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# BLOODSTAIN PATTERN ANALYSIS – A SYSTEMATIC REVIEW

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**Abstrak**

Pendahuluan: Analisis pola noda darah (BPA) adalah alat penting dalam investigasi forensik, terutama dalam kasus-kasus yang melibatkan kejahatan kekerasan seperti pembunuhan, penyerangan, dan penyerangan seksual. Analisis bercak darah dapat memberikan informasi berharga tentang lokasi dan pergerakan korban dan pelaku, jenis senjata yang digunakan, serta jumlah dan arah pukulan atau tembakan. Kurangnya landasan matematis yang obyektif adalah masalah kritis dalam skenario di mana kualitas bukti dapat sangat mempengaruhi persidangan dan kehidupan orang-orang yang terlibat dalam persidangan tersebut. Tinjauan sistematis memberikan metode yang ketat dan transparan untuk mengevaluasi bukti ilmiah, dan dapat membantu mengidentifikasi kekuatan dan kelemahan metodologi tertentu.Tujuan Penelitian ini adalah untuk menganalisis Pola Noda Darah . Metode: Untuk memastikan pengambilan komprehensif penelitian yang relevan, kami akan mencari basis data utama berikut: PubMed dan ScienceDirect melalui 1000 untuk rekan artikel ulasan (dalam semua bahasa) bukti yang terkait dengan analisis pola noda darah. Diskusi: Tinjauan sistematis ini merangkum empat makalah yang membahas berbagai aspek BPA. Makalah pertama memperkenalkan konsep dasar BPA dan penggunaan prinsip trigonometri untuk menentukan sudut benturan noda darah. Makalah kedua mempresentasikan temuan eksperimental tentang penggunaan trigonometri dalam BPA dan mengidentifikasi keterbatasannya dalam menentukan ketinggian darah yang disemprotkan ke atas. Makalah ketiga meneliti analisis noda darah melingkar dan menemukan bahwa kelompok mereka dapat memberikan informasi tidak langsung tentang jarak tumbukan ke dinding dan daerah asal. Makalah keempat memperkenalkan penggunaan model virtual untuk BPA dan menemukan bahwa lintasan garis lurus dapat digunakan untuk memperkirakan daerah asal dengan akurasi tinggi. Kesimpulan: Makalah ini menyoroti kompleksitas BPA dan pentingnya menggunakan kombinasi metode untuk menginterpretasikan pola noda darah secara akurat. Sangatlah penting untuk mempertimbangkan keterbatasan masing-masing metode dan menggabungkannya untuk

mendapatkan gambaran yang lebih lengkap tentang peristiwa yang terjadi di TKP. Penelitian lebih lanjut diperlukan untuk menyempurnakan dan meningkatkan metode yang digunakan dalam BPA dan mengembangkan pendekatan baru untuk menganalisis pola noda darah

**Kata kunci**: analisis pola noda darah; matematika; investigasi forensik

***Abstract***

*Introduction: Bloodstain pattern analysis (BPA) is a crucial tool in forensic investigations, particularly in cases that involve violent crimes such as homicides, assaults, and sexual assaults. The analysis of bloodstains can provide valuable information about the location and movement of the victim and perpetrator(s), the type of weapon used, and the number and direction of the blows or shots. The lack of an objective mathematical foundation is a critical issue in a scenario where the quality of evidences can strongly affect a court trial and the life of people involved in that trial. Systematic reviews provide a rigorous and transparent method for evaluating scientific evidence, and can help to identify strengths and weaknesses of a given methodology.Methods: To ensure comprehensive retrieval of relevant research we will search the following key databases: PubMed and ScienceDirect through 1000 for peer reviewed articles (in all languages) evidence related to bloodstain pattern analysis.Discussions: This systematic review summarizes four papers that discuss different aspects of BPA. The first paper introduced the basic concepts of BPA and the use of trigonometric principles to determine the impact angle of bloodstains. The second paper presented experimental findings on the use of trigonometry in BPA and identified its limitations in determining the height of blood sprayed upwards. The third paper examined the analysis of circular bloodstains and found that their clusters can provide indirect information on impact-to-wall distance and area of origin. The fourth paper introduced the use of virtual models for BPA and found that straight-line trajectories can be used to estimate the area of origin with high accuracy.Conclusions: These papers highlight the complexity of BPA and the importance of using a combination of methods to interpret bloodstain patterns accurately. It is essential to consider the limitations of each method and to use them in combination to obtain a more complete picture of the events that occurred at a crime scene. Further research is needed to refine and improve the methods used in BPA and to develop new approaches to analyzing bloodstain patterns*

