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EVALUATION OF RIGOR MORTIS AS AN INDICATOR OF ESTIMATED TIME OF DEATH: A SYSTEMATIC REVIEW

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ABSTRACT

Estimating the time of death is a crucial aspect of forensic investigations, with rigor mortis being one of the primary indicators used. This study aims to explore the role of rigor mortis in determining the post-mortem interval (PMI) based on a systematic review of recent literature from 2015 to 2020. A total of 30 articles were identified, with 10 meeting the eligibility criteria. The analysis showed that rigor mortis begins to develop within 1–4 hours after death, peaks within 6–12 hours, and resolves after 36–72 hours. Environmental factors, such as temperature and humidity, significantly influence the rate of rigor mortis development. Furthermore, the physiological conditions of burial, metabolic state, and physical activity prior to death also contribute to variations in the onset and duration of rigor mortis. These findings highlight the importance of considering external factors such as environmental temperature and humidity, as well as internal factors including the physiological state of the corpse, metabolic analysis conditions, and physical activity prior to death in reporting time of death to improve forensic accuracy. The novelty of this study lies in its potential to consolidate these disparate findings into an evidence-based framework. Unlike traditional observation, systematic observation employs rigorous methods of selection, assessment, and synthesis to ensure comprehensive coverage of the available *literature. The research concludes that integrating rigor mortis with multimodal indicators (livor mortis, algor mortis, decomposition) is crucial for reliable forensic practice.*

Keywords: *Rigor mortis, post-mortem interval, forensic, death time*

ABSTRAK

Memperkirakan waktu kematian merupakan aspek penting dalam investigasi forensik, dengan rigor mortis sebagai salah satu indikator utama yang digunakan. Penelitian ini bertujuan untuk mengevaluasi peran rigor mortis dalam menentukan interval post-mortem (PMI) berdasarkan tinjauan sistematis literatur terbaru dari tahun 2015 hingga 2020. Sebanyak 30 artikel diidentifikasi, dengan 10 artikel memenuhi kriteria kelayakan. Analisis menunjukkan bahwa rigor mortis mulai berkembang dalam 1-4 jam setelah kematian, mencapai puncaknya dalam 6-12 jam, dan menghilang setelah 36-72 jam. Faktor lingkungan, seperti suhu dan kelembapan, memiliki pengaruh yang signifikan terhadap kecepatan perkembangan rigor mortis. Selain itu, kondisi fisiologis jenazah, kondisi metabolik, dan aktivitas fisik sebelum kematian juga berkontribusi terhadap variasi onset dan durasi rigor mortis. Temuan ini menekankan pentingnya mempertimbangkan faktor eksternal seperti suhu dan kelembapan lingkungan, maupun faktor internal termasuk kondisi fisiologis jenazah, kondisi metabolik, dan aktivitas fisik sebelum kematian dalam memperkirakan waktu kematian untuk meningkatkan akurasi analisis forensik. Kebaruan penelitian terletak pada potensinya untuk mengkonsolidasikan temuan-temuan yang berbeda ini ke dalam kerangka kerja berbasis bukti. Tidak seperti tinjauan tradisional, tinjauan sistematis menerapkan metode seleksi, penilaian, dan sintesis yang ketat untuk memastikan cakupan literatur yang tersedia secara komprehensif. Kesimpulan penelitian integrasi rigor mortis dengan indikator multimoda (livor mortis, algor mortis, dekomposisi) sangat penting untuk praktik forensik yang andal.

Kata kunci: Rigor mortis, interval post-mortem, forensik, waktu kematian

INTRODUCTION

Estimating the post-mortem interval (PMI) is one of the most critical yet challenging aspects of forensic science, with rigor mortis traditionally regarded as a key indicator. Classical descriptions suggest rigor mortis follows a predictable sequence onset within 2–4 hours, peak at 6–12 hours, and resolution around 72 hours postmortem (Kristanto & Wangko, 2015). However, contemporary forensic research increasingly highlights the variability of this process, showing that rigor mortis progression is strongly influenced by biological and environmental conditions such as age, cause of death, muscle mass, and ambient temperature (Kliewer et al., 2021; Ranjan et al., 2019). This variability questions the reliability of rigor mortis as a universally applicable marker for PMI estimation.

