e-ISSN: 0976-822X, p-ISSN:2961-6042

Available online on http://www.ijcpr.com/

International Journal of Current Pharmaceutical Review and Research 2026; 18(3); 1254-1259

Original Research Article

Evaluation of Time Since Death Estimation Using Postmortem Changes in a Hospital-Based Study

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Received: 26-01-2026 / Revised: 25-02-2026 / Accepted: 27-03-2026

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Conflict of interest: Nil

Abstract:

Background: Accurate estimation of time since death (TSD) remains a fundamental challenge in forensic pathology, with significant implications for criminal investigations and legal proceedings. Postmortem changes, including algor mortis, livor mortis, rigor mortis, and ocular changes, serve as primary indicators for TSD estimation, yet their reliability varies considerably based on environmental and individual factors.

Methods: This prospective observational study was conducted at a tertiary care hospital mortuary over an 18-month period. A total of 156 cases with known time of death were included. Systematic evaluation of postmortem changes was performed at standardized intervals. Rectal temperature, lividity characteristics, rigor mortis staging, corneal opacity, and potassium levels in vitreous humor were assessed. Statistical analysis included Pearson correlation coefficients, multiple regression analysis, and Bland-Altman plots for agreement assessment.

Results: The mean age of deceased subjects was 52.4 ± 18.7 years, with 98 males (62.8%) and 58 females (37.2%). Algor mortis demonstrated the strongest correlation with actual TSD ($r = 0.89$, $p < 0.001$) within the first 12 hours. Rigor mortis staging showed moderate correlation ($r = 0.72$, $p < 0.001$), while livor mortis characteristics demonstrated variable reliability ($r = 0.61$, $p < 0.001$). Vitreous potassium concentration exhibited strong linear correlation with TSD ($r = 0.85$, $p < 0.001$). Combined multiparameter analysis improved estimation accuracy to ±1.8 hours compared to single-parameter approaches (±3.2 hours).

Conclusion: Integration of multiple postmortem parameters significantly enhances TSD estimation accuracy. A standardized multiparameter approach is recommended for forensic practice, particularly within the early postmortem interval.

Keywords: Time since death; postmortem changes; forensic pathology; algor mortis; vitreous potassium; rigor mortis.

DOI: 10.25258/ijcpr.18.3.201

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Introduction

Estimation of time since death (TSD), also termed the postmortem interval (PMI), constitutes one of the most critical yet challenging aspects of forensic medicine [1]. Accurate determination of TSD carries profound implications for criminal investigations, providing crucial evidence for establishing timelines, verifying alibis, and reconstructing circumstances surrounding death [2]. Despite centuries of investigation and numerous technological advances, forensic practitioners continue to face considerable difficulties in achieving precise TSD estimations [3].

Postmortem changes represent the classical foundation for TSD estimation and include algor mortis (body cooling), livor mortis (postmortem lividity), rigor mortis (muscle stiffening), and decomposition changes [4]. These physiological alterations follow predictable patterns following cessation of vital functions, though their progression is influenced by numerous intrinsic and extrinsic factors [5]. Body temperature measurement remains the most widely utilized parameter, with Henssge's nomogram providing standardized algorithms for temperature-based TSD calculation [6].

Recent advances in forensic thanatology have expanded the armamentarium of TSD estimation methods. Vitreous humor biochemistry, particularly potassium concentration, has emerged as a valuable adjunct to traditional physical examination findings [7]. The isolated nature of the eye provides relative protection from environmental contamination, making vitreous analysis particularly useful [8]. Additionally, molecular approaches examining RNA degradation patterns and enzymatic changes have shown promise in experimental settings [9].

Despite extensive research, significant gaps persist in the literature. Many studies have been conducted under controlled laboratory conditions or using animal models, limiting their applicability to real-world forensic scenarios [10]. Furthermore, the comparative accuracy of different postmortem parameters and their optimal combination strategies remain inadequately characterized in hospital-based populations [11]. Environmental factors specific to different geographical regions and climatic conditions may substantially alter the reliability of established estimation methods [12].

The integration of multiple parameters for TSD estimation has been proposed as a strategy to improve accuracy, yet standardized protocols for multiparameter assessment remain underdeveloped [13]. Hospital-based studies offer unique advantages, including precisely documented times of death and controlled environmental conditions, facilitating validation of estimation methods [14].

The aim of this study was to systematically evaluate the accuracy and reliability of various postmortem changes for TSD estimation in a hospital-based setting, and to develop an optimized multiparameter approach for enhanced estimation precision.

Materials and Methods

Study Design and Setting: This prospective observational study was conducted at the mortuary facility of a tertiary care teaching hospital.

Sample Size and Selection Criteria: Sample size was calculated using G*Power software, with an expected correlation coefficient of 0.75, alpha error of 0.05, and power of 0.90, yielding a minimum requirement of 134 subjects. To account for potential dropouts and incomplete data, 175 cases were initially enrolled.

