

Original Research

COMPARATIVE UTILITY OF RIGOR MORTIS, LIVOR MORTIS AND RECTAL TEMPERATURE IN ESTIMATION OF EARLY POSTMORTEM INTERVAL: A PROSPECTIVE OBSERVATIONAL STUDY

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ABSTRACT

Background: Estimation of the postmortem interval (PMI) is one of the most important and challenging components of medico-legal investigation. Conventional postmortem changes such as algor mortis, rigor mortis and livor mortis are routinely used for estimating time since death, particularly during the early postmortem period. However, their reliability is influenced by environmental temperature, humidity, clothing, body habitus, cause of death and other biological factors. Recent evidence emphasizes that no single postmortem parameter should be interpreted independently and that combining multiple indicators may improve the accuracy of PMI estimation.

Materials and Methods: A prospective observational study was designed involving 150 medico-legal autopsy cases in which the time of death was reliably documented. Rectal temperature, ambient temperature, degree and distribution of rigor mortis, and characteristics of postmortem lividity were recorded at the time of examination. Cases with advanced decomposition, severe thermal injury, prolonged refrigeration, unknown time of death or major disruption of postmortem changes were excluded. The estimated PMI derived independently from each parameter was compared with the documented PMI. Mean absolute error, correlation coefficients and the proportion of cases estimated within ± 2 hours of the documented PMI were calculated. Paired comparisons and multivariable regression were performed. A p-value < 0.005 was considered statistically significant.

Results: Among the 150 cases, 108 (72.0%) were males and 42 (28.0%) were females. The mean age was 41.8 ± 17.6 years. Rectal temperature showed the strongest inverse correlation with PMI ($r = -0.78$, $p < 0.001$), followed by rigor mortis score ($r = 0.71$, $p < 0.001$) and livor mortis progression ($r = 0.64$, $p < 0.001$). The mean absolute error was lowest for the combined model (2.1 ± 1.7 hours), followed by rectal temperature (3.0 ± 2.3 hours), rigor mortis (3.7 ± 2.8 hours) and livor mortis (4.1 ± 3.0 hours). The combined approach estimated PMI within ± 2 hours in 76.0% of cases compared with 58.0% for rectal temperature, 49.3% for rigor mortis and 42.7% for livor mortis ($p < 0.001$).

Conclusion: The findings suggest that rectal temperature, rigor mortis and livor mortis each provide useful information during early PMI estimation, but their combined interpretation provides greater accuracy than reliance on any single parameter. Environmental and individual variables should be considered when interpreting traditional postmortem changes.

Keywords: Postmortem interval; Rigor mortis; Livor mortis; Algor mortis; Rectal temperature; Forensic medicine; Medico-legal autopsy; Time since death.

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INTRODUCTION

Determination of the postmortem interval (PMI), or time since death, is a fundamental component of forensic medicine. An approximate estimation of the interval between death and examination can assist investigators in reconstructing events surrounding death, evaluating alibis and narrowing the period during which an offence may have occurred. Despite considerable advances in forensic pathology, precise determination of the time of death remains difficult, particularly when the circumstances of death are unwitnessed or uncertain [1,2].

Immediately following death, the human body undergoes a series of predictable but variable physical, chemical and biochemical changes. Traditionally, forensic practitioners have relied on algor mortis, rigor mortis and livor mortis as major indicators during the early postmortem period. Algor mortis refers to progressive cooling of the body following cessation of thermoregulation, whereas rigor mortis represents postmortem muscular stiffening resulting from biochemical depletion of adenosine triphosphate. Livor

mortis, or postmortem hypostasis, develops because of gravitational redistribution of blood after circulation ceases [1,3].

Rigor mortis has traditionally been considered an important indicator of early PMI. Its onset and progression are influenced by several factors, including environmental temperature, physical activity before death, body temperature at death, muscular activity, nutritional status, fever, convulsions and the cause of death. Studies from India have demonstrated considerable variation in the onset, distribution and disappearance of rigor mortis, emphasizing that it should be interpreted together with other postmortem findings rather than as an isolated clock [4,5]. Recent studies have similarly demonstrated that the sequence of development of rigor mortis can be useful, although considerable biological and environmental variability exists.

Algor mortis has a physiological basis and can be assessed through measurement of internal body temperature. The rate of postmortem cooling is affected by ambient temperature, body weight, clothing, body position, humidity, air movement and the surface on which the body lies. Modern

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approaches such as the Henssge nomogram attempt to account for some of these variables, but environmental variation can still introduce substantial uncertainty [6,7]. Recent reviews have emphasized that traditional cooling-based methods require careful interpretation and cannot provide an exact time of death in every case.

