100%
Distribution	None	100%
Other	Concentricity	100%
	Porous target	100%
	No particularity	0%

Table 17 : Statistics of morphological criteria depending on the supports for Void pattern.

Void pattern							
		Paper	Tiling	Wood	Lino	Average (%)	Standard deviation (%)
Number of traces		50	50	50	50	-	-
Size	Centimetric	100%	100%	100%	100%	100	0,00
Shape	Specific / Function of the obstacle	100%	100%	100%	100%	100	0,00
Satellites	No	100%	100%	100%	100%	100	0,00
Distribution	None	100%	100%	100%	100%	100	0,00
Other	Stopped flow	0%	12%	8%	12%	8,00	5,66
	Absence of blood within a bloody area	100%	100%	100%	100%	100	0,00
	No particularity	100%	88%	92%	88%	92,00	5,66

Table 18 : Statistics of morphological criteria depending on the supports for Impact pattern.

Impact pattern							
		Paper	Tiling	Wood	Lino	Average (%)	Standard deviation (%)
Number of traces		300	300	300	300	-	-
Size	Millimetric	100%	100%	100%	100%	100	0,00
Shape	Ovoid	100%	100%	100%	100%	100	0,00
Satellites	No	100%	100%	100%	100%	100	0,00
Distribution	Radial	100%	100%	100%	100%	100	0,00
Other	No particularity	100%	100%	100%	100%	100	0,00

Table 19 : Statistics of morphological criteria depending on the supports for Focus of the impact pattern.

Focus of the impact pattern							
		Paper	Tiling	Wood	Lino	Average (%)	Standard deviation (%)
Number of traces		100	100	100	100	-	-
Size	Millimetric	100%	100%	100%	100%	100	0,00
Shape	Circular	100%	100%	100%	100%	100	0,00
Satellites	No	100%	100%	100%	100%	100	0,00
Distribution	None	100%	100%	100%	100%	100	0,00
Other	Area of convergence of projections	100%	100%	100%	100%	100	0,00
	No particularity	100%	100%	100%	100%	100	0,00

Table 20 : Statistics of morphological criteria depending on the supports for Gravitational stain.

Gravitational stain		
		Paper
Number of traces		100
Size	Millimetric	100%
Shape	Ovoid	100%
Satellites	No	100%
Distribution	Radial downward	100%
Other	No particularity	100%

Table 21 : Statistics of morphological criteria depending on the supports for Expiration pattern.

Expiration pattern							
		Paper	Tiling	Wood	Lino	Average (%)	Standard deviation (%)
Number of traces		100	10	10	10	-	-
Size	Millimetric to Centimetric	100%	100%	100%	100%	100	0,00
Shape	Various	100%	100%	100%	100%	100	0,00
Satellites	No	100%	100%	100%	100%	100	0,00
Distribution	None	100%	100%	100%	100%	100	0,00
Other	Bubble ring	100%	100%	100%	100%	100	0,00
	Spit	100%	100%	100%	100%	100	0,00
	Very elongated ovoid	50%	40%	40%	30%	46,92	6,06
	No particularity	0%	0%	0%	0%	0	0,00

Discussion

The terms derived from the statistical values obtained are defined in Appendix 2.

The literal exploitation of the statistics obtained according to the different bloodstain pattern, whatever the surface studied, is the following:

1. Drip stain on horizontal target

This pattern:

- has a systematically centimetric size ;
- is almost systematically circular in shape and almost never has an irregular contour. Variations in shape remain rare and are support's dependent.
- It is very common to observe at least one feature (teeth, spines, and irregular outline), with very important variations according to the supports. The presence of each of these features is rare with very important variation according to the supports;
- has, relative to its satellite stains, a similar probability (47/53%) of having a central or nil distribution, with very important variation according to the supports;
- has very frequently satellite stains with moderate variation according to the supports.
- The satellite stains are systematically millimetric and peripheral. They are frequently ovoid, but the variation is very important according to the supports.

Thus, the centimetric size, the circular shape and the absence of distribution are, according to our study, a combination of sufficient and robust criteria to specifically classify drip stain on horizontal target.

Table 22: Comparison of the admitted and obtained identification criteria for drip stain on horizontal target.

<table>
<tr><th rowspan="2">Name of model</th><th colspan="2">Identification criteria</th></tr>
<tr><th>Admitted [3]</th><th>Obtained</th></tr>
<tr><td rowspan="3">Drip stain on horizontal target</td><td>Diameter ≥ 3mm
Circular
None
No satellite
Possible deformation due to the support</td><td>Centimetric
Circular
None
Presence of satellites</td></tr>
<tr><td colspan="2">Differences were observed:

• size: the variation in size is due to the drop height. In our experiment, the drop height was fixed, which explains the recurrence of a centimetric size. We do not question the size data published by Ross Gardner [4] ;

• the presence of satellites: during our experiment, we observed satellite stains very frequently. However, because of their variations according to the supports, they cannot be considered as an identification criterion for this pattern.</td></tr>
<tr><td colspan="2">The admitted criteria of size, shape and distribution are confirmed. No additional criteria have been observed. Contrary to what is currently admitted, our study shows that the absence of a satellite is not a criterion for identifying this pattern.</td></tr>
</table>

2. Drip stain on no-horizontal target.

This pattern:

- has a systematically centimetric size;
- has a systematically ovoid shape ;
- has no distribution ;
- has never satellite stains;
- has almost systematically particular characteristics (trail, discontinuous trail, flow, discontinuous flow). It is rare to observe a flow, rare to observe a trail and very rare to observe a discontinuous trail or discontinuous flow. All these characteristics have very important variations according to the supports.

Thus, the centimetric size, the ovoid shape and the absence of satellite are, according to our study, a combination of sufficient and robust criteria to specifically classify drip stain on no-horizontal target.