Much of the literature continues to present rigor mortis descriptively, focusing on generalized timelines without sufficient critical evaluation of the confounding factors that influence its progression. While traditional forensic teachings emphasize sequential stiffening from small to large muscle groups, recent studies suggest that this order may be inconsistent, particularly in different climates or in bodies with pre-existing pathological conditions (Ding et al., 2022). Such findings point to a disconnect between classical assumptions and empirical realities, raising the need for updated evidence-based synthesis.

Methodological inconsistency further complicates the reliability of rigor mortis in PMI estimation. Many studies are case-specific, based on small sample sizes, or conducted under uncontrolled environmental conditions, which limits their generalizability (Khartade et al., 2017). Moreover, rigor mortis is often studied in isolation, despite forensic practice requiring the integration of multiple postmortem changes such as livor mortis, algor mortis, and biochemical markers (Ozawa et al., 2013). This fragmented approach results in a lack of comprehensive understanding of rigor mortis within the broader context of postmortem changes.

The research gap becomes clear when considering the absence of systematic synthesis of recent forensic studies on rigor mortis. Although rigor mortis has been studied extensively, the findings remain scattered, inconsistent, and difficult to apply in standardized forensic protocols. There is currently no unified framework that consolidates recent data to assess how rigor mortis interacts with external variables or how it can be best applied in real-world medicolegal contexts. This gap hinders forensic practitioners, who are left to rely on outdated or incomplete information.

The novelty of a systematic review lies in its potential to consolidate these disparate findings into an evidence-based framework. Unlike traditional reviews, a systematic review applies rigorous selection, appraisal, and synthesis methods to ensure comprehensive coverage of the available literature. A review focused on rigor mortis published between 2015 and 2020 is particularly valuable, as this period marks significant advancements in forensic methodology, including experimental designs with greater control, interdisciplinary approaches, and studies conducted in varied geographical and climatic settings (Bharat Kumar & Sheikh, 2017; Kliewer et al., 2021).

Conducting a systematic review specifically from 2015–2020 is necessary because it captures a crucial period of transition in forensic research. During these years, forensic scientists increasingly integrated biochemical, molecular, and imaging techniques to complement classical observations of rigor mortis, producing more precise and context-sensitive findings (Ding et al., 2022; Sugatha & Ramana, 2019). Additionally, studies in this timeframe reflect growing recognition of regional and environmental diversity in PMI estimation, offering broader applicability of findings across different forensic contexts. Synthesizing this literature ensures that forensic practice keeps pace with contemporary scientific knowledge.

Rigor mortis continues to be an important tool for PMI estimation, but its limitations, variability, and inconsistent documentation necessitate a critical re-examination. The research gap lies in the lack of a systematic synthesis of recent evidence, while the novelty of this study is its explicit focus on consolidating and evaluating literature from 2015–2020. Such a systematic review is necessary to refine forensic protocols, improve the accuracy of PMI estimation, and strengthen the evidentiary basis of medicolegal investigations in diverse settings.

METHOD

This study adhered to the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines, which provide a transparent framework for conducting systematic reviews. The literature search was carried out using Publish or Perish (8th edition) software, with Google Scholar and Crossref serving as the primary search engines. The keywords applied were “rigor mortis,” “time of death,” and “forensics.” The search was limited to articles published between January 2015 and December 2020, with an additional restriction to English-language publications.

Inclusion criteria required that articles (1) directly investigated rigor mortis in relation to postmortem interval (PMI) estimation, (2) presented original empirical data or structured forensic observations, and (3) were published in peer-reviewed outlets. Exclusion criteria included reviews, editorials, conference abstracts, case reports without analytical depth, and studies unrelated to PMI estimation. Number of Articles at Each Stage: Initial Search: The database search yielded 423 records across Google Scholar and Crossref. After Removing Duplicates: 312 unique articles remained. Title and Abstract Screening: 240 articles were excluded for irrelevance (e.g., studies focusing solely on biochemical or genetic markers without discussing rigor mortis, or those outside forensic PMI estimation). A total of 72 articles were retained. Full-Text Review: After full-text assessment, 62 articles were excluded due to lack of methodological clarity, absence of primary data, or focus outside rigor mortis. Final Inclusion: 10 articles met all eligibility criteria and were included in the final qualitative synthesis. This screening process ensured that only the most relevant and methodologically rigorous studies from 2015–2020 were analyzed.