***Keyword**s: bloodstain pattern analysis; mathematics; forensic investigations*

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## INTRODUCTION

Bloodstain pattern analysis (BPA) is a crucial tool in forensic investigations, particularly in cases that involve violent crimes such as homicides, assaults, and sexual assaults (Jauhani, 2019) . BPA involves the systematic examination of bloodstains found at a crime scene in order to gain information about the nature and sequence of events that occurred during the crime (Jauhani, 2020) . The analysis of bloodstains can provide valuable information about the location and movement of the victim and perpetrator(s), the type of weapon used, and the number and direction of the blows or shots. Mathematics, particularly trigonometry, plays a significant role in the analysis of bloodstains. The use of trigonometry allows for the determination of important factors such as the angle and velocity of bloodstains, which can be used to reconstruct the events of a crime (Wijayatni, 2010).

BPA plays a crucial role among the investigation activities. In fact, it studies the distribution, size and shape of bloodstains left at crime scenes in order to allow investigators to gain information useful for the reconstruction of bloody events and answer 45 questions such as: where did the blood come from?, what caused the wounds? and from what direction was the victim wounded? 1 Given the importance of trigonometry in BPA, there is growing interest in the development and validation of systematic review methodologies to evaluate the effectiveness and reliability of mathematical models and techniques used in bloodstain pattern analysis. The lack of an objective mathematical foundation is a critical issue in a scenario where the quality of evidences can strongly affect a court trial and the life of people involved in that trial. Systematic reviews provide a rigorous and transparent method for evaluating scientific evidence, and can help to identify strengths and weaknesses of a given methodology.

This systematic review aims to critically assess the current state of trigonometry in BPA by evaluating the effectiveness and reliability of mathematical models and techniques used in bloodstain pattern analysis. By conducting a comprehensive search of the literature and using rigorous inclusion and exclusion criteria, this review aims to provide an unbiased assessment of the state of trigonometry in BPA. Ultimately, this review aims to identify areas where further research and development is needed to improve the effectiveness and reliability of mathematical models and techniques used in bloodstain pattern analysis, and to provide guidance on best practices for the use of trigonometry in BPA. The purpose of this research is to analyze the pattern of blood stains(Anggereini, 2008).

## RESEARCH METHOD

We searched PubMed and Science Direct databases from inception through 1000 for peer reviewed articles (in all languages) evidence related to bloodstain pattern analysis. We used the phrases “PubMed (((Math OR Mathematics OR Trigonometry) AND (Bloodstain OR Bloodstains) AND (Forensic OR Forensics)))”; Science Direct with the keyword (Math OR Mathematics OR Trigonometry AND Bloodstain OR Bloodstains AND Forensic OR Forensics). Reference list from articles identified by the search, as well as key review articles conducted by author and we did not impose any language or other restrictions on the beginning of searches.

Study selection

Our search generated a list of abstracts. Any uncertainty on the eligibility of the studies that was based on tittle and abstract made the reviewers read full paper. The study flow diagram was shown in **Flowchart 1.**

To be considered for inclusion, studies must explicitly define and describe the mathematical models and techniques used in bloodstain pattern analysis to provide guidance on best practices in forensics investigation. Study design and setting reported in **Table 1.**

**Table 1.** Article Inclusion and Exclusion Criteria

| | **Inclusion Criteria** | **Exclusion Criteria** |
|---|---|---|
| Types of studies | Controlled clinical trials (randomized control trials), observational studies, meta-analysis, case report | - Did not explain the mathematical models and techniques used in bloodstain pattern analysis<br>- review<br>- High bias studies<br>- Expert opinions or commentary paper |
| Types of Participants | Forensic investigations using mathematical models in bloodstain pattern analysis | Forensic investigations that not using mathematical models in bloodstain pattern analysis |

*Assessment of study quality*

All authors participated in summarizing and systematically assessing the evidence through the use of standard abstraction forms. The team will test the screening and abstraction forms on multiple articles before beginning the abstraction and review process. Screening and data collection forms may undergo revisions by the team. The result are presented in the evidence tables **(Table 2.).**

Data Extraction

Data extracted from the identified publication included: study design, mathematical models, results, conclusions, and comments. We used a table where each piece of information was written descriptively **(Table 2).**

## RESULTS AND DISCUSSION

### A. Research Results

329 studies were identified in our study. The flowchart literature through the assessment process for the update of this review is shown in **Flowchart 1.**

