

# Estimation of Time Since Death from Rigor Mortis - An Autopsy Study in Tertiary Care Hospital of Malwa Region of Punjab state of India

Rajiv Joshi<sup>1\*</sup>, Ashwini Kumar<sup>1</sup>, Gurjeet Singh<sup>1</sup>, Alwin Varghese<sup>1</sup>, Ravdeep Singh<sup>1</sup>, Harvinder S. Chhabra<sup>2</sup>

<sup>1</sup>Department of Forensic Medicine and Toxicology, Guru Gobind Singh Medical College & Hospital, Faridkot, Punjab, India

<sup>2</sup>Harvinder Singh Chhabra, MO (Specialist), Civil Hospital, Fatehgarh Sahib

## ABSTRACT

**Background:** Postmortem interval estimation is an important tool in forensic medicine. Estimating time since death is extremely important in cases where there is doubt about the period of death. After death, many changes occur in a regular sequence and can be used to arrive at an approximate time since death. When a post-mortem is conducted, doctor conducting the post-mortem examination has to give his opinion about post-mortem interval i.e. the probable time that elapsed between death and post-mortem examination even in cases of decomposed dead bodies. While giving this opinion, we always think we should have some other dependable methods to be more accurate in answering this question. Algor mortis, Rigor mortis, and Livor mortis have been the basis for ascertaining the post-mortem interval collectively. Among them, Rigor Mortis is an important indicator of post-mortem interval. Although it is a dependable tool for estimating post-mortem interval, it is influenced by many endogenous and exogenous factors like nature of death, nature of the body, temperature, humidity etc. Time of death is almost always asked by investigating authorities to connect the crime with criminals.

Determining the death time has always been a topic of keen interest amongst forensic pathologists from its inception to date. Many workers in forensic medicine have tried to investigate to determine the time of death based on post mortem findings. To date, it is still an important and fascinating criterion to ascertain the time since death. With this study, we aimed to demonstrate the intricacies of Rigor Mortis with fluctuating temperature and humidity of the local region. We planned to estimate and compare the post-mortem interval based on Rigor Mortis in different body muscles.

**Materials and Methods:** This study was conducted in the Department of Forensic Medicine and Toxicology at G.G.S. Medical College, Faridkot after taking clearance from the institutional ethics committee. Thirty medico-legal autopsy cases were included in the study where the exact time of death was known and included only hospital deaths. The relatives of the deceased were explained the purpose and nature of the study and provided with the patient information sheet and informed consent was taken. The details of the cases were noted from the hospital bed head ticket, relative interview and the police inquest papers. The exact temperature and humidity were noted at the start of autopsy using a digital hygrometer.

**Results:** A total of 30 cases were observed out of which males outnumbered the females by approximately 3:1. Maximum cases consisted of Roadside Accidents (43.3%) followed by poisoning, assault and hanging, in that order. The average temperatures during the study months varied from a maximum of 41.3°C (June) to a minimum of 33.7°C (July). The average humidity varied from a maximum of 62.6% (July) to a minimum of 29.3% (May). The average temperatures during the study months varied from a maximum of 41.3°C (June) and a minimum of 33.7°C (July). The average humidity during the study months varied from a maximum of 62.6% (July) and a minimum of 29.3% (May). Fully established Rigor Mortis was observed at a minimum of 10 hours and a maximum of 29 hours in May and June.

**Keywords:** Humidity, Postmortem Interval, Postmortem, Rigor Mortis, Temperature.

*Int J Eth Trauma Victimology* (2021). DOI: 10.18099/ijetv.v7i02.3

## INTRODUCTION

Thanatology is the branch of science which deals with all the aspects of death. There is usually a progression from clinical death to brain death, biological death, and finally cellular death. Brain death follows clinical death immediately due to lack of oxygen. It involves the cerebral cortex, the cerebellum, and finally lower brain centres die. Ultimately the brainstem and vital centres get involved, and the process of cellular death begins.<sup>1</sup>

After death, many physiochemical changes such as Algor mortis, rigor mortis, hypostasis and decomposition occur, leading to the dissolution of all soft tissues. Corneal clouding

**Corresponding Author:** Rajiv Joshi, Department of Forensic Medicine and Toxicology, Guru Gobind Singh Medical College & Hospital, Faridkot, Punjab, India, e-mail: drrajivfmt@gmail.com

**How to cite this article:** Joshi R, Kumar A, Singh G, Varghese A, Singh R, Chhabra HS. Estimation of Time Since Death from Rigor Mortis- An Autopsy Study in Tertiary Care Hospital of Malwa Region of Punjab state of India. *Int J Eth Trauma Victimology*. 2021;7(2):10-15.