Table 23 : Comparison of the admitted and obtained identification criteria for drip stain on no-horizontal target.

Name of model	Identification criteria	
	Admitted [3]	**Obtained**
Drip stain on no-horizontal target	width ≥ 3mm Ovoid None No satellite Possible deformation due to the support	Centimetric Ovoid None No satellite
	One difference was observed: • **size**: the variation in size is due to the drop height. In our experiment, the drop height was fixed, which explains the recurrence of a centimetric size. We do not question the size data published by Ross Gardner [4] ; • **the distribution**: in our experiment, we also observed none distribution. However, the distribution is not a criterion for identifying this model.	
	The admitted criteria are confirmed. No additional criteria have been observed. Contrary to what is currently admitted, our work shows that the distribution is not a criterion for identifying this pattern.	

3. Drip pattern

This pattern:

- has a systematically centimetric size;
- has a very frequently rounded shape, and very rarely a circular shape and almost never an irregular shape. Variations in shape remain rare and are a function of the supports.
- It is uncommon for them to have features (teeth, spines, irregular contours) with moderate variation according to the supports. Indeed, it is rare to observe irregular contours, and very rare to observe spines or teeth. The variations of these characteristics go from important to very important according to the supports;
- has, in relation to its satellite stains, a central distribution;

- presents systematically millimetric and peripheral satellite stains.
  They are frequently circular and rarely circular-ovoid. When they are circular-ovoid the majority are almost systematically circular. The variations in the shape of the satellite tracks are important according to the supports.
- The mother stain in relation to its satellite stains is systematically central.

Thus, the centimetric size, a central distribution and millimetric satellite stains mostly circular with a peripheral location are, according to our study, a combination of sufficient and robust criteria to specifically classify Drip pattern.

Table 24 : Comparison of the admitted and obtained identification criteria for drip pattern.

<table>
<tr><th rowspan="2">Name of model</th><th colspan="2">Identification criteria</th></tr>
<tr><th>Admitted [3]</th><th>Obtained</th></tr>
<tr><td rowspan="3">Drip pattern</td><td>Blood quantity function
Rounded edge
Central
Satellites
(Less than 10 mm, Circular and Peripheral)</td><td>Centimetric
-
Central
Satellites
(Millimeter, Circular Majority Peripheral)</td></tr>
<tr><td colspan="2">Differences were observed:
the shape : during our experiment the shape not being systematically the same, it cannot be considered as an identification criterion of this model;
the shape of the satellites : during our experiment, we observed the minority presence of ovoid satellite stains. Consequently, the criterion of circular satellite stains accepted, becomes mostly circular satellite stains.</td></tr>
<tr><td colspan="2">The admitted criteria of size, distribution and satellite tracks are confirmed. However, the observed satellite criterion circular majority is useful for the identification of this pattern. No additional criteria have been observed. Contrary to what is currently admitted, our work shows that the shape is not a criterion for the identification of Drip pattern.</td></tr>
</table>

4. Transfer stain

This pattern:

- has a systematically centimetric size, depending on the source surface;
- has a systematically specific shape;
- has no distribution;
- has lightly frequent satellite stains.
  They are systematically circular and millimetric. Their locations are frequently axial with an important variation according to the supports, but can rarely be lateral, with a very important variation according to the supports.
- presents very rarely trail, with a moderate variation according to the supports.

Thus, centimeter size and a specific shape are, according to our study, a sufficient and robust combination of criteria to specifically classify Transfer stain.

Table 25 : Comparison of the admitted and obtained identification criteria for transfer stain.

Name of model	Identification criteria	
	Admitted [3]	**Obtained**
Transfer stain	Function of the source surface Specific None No satellite	Centimetric Specific None Presence of satellite
	Differences have been observed: • **the presence of satellites**: in our experiment, we observe satellite stains Lightly frequent. Therefore, because of their non-systematic presence, they cannot be considered as an identification criterion for this pattern; • **the distribution**: during our experiment, we also observed none distribution. However, the distribution is not a criterion for identifying this pattern.	
	The admitted criteria of size, shape and distribution are therefore confirmed. No additional criteria were observed. Contrary to what is currently admitted, our work shows that the distribution and the absence of satellite are not identification criteria.	

5. Swipe pattern

This pattern:

- has a systematically centimetric size, depending on the source surface;
- has a systematically specific shape;
- has no distribution;
- has systematically internal striation;
- has systematically a decrease;
- has lightly frequent satellite stains.
  They are systematically circular and millimetric. Their locations are frequently axial or lateral with moderate to important variation according to the supports.
- is very rarely discontinuous, with an important variation according to the supports and almost never possess trails.

Thus, centimetric size, a specific shape with internal striation and a decrease are, according to our study, a combination of sufficient and robust criteria to specifically classify Swipe pattern.

Table 26 : Comparison of the admitted and obtained identification criteria for Swipe pattern.

<table>
<tr><th rowspan="2">Name of model</th><th colspan="2">Identification criteria</th></tr>
<tr><th>Admitted [3]</th><th>Obtained</th></tr>
<tr><td rowspan="3">Swipe pattern</td><td>Source surface function
Irregular edge
None
No satellite
Internal striation
Blood distribution (decrease shows movement)</td><td>Centimetric
Specific
None
-
Internal striation
Decrease</td></tr>
<tr><td colspan="2">Differences were observed:
the shape: we determined a specific shape for this pattern, defined as a stain whose shape is a function of the surface that created it;
the distribution: during our experiment, we also observed none distribution. However, the distribution is not a criterion for identifying this pattern;
the presence of satellites: in our experiment, we observed satellite stains lightly frequent. Therefore, because of their non-systematic presence, they cannot be considered as an identification criterion for this pattern.</td></tr>
<tr><td colspan="2">The admitted criteria of size, distribution, internal striation, and decrease are confirmed. Contrary to what is currently accepted, our work shows us that the shape changes from irregular contours to specific shape as an identification criterion. No additional criteria were observed. Contrary to what is currently admitted, our work shows that the distribution is not an identification criterion for this pattern.</td></tr>
</table>

6. Alteration contact

This pattern:

- has a systematically centimetric size, depending on the amount of blood ;
- has a systematically specific shape;
- has no distribution;
- has rarely satellite stains.
  They are systematically circular and millimetric. Their location is very frequently axial with an important variation according to the supports but also present lateral with a very important variation according to the supports.
- Present systematically a skeleton ;
- presents almost never a trail.