**Flowchart 1.** Study flow diagram in this review

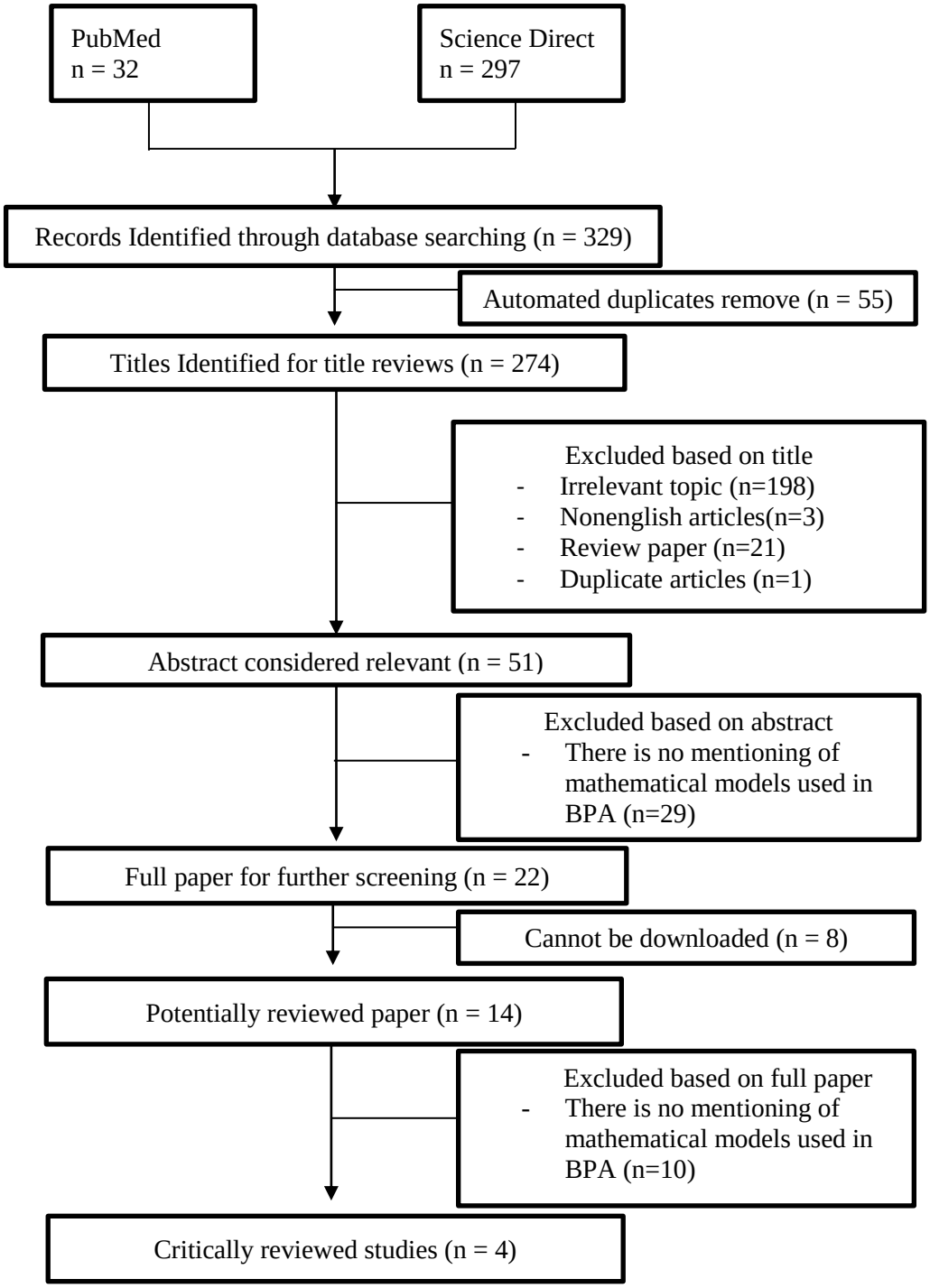

**Table 2.** Characteristics and outcomes of the included studied

| No | Author | Locations | Methods | Discussions | Conclusions |
|---|---|---|---|---|---|
| 1. | Giovanni, et al., 2016[2] | School of Science and Technology, Nottingham Trent University, Clifton Lane, Nottingham, United Kingdom | Experimental study | • This paper explains the basic concepts of BPA described by starting from the aforementioned physical features of blood, a BPA analyst can determine the impact angle of blood on a at surface by evaluating the shape of the blood spatter stain through trigonometric principles. In detail, the analyst has to locate each spatter and measure its | The main goal of this research is to introduce a very first formal representation of one of the most useful and applied forensic discipline: BPA. This new modelling of BPA will start a new research line in forensics involving the application of different optimisation approaches such as evolutionary algorithms, clustering techniques and so on, to 325 compute bloodstain patterns and their regions of origin in a precise and objective way. In the future, we expect that other researchers will re_ne our proposal in order to make automatic BPA more and more fast |