**Source of support:** Nil

**Conflict of interest:** None

**Received:** 10/11/2021;

**Received in revised form:** 30/09/2021;

**Accepted:** 06/10/2021;

**Published:** 31/12/2021

occurs after death with an increase in its intensity until the cornea loses its turgor whether the eyelids remain open or not.<sup>2,3</sup> The importance of these changes is that they occur in a regular sequence and can be used to arrive at an approximate time of death.<sup>4,5</sup> The changes that occur after death and help estimate the approximate time since death can be classified into Immediate, early and late changes. Doctors in courts are often asked to comment upon the time since death. Estimating the time of death is notoriously one of the most difficult and inaccurate techniques in forensic pathology and various pieces of evidence must be correlated to each other to arrive at some sensible time bracket within which the death could have occurred.<sup>6</sup> The autopsy surgeon should do his best to arrive at the closest possible deduction as to the time elapsed since death. The courts are now depending more and more on scientific evidence for establishing the proof of a crime.<sup>7</sup>

Among the triad, Algor mortis is the cooling of the body after death. The body temperature at the time of death is generally 37°C which falls to the surrounding temperature by 12 to 18 hours after death. The liver mortis or post-mortem staining generally appears over-dependent parts of the body within ½ - 1 hour of death and gets fixed within 6 to 8 hours after death. Similarly, the rigor mortis, which is cadaveric rigidity, starts developing within 1 to 2 hours after death and takes around 12 hours after death for complete development and remains in the developed stage for further 12 hours and disappears in the next 12 hours generally. This can give the approximate time since death till 36 hours after death. Many other sophisticated techniques like biochemical studies of C.S.F., Vitreous Humor, Aqueous humor, etc. have been tried to reach the accuracy regarding time since death.<sup>8</sup>

During the stage of rigor mortis, if the position of the dead body is unusual with flexion at some major joints, it will remain rigid in the same position. If the rigor mortis is the well-established stage, the flexed limbs continue to stay flexed and will defy gravity, even when the support beneath them is missing. An unusual position in which the limbs are stiff and defy gravity could be due to putrefaction.<sup>9</sup>

Developed rigor mortis once damaged by any means will never recur again in the body. The disappearance of rigor mortis denoted by flaccidity of muscles is caused by the action of alkaline liquids produced by putrefaction.<sup>10</sup> Shapiro<sup>11</sup> demonstrated Rigor's sequential progression of development from the head downward. Further, in 1960, Bendell studied the biophysics of muscular contraction, which led to a better understanding of rigor mortis. He stated that voluntary muscles consist of bundles of long fibers of the dimension of human hair. Each fibre is formed of densely packed myofibrils extending through its whole length. These myofibrils are the contractile elements, and they are made up of proteins filaments, myosin filaments and actin filaments.<sup>12</sup>

According to literature, Rigor Mortis appears about 1–2 hours after death, gets well-established in the entire body in about 9–12 hours. It is maintained for about 12 hours and then gradually passes off in the same order as it appeared in the next 12 hours.<sup>13</sup>

The primary reason for rigor mortis is the loss of adenosine triphosphate from the anoxic tissue. Rigor mortis starts to develop 2–4 hours after death and develops fully by

6 to 12 hours and gradually dissipates until approximately 72 hours after death. It has been found that post-mortem muscle proteolysis is responsible for the relaxation following rigor mortis.<sup>14</sup>

A uniform time of appearance and disappearance of Rigor Mortis cannot be made applicable throughout a vast and diverse country like India where different weather conditions exist throughout its various parts at a given time.