Data extraction was performed using a structured data extraction sheet designed for this review. The following details were systematically collected from each included study: 1) Bibliographic details (author, year, journal, and country of study). 2) Study design (experimental, observational, or case analysis). 3) Sample characteristics (number of cases, demographic details, cause of death). 4) Environmental factors (temperature, humidity, body storage conditions, climate). 5) Method of rigor mortis assessment (visual scoring, joint movement resistance, biochemical or imaging correlation). 6)Timeframe of rigor mortis progression (onset, peak, and resolution as reported). 7) Confounding variables (physiological conditions, pathological states, or external influences). 8) Key findings and conclusions related to PMI estimation accuracy. The extracted data were synthesized qualitatively to identify common trends, methodological strengths, limitations, and gaps in the literature.

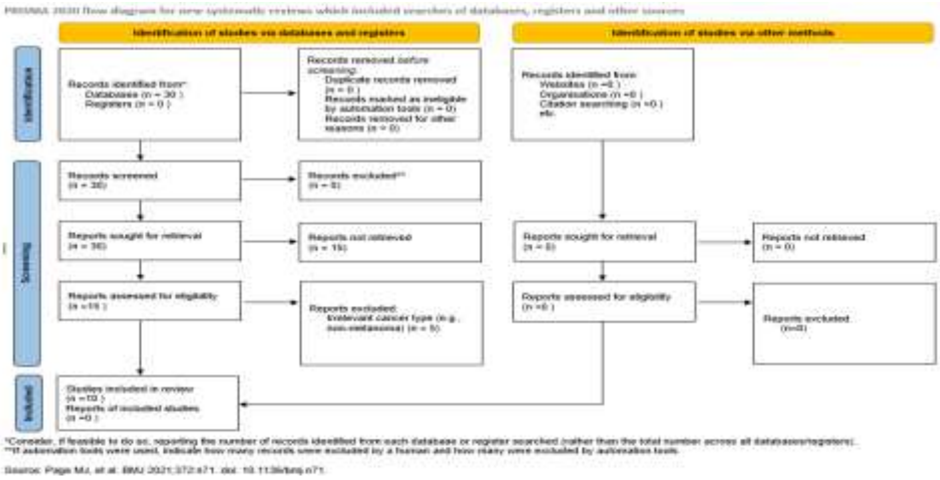

Figure 1. Systematic reviews

RESULT AND DISCUSSION

Tabel 1. Authors and Research Objectives

No	Author and Year	Research Objectives	Conclusions
1	Shivpoojan Kori, 2018	Examines time of death estimation based on rigor mortis in a forensic context.	Rigor mortis can be used to estimate time of death up to 36 hours after death considering environmental factors and body condition.
2	H.K. Khartade et al., 2017	Examined the development of rigor mortis based on the cause of death and the medium in which the body was found.	Rigor mortis appears earlier in deaths from infection, head injury, and poisoning compared to cases of hanging. Rigor also develops more slowly in water environments than air.
3	R.B. Sukhadeve et al., 2016	Examining the development of rigor mortis to estimate the time since death by considering the factors of age, gender, body weight, and ambient temperature.	Rigor mortis appears faster and lasts shorter in children and the elderly. Higher body weight slows the onset of rigor mortis. Higher ambient temperature accelerated the onset and reduced the duration of rigor mortis. Gender had no significant

			influence on the development of rigor mortis.
4	Chiara Crostack et al., 2017	Examines the phenomenon of re-establishment of rigor mortis after mechanical loosening in bodies that have experienced sudden death outside the hospital.	Rigor mortis can re-establish up to 20 hours after death, contrary to previous assumptions limiting it to 8-12 hours. This phenomenon is not influenced by body temperature or environment, and in some cases, the rigor that returns is even stronger than before loosening.
5	Sabina Bashir & Deepak Walia, 2020	Examines the role of rigor mortis in estimating time of death and the factors that influence it.	Rigor mortis begins to appear 2-4 hours after death, fully develops within 6-12 hours, and disappears within 72 hours. Factors such as temperature, humidity, and body condition affect the duration of rigor mortis.
6	(Kaur, Comini, et al., 2015)	Assess the various factors that influence rigor mortis to help estimate the death time.	Rigor mortis starts around 1-2 hours after death, peaks within 9-12 hours, and lasts up to 36 hours before disappearing. The temperature and humidity of the environment greatly affect this process-in high temperatures, rigor mortis appears and disappears faster, while in low temperatures, the process is slower and lasts longer. Other factors such as the condition of the muscles before death, nutritional status, and clothing also play a role in the duration of rigor mortis.
7	Rajiv Joshi et al, 2021	Examining the relationship between rigor mortis and estimated time of death based on environmental temperature and humidity.	Rigor mortis begins to appear within 1-2 hours after death, fully develops within 9-12 hours, and lasts up to 36 hours. At high temperatures with low humidity, rigor mortis appears faster and lasts shorter, while at low temperatures with high humidity, the process is longer. This study emphasizes the importance of considering environmental factors when estimating time of death.
8	Hilal et al., 2017	PMI estimation is still depend on early and late postmortem changes as algor mortis, rigor mortis, hypostasis and putrefaction .	PMI estimation is the time between time of death and time of identification of corpse. It has a role in forensic medicine specially in crimes. It helps to aid the police in their investigation and reduce the number of assailant. PMI estimation is still depend on early and late

