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Review

Bloodstain classification methods: A critical review and a look to the future

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ABSTRACT

Classifying bloodstains is an essential part of Bloodstain Pattern Analysis. Various experts have developed methods. Each method considers the same basic bloodstain pattern types. These use either terminology based on the observable characteristics or the mechanistic cause of the bloodstain patterns as part of the classification process. This review paper considers ten classification methods from fourteen sources, which are used to classify bloodstain patterns. There are fundamental differences in how the patterns are classified, how differentiated the classification is, and whether the classification process uses clear, unambiguous criteria, and is susceptible to contextual bias. Experts have also reported issues with classifying bloodstains that have indistinguishable features. These differences expose key limitations with current classification methods: mechanistic terminology is too heavily relied on, and the classification process is susceptible to contextual bias. The development of an unambiguous classification method, based on directly observable characteristics within bloodstain patterns is recommended for future work.

1. Introduction

The classification of bloodstain patterns is an essential part of bloodstain pattern analysis (BPA) that involves grouping bloodstains with similar characteristics into specific categories using established criteria [12,22,29]. According to scholars, bloodstain pattern classification can be conducted without the use of contextual information or evidence [12,35–37,40,41,45] and, by avoiding its usage, the classification process becomes an "objective analysis" [48, pp. 554]. Some classification methods go further than grouping bloodstains with similar observable pattern characteristics by using them to associate a causal mechanism [2,3].

As part of the review of Forensic Science in the 2009 National Research Council report, BPA was criticized for its lack of objectivity and rigour in the decision-making processes and the conclusions drawn by analysts [30]. Although there was then an increase in published work to show the scientific legitimacy of the discipline and to quantify uncertainties (examples include [1,5–7,15,26,27]), there has been little scholarly work in relation to bloodstain classification. This continues despite the National Research Council report explicitly emphasizing the necessity for objectivity and rigour when making decisions and drawing conclusions. It has already been recognized that an internationally standardized approach is crucial, given that it will increase rigour and consistency, enable all analysts to interpret one another's reports, and allow for standardized BPA education and training [10,16]. Attempts have been made to standardize the methodology using a taxonomic system [12,17,31], but there currently is not a nationally or internationally standardized method [10]. Additionally, even though the Academy Standards Board (ASB) has provided standardized terminology [34], it is only advisory, as it is up to individual analysts and organizations to determine the terminology and methods to utilize. It is also important to note that the ASB standard terminology is mechanistic in nature, so it is of little help in the classification process or in the development of a classification system based on directly observable characteristics.

This paper collates key bloodstain classification methods that are reported in academic and grey literature[1] into a single location, provides a description of each of the methods, and then presents a critical review and evaluation of these approaches to initiate the development of an unambiguous and reproducible method.

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[1] Grey literature is information produced outside traditional commercial and academic publishing and distribution channels, such as reports, policy documents, government documents and white papers. In relation to this manuscript, this would include the working documents from NIST OSAC.

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2. Classification methods

Classification in BPA is the process of identifying the observable characteristics of a bloodstain pattern before grouping it into a specific category using established criteria [12,22,29]. There are two levels to this process, the first being descriptive classification, which identifies the observable characteristics of the bloodstain pattern. It is a necessary stage in the process but can be of limited value when determining how the pattern was created. The second level is mechanistic classification, which considers how the pattern was created. Often, this is unknowable, so mechanistic classification relies upon inferences made by the expert to link the pattern created to the mechanism that caused it.

Since the inception of BPA, different methods have been developed to classify bloodstain patterns [11,12,17,19,21,22,25,28,38,39,44,46,47]. These methods have two central aspects in common. First, most methods consider the same basic bloodstain pattern types [12]. These include the patterns that are produced when blood is: (i) dispersed by a force from a point source (e.g. impact-type and expirated-type patterns); (ii) ejected from a moving object over time (e.g. castoff-type patterns); (iii) ejected under high pressure (e.g. arterial-type patterns); (iv) dispersed through the air due to gravity (e.g. drip-type patterns); (v) accumulated on or flows on a surface (e.g. pooling, and flowing-type patterns); (vi) and, deposited due to transfer (e.g. patterns resulting from the transfer of blood onto a target) [12]. Bevel and Gardner use this central aspect to compare their method with the methods of other experts, demonstrating that these reproducible bloodstain pattern types are consistent [12]. It should be noted that the way these basic bloodstain pattern types are grouped, and the phraseology used to describe them, may not be defined using the appropriate fluid dynamics concepts. These basic bloodstain pattern types describe current understanding and methods without the need for additional research into the fluid dynamics of the different patterns. However, as this extensive area of research is undertaken, incorporating a more accurate and detailed understanding of fluid dynamics should be implemented, and the way the basic bloodstain pattern types are categorized should be amended to reflect this.

The second central aspect is that the terms used to describe and ultimately classify bloodstain patterns are either based on the directly observable characteristics or the creation mechanism of the bloodstains and the pattern [12]. This is despite the fact that classification should be based solely on physical characteristics [12,22,29], as associating a mechanism is part of reconstruction rather than classification. Those methods that use mechanistic terminology use the creation mechanism to group and, therefore, classify bloodstain patterns.

Most classification methodologies have the same central aspects and, therefore, effectively describe and classify the same information from different viewpoints. Critical to the differences between the different methods are the core classification principles, the criteria used to compare the bloodstain when classifying, and the semantics of terminology used to name the bloodstains. As many classification methods exist, different analysts may classify the same bloodstain pattern differently, resulting in a difference of opinion between experts.

The classification methods discussed in this section are the product of a review of academic and grey literature for bloodstain classification methods. Several databases were used to generate the literature. The broad search terms employed were chosen to ensure a wide range of results and to minimize the exclusion of relevant literature. The titles and abstracts of the search results were used to determine whether the inclusion criteria were met. The inclusion criteria for the literature search were:

1. The document discusses the classification of bloodstain patterns, AND/OR.
2. The document discusses one or more methods of bloodstain classification, AND/OR.
3. The document discusses factors that influence, issues that affect, or the benefits and limitations of, the classification of bloodstain patterns and the methods used in this process, including terminology.

The results of the formal literature search strategy are presented in Table 1.

In addition to the literature selected from the formal literature search strategy, further sources of information were utilized to support this review. The reference/citation lists of the selected literature were investigated for additional relevant literature that was missed in the database search. Other sources of literature were also considered that were not included as part of the database search, such as The Journal of Bloodstain Pattern Analysis, policy documentation from the Forensic Science Regulator and NIST OSAC, and general Forensic Science textbooks, which include a chapter on BPA. Fifty-six pieces of literature were utilized for this review, and fourteen sources outlining a complete classification method were used.

The classification methods are presented in order to show the chronological development. All the figures within this section have been adopted from their source text or figures for publication and recreated in this format for consistency in their presentation within the manuscript. The reference to the source used to generate the figure is provided in the figure heading.

2.1. Classification by velocity

Dr. Paul Kirk initially proposed classification by velocity in 1963 [44,46,47], which related velocity to the drops in flight. In this method, bloodstains are categorized as low-velocity impact spatter (LVIS), medium velocity impact spatter (MVIS), or high velocity impact spatter (HVIS). The criteria used to classify bloodstains in this method is the size and shape of the bloodstains within the pattern. LVIS reportedly results in circular or elliptical stains with either smooth or spikey edges depending upon the characteristics of the surface the drop impacted. MVIS may produce medium-sized stains shaped like bowling pins, with the narrower end providing directionality. HVIS is shaped like an exclamation point as the stains are very narrow ellipses with satellite spatter around the parent stain. When Kirk proposed this method, there were no specific values for the size of the stains. However, when MacDonell reworked this methodology in 1971, specific values were assigned to LVIS, MVIS, and HVIS [28]. The meaning of velocity also changed from the velocity of the drops in flight to the velocity of the object hitting the target [28,44]. These alterations changed how LVIS, MVIS, and HVIS were characterized. HVIS was subsequently characterized by a mist-like appearance due to the high velocity impact (≥25 ft/second or ≥100 ft/second) that created the spatter [22,28]. MVIS was characterized as individual stains of ≤2 mm in diameter [25] generated because of a medium velocity impact (5-25 ft/sec) [28]. A low impact velocity was associated with LVIS, which had no size ranges provided due to the high variability of the stain sizes [28]. Using the velocity of the impact as the method of classifying bloodstains implies that the core principle is based on the creation mechanism.