Nysten (in 1811) stated that "rigidity persists longer in cold, wet air than in fresh, dry air". It could be due to early and increased breakdown of ATP in the hot weather and an early setting of the putrefaction.<sup>15</sup> Rigor supervenes and disappears rapidly in cases of violent exercise before death. The poisons that cause violent muscle contraction for some time before death e.g., strychnine, the Rigor Mortis is established rapidly and remains for a long time.

As is clear from the above, the area of consideration is vast and complex and through this study, we have tried to focus on the estimation of time since death from Rigor Mortis by studying Rigor Mortis in the body's voluntary muscles.

## MATERIAL AND METHODS

This study was conducted in the Department of Forensic Medicine from 1<sup>st</sup> May 2019 to 31<sup>st</sup> August 2019 after taking clearance from the institutional ethics committee. Thirty medico-legal autopsies cases were included where the exact time of death was known, including only hospital deaths. The relatives of the deceased were explained the purpose and nature of the study and provided with the patient information sheet. Informed consent was taken. The case details were noted from the hospital bed head ticket, relative interview and the police inquest papers. The exact temperature and humidity were noted at the start of autopsy using a digital hygrometer.

The presence or absence of Rigor Mortis was observed in the voluntary muscles of the body of the corpse. In the joints, the presence or absence of Rigor Mortis was noted by observing their movements to check for any resistance offered.

The exclusion criteria included:

- Advanced putrefied bodies.
- Bodies with musculoskeletal deformities.
- The deceased had a history of chronic debility diseases
- The deceased had a severe emotional disturbance or violent exercise before death.

## Observations

After getting ethical clearance from the institutional ethics committee this study was undertaken in the Department of Forensic Medicine and Toxicology. In all thirty cases, meeting the inclusion and exclusion criteria were selected and the data was recorded and analyzed. Following were the observations –

Maximum cases comprised roadside accidents (43.3%) followed by poisoning, assault and hanging. In three cases, the circumstances of the death were not clear. (Table 1)

A total of 30 cases were observed out of which males outnumbered the females by a ratio of approximately 3:1. (Table 2)

The average temperature varied from a maximum of 41.3°C (in June) to a minimum of 33.7°C (in July). The average humidity varied from a maximum of 62.6% (in July) to a minimum of 29.3% (in May) (Table 3 and Figure 3).

Cases were distributed according to rigor mortis status, post-mortem interval, temperature and humidity in different months during the period of study:

• **May 2019**

In May 2019, the maximum recorded temperature was 41°C and the minimum recorded temperature was 28°C with a mean of 35 and a standard deviation of + 4.3. Humidity varied from a maximum of 62% and a minimum of 12% with a mean of 33.1 and a standard deviation of 14.8. Post-mortem Interval varied from a maximum of 32 hours and a minimum of 10 hours with a mean of 20.5 and a standard deviation of + 7.2. (Table 4)

• **June 2019.**

For June, the maximum recorded temperature was 42°C and the minimum recorded temperature was 41°C with a mean of 41.3 and a standard deviation of + 0.5. Humidity varied from a maximum of 39 % and a minimum of 23 % with a mean of 30.3 and a standard deviation of 6.6. Post-mortem Interval varied

from a maximum of 33 hours and a minimum of 18 hours with a mean of 25.6 and a standard deviation of + 7.5. (Table 5)

• **July 2019**

For July, the maximum recorded temperature was 40 °C and the minimum recorded temperature was 28 °C with a mean of 33.7 and a standard deviation of + 4.1. Humidity varied from a maximum of 93 % and a minimum of 31 % with a mean of 62.6 and a standard deviation of 17.7. Post-mortem Interval varied from a maximum of 41 hours and a minimum of 14 hours with a mean of 26 and a standard deviation of + 7.7. (Table 6)

For August, the maximum recorded temperature was 36°C and the minimum recorded temperature was 25 °C with a mean of 30.8 and a standard deviation of ± 4.2. Humidity varied from a maximum of 84 % and a minimum of 50 % with a mean of 61.8 and a standard deviation of 13.2. Post-mortem Interval varied from a maximum of 43 hours and a minimum of 13 hours with a mean of 26.1 and a standard deviation of ± 12.5. (Table 7)

Table 8 shows the Cases in which Rigor Mortis was present.