			postmortem changes as algor mortis, rigor mortis, hypostasis and putrefaction. But recently there are new methods as detection of new biomarkers, using of microscopic changes that occur after death in multiple organs with success of these trials was noted and a correlation between them and PMI was found. DNA and RNA also participate in estimating time since death by detection the rate of degradation and its relation with PMI .
9	Ranjan et al., 2019	Observe the estimated time of death based on post-mortem changes, such as livor mortis, rigor mortis, and decomposition.	Rigor mortis is fully developed in 3-24 hours and disappears after 36 hours. Livor mortis develops and persists within 6-24 hours after death. Discoloration due to decomposition begins to appear in 24-36 hours, with the whole body becoming blackish green after 36 hours.
10	Madea, 2016	Examine various methods of estimating time of death in forensic practice, including rigor mortis, livor mortis, body cooling and decomposition.	Rigor mortis develops within 3-24 hours and disappears after 36 hours. Livor mortis begins to appear in 20-30 minutes, settles in 6-12 hours, and becomes unmovable after 12-24 hours. Body cooling follows an exponential curve and the nomogram method has become the gold standard in determining time of death. Decomposition becomes apparent after 24 hours and progresses according to environmental factors.

The study by Kori (2018) emphasized the classical understanding of rigor mortis progression and its application to estimating time of death within 36 hours. The main contribution of this work was reaffirming environmental influences such as temperature and humidity while stressing the need to consider surrounding circumstances. In contrast to later studies, Kori's approach was more descriptive and less experimental, focusing on reaffirming well-established patterns.

By comparison, Khartade et al. (2017) moved beyond descriptive timelines and systematically examined rigor mortis in relation to both cause of death and environmental context. With 141 autopsy cases, their study introduced variation based on pathological causes such as infections and poisoning that accelerated rigor mortis, while bodies found in water showed delayed onset. This highlighted that rigor mortis cannot be generalized without considering cause-specific and environmental conditions, which was less emphasized in Kori's work.

The research by Sukhadeve et al. (2016) introduced additional biological variables such as age, gender, and body weight. Their findings revealed that rigor mortis appeared sooner and lasted shorter in children and the elderly, while heavier bodies experienced delayed onset. Unlike Khartade et al., who prioritized cause of death and setting, Sukhadeve focused on demographic and physiological influences, demonstrating that both biological and external environments shape rigor mortis but in different ways.

A unique dimension was explored by Crostack et al. (2017), who investigated the re-establishment of rigor mortis after mechanical loosening. Unlike other studies that described onset and duration, Crostack challenged the assumption that rigor cannot return once broken, showing reappearance up to 20 hours after death, sometimes stronger than before. This introduced methodological novelty and questioned long-held forensic beliefs, distinguishing this study as experimental and disruptive compared to observational works like Kori or Khartade.

Bashir & Walia (2020) conducted their study on 100 medico-legal cases, reaffirming the standard timeline (onset 2–4 hours, peak 6–12 hours, resolution by 72 hours). Their focus was on voluntary and involuntary muscles, which was not directly addressed in earlier works. Their findings reinforced environmental effects, particularly temperature and humidity, but their contribution was to widen the scope of muscles examined, ensuring rigor mortis was understood in a more holistic anatomical sense.

In contrast, Kaur et al. (2015) highlighted the importance of pre-death conditions, such as muscle activity, nutrition, and clothing. This expanded the understanding of rigor beyond immediate postmortem biology into lifestyle and physiological status before death. Compared to Bashir and Walia's focus on muscle groups, Kaur's emphasis was on how pre-existing conditions shape rigor mortis duration and variability, showing a broader biopsychosocial perspective.