2.2. Classification by the movement of blood

Parker et al. suggested this classification system in 1982, which uses blood motion as the basis for differentiation [38]. Fig. 1 illustrates the two bloodstain categories and their associated subcategories. According to this method, blood-impact spatter patterns are generated when static blood is hit by an object, putting the blood into flight. In contrast, the blood spot dispersion category includes stains generated by blood that was not static before flight [38]. This method uses the characteristics of the bloodstain patterns to determine the motion used to generate the pattern. These directly observable characteristics can be seen in Table 2 and were generated from the results of a series of experiments conducted by Parker et al. In these experiments, they observed the relative motion

Table 1
The databases and search terms used in the literature review search strategy show how many results each search term produced and how many met the inclusion criteria. TB in the selected column denotes that the results were too broad. The cells shaded in grey denote a duplication of relevant literature with the previous search terms, and the number shown is the number of newly selected literature that does not include these duplicates.

Database	Search Date	Search Terms	Filters	Results	Selected
ScienceDirect	14/02/2024	Bloodstain **AND** classification	None	877	TB
		"Bloodstain pattern" **AND** classification	None	184	TB
		Bloodstain pattern analysis **AND** classification	None	120	TB
		Bloodstain **AND** "Pattern classification"	None	22	8
		Objective classification bloodstain patterns	None	2	0
Web of Science	14/02/2024	Bloodstain **AND** classification	None	75	8
		"Bloodstain pattern" **AND** classification	None	23	2
		Bloodstain pattern analysis **AND** classification	None	22	0
		Bloodstain **AND** "Pattern classification"	None	7	0
		Objective classification bloodstain patterns	None	4	0
Google Scholar	14/02/2024	Bloodstain **AND** classification	Include citations removed	18100	TB
		"Bloodstain pattern" **AND** classification	Include citations removed	1220	TB
		Bloodstain pattern analysis **AND** classification	Include citations removed	1030	TB
		Bloodstain **AND** "Pattern classification"	Include citations removed	176	9
		"Objective classification" **AND** "bloodstain patterns"	Include citations removed	30	0
Staffordshire University Library	14/02/2024	Bloodstain **AND** classification	None	98	4
		"Bloodstain pattern" **AND** classification	None	40	0
		Bloodstain pattern analysis **AND** classification	None	30	0
		Bloodstain **AND** "Pattern classification"	None	12	0
		Objective classification bloodstain patterns	None	8	0
Europe PMC	14/02/2024	Bloodstain **AND** classification	None	104	0
		"Bloodstain pattern" **AND** classification	None	24	0
		Bloodstain pattern analysis **AND** classification	None	20	0
		Bloodstain **AND** "Pattern classification"	None	8	0
		"Objective classification" **AND** "bloodstain patterns"	None	2	0
ProQuest: Dissertations and Theses	14/02/2024	Bloodstain **AND** classification	None	42	0
		"Bloodstain pattern" **AND** classification	None	6	0
		Bloodstain pattern analysis **AND** classification	None	6	0
		Bloodstain **AND** "Pattern classification"	None	0	N/A
		Objective classification bloodstain patterns	None	37	0
		"Bloodstain Pattern Analysis"	None	15	0
				TOTAL	**31**

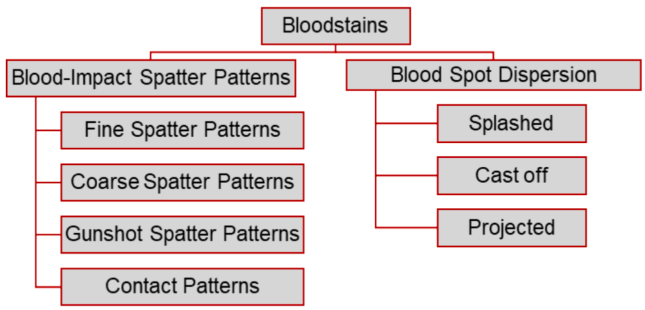

Fig. 1. The classification of bloodstains by movement of blood method with associated subcategories [38].

of the blood and the target where the bloodstain was produced to describe and classify the pattern. This method cannot be used in operational casework, as the relative motion is not directly observable, and only the resulting bloodstain can be used in this process with inferences made to the mechanisms that resulted in the bloodstain.

2.3. Classification by size

Laber, in 1985, proposed that bloodstain patterns should be classified according to the size of the individual bloodstains that make up the pattern rather than velocity alone. Although it does not entirely remove the idea of velocity, by basing the classification on size, the method uses directly observable characteristics in the classification process [25]. Table 3 demonstrates the categories, their size ranges, and examples of pattern types for the Classification by Size method. Laber states that the individual bloodstains within the pattern are predominately of the diameter size shown in Table 3**.** However, he does not provide a percentage of bloodstains expected to be found at the stated diameter size [25]. He also uses the terms 'stain size' and 'diameter' interchangeably without defining them, so, for this paper, the assumption is made that Laber is referring to width.

2.4. Spatter, nonspatter, and composite bloodstains

Anita Wonder proposed the spatter, nonspatter, and composite bloodstain classification method in 2001, as shown in Fig. 2. This method uses what she defines as 'objective criteria', particularly for the spatter stains (specifically, (i) the shape of the pattern, (ii) the alignment of the stains in the pattern, (iii) the alignment of the stains with respect to each other, (iv) the density and distribution of the bloodstains, (v) the diameter of the bloodstains) to aid in the classification of the bloodstain patterns [44]. These 'objective criteria,' shown in Fig. 3, allow experts to distinguish easily between the different spatter pattern categories. This method uses mechanistic terminology to define the categories despite using 'objective criteria' that are based on the bloodstains' directly observable characteristics.

2.5. Passive, transfer, projected, and miscellaneous bloodstains

Radzicki was the first scholar to categorize bloodstains based on the mechanism that caused them [39], which was later adopted and adapted by Bevel and Gardner [11]. Some categories and terminology used to characterize the bloodstains were altered due to their adaption. Fig. 4 illustrates the classification method (passive, transfer, projected and miscellaneous) and how those categories are further subcategorized to provide a classification with greater differentiation. This methodology is one of Europe's most used classification systems [8]. Bevel and Gardner acknowledged that this method did not clearly or effectively articulate the criteria for distinguishing the different pattern types [12]. It is for this reason that no criteria are presented here.

Table 2
A summary table of the observable characteristics for the different categories of bloodstain patterns in the classification system used by Parker et al., and the mechanisms associated with the characteristics [38].