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| | | | | length L (major diameter) and width W (minor diameter) using a scale, a ruler or calipers then, he or she computes the angle of impact α by using the following formula: $\alpha = \arcsin\frac{W}{L}$ and then looking for area of convergence and region of origin<br>• In the next section, this paper explains the BPA optimization problem that can be solved by using a well-known optimisation method such as | and precise. |

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| | | | | genetic algorithms | |
| 2 | Makovicky et al., 2013[3] | Parkland College, USA | Experimental study | • This paper conducts experiments to test the concept of trigonometry in BPA with criminal acts, namely with compared measurements of the lengths of trajectory of impact and the height of the blood sprayed upwards from a distance of 1, 3, 5 and 10 meters. The experiment was based on two main presumptions Best was the knowledge of the | has a large and important role in bloodstain analysis. In spite of the lack of total accuracy, this paper recommend using this method widely and more ohen for investigation and verification of individual acts in criminal and forensic practice. |

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| | | | | value of the distance and the angle of impact of the bloodstain, the second, the ability of the blood to reach a certain height and the angle of its impact.<br>• The results indicate that the method for these requirements differs from the real values, while increasing the measurement with the indicated spot of the shot. Aside from the unique values which were calculated, other results of the | |

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| | | | | impact of the distance of drops of bloodstain were considered of lower value, and the values concerning the height of the bloods stains after the shot higher than real values | |
| 3. | Kettner, et al., 2014[4] | Department of Experimental ForensicMedicine, Institute of Forensic Medicine, Saarland University Medical School, Homburg/Saar, Germany | Experimental study | • This paper studies the patterns formed by circular bloodstains from drops of blood that hit adjacent surfaces at a 90-degree angle are thought to provide indications of the height of the impact.<br>• In this study, | The findings suggest that patterns of circular bloodstains cannot be used as direct indicators of impact height, but combined analysis of their clusters may lead to indirect determination of impact-to-wall distance and area of origin. |

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| | | | | blunt force exerted against a pool of blood, which was used as a surrogate for a bleeding wound, was carried out for five different impact-to-wall distances. The blunt force consisted of a hammer head that was dropped from a height of 1.5 m.<br>• The patterns containing bloodstains produced by the droplets were analysed by measuring the circular bloodstains within the | |

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| | | | | patterns.<br>• All the experiments showed that there were two distinct patterns or clusters of circular bloodstains that occurred at different heights above the impact site that were projected in a garland or crown-like form of a "Worthington splash" after impact.<br>• The findings suggest that patterns of circular bloodstains cannot be used as direct indicator | |

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| | | | | s of impact height. | |
| 4. | Connolly, et al., 2012[5] | Ontario Provincial Police, Forensic Identification Service Unit, Peterborough, Ontario, Canada and Department of Pure & Applied Chemistry, The Centre for Forensic Science, University of Strathclyde, Glasgow, Scotland, United Kingdom | Experimental study | • This project examines the influence of alpha angle variations on the estimation of area of origin in impact patterns using directional analysis.<br>• The primary aims of this research were to developing a virtual model of a bloodstain impact pattern to use for alpha angle variations and determine the validity of the model through application to a real bloodstai | The virtual model was validated as a conservative indicator, by means of overestimation, of the influence of alpha angle inaccuracy on area of origin. The study confirms that with proper stain selection, straight-line trajectories to estimate area of origin are valid and reliable. |

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| | | | | n impact patterns.<br>• Computer based modelling was used to create two virtual bloodstain impact patterns. In the creation of these patterns the assumption of straight-line trajectories was utilized to allow for the use of basic trigonometry to define the properties of the virtual bloodstains<br>• From the bloodstain coordinates and the area of origin coordinates the alpha (α) and gamma (γ) angles | |

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| | | | | were calculated for each bloodstain within the two virtual impact patterns.<br>• And this study using real bloodstain impact, five bloodstain impact patterns, A–E, were created using disease free sheep blood heated to approximately 37 8C to more closely represent human blood. A sheet of smooth white paper approximately 100 cm by 80 cm was fixed to the wall at a height of 56 cm | |