Joshi et al. (2021) adopted a more controlled approach by using digital hygrometers to measure environmental variables like temperature and humidity during autopsies. Their smaller sample size of 30 cases was offset by precise measurement tools, which contrasted with earlier descriptive accounts. This allowed them to quantify environmental effects more rigorously. Unlike Kaur (2015), who stressed pre-death activity, Joshi offered an evidence-based account of how microclimatic factors directly affect rigor mortis dynamics.

Hilal et al. (2017) emphasized that postmortem interval (PMI) estimation continues to rely heavily on traditional markers such as algor mortis, rigor mortis, hypostasis, and putrefaction. These changes remain fundamental in forensic practice because they are observable, relatively easy to document, and have long been established in medicolegal investigations. The study reinforced the notion that PMI estimation represents the elapsed time between death and corpse examination, a factor with critical importance in criminal investigations for narrowing suspect pools and guiding police inquiries.

Unlike many earlier works that focused only on classical postmortem changes, Hilal et al. (2017) also highlighted the emergence of newer scientific methods in PMI estimation. The authors discussed the role of biomarkers and microscopic changes occurring in various organs after death, suggesting that these cellular-level alterations can provide more precise correlations with PMI. This reflects an important shift from purely macroscopic forensic observations to laboratory-based molecular approaches that may enhance accuracy and reproducibility.

A particularly novel aspect of Hilal et al.'s work was the recognition of DNA and RNA degradation as measurable indicators of PMI. By analyzing the rate of nucleic acid breakdown, researchers can establish more objective timelines that complement traditional observations of rigor mortis and other physical signs. This integrative perspective marked a transition in forensic science from relying solely on visible postmortem changes to incorporating molecular biology and biochemical evidence thereby bridging the gap between classical forensic medicine and modern analytical science..

Similarly, Ranjan et al. (2019) emphasized comparative postmortem changes, but with a larger sample of 140 cases. Unlike Das et al. (2024), which suggested specific timeframes (rigor beginning around 3 hours, disappearing at 36), Ranjan showed a broader range (rigor 3–24 hours) alongside livor and decomposition timelines. Their study highlighted variability, suggesting that overlapping postmortem signs should be carefully interpreted rather than rigidly timed.

Madea (2016) provided a different perspective as a review rather than empirical research. His work stressed the limitations of rigor mortis as a standalone indicator and argued for the superiority of algor mortis (body cooling) combined with nomograms. Unlike experimental studies such as Crostack (2017) or Joshi (2021), Madea's strength was in synthesizing knowledge and advocating for integrated, multi-method forensic practice.

Looking at methodology, sample size emerges as a major difference. Kaur (2015) involved 500 autopsies, Khartade (2017) studied 141, while Joshi (2021) examined only 30. This variation influenced the generalizability of findings: larger datasets provided statistical reliability, while smaller controlled studies allowed for precise but less generalizable insights.

Another major difference is in focus and scope. Some studies (Bashir & Walia, 2020; Kori, 2018) reaffirmed classical timelines with slight modifications, while others (Crostack et al., 2017; Das et al., 2024) challenged or broadened the framework by introducing new phenomena or integrating rigor with other markers. This shows a tension between traditional validation studies and innovative approaches seeking to redefine PMI estimation practices.

Finally, the temporal context distinguishes the studies. Earlier works (Kaur et al., 2015; Sukhadeve et al., 2016) emphasized descriptive documentation of influencing factors, while more recent ones (Das et al., 2024; Joshi et al., 2021) leveraged technological tools and comparative frameworks. This evolution reflects a methodological shift in forensic science: from broad descriptive generalizations toward controlled, multi-variable, and integrative analyses of postmortem changes.