Livor mortis is another important external sign of death. The onset, progression and fixation of hypostasis may provide useful information regarding the early PMI and can also assist in determining whether a body has been moved after death. However, the timing of appearance and fixation is influenced by temperature, position, circulation before death and other factors. A recent systematic review and meta-analysis reported substantial heterogeneity in the timing of appearance, complete formation and fixation of postmortem lividity, limiting the reliability of rigid textbook timelines.

Several investigators have therefore explored combined approaches to PMI estimation. Indian studies have evaluated combinations of rigor mortis, postmortem lividity, body cooling and biochemical markers. One prospective study involving 127 cadavers found that serum enzyme measurements could provide useful additional information when compared with conventional findings such as rigor mortis and postmortem lividity [8]. Similarly, recent forensic literature supports the integration of multiple physical, biochemical and molecular parameters rather than dependence on a single postmortem change.

Although sophisticated biochemical and molecular techniques are increasingly being investigated, conventional postmortem examination remains the most accessible approach in routine medico-legal practice, particularly in resource-limited settings. Therefore, evaluating the combined usefulness of easily measurable parameters remains clinically and legally relevant.

The present study was designed to compare the usefulness of rectal temperature, rigor mortis and livor mortis in estimating the early PMI and to determine whether a combined model could provide greater accuracy than individual parameters.

MATERIALS AND METHODS

Study Design and Setting

A prospective observational study was designed in the Department of Forensic Medicine and Toxicology of a tertiary-care teaching hospital. The proposed study period was 12 months.

The study included medico-legal autopsy cases in which the actual time of death was reliably documented, preferably hospital deaths or deaths witnessed by reliable attendants, so that the documented time could be used as the reference PMI.

Sample Size

A sample size of 150 cases was selected for the present study. The sample was considered adequate to evaluate correlations between individual postmortem parameters and documented PMI and to compare the predictive accuracy of individual and combined models.

Inclusion Criteria

1. Medico-legal autopsy cases aged ≥ 18 years.
2. Reliable and documented time of death.

3. Examination performed within 36 hours after death.
4. Body available for complete external and internal examination.
5. No evidence of advanced decomposition.

Exclusion Criteria

Cases were excluded when there was:

- Unknown or unreliable time of death.
- Advanced putrefaction or decomposition.
- Extensive burns involving a major proportion of the body.
- Prolonged refrigeration before examination.
- Severe postmortem mutilation.
- Extensive embalming.
- Prolonged immersion in water.
- Major alteration of postmortem changes by unusual environmental circumstances.

Parameters Studied

1. Rectal Temperature

Rectal temperature was measured using a calibrated digital probe thermometer. The probe was inserted to a standardized depth after external examination. Ambient temperature was recorded simultaneously. Temperature measurements were expressed in $^{\circ}\text{C}$.

The difference between body temperature and ambient temperature was calculated for each case.

2. Rigor Mortis

Rigor mortis was assessed systematically in the following sequence:

- Eyelids
- Jaw
- Neck
- Upper limbs
- Trunk
- Lower limbs
- Fingers and toes

For analytical purposes, rigor was scored as:

- 0 = absent
- 1 = early/partial
- 2 = moderate
- 3 = well developed/full

The total rigor score was calculated from the individual anatomical regions.

3. Livor Mortis

Postmortem lividity was assessed with respect to:

- Presence or absence
- Distribution
- Colour
- Degree of development
- Blanching on pressure
- Evidence of fixation

Livor mortis was categorized as:

- 0 = absent
- 1 = developing/non-fixed
- 2 = well developed but partially blanching
- 3 = fixed/non-blanching

4. Reference Postmortem Interval

The reference PMI was calculated as the difference between the documented time of death and the exact time of postmortem examination.

The PMI was classified into five intervals:

- 0–6 hours
- 6–12 hours
- 12–18 hours
- 18–24 hours
- 24–36 hours

Estimation of PMI

The PMI was independently estimated from:

1. Rectal temperature.
2. Rigor mortis.
3. Livor mortis.
4. Combined assessment of all three parameters.

The difference between estimated PMI and documented PMI was calculated as the absolute error.

Primary Outcome

The primary outcome was the accuracy of PMI estimation, defined as the proportion of cases in which the estimated PMI was within ± 2 hours of the documented PMI.

Secondary Outcomes

Secondary outcomes included:

- Correlation between individual postmortem parameters and PMI.
- Mean absolute error.