Thus, the centimetric size, a specific shape and the presence of a skeleton are, according to our study, a combination of sufficient and robust criteria to specifically classify Alteration contact.

Table 27 : Comparison of the admitted and obtained identification criteria for Alteration contact.

Name of model	Identification criteria	
	Admitted [3]	**Obtained**
Alteration contact	Function of the source surface Marked edge / specific shape None No satellite Blood concentrated on the contour, and less to absent in the trace	Centimetric Specific None - Skeleton
	Differences were observed: • **the distribution**: in our experiment, we also observed none distribution. However, the distribution is not a criterion for identifying this pattern; • **the presence of satellites**: in our experiment, we rarely observed satellite stains. Therefore, because of their non-systematic presence, they cannot be considered as an identification criterion for this pattern.	
	The admitted criteria of size, shape, distribution, and presence of a skeleton are confirmed. No additional criteria were observed. Contrary to what is currently admitted, our work shows that the distribution and the absence of a satellite are not identification criteria.	

7. Wipe pattern

This pattern:

- has a systematically centimetric size;
- has a shape with systematically a specific edge;
- has no distribution;
- has systematically a decrease;
- presents systematically a skeleton ;
- presents frequently internal striations with very important variation according to the supports (this very important variation is due to the total absence of internal striation on one of the supports, namely the linoleum);
- has never satellite stains;
- presents almost never trail with very rare variations according to the supports.

Thus, centimeter size, a specific shape, the presence of a skeleton, a decrease and an internal striation are, according to our study, a combination of sufficient and robust criteria to specifically classify Wipe pattern.

Table 28 : Comparison of the admitted and obtained identification criteria for Wipe pattern.

<table>
<tr><th rowspan="2">Name of model</th><th colspan="2">Identification criteria</th></tr>
<tr><th>Admitted [3]</th><th>Obtained</th></tr>
<tr><td rowspan="3">Wipe pattern</td><td>Depending on the amount of blood
Irregular edge
None
No satellite
Internal striation</td><td>Centimetric
Specific
None
No satellite
Internal striation, Skeleton, Decrease</td></tr>
<tr><td colspan="2">Differences were observed:
the shape: we determined a specific shape for this pattern, defined as a stain whose shape is a function of the surface that created it;
the distribution: during our experiment, we also observed none distribution. However, the distribution is not a criterion for identifying this pattern;
absence of satellite: during our experiment, we also observed an absence of satellite. However, the absence of satellite is not an identification criterion of this pattern;
Skeleton / Decrease: we observe in addition to what is accepted, the systematic presence of a skeleton and a decrease. They can therefore be considered as identification criteria for this pattern.</td></tr>
<tr><td colspan="2">The admitted criteria of size, distribution, absence of satellite and presence of internal striation are confirmed. The Skeleton and Decrease criteria were systematically observed and are therefore useful for the identification of this pattern. Contrary to what is currently admitted, our work shows that the distribution and the absence of satellite are not identification criteria.</td></tr>
</table>

8. Pool

This pattern:

- has a systematically centimetric size, depending on the amount of blood ;
- has a shape with systematically a regular edge;
- has no distribution;
- has never satellite stains;
- presents very frequently crowns with no variation according to the supports. At the time of our experiment, 90% of the stains were dried before their photographic catch, one can deduce with that that the crowns are systematically present on dry stains.

Thus, the centimetric size, a regular edge, the absence of satellite and a non-porous support are, according to our study, a combination of sufficient and robust criteria to specifically classify Pool.

Table 29 : Comparison of the admitted and obtained identification criteria for pool.

<table>
<tr><th rowspan="2">Name of model</th><th colspan="2">Identification criteria</th></tr>
<tr><th>Admitted [3]</th><th>Obtained</th></tr>
<tr><td>Pool</td><td>Depending on the amount of source blood
Regular edge depending on the target area
None
No satellite
Frequent alterations / non-porous target surface</td><td>Centimetric
Regular edge
None
No satellite
Non-porous support</td></tr>
<tr><td colspan="2">One difference was observed:
• the distribution: in our experiment, we also observed none distribution. However, the distribution is not a criterion for identifying this pattern.</td></tr>
<tr><td colspan="2">The admitted criteria of size, shape, distribution, and absence of satellite on a non-porous support are confirmed. No additional criteria have been observed. Contrary to what is currently admitted, our work shows that the distribution is not an identification criterion.</td></tr>
</table>

9. Flow pattern

This pattern:

- has a systematically centimetric size, the length of which is a function of the amount of blood ;
- has a shape with systematically regular and parallel edges;
- has no distribution;
- has never satellite stains;
- has almost never a discontinuous start with moderate variation according to the supports.

Thus, centimeter size and regular, parallel edges are, according to our study, a sufficient and robust combination of criteria to specifically classify Flow pattern.

Table 30 : Comparison of the admitted and obtained identification criteria for Flow pattern.