Bloodstain Pattern Type	Observable Characteristics	Mechanisms Indicated
Splashed Bloodspot Dispersion	1. The central stain is of a nondescript pattern that is slightly pooled with very few individual blood drops in the central stain. 2. Streaks of blood radiating outward from the central stain. 3. Fine satellite spatters radiate outward from the central stain; very few are round.	1. The large, singular central stain indicated that the blood did not break up when falling. 2. The streaks could indicate the height from which the blood fell by how pronounced they are. 3. How dispersed the fine satellite spatter indicates how high the blood fell from.
Cast off Bloodspot Dispersion	1. Individual spots deposited are in an approximately linear trail or path that exhibits an arc pattern. 2. Individual spots were of a variety of sizes and, when circular, were no larger than 6-7 mm. 3. The dispersion of the individual spots from the midline of the trail/path was larger when the individual drops were smaller. 4. The individual spots started off circular due to impact at or near 90 degrees but progressively became more elliptical due to impact at more acute angles. 5. The individual spots showed directionality.	1. The arc pattern occasionally indicated the hand the instrument was held in. 2. – 3. The smaller drops indicated a more forceful swing. 4. The progressive elongation of the individual spots indicated the direction of the swing. 5. The directionality could occasionally indicate whether the swing was perpendicular or at an oblique angle to the target.
Projected Bloodspot Dispersion	1. There was a central stain with smaller spots deposited around it. 2. Extensive needle-like streaks are radiating from the central stain. 3. Fine satellite spatter with a spine-like appearance radiating from the central stain with very few round spots. 4. Blood drips from the central stain present when this type of bloodstain is found on a vertical surface.	1. The high number of smaller individual spots indicated that the blood broke up as it was projected. 2. – 3. The spine-like appearance of fine satellite spatter is due to the highly acute impact angle. Dispersion of these types of bloodstains decreased as the distance the blood travelled increased. 4. Blood drips are present due to gravity acting on the volume of blood in the central stain.
Coarse and Fine Spatter Patterns	1. Individual blood drops were predominately 3mm, with some occasionally larger up to 10mm and some barely visible. 2. The individual spots were randomly dispersed in a pattern of varying shapes. 3. The stains radiated from a central stain, with the spots closer to the centre being more circular and those further away more elliptical. 4. Many individual drops showed directionality. 5. The concentration of individual spots varied.	1. The size range was due to how the blood broke up when impacted with force. 2. The shape of the pattern was influenced by the geometric configuration of the surface impacted and the item that impacted the blood. 3. The individual circular spots impacted at or near 90 degrees, while those further away impacted at more acute angles. 4. The directionality and height-to-width determinations allow a three-dimensional point of origin to be determined.

(*continued on next page*)

Table 2 (*continued*)

Bloodstain Pattern Type	Observable Characteristics	Mechanisms Indicated
		5. The greater the distance between the target and the impact site, the greater the level of dispersion, but the concentration of the spots decreased as they were spread over a larger area.
Gunshot Spatter Patterns	1. Blood was deposited in a fine mist-like pattern with drops between 0.25 and 0.025 mm. 2. The mist-like droplets were deposited in a cone-shaped pattern. 3. A stellate dispersion pattern can be seen on the target impacted by the forespatter. 4. The backspatter was less densely concentrated than the forespatter. 5. In some gunshot patterns, sidespatter was present.	1. Due to the high energy impact, the blood broke up extensively to produce mist-like droplets. 2. – 3. How pronounced the stellate pattern is changes with the distance between the forespatter target and the impact site, becoming less pronounced the greater the distance. 4. – 5. Sidespatter was generated during contact shots, and the amount decreased as the shot's distance increased.
Contact Patterns	1. Contact between body parts and the target results in a central stain with differences in the deposition level and, in some instances, produced spines. 2. Contact patterns from tools did not produce characteristics that could identify the tool. 3. Where fabrics made contact with a target, sometimes identifiable characteristics of the fabric could be seen. 4. The movement of an object during contact resulted in smears.	1. The difference in deposition was caused due to blood being squeezed out at a pressure point. The spines indicated the force applied in the contact. 2. – 3. – 4. The smears showed the direction of movement by their tapering nature.

Table 3
The classification by size method [25].

Category	Diameter Size Range	Example
Mist	Smaller than 0.1 mm	Spatter near a high velocity impact like a gunshot.
Fine	≤2 mm	Spatter from a medium velocity impact, like a beating or spatter found further away from a high velocity impact.
Medium	2–6 mm	Spatter from cast-off
Large	≥6 mm	Spatter generated from blood dripping from an object

2.6. *Active, passive, and transfer bloodstains*

Jackson and Jackson propose three bloodstain classification categories [21,51]. Initially presented in their 2004 book as a method of grouping bloodstains for the purposes of the specific publication, this method is still used in their most recent edition [21,51]. These categories are active, passive, and transfer, as shown in Fig. 5 with the subcategories for this system. Passive bloodstains only occur due to gravity, but active bloodstains are described as stains made when blood has travelled due to a force other than gravity [21]. Transfer stains are caused by contact with surfaces where at least one is wet with blood [21]. Given the longevity of this categorization system within their body of work, it would not be unreasonable to suggest that, despite its original purpose, it may have been adopted for use in casework by active practitioners as part of their classification process.

2.7. *Passive, spatter, and altered bloodstains*

The system proposed by James, Kish, and Sutton in 2005 [22] uses observable characteristics as the core principle of classification, but the terminology used to categorize the stains is mechanistic. Bloodstains are classified into passive, spatter, or altered stains, which are further subcategorized within these main classifications [22] (for a visual representation, readers are referred to the source text [22]). Most subcategories can be further differentiated to provide a highly specific classification for a bloodstain pattern. One criticism of this classification method [22] is that it fails to be genuinely taxonomic as it is only presented in a hierarchical format. The criteria for this hierarchy lacks effective articulation, with limited descriptions for each bloodstain pattern [12]. This paper concurs with this criticism in some respects, as the descriptive criteria James, Kish, and Sutton use are difficult to locate within their text and are not as effectively articulated as the criteria in the taxonomic system presented by Bevel and Gardner. It is for this reason that the criteria are not included here.

2.8. *Taxonomic classification systems*

Taxonomic classification systems use hierarchical rules to classify bloodstain patterns, with the pattern classification becoming more specific at each level of the hierarchy; for example, a spatter pattern is a broad classification, whereas an expiration pattern is a more specific classification within the spatter pattern group. Each hierarchical level has decision points where BPA analysts use clearly defined, unambiguous criteria to move through the taxonomy. The classification would stop at the previous level when a clear decision cannot be made due to ambiguity [12].

Bevel and Gardner updated their classification method for the third edition of their book to a taxonomic classification system [12]. The method presented in their 2008 book was a collaboration between Bevel, Gardner, and Esperança. Esperança's understanding of BPA and entomology background allowed him to contribute significantly to developing the presented taxonomic "decision map" [12]. The collaboration between these experts explains why Bevel and Gardner's classification method is based on directly observable characteristics and mechanisms. Their system established parent-sibling relationships between the different categories of bloodstain patterns at the decision points using clearly defined criteria based on the bloodstain pattern's observable characteristics. The method proposed initially in their 2008 book [12] subsequently went through some revisions to the method they use today [13].

The method has two main categories: spatter and non-spatter. Spatter is subcategorized as linear or non-linear depending upon the arrangement of the individual blood drops. Linear spatter, where the blood drops are arranged in a linear distribution, has three sub-classifications: spurt, cast-off and drip trail. Non-linear spatter, blood drops arranged in a non-linear distribution, has two additional sub-classifications: drip and radiating spatter; the latter is further differentiated into expiration, impact, and mist patterns. Non-spatter firstly distinguishes pattern transfer from other types of non-spatter. The remaining non-spatter is subcategorized as irregular or regular depending upon the margin of the bloodstain. Irregular non-spatter has three sub-classifications: blood into blood, gush/splash, and smear. Smear is further differentiated into swipe and wipe. Regular non-spatter is subcategorized as saturation, flow, or pool [13].