Table 9 shows the Cases in which Rigor Mortis was absent-

From the observations (as mentioned earlier), we can observe that temperature and humidity play an integral role in affecting the onset and duration of Rigor Mortis in the human body. The onset of Rigor Mortis is slow and duration longer in cold and humid weather, whereas the onset is rapid and duration is short in hot and dry weather. (Table 10)

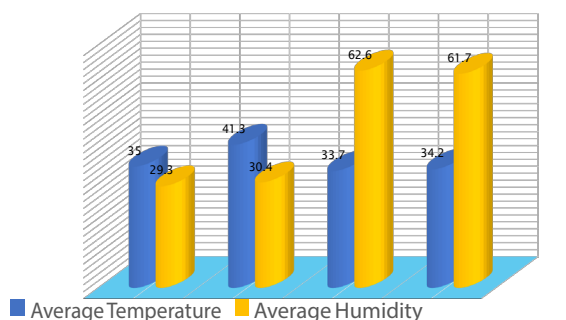


Figure 3: Average temperature and humidity, recorded during the period of study

Table 1: Distribution of cases on the alleged manner of death

Cause of death	Number of Cases	Total cases	Percentage
Roadside Accidents	13	30	43.3%
Poisoning	6	30	20%
Hanging	3	30	10%
Assault	5	30	16.7%
Miscellaneous Causes	3	30	10%

Table 3: Average temperature and humidity, recorded during the study

Months	May	June	July	August
Number of cases	9	3	10	8
Average Temperature (Only the temperatures of the days on which the cases were performed have been included.)	35°C	41.3°C	33.7°C	34.2°C
Average Humidity	29.3%	30.4%	62.6%	61.7%

Table 2: Distribution of cases according to gender.

Gender	Number of cases	Total cases	Percentage
Males	23	30	76.7 %
Females	7	30	23.3 %

Table 4: Post-mortem interval and status of Rigor Mortis for May 2019

	Postmortem Interval	Temperature	Humidity (%)
Case 1	32 hours	40°C	18
Case 2	18 hours	41°C	12
Case 3	22 hours	33°C	40
Case 4	13 hours	35°C	33
Case 5	25 hours	35°C	33
Case 6	16 hours	33°C	37
Case 7	20 hours	28°C	62
Case 8	29 hours	39°C	22
Case 9	10 hours	31°C	41
Mean	20.5 + 7.2	35 + 4.3	33.1 + 14.8

Table 5: Post-mortem interval and status of Rigor Mortis for June 2019.

	Postmortem Interval	Temperature	Humidity (%)
Case 1	33 hours	41°C	39
Case 2	18 hours	41°C	29
Case 3	26 hours	42°C	23
Mean	25.6 + 7.5	41.3 + 0.5	30.3 + 6.6



**Table 6:** Post-mortem interval and status of Rigor Mortis for July 2019.

	<i>Postmortem Interval</i>	<i>Temperature</i>	<i>Humidity (%)</i>
Case 1	28 hours	40°C	31
Case 2	22 hours	32°C	52
Case 3	18 hours	38°C	51
Case 4	18 hours	36°C	60
Case 5	29 hours	28°C	93
Case 6	32 hours	34°C	55
Case 7	26 hours	37°C	53
Case 8	14 hours	29°C	83
Case 9	32 hours	28°C	82
Case 10	41 hours	35°C	66
Mean	26 + 7.7	33.7 + 4.1	62.6 + 17.7

**Table 7:** Post-mortem interval and status of Rigor Mortis for August 2019

	<i>Postmortem Interval</i>	<i>Temperature</i>	<i>Humidity (%)</i>
Case 1	31 hours	28°C	53
Case 2	18 hours	36°C	55
Case 3	20 hours	36°C	61
Case 4	43 hours	29°C	84
Case 5	17 hours	29°C	84
Case 6	46 hours	36°C	50
Case 7	21 hours	27°C	51
Case 8	13 hours	25°C	56
Mean	26.1 + 12.5	30.8 + 4.2	61.8 + 13.2