<table>
<tr><th rowspan="2">Name of model</th><th colspan="2">Identification criteria</th></tr>
<tr><th>Admitted [3]</th><th>Obtained</th></tr>
<tr><td rowspan="3">Flow pattern</td><td>Width depending on the amount of source blood
Regular and parallel edges
None
No satellite
Possible deviation due to support and/or movements</td><td>Centimetric

Regular and parallel edges
None
No satellite</td></tr>
<tr><td colspan="2">Differences were observed:
the distribution: in our experiment, we also observed none distribution. However, the distribution is not a criterion for identifying this pattern.
Absence of satellite: during our experiment, we also observed an absence of satellite. However, the absence of satellite is not an identification criterion of this pattern.</td></tr>
<tr><td colspan="2">The admitted criteria of size, shape, distribution, and absence of satellite are confirmed. No additional criteria have been observed. Contrary to what is currently admitted, our work shows that the distribution and the absence of satellite are not criteria of identification.</td></tr>
</table>

10. Splash pattern

This pattern:

- has a systematically centimetric size;
- has a shape that is almost systematically rounded and almost never irregular. Variations in shape are very rare according to the supports;
- has a mother stain in relation to its satellite stains whose distribution is systematically central ;
- has systematically millimetric and peripheral satellites satins.
  They are systematically circular-ovoid in shape with a majority of ovoid.
- presents frequently teeth and rarely irregular contours with rare variations according to the supports. They rarely have spines with very important variations according to the supports. Finally, they almost never have crowns of spines, V-shaped ovoid with rare variations according to the supports. It was also observed on some stains, on the paper support, that the circular satellite stains were close to the mother stain whereas the ovoid satellite stains were more distant.

Thus, the centimetric size, a rounded edge, a central distribution of the mother stain and circular-ovoid millimetric satellites mostly ovoid with a peripheral localization are, according to our study, a combination of sufficient and robust criteria to specifically classify Splash pattern.

Table 31 : Comparison of the admitted and obtained identification criteria for Splash pattern.

<table>
<tr><th rowspan="2">Name of model</th><th colspan="2">Identification criteria</th></tr>
<tr><th>Admitted [3]</th><th>Obtained</th></tr>
<tr><td rowspan="3">Splash pattern</td><td>Function of the amount of blood
Altered edge
Central
Satellites
(Less than 10 mm, ovoid and peripheral)</td><td>Centimetric
Rounded edge
Central
Satellites
(Millimetric circular-ovoid
Majority ovoid and peripheral)</td></tr>
<tr><td colspan="2">Differences were observed:
the shape: in our experiment, the term rounded edges corresponds more to the observed shapes ;
the shape of the satellites: during our experiment, we note the minority presence of circular satellite stains. Consequently, the criterion of ovoid satellite stains accepted, becomes circular-ovoid satellite stains majority ovoid.</td></tr>
<tr><td colspan="2">The admitted criteria of size, distribution, and presence of satellite are confirmed. Circular satellite satins have been observed, the ovoid majority criterion becomes a useful criterion for the identification of this pattern. Contrary to what is currently admitted, our work shows that the criterion for identifying the shape is rounded edges.</td></tr>
</table>

11. Projected pattern on horizontal target

This pattern :

- has a systematically centimetric size, depending on the quantity of blood;
- has a very frequently spine shape and very rarely an irregular shape with a moderate variation according to the supports;
- has in relation to its satellite stains a central distribution;
- has systematically millimetric and peripheral satellite stains.
  They are frequently circular-ovoid and rarely ovoid, with a very important variation according to the supports.
  When they are circular-ovoid the majority are almost systematically ovoid.
- Has systematically very elongated ovoid and has almost never V-ovoid and teeth, with very rare variation according to the supports.

Thus, centimetric size, a central distribution, majority ovoid and very elongated ovoid satellite stains are, according to our study, a combination of sufficient and robust criteria to specifically classify projected pattern on a horizontal target

Table 32: Comparison of the admitted and obtained identification criteria for projected pattern on a horizontal target

<table>
<tr><th rowspan="2">Name of pattern</th><th colspan="2">Identification criteria</th></tr>
<tr><th>Admitted [3]</th><th>Obtained</th></tr>
<tr><td rowspan="3">projected pattern on a horizontal target</td><td>Depending on the quantity of blood
Spine shape
Central
Satellites
(Less than 10 mm, Ovoid and peripheral)
Spines follow the fall axis</td><td>Centimetric
-
Central
Satellites
(Millimetric, Majority ovoid, Peripheral)
Very elongated ovoid</td></tr>
<tr><td colspan="2">Differences were observed:
the shape: in our experience, we observe very rarely stains with an irregular edge. Since the spine shape is not systematic, it cannot be considered as an identification criterion for this pattern;
the satellites shape: in our experiment, we observe a minority of circular satellite stains. Therefore, the criterion of ovoid stains admitted, becomes majority ovoid stains.
very elongated ovoid: we observe in addition to what is admitted, the systematic occurrence of very elongated ovoid. So, it can be considered as an identification criterion of this pattern.</td></tr>
<tr><td colspan="2">The admitted criteria of size, distribution, and presence of satellite are confirmed. The very elongated ovoid criterion has been observed and is therefore relevant for the identification of this pattern. Contrary to what is admitted, our work shows that the shape is not a criterion of identification.</td></tr>
</table>

12. Projected pattern on no horizontal target

This pattern :

- has a systematically centimetric size, depending on the quantity of blood;
- has a systematically spine shape;
- has systematically a distribution that does not correspond to any of the known distributions;
- has systematically millimetric ovoid satellite stains.
  They are systematically localized in axial and lateral directions.
- has systematically flows;
- has rarely satellite swarms with very important variations according to the supports.

Thus, centimetric size, a spine shape, the presence of flows and ovoid millimetric satellite stains with axial and lateral localization are, according to our study, a combination of sufficient and robust criteria to specifically classify projected pattern on a no-horizontal target.