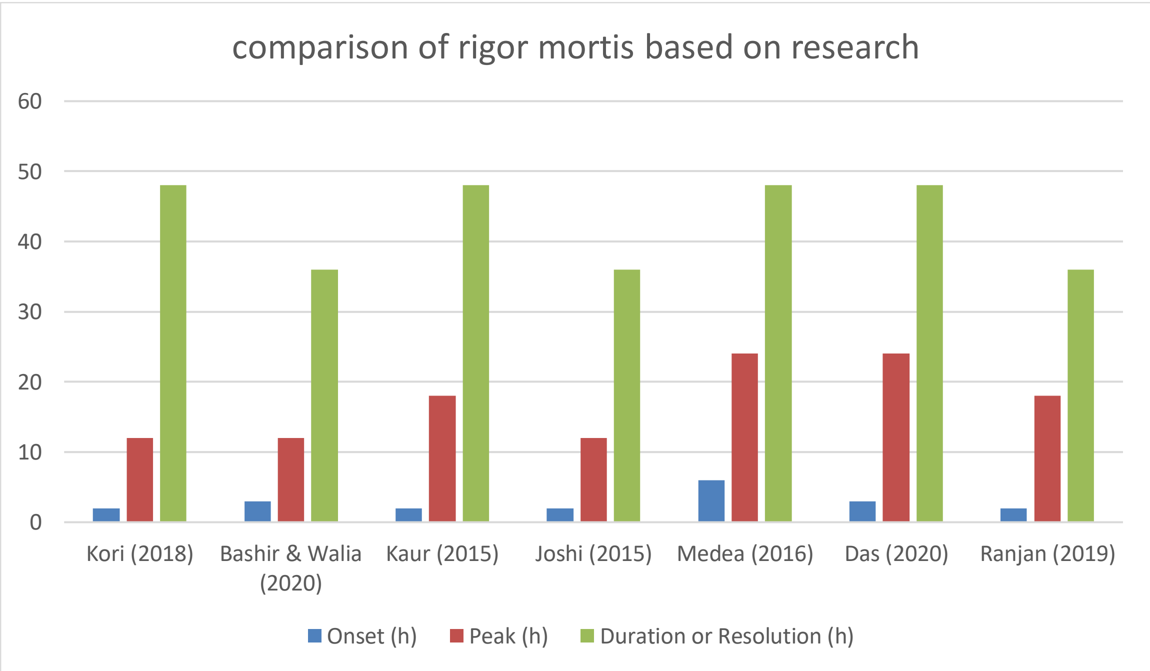

Figure 2. Comparison of Rigor Mortis Based on Research

LIMITATION OF THE STUDY

This systematic review is limited by the heterogeneity of the included studies in terms of methodology, sample characteristics, environmental conditions, and rigor mortis assessment criteria. Variations in ambient temperature, cause of death, age, and physical condition of the deceased were inconsistently reported or controlled, making cross-study comparisons difficult. Moreover, many studies used qualitative descriptors of rigor mortis progression without objective or standardized tools, reducing the reproducibility and reliability of their findings. These factors limit the ability to draw definitive conclusions or establish universal postmortem interval estimations based solely on rigor mortis.

Another limitation lies in the restricted scope of literature reviewed. The review included only peer-reviewed articles published in English and indexed in selected databases, which may have introduced language and publication bias. Additionally, the exclusion of gray literature such as forensic reports, theses, and institutional data may have led to the omission of valuable practical insights. The lack of high-quality, controlled studies further weakens the strength of evidence supporting rigor mortis as a standalone forensic indicator. Future research should aim for standardized rigor mortis assessment protocols and incorporate larger, diverse samples under controlled conditions to enhance the forensic applicability of findings.

CONCLUSIONS AND SUGGESTIONS

Rigor mortis, characterized by the postmortem stiffening of skeletal muscles due to biochemical mechanisms such as adenosine triphosphate (ATP) depletion and calcium ion influx, remains a fundamental parameter in estimating the post-mortem interval (PMI). Its onset and progression are subject to considerable variability influenced by extrinsic factors, notably ambient temperature and humidity, as well as intrinsic factors including the decedent's physiological state, metabolic conditions, and pre-mortem physical activity. Empirical evidence from forensic studies indicates that rigor mortis generally manifests within 2 to 4 hours after death, attains maximal rigidity between 6 and 12 hours, and gradually resolves over a period of 36 to 72 hours. Nevertheless, significant deviations from these temporal patterns are frequently documented, particularly under extreme environmental conditions or in cases involving pathological states. Such heterogeneity underscores the limitations of relying solely on rigor mortis for PMI determination. Therefore, it is imperative to integrate rigor mortis findings with additional postmortem indicators, such as livor mortis distribution and core body temperature measurements, to enhance the precision of death time estimations. A comprehensive understanding of the multifactorial influences on rigor mortis is essential for forensic practitioners to improve the accuracy and reliability of medico-legal death investigations. This review highlights the variability of rigor mortis progression reported in studies from 2015–2020, underscoring its limited standalone value for PMI estimation. Integrating rigor mortis with multimodal indicators (livor mortis, algor mortis, decomposition) is essential for reliable forensic practice.

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ETHICAL CONSIDERATIONS

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Conflict of Interest Statement

There is no conflict of interest between the authors.

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