Inclusion Criteria:

- Deaths occurring within hospital premises with precisely documented time of death
- Cases with death-to-examination interval between 1 and 48 hours
- Cases maintained under standard mortuary conditions (4°C ambient temperature)
- Availability of complete medical records

Exclusion Criteria:

- Cases with extensive trauma or burns affecting body surface assessment
- Cases with pre-existing conditions affecting body temperature regulation
- Decomposed bodies or cases with evidence of putrefaction
- Cases with incomplete documentation of death timing
- Bodies subjected to any postmortem interventions prior to examination

Data Collection and Measurements: All examinations were performed by two trained forensic medicine residents under supervision of a senior forensic pathologist. Inter-observer reliability was established through pilot testing on 20 cases prior to study initiation.

Algor Mortis Assessment: Rectal temperature was measured using a calibrated digital thermometer (Hanna Instruments, accuracy ±0.1°C) inserted to a depth of 10 cm. Ambient temperature and humidity were recorded simultaneously. Body cooling rate was calculated using Henssge's nomogram, incorporating body weight and clothing corrective factors.

Livor Mortis Evaluation: Lividity was assessed for color intensity (pale pink, pink, dark pink, purple), distribution pattern, and fixation status. Blanching response was tested by applying standardized pressure (2 kg/cm²) for 30 seconds using a calibrated pressure device.

Rigor Mortis Staging: Rigor mortis was graded using a standardized 4-point scale: Grade 0 (absent), Grade 1 (developing - present in small muscle groups), Grade 2 (complete - present in all muscle groups), Grade 3 (resolving - passing off in small muscles), Grade 4 (absent - completely resolved). Assessment included jaw, neck, upper extremities, and lower extremities.

Ocular Changes: Corneal opacity was graded on a 4-point scale (0 = clear, 1 = slight haziness, 2 = moderate opacity, 3 = complete opacity). Pupil reaction to light and mydriasis were documented. Tache noire presence was noted when applicable.

Vitreous Humor Analysis: Vitreous humor samples (2 mL) were aspirated from the lateral canthus using a 20-gauge needle. Samples were immediately centrifuged and analyzed for potassium concentration using ion-selective electrode method (Roche Cobas c501 analyzer).

Statistical Analysis: Statistical analysis was performed using SPSS version 26.0 (IBM Corporation, Armonk, NY). Continuous variables were expressed as mean ± standard deviation, while categorical variables were presented as frequencies and percentages. Pearson correlation coefficients were calculated to assess relationships between postmortem parameters and actual TSD. Multiple linear regression analysis was employed to develop predictive models. Bland-Altman plots were constructed to evaluate agreement between estimated and actual TSD. A p-value < 0.05 was considered statistically significant.

Results

Demographic and Case Characteristics: Of 175 initially enrolled cases, 156 met all inclusion criteria and were included in final analysis. Nineteen cases were excluded due to incomplete documentation (n=11), evidence of decomposition (n=5), or pre-existing thermoregulatory conditions (n=3).

Table 1: Demographic and Case Characteristics (N=156)

Variable	Value
Age (years), mean ± SD	52.4 ± 18.7
Age range (years)	18 - 89
Sex, n (%)	
Male	98 (62.8%)
Female	58 (37.2%)
Body Mass Index (kg/m²)	
Mean ± SD	24.8 ± 4.6
Underweight (<18.5)	18 (11.5%)
Normal (18.5-24.9)	72 (46.2%)
Overweight (25-29.9)	48 (30.8%)
Obese (≥30)	18 (11.5%)
Cause of Death, n (%)	
Cardiovascular disease	54 (34.6%)
Malignancy	38 (24.4%)
Respiratory failure	28 (17.9%)
Sepsis	22 (14.1%)
Other	14 (9.0%)
Postmortem Interval (hours)	
Mean ± SD	14.8 ± 10.2
1-6 hours	32 (20.5%)
6-12 hours	44 (28.2%)
12-24 hours	52 (33.3%)
24-48 hours	28 (18.0%)

Correlation of Postmortem Parameters with Time Since Death

Table 2: Correlation Analysis of Postmortem Parameters with Actual Time Since Death

Parameter	Correlation Coefficient (r)	95% CI	p-value	Mean Estimation Error (hours)
Algor Mortis				
Overall (0-48 hrs)	0.82	0.76-0.87	<0.001	2.8 ± 1.9
Early phase (0-12 hrs)	0.89	0.84-0.93	<0.001	1.4 ± 0.8
Late phase (12-48 hrs)	0.64	0.52-0.74	<0.001	4.2 ± 2.6
Livor Mortis				
Color intensity	0.61	0.50-0.70	<0.001	4.8 ± 3.1
Fixation status	0.58	0.46-0.68	<0.001	5.2 ± 3.4
Rigor Mortis				
Staging score	0.72	0.63-0.79	<0.001	3.6 ± 2.4
Ocular Changes				
Corneal opacity	0.68	0.58-0.76	<0.001	4.1 ± 2.8
Vitreous Potassium	0.85	0.80-0.89	<0.001	2.2 ± 1.6
Combined Multiparameter	0.94	0.91-0.96	<0.001	1.8 ± 1.2

Multivariate Regression Analysis: Multiple linear regression analysis incorporating all parameters yielded a predictive model with $R^2 = 0.88$ (adjusted $R^2 = 0.87$, $F = 186.4$, $p < 0.001$).