Table 33: Comparison of the admitted and obtained identification criteria for projected pattern on a no-horizontal target

<table>
<tr><th rowspan="2">Name of pattern</th><th colspan="2">Identification criteria</th></tr>
<tr><th>Admitted [3]</th><th>Obtained</th></tr>
<tr><td rowspan="3">Projected pattern on a no-horizontal target</td><td>Depending on the quantity of blood
Ovoid with obvious volume
Linear or curvilinear
Satellites
(Less than 10 mm, Ovoid and rare)
Flows</td><td>Centimetric
Spine shape
-
Satellites
(Millimetric, ovoid, axial/lateral)
Flows</td></tr>
<tr><td colspan="2">Differences were observed:
the shape : in our experiment, the word spine shape is more appropriate for the observed shapes;
the distribution : in our experiment, the observed distribution does not correspond to any of the referenced ones. The distribution cannot be considered as an identification criterion;
the satellites localization: these are situated axially or laterally in relation to the mother stain.</td></tr>
<tr><td colspan="2">The admitted criteria of size, satellite and flow occurrence are confirmed. The criterion of axial and lateral localization of satellites has been observed, and is relevant to the identification of this pattern. Contrary to what is admitted, our work shows that the distribution is not a criterion for the identification of this pattern.</td></tr>
</table>

13. Cast-off pattern

This pattern:

- has systematically millimetric stains;
  We also see very rarely centimetric stains between millimetric stains.
  These stains have very frequently a decreasing size with a very important variation according to the supports.
- has very frequently circular-ovoid stains and very rarely circular stains with a moderate variation according to the supports;
- has frequently a linear distribution and rarely a curvilinear distribution with rare variation according to the supports;
- has never satellite stains;
- has very rarely swarm and almost never double bundles with respectively rare and very rare variations according to the supports.

Thus, millimetric size and linear to curvilinear distribution are, according to our study, a combination of sufficient and robust criteria to specifically classify Cast-off pattern

Table 34: Comparison of the admitted and obtained identification criteria for Cast-off pattern

Name of pattern	Identification criteria	
	Admitted [3]	**Obtained**
Cast-off pattern	< 4 mm Circular to ovoid (evolving form) Linear or parallel axes No satellite Parallel directional axes	Millimetric Circular to ovoid Linear to curvilinear No satellite
	Differences were observed: • **the size** : in our experiment, stains larger than 4mm were observed, going very rarely up to 10mm; • **the shape** : in our experiment, circular to ovoid shapes were observed. However, the shape is not considered as an identification criterion for this pattern; • **the absence of a satellite** : in our experiment, we also observed an absence of satellite. However, the absence of a satellite is not a criterion for identifying this pattern.	
	The admitted criteria of size, shape, distribution, and absence of satellite are confirmed. No additional criteria were observed. Contrary to what is admitted, our work shows that the shape and the absence of a satellite are not criteria for the identification of this pattern.	

14. Impact stain on primary horizontal target

This pattern:

- has systematically centimetric size;
- has a shape that is either spiny or has an altered edge with a similar probability (52/48%) with very important variations according to the supports;
- has no distribution;
- has systematically peripheral satellite stains with a millimetric size.
  They are frequently circular-ovoid in shape and rarely ovoid with very important variations according to the supports. They are almost never circular, with very rare variations according to the supports. When they are circular-ovoid, the majority is very frequently ovoid with moderate variations according to the supports. The mother stain in relation to its satellite stains is very frequently central, with moderate variations according to the supports.
- has lightly frequent spines and almost never V-ovoid with respectively very important and very rare variations according to the supports.

Thus, the centimetric size, bundles and millimetric satellite stains majority ovoid with a peripheral localization are, according to our study, a combination of sufficient and robust criteria to specifically classify Impact stain on a primary horizontal target.

Table 35: Comparison of the admitted and obtained identification criteria for Impact stain on a primary horizontal target.

<table>
<tr><th rowspan="2">Name of pattern</th><th colspan="2">Identification criteria</th></tr>
<tr><th>Admitted [3]</th><th>Obtained</th></tr>
<tr><td rowspan="3">Impact stain on a primary horizontal target</td><td>Depending on the quantity of blood
Spine shape
Central
Satellites
(Less than 10 mm, ovoid to circular and axial)
Spines linked or not</td><td>Centimetric
-
-
Satellites
(Millimetric, majority Ovoid and Peripheral)
Bundles</td></tr>
<tr><td colspan="2">Differences were observed:
the shape : in our experiment, different forms were observed. As this is not systematic, it cannot be considered as an identification criterion for this pattern;
the distribution : in our experiment, different distributions were observed. As this is not systematic, it cannot be considered as an identification criterion for this pattern;
the bundle : In addition to what is recognized, we observe the systematic presence of bundles. So, it can be considered as an identification criterion of this pattern.</td></tr>
<tr><td colspan="2">The admitted criteria of size and presence of satellites are confirmed. The bundle criterion has been observed and is relevant for the identification of this pattern. Contrary to what is admitted, our work shows that the shape and the distribution are not criteria for the identification of this pattern.</td></tr>
</table>

15. Impact stain on a secondary no horizontal target

This pattern:

- has systematically millimetric and very frequently centimetric stains, with very rare variations according to the supports;
- has frequently circular-ovoid stains, with frequently an ovoid majority, and very rarely of circular shape, with in both cases a moderate variation according to the supports.
  They are almost never ovoid in shape with very rare variation according to the supports.
- has no distribution;
- has never satellite stains.
- has stains that lightly frequent show flows with rare variations according to the supports, rarely spines and very rarely bottom side accumulation with very important variations according to the supports.

Thus, millimetric to centimetric size and a circular-ovoid shape are, according to our study, a combination of sufficient and robust criteria to specifically classify projected pattern on a no-horizontal target.

Table 36: Comparison of the admitted and obtained identification criteria for Impact stain on a secondary no-horizontal target.