Esperança also devised a taxonomic approach, which is referred to as an Identification Key, as shown in Fig. 6, that is based on the "what you see is what you get" (WYSIWYG) principle [17]. In this method, a set of

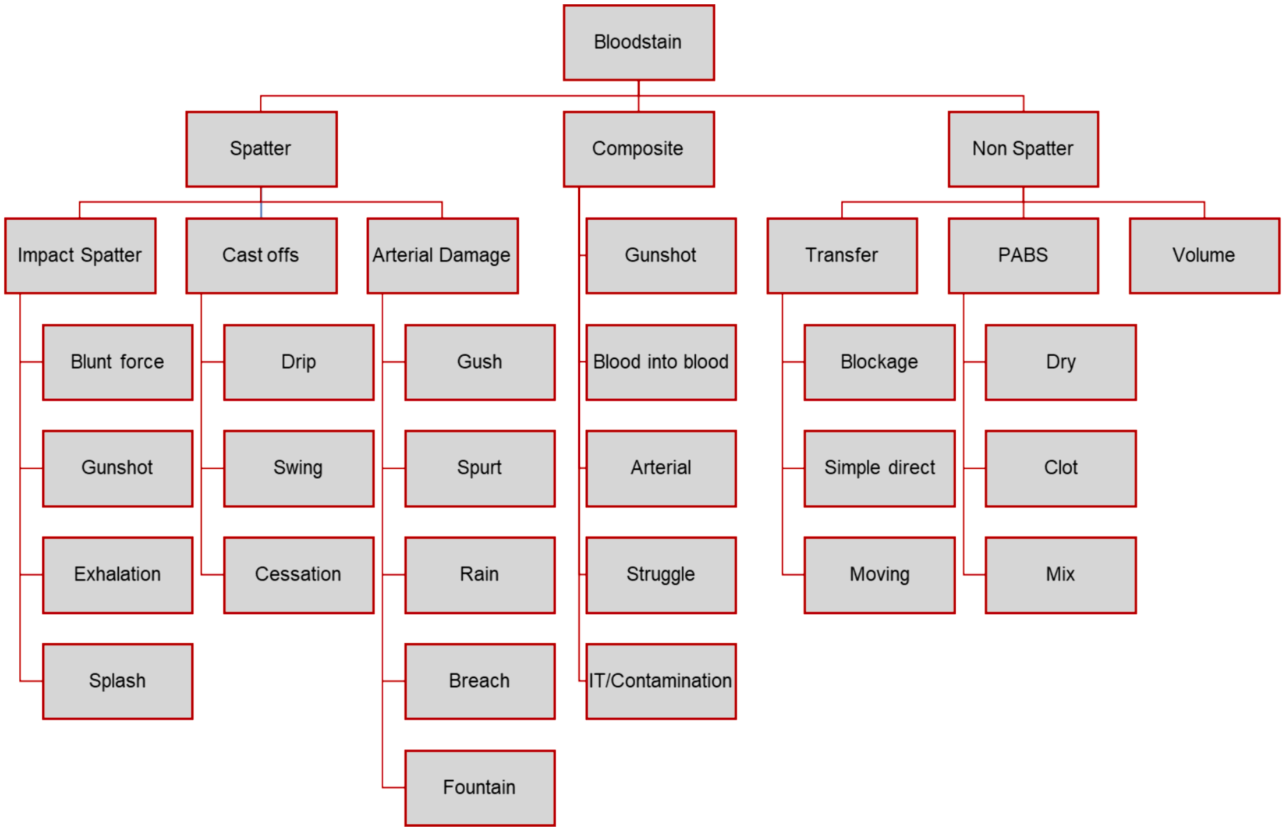

Fig. 2. The spatter, nonspatter, and composite bloodstain classification method [44].

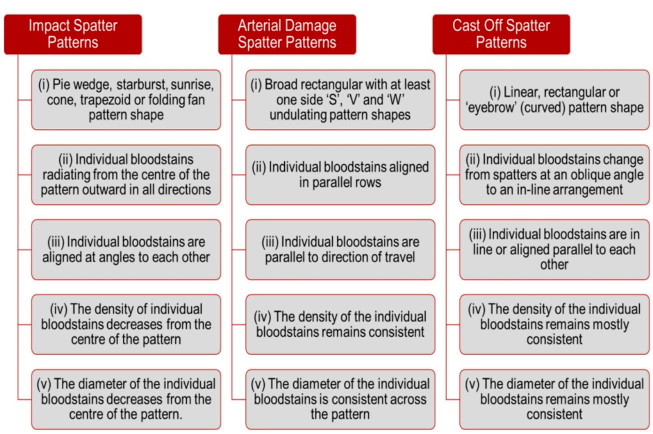

Fig. 3. The 'objective criteria' Wonder [44] used to differentiate between the different categories of spatter patterns for classification.

criteria is generated from the bloodstain pattern's directly observable characteristics. These criteria are compiled by first considering all the descriptive information of the bloodstain pattern before focusing on the specific descriptive information for the pattern present that will allow it to be differentiated from other bloodstain patterns. Information about the target on which the bloodstain pattern is deposited is also required at this stage. Finally, the criteria are sorted so that a classification can be made using the dichotomous taxonomic key whilst considering that different bloodstain patterns may share criteria. It is the application of the criteria using dichotomous questions which allows bloodstains to be distinguished from each other [17].

Taxonomic Classification Systems have been criticized by some [2,53]. One reason for this criticism is that the line between observations

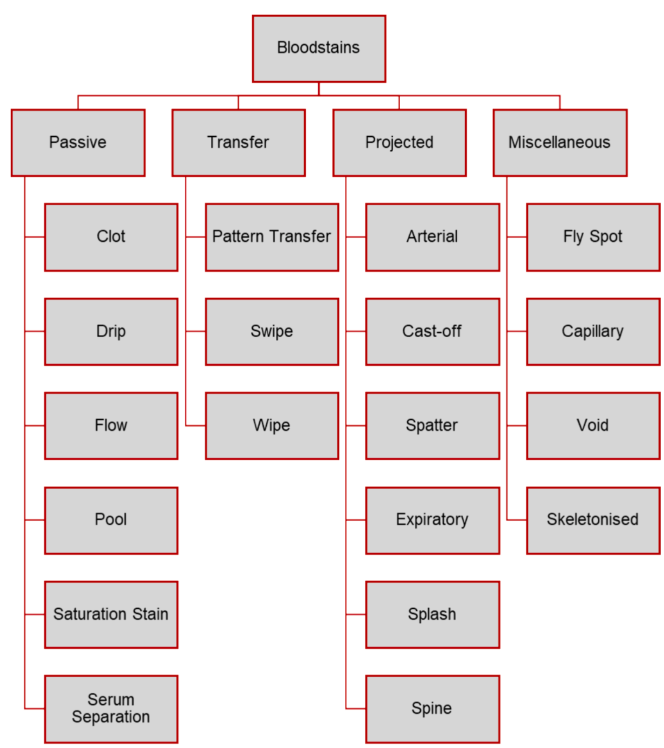

Fig. 4. The passive, transfer, projected, and miscellaneous bloodstains classification method with associated subcategories, as proposed by Bevel and Gardner [11].