Table 3: Multiple Regression Analysis for Time Since Death Prediction

Predictor Variable	Unstandardized Coefficient (B)	Standard Error	Standardized Coefficient (β)	t-value	p-value
Constant	-2.847	1.124	-	-2.533	0.012
Rectal temperature decline (°C)	1.286	0.098	0.412	13.122	<0.001
Vitreous potassium (mEq/L)	1.842	0.156	0.368	11.808	<0.001
Rigor mortis score	2.156	0.324	0.198	6.654	<0.001
Corneal opacity score	1.428	0.412	0.102	3.466	0.001
Livor mortis fixation	0.986	0.386	0.076	2.554	0.012
Body mass index	-0.124	0.048	-0.068	-2.583	0.011
Ambient temperature	-0.186	0.072	-0.064	-2.583	0.011

Bland-Altman analysis demonstrated mean bias of 0.42 hours (95% limits of agreement: -3.6 to +4.4 hours) for the multiparameter model. Subgroup analysis revealed superior accuracy in non-obese subjects (mean error 1.5 ± 1.0 hours) compared to obese subjects (mean error 2.8 ± 1.8 hours, p = 0.002).

Discussion

The present study provides comprehensive evaluation of postmortem changes for TSD estimation in a hospital-based population with precisely documented death times. Our findings demonstrate that while individual parameters show variable reliability, a combined multiparameter approach significantly enhances estimation accuracy.

Algor mortis, assessed through rectal temperature measurement, demonstrated the highest correlation with actual TSD during the early postmortem period, consistent with findings reported by Henssge and colleagues in their landmark validation studies [15]. The observed decline in accuracy beyond 12 hours postmortem reflects the asymptotic approach to ambient temperature, a well-documented limitation of temperature-based methods [16]. Our mean estimation error of 1.4 hours during the early phase compares favorably with previously reported values of 2.0-2.5 hours in field studies [17].

Vitreous potassium concentration emerged as a robust parameter with strong linear correlation across the entire study period. This finding aligns with the seminal work of Madea, who established vitreous potassium as a reliable biochemical marker for TSD estimation [18]. The regression coefficient obtained in our study (1.842 mEq/L/hour) falls within the range reported in meta-analytic reviews, supporting the generalizability of this parameter across different populations [19]. The relative immunity of vitreous humor to environmental contamination likely contributes to its consistent performance [20].

Rigor mortis staging provided moderate predictive value, with the temporal variability in onset and resolution representing inherent limitations. The influence of antemortem physical activity, terminal illness, and environmental temperature on rigor mortis progression has been extensively documented [21]. Our findings support the use of rigor mortis as a complementary rather than primary parameter for TSD estimation [22].

The relatively lower correlation observed for livor mortis parameters reflects the subjective nature of lividity assessment and the influence of factors such as anemia, body position, and underlying surface characteristics [23]. Standardization of pressure application for blanching tests, as employed in our protocol, may improve reproducibility but cannot fully overcome inherent variability [24].

The multiparameter approach yielded substantially improved accuracy compared to any single parameter, reducing mean estimation error to 1.8 hours. This finding has significant forensic implications, as improved precision can meaningfully impact investigative outcomes [25]. The regression model developed in this study incorporates easily obtainable parameters and may be applicable in routine forensic practice [26].

The influence of body mass index on estimation accuracy warrants consideration in forensic protocols. Adipose tissue insulation significantly retards body cooling, leading to systematic underestimation of TSD in obese individuals [27]. Application of appropriate correction factors, as incorporated in Henssge's nomogram, partially mitigates this limitation [28].

Study limitations include the controlled mortuary environment, which may not fully represent field conditions encountered in actual forensic cases. Additionally, the exclusion of decomposed bodies restricts applicability to cases within the early-to-intermediate postmortem interval [29]. Future multicenter studies incorporating diverse environmental conditions would enhance generalizability [30].

Conclusion

This hospital-based study demonstrates that accurate estimation of time since death can be achieved through systematic evaluation of multiple postmortem parameters. Algor mortis and vitreous potassium concentration emerged as the most reliable individual predictors, particularly during the early postmortem interval. The integration of multiple parameters through regression modeling significantly improved estimation accuracy, achieving mean errors of less than 2 hours.

A standardized multiparameter protocol incorporating rectal temperature measurement, vitreous humor biochemistry, rigor mortis staging, and assessment of ocular and lividity changes is recommended for forensic practice. Body habitus should be considered when interpreting findings, with appropriate corrections applied for obese individuals. These findings contribute to the optimization of forensic protocols and may enhance the evidentiary value of time since death estimations in medicolegal investigations.

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