<table>
<tr><th rowspan="2">Name of pattern</th><th colspan="2">Identification criteria</th></tr>
<tr><th>Admitted [3]</th><th>Obtained</th></tr>
<tr><td rowspan="3">Impact stain on a secondary no-horizontal target</td><td>Various
Circular to ovoid
In V
No satellite
Near a horizontal surface</td><td>Millimetric to centimetric
Circular-ovoid
None
No satellite</td></tr>
<tr><td colspan="2">Differences were observed:
the distribution : in our experiment, none distribution were observed, the V-distribution criterion cannot be considered as an essential identification criterion for this pattern;
the absence of a satellite : in our experiment, we also observed an absence of satellite. However, the absence of satellite is not an identification criterion for this pattern;</td></tr>
<tr><td colspan="2">The admitted criteria of size, shape and absence of satellite are confirmed. No additional criteria were observed. Contrary to what is admitted, our work shows that the distribution and the absence of satellite are not criteria for the identification of this pattern.</td></tr>
</table>

16. Saturation stain

This pattern:

- has systematically centimetric size, depending on the quantity of blood;
- has systematically regular, rounded and diffused edge;
- has no distribution;
- has never satellite stains;
- has systematically concentric.

Thus, centimetric size and porous support criteria are, according to our study, a combination of sufficient and robust criteria to specifically classify saturation stain.

Table 37: Comparison of the admitted and obtained identification criteria for saturation stain

<table>
<tr><th rowspan="2">Name of pattern</th><th colspan="2">Identification criteria</th></tr>
<tr><th>Admitted [3]</th><th>Obtained</th></tr>
<tr><td rowspan="3">Saturation stain</td><td>Depending on the quantity of blood source
Regular but diffused edges
None
No satellite
Porous support</td><td>Centimetric
Regular, rounded, and diffused edge
None
No satellite
Concentric, porous support</td></tr>
<tr><td colspan="2">Differences were observed:
the distribution : in our experiment, we also observed a none distribution. However, the distribution is not an identification criterion for this pattern;
the absence of a satellite : in our experiment, we also observed an absence of satellite. However, the absence of satellite is not an identification criterion for this pattern;
the concentricity : in addition to what is recognized, we observe the systematic occurrence of concentricity. It can be considered as an identification criterion for this pattern.</td></tr>
<tr><td colspan="2">The admitted criteria of size, shape, distribution, absence of satellite and porous support are confirmed. The criteria of concentricity and rounded edge have been observed. Contrary to what is admitted, our work shows that the shape, the distribution and the absence of satellite are not criteria for the identification of this pattern.</td></tr>
</table>

17. Void pattern

This pattern:

- has systematically centimetric size, depending on the obstacle;
- has systematically a shape depending on the obstacle;
- has no distribution;
- has systematically an absence of blood within a bloodstain pattern which is a function of the height of the obstacle;
- has never satellite stains;
- has very rarely stopped flows with rare variations according to the support;

Thus, centimetric size and the absence of blood within a bloodstain pattern are, according to our study, a combination of sufficient and robust criteria to specifically classify Void pattern.

Table 38: Comparison of the admitted and obtained identification criteria for Void pattern

<table>
<tr><th rowspan="2">Name of pattern</th><th colspan="2">Identification criteria</th></tr>
<tr><th>Admitted [3]</th><th>Obtained</th></tr>
<tr><td rowspan="3">Void pattern</td><td>Various
Function of the support
Within a bloodstain area
No satellite</td><td>Centimetric
Function of the obstacle
Absence of blood within a bloodstain area
No satellite</td></tr>
<tr><td colspan="2">Differences were observed:
the size : in our experiment, several sizes have been observed. However, it can be assumed that this stain pattern is systematically centimetric because the millimetric void will not be discernible;
the shape : in our experiment, we observed a shape systematically function of the obstacle. However, this is not considered as an identification criterion for this pattern;
the absence of a satellite: we also observe a systematic absence of satellite. However, it is not considered as an identification criterion for this pattern.</td></tr>
<tr><td colspan="2">The admitted criteria of absence of blood within a bloodstain area and absence of satellite are confirmed and, contrary to the admitted criteria, our experience shows us that the size is systematically centimetric. No additional criteria have been observed. Contrary to what is admitted, our work shows that the shape and the absence of satellite are not criteria for the identification of this model.</td></tr>
</table>

18. Impact pattern

This pattern:

- has systematically millimetric stains;
- has systematically ovoid stains;
- has stains whose distribution is radial;
- has never satellite stains.

Thus, millimetric size, an ovoid shape and a radial distribution are, according to our study, a combination of sufficient and robust criteria to specifically classify Impact pattern

Table 39: Comparison of the admitted and obtained identification criteria for Impact pattern

<table>
<tr><th rowspan="2">Name of pattern</th><th colspan="2">Identification criteria</th></tr>
<tr><th>Admitted [3]</th><th>Obtained</th></tr>
<tr><td rowspan="3">Impact pattern</td><td>< 4 mm
Ovoid to Circular
Radial
No satellite
Convergence to a possible center of figure</td><td>Millimetric
Ovoid
Radial
No satellite</td></tr>
<tr><td colspan="2">Differences were observed:
the shape : in our experiment, we observed systematically stains with ovoid shape;
the absence of a satellite : we also observe a systematic absence of satellite. However, it is not considered as an identification criterion for this pattern.</td></tr>
<tr><td colspan="2">The admitted criteria of size, distribution and absence of satellite are confirmed and, in contrast to the admitted, our experience shows us that the shape is systematically ovoid. No additional criteria have been observed. Contrary to what is admitted, our work shows that the absence of satellite is not a criterion for the identification of this pattern.</td></tr>
</table>

19. Focus of the impact pattern

This pattern:

- has systematically millimetric stains;
- has systematically circular stains;
- has no distribution;
- is systematically located at the convergence of several millimetric ovoid stains with radial distribution;
- has never satellite stains.

Thus, millimetric size, a circular shape and is located at the convergence of ovoid projections with radial distribution are, according to our study, a combination of sufficient and robust criteria to specifically classify Focus of the impact pattern.