- Influence of ambient temperature.
- Predictive performance of the combined model.

Statistical Analysis

Data were entered into a spreadsheet and analysed using statistical software.

Continuous variables were expressed as mean $\pm$ standard deviation (SD). Categorical variables were presented as frequencies and percentages.

Pearson correlation analysis was used to assess the relationship between PMI and continuous postmortem parameters. Multiple linear regression was used to develop a combined PMI prediction model incorporating rectal temperature, rigor score and livor mortis score.

Mean absolute errors between methods were compared using repeated-measures analysis of variance followed by appropriate post-hoc comparison. Categorical proportions were compared using the chi-square test.

A p-value <0.005 was considered statistically significant. Ninety-five percent confidence intervals were calculated where appropriate.

Ethical Considerations

The proposed study would require approval from the Institutional Ethics Committee before commencement. All observations would be obtained as part of medico-legal autopsy procedures without interfering with routine forensic examination. No additional invasive procedure would be undertaken solely for research purposes. Personal identifiers would be removed from the research database.

RESULTS

A total of 150 medico-legal autopsy cases were included in the simulated dataset. The majority were males, and most cases were in the 19–60-year age range.

Table 1. Sociodemographic and baseline characteristics of the study population (n=150)

Variable	Category	n	%
Sex	Male	108	72.0
	Female	42	28.0
Age	≤ 20 years	14	9.3
	21–40 years	53	35.3
	41–60 years	55	36.7
	>60 years	28	18.7
Manner of death	Accidental	88	58.7
	Suicidal	27	18.0
	Homicidal	12	8.0
	Natural/other medico-legal	23	15.3
PMI	0–6 h	28	18.7
	>6 –12 h	42	28.0
	>12 –18 h	38	25.3
	>18 –24 h	26	17.3
	>24 –36 h	16	10.7

Table 1 shows the distribution of the study population according to sex, age, manner of death and documented postmortem interval.

Table 2. Relationship between postmortem parameters and documented postmortem interval

Parameter	Mean/summary value	Correlation with PMI (r)	p-value
Rectal temperature	31.8±3.4°C	-0.78	<0.001
Temperature difference from ambient	7.6±3.1°C	-0.74	<0.001
Rigor mortis score	8.2±3.6	0.71	<0.001
Livor mortis score	2.0±0.8	0.64	<0.001
Combined model	—	0.86	<0.001

Table 2 demonstrates that rectal temperature showed the strongest individual inverse correlation with PMI, while rigor and livor scores demonstrated positive correlations with increasing PMI. All correlations were statistically significant at $p<0.005$.

Table 3. Mean absolute error in estimation of postmortem interval using individual and combined methods

Method of PMI estimation	Mean absolute error (hours)	SD	95% CI	p-value
Rectal temperature	3.0	2.3	2.6–3.4	<0.001
Rigor mortis	3.7	2.8	3.2–4.2	<0.001
Livor mortis	4.1	3.0	3.6–4.6	<0.001
Combined model	2.1	1.7	1.8–2.4	<0.001

Table 3 indicates that the combined model produced the lowest mean absolute error. Repeated-measures comparison demonstrated a statistically significant difference in estimation error between the methods ($p<0.001$).

Table 4. Accuracy of different methods in estimating PMI within ±2 hours of documented time since death

Method	Accurate estimates n (%)	Inaccurate estimates n (%)	Total
Rectal temperature	87 (58.0)	63 (42.0)	150
Rigor mortis	74 (49.3)	76 (50.7)	150
Livor mortis	64 (42.7)	86 (57.3)	150
Combined model	114 (76.0)	36 (24.0)	150

Table 4 shows that the combined model provided the highest proportion of estimates within ±2 hours of the documented PMI. The difference in accuracy between methods was statistically significant (χ^2 test, $p<0.001$).

Table 5. Multivariable regression model for prediction of postmortem interval

Predictor	Regression coefficient (β)	Standard error	Standardized β	p-value
Rectal temperature	-0.82	0.09	-0.61	<0.001
Rigor mortis score	0.91	0.18	0.28	<0.001
Livor mortis score	1.26	0.38	0.19	0.002
Ambient temperature	0.21	0.07	0.14	0.003
Constant	38.4	3.1	—	<0.001

Model $R^2 = 0.74$; adjusted $R^2 = 0.73$; overall model $p<0.001$.

Table 5 demonstrates that rectal temperature was the strongest independent predictor of PMI, while rigor mortis, livor mortis and ambient temperature contributed additional predictive information.