**Table 8:** Cases in which Rigor Mortis was present

<i>Case Number with Month</i>	<i>Post-mortem Interval</i>	<i>Rigor Mortis</i>	<i>Temperature</i>	<i>Humidity</i>
Case 2 May	18 hours	Present	41°C	12%
Case 3 May	22 hours	Present	33°C	40%
Case 4 May	13 hours	Present	35°C	33%
Case 5 May	25 hours	Present	35°C	33%
Case 6 May	16 hours	Present	33°C	37%
Case 7 May	20 hours	Present	28°C	62%
Case 8 May	29 hours	Present	39°C	22%
Case 9 May	10 hours	Present	31°C	41%
Case 2 June	18 hours	Present	41°C	29%
Case 3 June	26 hours	Present	42°C	33%
Case 1 July	28 hours	Present	40°C	31%
Case 2 July	22 hours	Present	32°C	52%
Case 3 July	18 hours	Present	38°C	51%
Case 4 July	18 hours	Present	36°C	60%
Case 5 July	29 hours	Present	28°C	93%
Case 6 July	32 hours	Present	34°C	55%
Case 7 July	26 hours	Present	37°C	53%
Case 8 July	14 hours	Present	29°C	83%
Case 9 July	32 hours	Present	28°C	82%
Case 1 August	31 hours	Present	28°C	53%
Case 2 August	18 hours	Present	36°C	55%
Case 3 August	20 hours	Present	36°C	61%
Case 5 August	17 hours	Present	29°C	84%
Case 7 August	21 hours	Present	27°C	51%
Mean	21.7 + 6.1	Present	34 + 4.7	50.3 + 20.2

## DISCUSSION

Rigor Mortis is best known of all signs of death and is the most deceiving sign of the triad. Rigor seems to be a common occurrence in the bodies of the extremely obese, although it occasionally occurs in the senile, bony and emaciated.

A total of 30 cases were studied of which males outnumbered the females by approximately 3:1. Maximum cases consisted of Roadside Accidents (43.3%) followed by poisoning, assault and hanging, in that order. In three cases, the circumstances of the death were not clear.



**Table 9:** Cases in which Rigor Mortis was absent

Case no with month	Post-mortem Interval	Rigor Mortis	Temperature	Humidity
Case 1 May	32 hours	Absent	40°C	18%
Case 1 June	33 hours	Absent	41°C	39%
Case 10 July	41 hours	Absent	35C	66%
Case 4 August	43 hours	Absent	29°C	84%
Case 6 August	46 hours	Absent	36°C	50%
Case 8 August	13 hours	Absent	25°C	56%
Mean	34.6 + 11	Absent	35.3 + 5.7	52.2 + 20.7

**Table 10:** Inferences

Period of Study	Remarks
May –June	Temperatures remained high and humidity was low. Rigor Mortis appeared early in cases and duration was short. Fully established Rigor Mortis was observed at a minimum of 10 hours and a maximum of 29 hours in May and June.
July–August	Temperatures remained low and humidity was high. The onset of Rigor Mortis was delayed, and duration increased. Complete Rigor Mortis lasted from 17 hours to 32 hours.

The average temperatures during the study months varied from a maximum of 41.3°C (June) and a minimum of 33.7°C (July). The average humidity during the study months varied from a maximum of 62.6% (July) and a minimum of 29.3 % (May).

In May, the maximum recorded temperature was 41°C and the minimum recorded temperature was 28°C with a mean of 35 and a standard deviation of + 4.3. Humidity varied from a maximum of 62% and a minimum of 12% with a mean of 33.1 and a standard deviation of 14.8. Post-mortem Interval varied from a maximum of 32 hours and a minimum of 10 hours with a mean of 20.5 and a standard deviation of + 7.2.

In June, the maximum recorded temperature was 42°C and the minimum recorded temperature was 41°C with a mean of 41.3 and a standard deviation of + 0.5. Humidity varied from a maximum of 39% and a minimum of 23% with a mean of 30.3 and a standard deviation of 6.6. Post-mortem Interval varied from a maximum of 33 hours and a minimum of 18 hours with a mean of 25.6 and a standard deviation of + 7.5.

In July, the maximum recorded temperature was 40°C and the minimum recorded temperature was 28°C with a mean of 33.7 and a standard deviation of ± 4.1. Humidity varied from a maximum of 93% and a minimum of 31% with a mean of 62.6 and a standard deviation of 17.7. Post-mortem Interval varied from a maximum of 41 hours and a minimum of 14 hours with a mean of 26 and a standard deviation of ± 7.7.