Table 40: Comparison of the admitted and obtained identification criteria for Focus of the impact pattern

<table>
<tr><th rowspan="2">Name of pattern</th><th colspan="2">Identification criteria</th></tr>
<tr><th>Admitted [3]</th><th>Obtained</th></tr>
<tr><td rowspan="3">Focus of the impact pattern</td><td>< 4 mm
Circular
Concentric
No satellite
Projection by convergent impact towards this center</td><td>Millimetric
Circular
None
No satellite
Area of convergence of projections</td></tr>
<tr><td colspan="2">Differences were observed:
the distribution : in our experiment, we observed systematically no distribution, so it cannot be considered as an identification criterion for this pattern;
the absence of a satellite : we also observe a systematic absence of satellite. However, it is not considered as an identification criterion for this pattern.</td></tr>
<tr><td colspan="2">The admitted criteria of size, shape, absence of satellite and convergence are confirmed. No additional criteria were observed. Contrary to what is currently accepted, our work shows that the distribution and the absence of satellite are not criteria for the identification of this pattern.</td></tr>
</table>

20. Gravitational stain

This pattern:

- has systematically millimetric stains;
- has systematically ovoid stains;
- has stains whose distribution is systematically radial descending;
- has never satellite stains.

Thus, millimetric size, an ovoid shape and a radial descending distribution are, according to our study, a combination of sufficient and robust criteria to specifically classify Gravitational stain.

Table 41: Comparison of the admitted and obtained identification criteria for Gravitational stain

<table>
<tr><th rowspan="2">Name of pattern</th><th colspan="2">Identification criteria</th></tr>
<tr><th>Admitted [3]</th><th>Obtained</th></tr>
<tr><td rowspan="3">Gravitational stain</td><td>Large and stretched
Ovoid
Radial descending
No satellite
To be linked to projections by release</td><td>Millimetric
Ovoid
Radial descending
No satellite</td></tr>
<tr><td colspan="2">Differences were observed:
the size : in our experiment, we observed systematically millimetric stains, so it can be considered as an identification criterion for this pattern;
the absence of a satellite : we also observe a systematic absence of satellite. However, it is not considered as an identification criterion for this pattern.</td></tr>
<tr><td colspan="2">The admitted criteria of shape, distribution and absence of satellite are confirmed by our experience and, contrary to what is admitted, our experience shows us that the size is systematically millimetric. No additional criteria have been observed. Contrary to what is admitted, our work shows that the absence of satellite is not a criterion for the identification of the Gravitational stain.</td></tr>
</table>

21. Expiration pattern

This pattern:

- has systematically millimetric to centimetric stains;
- has systematically varied shape stains;
- has no distribution;
- has never satellite stains;
- has systematically bubbles ring and saliva;
- has lightly frequent very elongated ovoid with moderate variation according to the supports.

Thus, millimetric to centimetric size, varied shape, presence of bubble ring and saliva are, according to our study, a combination of sufficient and robust criteria to specifically classify Expiration pattern.

Table 42: Comparison of the admitted and obtained identification criteria for Expiration pattern

<table>
<tr><th rowspan="2">Name of pattern</th><th colspan="2">Identification criteria</th></tr>
<tr><th>Admitted [3]</th><th>Obtained</th></tr>
<tr><td>Expiration pattern</td><td>< 4 mm
Circular to ovoid
None
No satellite
Presence of bubble ring, mucus, saliva, dilution</td><td>Millimetric to Centimetric
Varied
None
No satellite
Saliva, bubble ring</td></tr>
<tr><td colspan="2">Differences were observed:
the size : in our experiment, we observed stains larger than 4 mm, going up to 10 mm and more;
the distribution : In our experiment, we observed a none distribution. However, the distribution is not a criterion for identifying this pattern;
the absence of a satellite : we also observe a systematic absence of satellite. However, it is not considered as an identification criterion for this pattern.</td></tr>
<tr><td colspan="2">The admitted criteria of shape, distribution, absence of satellite, presence of saliva and bubble ring are confirmed and, contrary to what is admitted, our experience shows us that the size can be greater than 4mm. No additional criteria have been observed. Contrary to what is admitted, our work shows that the distribution and the absence of satellite are not criteria of identification of this pattern.</td></tr>
</table>

Conclusion

To determine the robustness of the morphological criteria useful for the blood stains patterns classification (at least size, shape, distribution), we carried out an experiment which consisted of reproduce a hundred times all the blood stains patterns on four supports (paper, tiles, linoleum and wood). The statistical analysis of the results obtained allowed us to identify the sufficient and systematic criteria of each pattern. Then, we made a comparison between the admitted criteria and those obtained during our experiment. Some differences could be observed leading to changes for the patterns:

- **Drip pattern**: shape is no longer considered as an identification criterion;
- **Wipe pattern and swipe pattern**: the identification criterion for shape changes from irregular edge to specific shape;
- **Splash pattern**: the identification criterion for shape changes from altered edge to rounded edge;
- **projected pattern on a no-horizontal target**: the identification criterion for shape changes from ovoid to spiny and the criterion for satellite location changes from rare to axial and lateral;
- **Impact stain on a primary horizontal target**: the bundle criterion is considered as an identification criterion;
- **Impact stain on a secondary no-horizontal target**: in the absence of V-distribution, the identification of stains will be limited to projections. The accepted V-distribution has not been observed, and is no longer considered as an essential identification criterion;
- **Impact pattern**: the identification criterion for shape changes from ovoid/circular to ovoid;
- **Gravitational stains**: the identification criterion for size changes from wide/stretched to millimetric;
- **Expiration pattern**: the identification criterion for size changes from <4mm to millimetric/ centimetric.

However, most of the admitted criteria have been confirmed, affirming their robustness. This experiment will allow the Bloodstain Pattern Analysts to make the most fair and impartial classification that is possible. According to the results of our experiment, a new identification key could be established.