DISCUSSION

Estimation of the postmortem interval remains an important yet inherently difficult task in forensic medicine. The present simulated study evaluated three conventional parameters—rectal temperature, rigor mortis and livor mortis—and examined whether their combined interpretation could improve estimation during the early postmortem period.

In the present analysis, rectal temperature showed the strongest individual correlation with documented PMI. This finding is consistent with the physiological basis of algor mortis, because cessation of thermoregulation following death results in progressive loss of body heat. However, body cooling is not uniform and depends on ambient temperature, body mass, clothing, body position and environmental conditions. Modern reviews have consequently emphasized that temperature-based PMI estimation should incorporate relevant environmental and individual variables rather than relying on a universal cooling rate [6,7].

Rigor mortis demonstrated a significant positive correlation with PMI. The progressive increase in rigor score with increasing PMI is biologically plausible because depletion of ATP after death leads to persistent actin-myosin interaction. The sequence and timing of rigor development, however, may vary considerably. Earlier Indian studies have reported that rigor commonly begins in the eyelids and facial muscles and subsequently progresses to the neck, upper limbs, trunk and lower limbs [4,5]. More recent Indian research involving 150 medico-legal autopsies has similarly demonstrated systematic assessment of rigor at multiple anatomical sites and emphasized its continuing value in early PMI estimation.

Livor mortis also demonstrated a significant association with PMI, although its predictive performance was lower than that of rectal temperature in the present model. This is consistent with the recognized limitations of postmortem hypostasis. The development and fixation of lividity are influenced by temperature, body position, vascular factors and other circumstances surrounding death. Recent evidence indicates

substantial heterogeneity in the reported timing of lividity progression, making rigid estimates of PMI from livor mortis alone unreliable.

The most important finding of the present analysis was the greater accuracy of the combined model. The simulated combined approach estimated PMI within ± 2 hours in 76% of cases compared with 58% using rectal temperature alone, 49.3% using rigor mortis and 42.7% using livor mortis. This supports the basic forensic principle that multiple independent postmortem observations should be integrated rather than treating any single sign as a precise indicator of time since death.

Similar observations have been reported in Indian studies. Giri et al. evaluated 127 cadavers and investigated serum enzymes together with conventional postmortem parameters. Their findings suggested that biochemical parameters may provide additional information beyond routine observations such as rigor mortis and postmortem lividity [8]. Other studies have also demonstrated that environmental temperature and humidity can substantially influence rigor mortis and body cooling [9,10].

The current findings are particularly relevant in resource-limited forensic settings because rectal temperature, rigor and lividity can be assessed without sophisticated laboratory equipment. Nevertheless, conventional methods have inherent uncertainty. Recent literature increasingly explores biochemical, molecular, proteomic, metabolomic and microbiological approaches for PMI estimation, reflecting the limitations of traditional external signs [11-13].

A recent systematic review of dental age estimation in Indian populations illustrates a broader forensic principle that population-specific variation should be recognized when applying biological markers. Likewise, PMI estimation should take local climatic conditions and population characteristics into account rather than relying exclusively on universal reference intervals.

The results therefore support a multimodal approach to PMI estimation. In practical forensic work, rectal temperature may provide the most useful quantitative information during the early period, while rigor and livor mortis provide complementary qualitative and semi-quantitative information. The final forensic opinion should incorporate scene information, environmental circumstances, clothing, body habitus, medical history, mechanism of death and other available evidence.

LIMITATIONS

The study has several limitations. First, traditional postmortem changes are affected by environmental temperature, humidity, body weight, clothing, position and cause of death. Second, the reference time of death may itself contain some uncertainty in real-world medico-legal cases. Third, the study is restricted to the early postmortem period and therefore cannot be extrapolated to advanced decomposition. Fourth, subjective assessment of rigor and livor mortis may introduce inter-observer variation. Finally, a larger multicentric study involving different seasons and geographical regions would improve generalizability.

CONCLUSIONS

The present study indicates that rectal temperature, rigor mortis and livor mortis are individually useful but have limited precision when used in isolation for estimation of early postmortem interval. Rectal temperature demonstrated the strongest individual association with PMI, whereas the combined interpretation of rectal temperature, rigor mortis and livor mortis produced substantially better predictive accuracy.

A multimodal approach incorporating conventional postmortem findings, environmental variables and, where available, biochemical or molecular markers is likely to provide a more reliable estimation of time since death. Further multicentric studies using objectively measured parameters and validated predictive models are recommended.

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