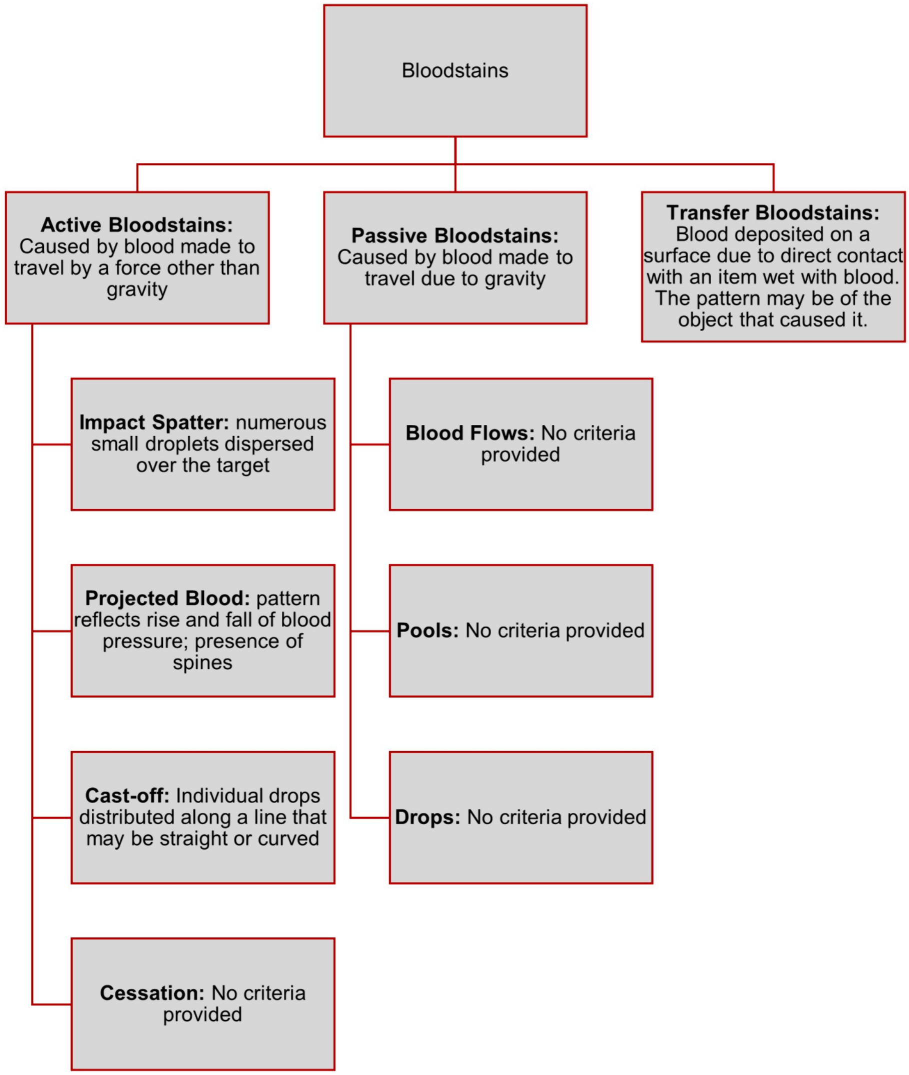

Fig. 5. The active, passive, and transfer bloodstains classification method with associated subcategories, as proposed by Jackson and Jackson in their 2017 book, which focuses on the causal mechanism of the bloodstains [21]. The criteria that Jackson and Jackson use to distinguish between the different bloodstain patterns are presented with the subcategories.

and reconstruction is blurred due to a lack of a standard methodology within BPA [2]. Others felt that the criteria used in the taxonomy were subjective [53]. The authors believe that Taxonomic Classification Systems are part of the solution to standardizing bloodstain classification due to their potential to have unambiguous criteria based solely on the directly observable characteristics of the bloodstain pattern. As Taxonomic Classification Systems have standardized and recognized decision points, they are logical choices as starting points in developing a standardized classification system.

2.9. Classification based on SWGSTAIN terminology

Work by Peschel et al. presents what could be considered a stand-alone classification system based on the terminology defined by SWGSTAIN [56]. Although they may not have intended this to be a classification method, it has been referred to in the literature [53]. The method is similar in structure to the work by Bevel and Gardner [11], with the notable difference that it includes the terms high, medium, and low-velocity impact spatter, not included in the work by Bevel and Gardner [11]. The work considers three basic categories: passive drops, transfer/contact patterns, and projected bloodstains, as well as secondary changes, which are shown in Fig. 7. Each type of bloodstain pattern within each category has been given a definition rather than criteria that the bloodstain pattern must meet to be classified as that type of bloodstain pattern.

2.10. Classification by energy

The classification by energy method proposes that bloodstains are classified by observing the energy pattern generated due to the speed of the object that created the spatter [19]. This method uses mechanistic terminology as a basis for the classification process. Three groups are proposed [19] with the size of the individual bloodstain as the criteria for classification: (i) low-energy stains, which have a size of ≥4 mm that are the result of gravity acting on the drop, (ii) medium-energy stains which have a size of 1–4 mm that are the result of a force or energy between 5 and 25 ft per second, (iii) high-energy stains which have a size of ≤1 mm that are the result of a force or energy greater than 100 ft per second. There is clarification with this classification method that "energy does not refer to the speed of the blood drops in flight" but rather "the speed refers to the force or energy of the wounding agent" [19, pp. 14]. As force, energy, and speed are all different physical concepts, the way this classification mechanism relates the three is inaccurate and non-scientific.

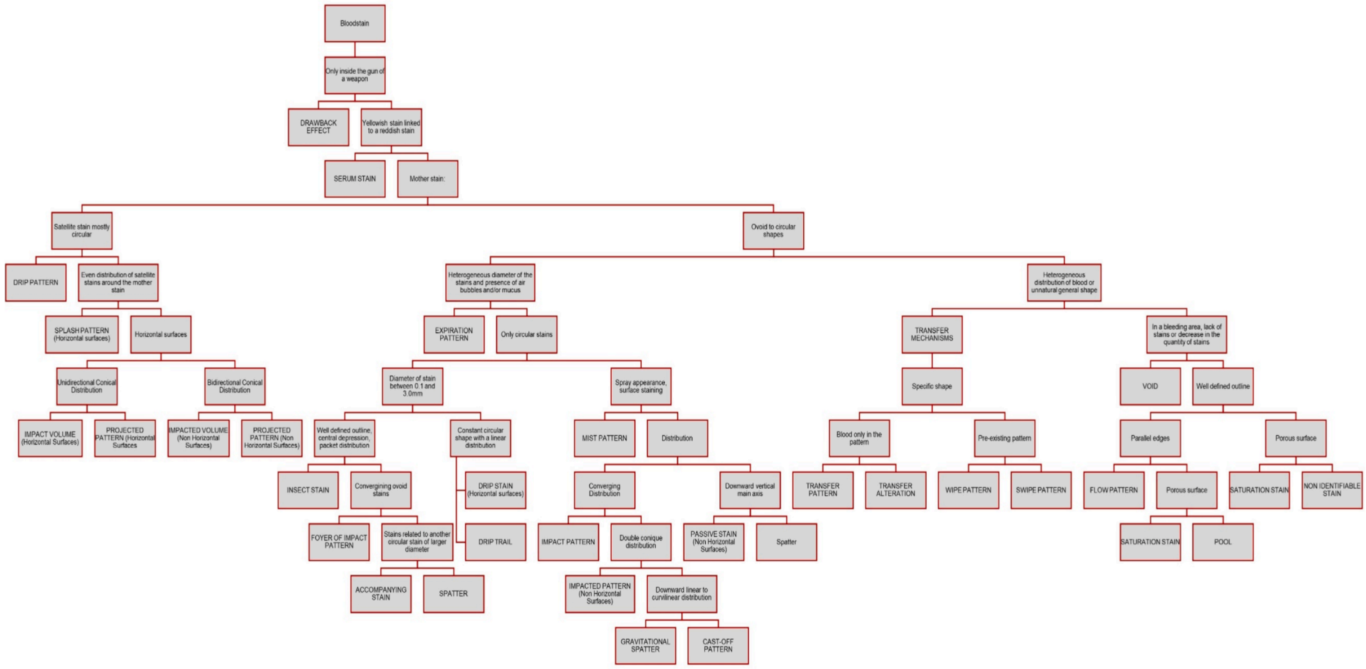

Fig. 6. The taxonomic classification method called an Identification Key, as proposed by Esperança, uses dichotomous questions based on the directly observable characteristics of the bloodstains to differentiate them [17]. When using this method, 'yes' answers lead to the left and down and 'no' answers to the right and down. If a question cannot be answered, the possible classification is any capitalized stain name below that point in the key.