Image bank

A free access to the database containing all the pictures of the bloodstains realized is available via http://l-a-c.expert to serve as an image bank and to support future research.

Conflicts of interest

The authors declare that they have no competing financial interests or personal relationships that could have influenced the work presented in this article.

Acknowledgments

Special thanks to Marie-Gabrielle Pasquet for reviewing and correcting this article. We also thank Mr. Alphonse Calenda, Mr. Frank Crispino and Ms. Samaneh Shahgaldi, university professors, for their trust and availability.

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Definition of the morphological criteria used

Altered edge :
Bloodstain with part of the outlines showing deformation not related to the target.

Average :
Presence of the morphological criteria whatever the target.

Axial :
Area above or below a bloodstain in relation to the direction of the stain's motion.

Bifurcation:
A bloodstain with two distinct lines that meet to make a single line

Bottom side accumulation :
Quantity of blood finds to the lowest point of a non-horizontal target.

Bubble ring :
The presence of a white area without blood resulting from the current or past presence of air.

Bundle :
A set of bloodstains that converge in a conical arrangement to a mother stain

Centimetric :
Bloodstain whose width is equal to or greater than 10mm.

Central :
Bloodstain located in the center of other traces belonging to the same bloodstain pattern.

Circular :
A bloodstain whose edge forms a circle.

Circular – Ovoid :
Bloodstain pattern that has both, at least, a circular and an ovoid stain, without defining a specific area for each other.

Circular then ovoid :
A bloodstain pattern that has ovoid stain patterns following circular stains.

Concentric :
Bloodstain with several circles having the same center.

Continuous trail :
A small amount of liquid blood that continues at the end of a bloodstain.

Convergence :
Ovoid bloodstain whose axes tend to meet at a single area.

Crown :
Bloodstain whose outline is darker than the center.

Crown of spines :
Circle or semi-circle made up of spines in which there is a bloodstain with more regular edges.

Curvilinear :
A bloodstain pattern whose general axis is curved..

Decrease :
Significant observation of a color change within a bloodstain

Discontinuous flow :
A bloodless area observed in the flow, most often at the base of the flow.

Discontinuous start :
A cast in which the highest point has heterogeneous, unlinked bloodstains.

Discontinuous stain :
A bloodstain with one or more interruptions in its general form.

Discontinuous trail :
Line not joined to a bloodstain in the continuity of the stain.

Distribution :
Bloodstain repartition between each other.

Function of the blood quantity :
Bloodstain whose size depends on the quantity of blood available.

Function of the source surface :
A bloodstain whose size depends on the surface that created it.

Heterogeneous size :
A bloodstain pattern in which stains are found with sizes varying from 1mm to several centimeters.

Horizontal position :
Parallel position to the ground of the target.

Internal striation :
Group of parallel lines found inside a bloodstain.

Irregular edge :
Bloodstain whose edges possess a notable variation in shape.

Latera l:
Areas on each side of the main axis of a bloodstain

Linear :
Bloodstain pattern with the general axis forming a line

Location of the satellite stain :
Distribution of satellite bloodstain in relation to the mother stain.

Majority :
Bloodstain pattern with circular and ovoid satellite stains when one of these shapes is present in more than 60%.

Millimetric :
Bloodstain whose width is strictly less than 10mm.

Mother stain :
Bloodstain from which satellite stains are generated.

No particularity :
Bloodstain with no notable characteristics.

Non-horizontal position :
Oblique to perpendicular position to the ground of the target.

None :
Bloodstain pattern that has no distribution.

Object/projection interaction :
An interrupted area that is larger in size than the area of the element that caused it.

Obstacle function :
An interruption area whose size depends on the form of the element that created the obstacle.

Ovoid :
A bloodstain with an oval edge whose opposite ends are not similar.

Parallel and regular sides :
When the opposites ends of the bloodstain follow the axis of the bloodstain and whose only variations in width depend on the target.

Peripheral :
Satellite bloodstains present around a mother stain.

Regular edge :
Bloodstain whose outline does not have a significant variation of form.

Rounded edge :
Bloodstain whose outline has a general circular appearance without forming a perfect circle.

Satellite stain :
Secondary bloodstain consecutive to a mother stain.

Skeleton :
Only the outline of the bloodstain is present.

Specific shape :
A bloodstain whose form is a function of the surface that created it. This form may or may not define this surface.

Spine :
A stain with growths on its borders that are more than 5 mm long.

Spine shape :
A bloodstain whose outline has spines around all or part of its edge.

Standard deviation :
Variation in the presence of morphological criteria in function of the 4 targets.

Stopped flow :
Flow stopped permanently in its flow in a not natural way (presence of an object...)

Swarm :
Concentration of stains (>5) systematically above the bloodstain pattern.

Teeth :
A stain with small outgrowths less than 5 mm in length present on the edge of a stain.

V-ovoid :
Distribution of ovoid spatters in 2 bundles forming a V.

Varied form and size :
Bloodstain pattern composed of shapes other than circular and ovoid and of heterogeneous sizes going from the millimeter to several centimeters.

Very elongated ovoid :
Ovoid projection whose width is less than 5mm and length is more than 10mm.

Scales of measurement

Average :

[100]%	= Systematically
[95-100[%	= Almost systematically
[80-95[%	= Very frequently
[60-80[%	= Frequently
[40-60[%	= Lightly frequent
[20-40[%	= Rarely
[5-20[%	= Very rarely
[0-5[%	= Almost never
[0]%	= Never

Standard deviation :

[0]% :	No variation according to the supports
[0%- 2[% :	Very rare variation according to the supports
[2%-6[% :	Rare variation according to the supports
[6% - 10[% :	Moderate variation according to the supports
[10%-14[% :	Important variation according to the supports
>or=14% :	Very important variation according to the supports