In August, the maximum recorded temperature was 36°C and the minimum recorded temperature was 25°C with a mean of 30.8 and a standard deviation of ± 4.2. Humidity varied from a maximum of 84% and a minimum of 50% with a mean of 61.8 and a standard deviation of 13.2. Post-mortem Interval varied from a maximum of 43 hours and a minimum of 13 hours with a mean of 26.1 and a standard deviation of ± 12.5.

The sequence of the establishment was as per the literature. It was first observed in eyelids, followed by lower jaw, neck, shoulder joint, elbow joint, wrist, fingers, hip joint, knee, ankle and finally, it was observed in the toes.

The disappearance of Rigor followed the same fashion as its appearance. Hence, according to findings it could be postulated that Rigor Mortis while being well-established in the upper limbs may not be seen in the lower limbs and conversely,

Rigor Mortis may be observed in the lower limbs while it has already disappeared from the upper limbs depending upon the death time. It has been observed that the lower limbs are the last to be affected by Rigor and last to exhibit disappearance too whereas eyelids and parts of the face are the first to be affected and the first ones to exhibit disappearance. In our study, the temperatures remained high and low humidity in May and June. Rigor Mortis appeared early in cases and duration was low. Fully established Rigor Mortis was observed at a minimum of 10 hours and a maximum of 29 hours in the months of May and June. Temperatures remained low and humidity was high months of July and August. The onset of Rigor Mortis was delayed and duration increased. Complete Rigor Mortis lasted from 17 hours to 32 hours. Other studies recorded similar findings. In the study conducted by Gorea,<sup>16</sup> the longest duration in which rigor mortis had not completely appeared in the body was 14 hours.

The average duration for fully developed rigor mortis was 17 hours 34 minutes and the shortest duration was 3 hours. This average duration was minimum at a temperature range of 31°C–35°C (10 hours 15 minutes). The average duration of disappearing rigor mortis was 19 hours 52 minutes with the longest duration as long as 39 hours. This duration increases with the decrease of temperature. The shortest duration in which the rigor mortis had completely disappeared was 15 hours. While Dalal *et al.*<sup>17</sup> found in their study that in April to June, fully developed rigor mortis lasted from 11 hours 25 minutes to 28 hours 25 minutes while in the quarter of July to September, complete rigor mortis lasted from 17 hours 15 minutes to 34 hours 20 minutes. The maximum temperature during these months ranged from 46.5°C to 26.6°C while minimum temperature ranged between 27.6°C to 12°C.



Relative humidity levels in these months varied between 9 to 31%. From October to December, fully developed rigor mortis lasted from 16 hours 25 minutes to 61 hours 5 minutes, while from January to March it lasted from 19 hours 5 minutes to 50 hours 15 minutes. The maximum temperature during these months ranged from 35.4°C to 13.6°C, while the minimum temperature ranged from 20°C to -2.6°C and the relative humidity varied between 97% to 65%. Sugatha *et al.*<sup>18</sup> in their study, observed that the average duration for the onset of rigor mortis was 8 hours and 39 minutes. The minimum duration in which rigor mortis had begun to appear in the body was 1 hour and 35 minutes while the longest maximum by which rigor mortis had not completely appeared in the body was 24 hours. The average duration for fully developed rigor mortis was 18 hours and 19 minutes, the shortest duration being 3 hours and 15 minutes and the longest 33 hours and 40 minutes. The average duration for disappearing rigor mortis was 34 hours and 36 minutes. The shortest duration by which rigor mortis had disappeared had 15 hours and 30 minutes, while one case was observed in which rigor mortis presented some parts of the body at 70 hours and 35 minutes. In 94.6% of cases, rigor mortis appeared first in the eyelids followed by lower jaw, neck, upper limbs, trunk, lower limbs and lastly fingers and toes. It disappeared in the same fashion. However, in 5.4% of cases, sequence was found to be erratic. In a study done by Deepak *et al.*<sup>19</sup>, the author stated that the onset and duration of rigor mortis are governed by various factors. In Indian conditions, it is different, compared to the temperate countries, when the time since death needs to be estimated. Rigor mortis starts within 2–3 hours and takes about 12 hours to develop, persists for another 12 hours, and takes about 12 hours to pass off.