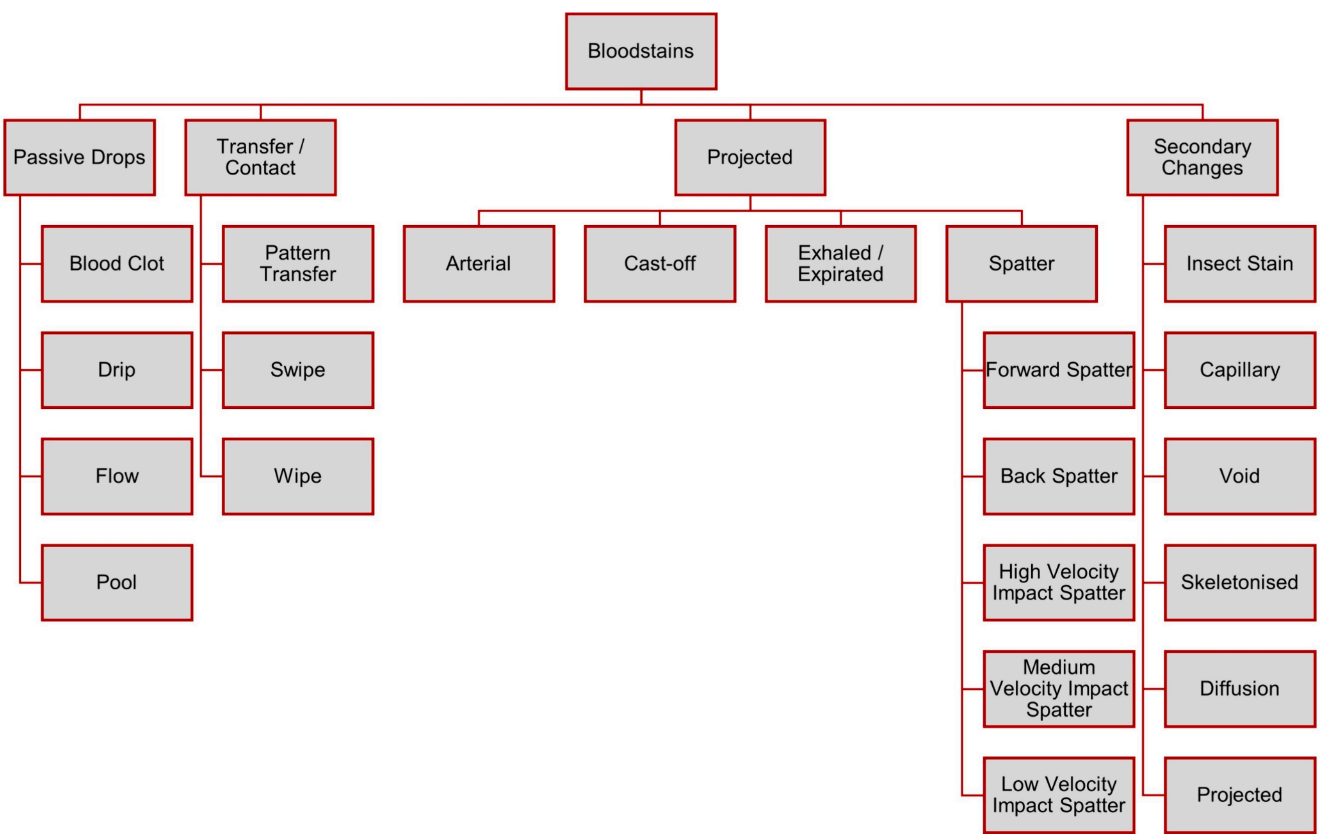

Fig. 7. The classification method presented in the work by Peschel et al. is based on the SWGSTAIN terminology [56].

Table 4
A summary comparison table of different bloodstain classification methods.

Classification method	Date developed?	Is the method functional?	What level of differentiation does the method provide?	Does the method differentiate between spatter and non-spatter?	Does the method use mechanistic terminology?	Does the method use directly observable features?	Does the method have issues with bloodstain patterns with indistinguishable features?	Does the method use clearly defined, unambiguous classification criteria?	Is the method susceptible to contextual bias?
By Velocity	1963 [44,46,47] 1971 [28]	Not in casework	Low	No	Yes	Yes	Yes	No	Yes
By Movement	1982 [38]	Not in casework	Low	Yes	Yes	Yes	Yes	No	Yes
By Size	1985 [25]	Yes	Low	No	No	Yes	Yes	No	Yes
Spatter, Nonspatter and Composite	2001 [44]	Yes	High	Yes	Yes	Yes	Yes	Yes	Yes
Passive, Transfer, Projected, and Miscellaneous	2002 [11]	Yes	Medium	Yes	Yes	Unclear	Yes	No	Yes
Active, Passive, and Transfer	2004 [21,51]	Yes	Low	Yes	Yes	Partially	Yes	No	Yes
Passive, Spatter and Altered	2005 [22]	Yes	High	Yes	Yes	Unclear	Yes	No	Yes
Taxonomic Classification Systems	2008 [12] 2019 [13] No date [17]	Yes	Dependent	Dependent	Dependent	Yes	Yes	Yes	Dependent
Based on SWGSTAIN terminology	2011 [56]	Not in casework	Medium	Yes	Yes	Unclear	Yes	No	Yes
By Energy	2022 [19]	Not in casework	Low	No	No	Yes	Yes	No	Yes

3. Results and discussion

This paper has presented ten different approaches to the classification of bloodstains from fourteen sources. A summary of the results of this literature search can be seen in Table 4. Each question considered here stems from limitations exposed when conducting the literature review. Each question and the related limitations are explained in detail below.

The date the classification method was developed is provided here to demonstrate the chronology of the development of classification. Where more than one expert has contributed to developing that classification method, each contribution date is shown chronologically.

The next question deals with functionality. In the context of this article, the term 'functional' means the classification method can distinguish between different groups or categories of bloodstain patterns. As this is the purpose of classification, distinguishing between different bloodstain patterns is paramount. In some circumstances, the method is functional but unsuitable for operational casework, and this is stated as such. A classification method is unsuitable for casework if it relies too heavily on unknowable information or has been discredited by the BPA community.

The level of differentiation refers to the classification's specificity, which relates to the number of groups and subgroups in the classification method. Differentiating between bloodstain patterns is an essential requirement of any classification method. A low level of differentiation is an issue for bloodstain classification as patterns with similar observable characteristics cannot be distinguished, negatively impacting any further analysis required, such as reconstructing events. Methods with many groups and subgroups have a high level of differentiation; those with only a few groups and no subgroups have a low level of differentiation. The average number of groups and subgroups for the ten presented methods is 18, and the standard deviation is 14, with both rounded to two significant figures. This has been used to distinguish between low, medium, and high differentiation. If the number of groups and subgroups is below 17, then the method has low differentiation; if the number is between 18 and 31, then it is medium differentiation, and if the number is 32 or greater, then this is high differentiation.

The next question considers whether the method differentiates between spatter and non-spatter and relates to the question regarding mechanistic terminology and associated limitations. The question is framed to elicit a yes or no response, as the classification method either does or does not make this distinction.

Whether the method uses mechanistic terminology is a significant question, as using mechanistic terms blurs the line between classification and reconstruction whilst potentially encouraging analysts to pre-emptively relate a cause to the bloodstain pattern without a complete analysis. This question is framed for a yes–no response.

Basing the classification method on directly observable characteristics is important as this is the fundamental purpose of the bloodstain classification process. Observable characteristics provide a descriptive basis for grouping the bloodstain patterns into specific categories using established criteria [12,22,29]. This reduces the risk of contextual bias from ambiguity and subjectivity. It also removes the mechanism, separating the classification and reconstruction processes. Hence, analysts are more likely to complete a full analysis without pre-emptively relating the cause. This question is framed for a yes–no response.

Some bloodstain patterns have indistinguishable features [3,4,14,24,41,42], which are directly observable characteristics within the bloodstain pattern that are highly similar to different pattern types. Examples of bloodstains with similar features include forward spatter patterns and expiration patterns; wipes and swipes; and, impact patterns, expiration patterns, and cessation patterns [43]. These features make distinguishing between these patterns difficult; therefore, the most effective classification methods are those that can do this. This question identifies whether the classification method has issues with bloodstain patterns with indistinguishable features.

Whether the method uses clearly defined, unambiguous classification criteria is important to ensure the classification's objectivity, accuracy, and reliability. Analysts can present the processes used to interpret and evaluate the bloodstains to provide an accurate and unambiguous classification when the criteria used are also unambiguous. Analysts can review each other's work easily if the criteria are clearly defined, as there is clarity in the exact processes and information used, which is an essential part of forensic work because of the requirement for an auditable trail. Using clearly defined criteria is designed to improve the repeatability, reproducibility, and consistency of bloodstain classification. A classification method is deemed to have clearly defined, unambiguous criteria if there is a set of specific criteria based on the directly observable characteristics of the bloodstain pattern that can be used to distinguish it from other patterns. The criteria must, however, not be too prescriptive; otherwise, they can become ambiguous. The criteria must be simple to follow and understand so the decision-making process can be explained to another analyst if required. The question is framed for a yes–no response.