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| | | | | from the floor as a target surface for the blood droplets.<br>• It was found that the size of the area of origin influences the level of accuracy required in alpha angle estimations: larger areas of origin tolerated larger errors. Practical applications of the virtual model using real bloodstain patterns demonstrated that alpha angle measurements may show an inaccuracy of approximately | |

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| | | | | 0–12$^{o}$ within a single pattern. The averaging process that occurs in estimating the area of origin lessens the influence of a few large variations, such that, there is no significant change in the area of origin estimation. | |

**B. Discussion**

Bloodstain pattern analysis (BPA) is a forensic discipline that involves the interpretation of bloodstains left at a crime scene to reconstruct the events that occurred (Sandwinata, 2018) . In this systematic review, we will discuss four papers related to bloodstain analysis, with a focus on the basic concepts of BPA and the use of genetic algorithms to optimize BPA methods. Giovanni, et al. in their paper provides an introduction to the basic concepts of BPA. The paper describes how physical features of blood (Indrawanti & Mandyartha, 2018) , such as the shape and size of the blood droplet, can be used to determine the impact angle of blood on a surface. The paper explains how trigonometric principles can be used to calculate the impact angle and how this information can be used to reconstruct the events that occurred. The paper also highlights the importance of proper documentation and preservation of bloodstains at a crime scene. This paper also discusses new methods for solving the BPA optimization problem using genetic algorithms. The paper explains how genetic algorithms can be used to optimize the parameters used in BPA, such as the impact angle and velocity of the blood droplet.

The paper shows that genetic algorithms can significantly improve the accuracy of BPA and reduce the time required for analysis.The paper concludes that genetic algorithms have great potential for improving BPA methods (Vitiello et al., 2016).

The second paper, conducted by Makovicky et al., describes an experiment that aimed to test the concept of trigonometry in BPA with criminal acts. The experiment involved measuring the lengths of trajectory of impact and the height of the blood sprayed upwards from a distance of 1, 3, 5, and 10 meters. The results of the experiment suggest that the concept of trigonometry in BPA with criminal acts may not always be accurate. While the unique values that were calculated were accurate, the other results were not. This suggests that other factors, such as the velocity and angle of the blood droplet, may also affect the final result (Makovický, Horáková, Slavík, Mošna, & Pokorná, 2013).

The third paper describes a study that aimed to investigate the patterns formed by circular bloodstains from drops of blood that hit adjacent surfaces at a 90-degree angle. The patterns containing bloodstains produced by the droplets were analysed by measuring the circular bloodstains within the patterns. The findings suggest that patterns of circular bloodstains cannot be used as direct indicators of impact height. However, combined analysis of their clusters may lead to an indirect determination of impact-to-wall distance and area of origin. The results of the study suggest that while circular bloodstains cannot be used as direct indicators of impact height, thmay still provide valuable information for BPA. The analysis of clusters of circular bloodstains can provide an indirect determination of impact-to-wall distance and area of origin. This highlights the importance of using multiple BPA techniques in combination to obtain the most accurate reconstruction of the events that occurred. The study also emphasizes the need for further research into the limitations and accuracy of BPA methods. While circular bloodstains may not provide direct indicators of impact height, other BPA methods may be able to provide more accurate measurements. It is essential to use multiple methods and compare their results to ensure the accuracy of the reconstruction (Kettner et al., 2015) .

Connolly et al., in their paper paper describes a study that aimed to develop a virtual model of a bloodstain impact pattern to use for alpha angle variations and determine the validity of the model through application to real bloodstain impact patterns. Computer-based modelling was used to create two virtual bloodstain impact patterns. In the creation of these patterns, the assumption of straight-line trajectories was utilized to allow for the use of basic trigonometry to define the properties of the virtual bloodstains. Five real bloodstain impact patterns, A–E, were created using disease-free sheep blood. The results of this study demonstrate the usefulness of computer-based modelling in BPA. The virtual model developed in this study provides a conservative indicator of the influence of alpha angle inaccuracy on the area of origin estimation. The study also confirms that with proper stain selection, straight-line trajectories to estimate the area of origin are valid and reliable. However, the study has some limitations. The virtual model only considered straight-line trajectories, which may not be accurate for all bloodstain patterns. Further research is needed to determine the limitations and accuracy of virtual modelling in BPA (Connolly, Illes, & Fraser, 2012) .

## CLONCUSION

These papers highlight the complexity of BPA and the importance of using a combination of methods to interpret bloodstain patterns accurately. It is essential to

consider the limitations of each method and to use them in combination to obtain a more complete picture of the events that occurred at a crime scene. Further research is needed to refine and improve the methods used in BPA and to develop new approaches to analyzing bloodstain patterns.

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