Although classification is a process that can be completed without contextual information [36], contextual bias is still a risk during a classification. Contextual bias has been raised as a concern during the classification process. The three key sources of contextual bias are ambiguity, subjective methodology, and a context-rich environment [35,36,45], which are each relevant to BPA. The ambiguous nature of classification due to bloodstain patterns with indistinguishable features, an issue experienced by all classification methods, can cause the process to be prone to contextual bias. Additionally, the mechanistic nature of the terminology used often causes issues with bias [3,4,20,23,24,36,41,42] because it introduces the cause of a bloodstain pattern before a complete analysis can be undertaken, further introducing contextual bias alongside subjective judgements [4,9,14]. The risk of contextual bias through ambiguity, subjective methodology, and a context-rich environment has influenced many of the questions in Table 4**.** This question considers whether the classification method is prone to contextual bias (shown as yes) or not (shown as no).

For some questions, 'dependent' is a potential answer for the Taxonomic Classification Systems, as how the method is developed (such as how the questions are constructed) influences the outcome.

The authors were surprised by the relative dissimilarity of the terms used to name the bloodstain patterns in the classification process despite the publication of a standardized terminology [34]. Even though the ASB terminology is only advised, it would make sense that a classification system would use these terms to ensure standardization when discussing bloodstain patterns. However, the authors were pleased that all the summarised classification methods shared some commonalities. These findings support published work that has highlighted a lack of a standardized, validated classification methodology [4,41]. These similarities and differences have been identified by the authors and are discussed in more detail below.

Although all the methods that have been discussed previously are functional, some of the methods should not be used in casework. Classification by Velocity has long since been abandoned by the discipline due to its significant limitations [44,49,50], such as the introduction of ambiguity and confusion due to the change in meaning for the terms 'velocity' (does it refer to the velocity of the blood droplet in flight or the velocity of the object hitting the target?) and 'impact' (does it refer to the object impacting the victim or the blood drops impacting the target?) [44]. As such, it is unsuitable for use in operational casework. As Classification by Energy is a reworking of Classification by Velocity, this, too, is unsuitable for casework. Classification based on SWGSTAIN terminology [56] is also unsuitable for casework as it includes classification using velocity and terminology that is now outdated. Classification by Movement is unsuitable for casework, considering that it relies so heavily on the mechanisms that generated the bloodstain patterns, which cannot be observed.

Some classification systems offer the investigator increased opportunities to differentiate between bloodstain patterns [22,44] compared to others where differentiation is reduced [11,21,38,56]. For example, despite the benefit of focusing on the directly observable characteristics of the bloodstain patterns, Classification by Size does not consider enough attributes to fully differentiate the various types of bloodstain patterns that could be produced. Classification by Velocity and by Energy also have a limited number of groups [19,25,28], so these classification systems are unrepresentative of the diversity of the types of bloodstain patterns that can form. Those with high levels of differentiation can provide greater specificity during classification with more representative categories. However, care should be taken not to 'force' a classification when there are many subcategories. Analysts must be able to provide a broader classification if the directly observable characteristics are insufficient to be more specific. The structure of taxonomic classification systems determines the level of differentiation provided, with the previous taxonomic examples showing high levels of differentiation.

Classification methods use two categories of terminology: First, terminology based on the directly observable characteristics of the bloodstain patterns [25], such as the size of the bloodstains, and second, terminology based on the mechanism that caused the bloodstain pattern [11,12,13,17,19,21,22,38,44,56] like wipe, impact spatter, and expirated. Mechanistic terminology is a key limitation for many current classification methods BPA analysts use. As mechanistic terminology is closely associated with the cause of the bloodstain pattern, the cause may be concluded before a complete analysis. This increases the risk of contextual bias and thus reduces the accuracy of the conclusions drawn [2–4,9,14,20,23,24,36,41,42]. Poor accuracy at the classification stage can have a profoundly negative impact on the subsequent analysis undertaken, which has implications for future trials where this evidence is required. Using mechanistic terminology confuses the boundaries between classification and reconstruction, with currently no protocol to distinguish between the two, which has also been reported by Laber et al. [24] and Taylor et al. [41]. Associated with the nature of how bloodstain patterns are differentiated is whether the classification method distinguishes between spatter patterns and non-spatter patterns. Whether Taxonomic Classification Systems distinguish between spatter and non-spatter depends on how the taxonomy is built and its terminology.

Despite most classification methods using mechanistic terminology, some systems [12,13,17,25,28,38,44] use directly observable characteristics to differentiate the bloodstain patterns. Using these characteristics is highly beneficial for a more objective classification but requires clearly defined, unambiguous criteria to improve objectivity.

Several classification methods reportedly lack clearly defined, unambiguous criteria [11,21,22,38,56]. As a result, there is a lack of understanding of the properties and characteristics used to classify bloodstain patterns when utilizing these methods [2,3]. This is a fundamental limitation because the lack of clarity can result in an inaccurate classification, mainly if the analyst is inexperienced. Analysts who review the classification may not fully understand how that classification was reached, causing problems when the evidence is presented in court. Additionally, the ambiguity associated with the classification criteria contributes to the risk of contextual bias.

Other methods, conversely, do use unambiguous criteria. A key advantage of the method presented by Wonder [44] is that it uses an unambiguous decision-making process to form classifications based on the directly observable characteristics of the individual bloodstains and the pattern. Taxonomic Classification Systems use comprehensive, unambiguous criteria to give analysts standardized and recognized decision points. The criteria used in Taxonomic Classification Systems focus on a wide range of directly observable characteristics of the bloodstain patterns to ensure a high degree of differentiation between the different pattern types. The hierarchical nature of the system and the unambiguous criteria mean complex bloodstain patterns can be classified generally or partially without forcing a highly specific classification [12,17], which can happen with other classification systems. The use of unambiguous classification criteria, such as those presented by Wonder [44], Bevel and Gardner [12], and Esperança [17], allows for unambiguous decision-making and therefore improved accuracy, reliability, and reproducibility [2]. The criteria used for unambiguous classification need to be chosen with care; otherwise, the criteria themselves can become a source of bias if they are not unambiguous or the criteria for the bloodstain pattern are poorly chosen and unrepresentative of the variety of bloodstain patterns seen in operational casework.

Prescriptive criteria can also overlap, which causes difficulties for the investigator and impacts the approach's repeatability. Classification by Velocity, Size, and Energy, as suggested by MacDonnell [28], Laber [25], and Gravel and White [19], all report this issue. As Classification by Velocity assigns absolute limits to the values of velocity, the method become too prescriptive and do not account for known exceptions to the rules. Laber's work shows numerous examples of this [25]. Additionally, the values assigned to velocity by MacDonnell [28] are arbitrary, and there is no explanation for the scientific foundation for how the values were determined. This same issue is true for the values assigned to the size of the individual bloodstains, which is also demonstrated by the illustrated examples within Laber's work [25] that show all velocities produce spatter outside their arbitrarily assigned size range. The specific and definitive size ranges in Classification by Energy are also too prescriptive, resulting in decreased accuracy and reliability when classifying. The definitive boundaries for the different groups lead to overlap; for example, a stain of 1 mm could be classified as either a medium-energy or a high-energy stain. Laber developed his Classification by Size method to eliminate the issues caused by overlap in the Classification by Velocity method [25]. However, there is an overlap in the size ranges for fine, medium, and large spatter. This reduces the reliability of the classification of bloodstain patterns that fall at the boundaries of the size ranges. For example, medium is considered to be 2–6 mm, and large is 6 mm or greater. The difficulty is associated with the classification of stains around the classification boundaries, given that the shapes of the stains are not uniform. This limitation can be resolved by applying statistical descriptions of the sizes of the bloodstains within the pattern. Using statistics is important in providing an unambiguous method for distinguishing between the sizes of the individual stains in different bloodstain pattern types, improving the objectivity of the analysis. Statistical descriptions can also help when trying to answer challenging yes–no questions, such as those related to size, as part of the unambiguous classification criteria. As a bloodstain pattern can be made up of thousands of individual bloodstains, it is difficult to answer, 'yes' or 'no' to a question like "Are the bloodstains smaller than Xmm?" as many of the stains will be smaller but equally many of the stains could be larger. A representative sample of individual bloodstains would need to be measured to reach this stage, equating to hundreds of bloodstains. This process is a time-consuming challenge, and there is still the potential that the 'yes' or 'no' is incorrect. Having a statistical description of the distribution of sizes within the bloodstain pattern, as well as having the questions used as part of the classification criteria rephrased to suit the statistical descriptions, would help eliminate this issue. Determining these statistical descriptions for the different types of bloodstain patterns is an important area currently under research, for example, the recent open-source software that provides statistical descriptions of spatter stains [52]. However, how these statistical descriptions can be used to generate appropriate questions as part of the unambiguous classification criteria needs significant further research.

The reviewed classification methods can be complex because some bloodstain patterns have indistinguishable features [3,4,14,24,41,42]. In some cases, the bloodstain patterns are the issue as they are intrinsically problematic to differentiate between, and in some cases, they are even impossible to differentiate. In these scenarios, the classification method should allow the analyst to provide a broader classification rather than trying to provide a precise but inaccurate classification. In addition, some classification methods are better at differentiating between problematic bloodstain patterns than others. This is the result of poorly defined classification criteria. As the current classification methods cannot fully differentiate between these bloodstain patterns, classifying bloodstains with indistinguishable features is complex and ambiguous. A classification may be impossible to achieve when an intrinsically problematic pattern requires classification by a method that has difficulties differentiating between problematic patterns. Indistinguishable features impact classification: the outcome can be so broad that it is of little use, no classification can be presented, or the classification is inaccurate. Any of these scenarios are detrimental to additional analysis. Improving the current understanding of the fluid dynamics of the mechanisms that generate bloodstain patterns will aid in determining the directly observable characteristics of the different bloodstain patterns. The findings from this type of research would help differentiate bloodstain patterns with these indistinguishable features. One such example is using fluid dynamics to distinguish between spatter from a gunshot and expirated spatter; arterial spurting and cast-off from a swinging object; wipes and swipes; and impact spatter, expirated spatter, and cessation cast-off, as these have been cited as complex patterns with indistinguishable features [43]. The relationship between fluid dynamics and BPA has been established, including the relations between fluid dynamics concepts and key bloodstain patterns [6]. Using quantitative methods to classify bloodstains, such as the method developed by Arthur et al. [2], could also help statistically describe pattern features to aid in this process. By combining both the principles of fluid dynamics and quantitative statistical methods within the bloodstain classification process, clearly defined criteria can be produced due to an improved understanding of the directly observable characteristics of the different bloodstain pattern types. These criteria would remove the issue of bloodstain patterns with indistinguishable features.

The methods discussed here have issues relating to the three key sources of contextual bias; therefore, contextual bias is a risk for classifications made using these methods. All except one classification method (Classification by Size) uses mechanistic terminology, which blurs the line between classification and reconstruction, introducing ambiguity. Those methods that lack clearly defined, unambiguous classification criteria (namely Classification by Velocity, Size, Movement, and Energy; Passive, Transfer, Projected and Miscellaneous; Active, Passive, and Transfer; Passive, Spatter and Altered; and Classification based on SWGSTAIN terminology) [11,19,21,22,25,28,38,56] also introduce ambiguity and subjectivity. Ambiguity and subjectivity are key sources of contextual bias, which reduces the reliability and accuracy of classifications made with methods that are prone to these. Classification, as a process, is also prone to contextual bias. The lack of a standardized methodology further compounds the individual issues, resulting in an additional risk of contextual bias [20,35,36,45]. Additionally, as BPA is a context-rich environment [35,36,45,55], this contextual information could influence the outcome of bloodstain classification [35,45,55] despite the classification process not requiring any contextual information [36]. Further bias and unreliability are introduced to the classification process before the classification can take place by grouping individual bloodstains into a bloodstain pattern. Any error in the mental operation of grouping the stains results in an inaccurate pattern that is classified incorrectly.

A summary of the comparisons between the different bloodstain classification methods is presented in Table 4. The table demonstrates the key commonalities and differences, and outlines the key evaluation points for the methods discussed previously.

This paper has highlighted the variety of terminology used to describe bloodstain patterns despite the publication of standardized terminology [30] that aligns with similar regulatory guidance from the Forensic Science Regulator that details the codes of practice and conduct for BPA [18]. Much of the terminology used in BPA describes the mechanism used to create the bloodstain pattern rather than describing the bloodstain pattern's directly observable characteristics, using a well-established decision-making process [3,4,20,23,24,32,33,36,41,42].

However, much of the research has suggested that BPA terminology needs to be reviewed to change to be more descriptive and less mechanistic to improve precision and reduce ambiguity as well as cover all commonly identified patterns within operational casework [3,4,20,23,32,33,35,41,42,54].

An assessment of research needs by the OSAC Bloodstain Pattern Analysis Subcommittee in 2020 found that there was limited research to address this issue [33]. A validated classification method was recommended to be developed using descriptive terminology based on the directly observable characteristics of bloodstain patterns [32,33]. To develop this, the underpinning data used to generate the classification method would also require validation to ensure that the resulting method was robust and suitable for operational casework given the requirements for ISO accreditation. The work by the OSAC Bloodstain Pattern Analysis Subcommittee, along with this paper, has demonstrated that further work is needed regarding bloodstain classification that builds up to the production of a bloodstain classification method that is a standardized, unambiguous method that uses directly observable characteristics of bloodstain patterns.

4. Conclusions

Several classification methods are discussed in the BPA literature, spanning over sixty years. There are some fundamental commonalities and differences between these methods, with the differences exposing limitations within the methods. Despite all the methods being functional, the degree of differentiation varies between the published methods. One crucial difference is the nature of the terminology used to classify bloodstain patterns, either by using the bloodstain pattern's directly observable characteristics or by the mechanism that generated the pattern. However, using mechanistic terminology can result in subjective conclusions. Another key difference is the use of clearly defined, unambiguous classification criteria. The methods that use these criteria are more repeatable and reproducible, offering greater consistency when classifying bloodstain patterns. Issues arising during the classification of bloodstain patterns with indistinguishable features are an area of commonality for all classification methods. These issues make classifying these bloodstain patterns complex and often result in ambiguity.

Due to BPA's often subjective, ambiguous, and context-rich nature, bloodstain classification is exposed to, and at risk of, contextual bias. Contextual bias has a more significant impact due to the other limitations of the current classification methods, namely mechanistic terminology, and a lack of clearly defined, unambiguous classification criteria, contributing to this bias. It can alter the decisions made during classification despite the process not requiring any contextual information. By developing a standardized classification methodology that resolves these issues, the effect of contextual bias will be reduced. By focusing on the bloodstain patterns' directly observable characteristics and logically defining these characteristics as criteria for classification, ambiguity and subjectivity are removed. Additionally, introducing a standardized classification methodology solidifies the difference between classification and reconstruction so that access to contextual information can be reduced during classification to remove the risk of contextual bias.

The BPA community needs an unambiguous, standard methodology that distinguishes between classification and reconstruction and uses less mechanistic descriptions. Developing a methodology that meets these needs addresses the limitations of the current methods being utilized. Research should focus on generating terminology based on the directly observable characteristics of bloodstain patterns rather than relying on inferences and using these to establish clear and unambiguous criteria for classifying bloodstain patterns. The resulting methodology will have improved repeatability, reproducibility, and consistency, demonstrating the robust nature of the decision-making processes in bloodstain classification. Any underpinning data used to generate this terminology must be validated to ensure the robustness of any future classification method. Additional research should also focus on improving the understanding of fluid dynamics for different bloodstain patterns to help differentiate bloodstain patterns that are currently highly complex due to indistinguishable features. It should also generate statistical descriptions of the sizes of bloodstains within the different types of patterns. Both research areas are important for improving the objectivity of classification methods and improving understanding of the formation of the directly observable characteristics used to distinguish between bloodstain patterns. These research areas will help generate the criteria to be used as part of the unambiguous, standard classification method requiring development.

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