## CONCLUSION

Rigor Mortis is a physiochemical process and dependent upon several factors including temperature, humidity, cause of death, age, physical build of the body etc. So, Nysten's Rule of 12, which states that "Rigor Mortis appears in 12 hours, remains apparent for 12 hours and disappears in the next 12 hours", does not hold in every case as has been observed in this study. In a diverse country like India, where wide variations in weather conditions can be observed, the post-mortem interval of state may be very different from others. Therefore, every state should have its table of Rigor Mortis status so that it proves to be an effective tool for measuring the post-mortem interval Rigor Mortis is and will remain an important benchmark to calculate the time since injury. Its dependence on multiple factors may confound the results but a learned physician is less likely to be misled. The sample size of our study was small due to which several other factors affecting the process of Rigor Mortis could not be studied and may have confounded our results. More regional studies with a larger sample are needed to reach a definite conclusion.

## Ethical Clearance

Clearance was taken from Institutional Ethics Committee.

## REFERENCES

1. Reddy KSN, Murty OP. Post-mortem changes. In: The essentials of Forensic Medicine and Toxicology. 34th ed. New Delhi: Jaypee brothers medical publishers pvt ltd. 2014;152-178.
2. Saukko P, Knight B. Knight's forensic pathology. 3rd ed. London: Edward Arnold Ltd. (Hodder Headline Group); 2004;52–97.
3. Prasad BK. Post-mortem ocular changes: a study on autopsy cases in Bharatpur Hospital. Kathmandu Univ Med J. 2003;1(4): 276-277.
4. Tilstone WJ, Tilstone W, Savage KA, Clark LA. Forensic science: An encyclopedia of history, methods, and techniques. ABC-CLIO; 2006;271.
5. Gordon I, Shapiro HA. Forensic medicine: a guide to principles. 3rd ed. Edinburgh: Churchill Livingstone; 1988;12-54.
6. Helpert, M and Knight, B.H. Autopsy, W.H. Allen, A. Star Paperback, London, 1982;148-152.
7. Fiddes FS, Patten TD. A percentage method for reporting the fall in body temperature after death. Its use in estimating the time since death with a statement of theoretical basis of the percentage model. J Forensic Med. 1958;5:2-15.
8. Shivpoojan K. Time since death from Rigor Mortis: Forensic Prospective. J Forensic Sci & Criminal Inves 2018; 9(5): 555771.
9. Bate-Smith EC, Bendall JR. Rigor mortis and adenosine triphosphate. The Journal of physiology. 1947 Jun 2;106(2):177-185.
10. Dettmeyer RB, Verhoff MA, Schütz HF. Forensic medicine: fundamentals and perspectives. Springer Science & Business Media; 2013..
11. Hayman J, Oxenham M. Human body decomposition. Academic Press; 2016.
12. Rall JA. Molecular Mechanism of Force Production: From the Difficult 1980s to the Supercharged 1990s and Beyond. In: Mechanism of Muscular Contraction 2014;395-466. Springer, New York, NY.
13. Aggrawal A. Signs of death and changes following death. In: Textbook of Forensic Medicine and Toxicology. 1st ed. New Delhi: Avichal publishing company. 2016;173-99.
14. Liu X, Pollack GH. Stepwise sliding of single actin and myosin filaments. Biophysical journal. 2004 Jan 1;86(1):353-358.
15. Vij K. Death and its medicolegal aspects (Forensic thanatology). In: Textbook of Forensic Medicine and Toxicology. 6th ed. New Delhi: Reed Elsevier India Private Limited. 2014;71-96.
16. Gorea RK. Study of postmortem interval from rigor mortis. Journal of Punjab Academy of Forensic Medicine and Toxicology. 2002;2:25-30.
17. Dalal JS, Tejpal HR, Chanana A, Kaur N. Medicolegal study of rigor mortis to estimate postmortem interval. Journal of Indian Academy of Forensic Medicine. 2006;28(2):49-51.
18. M. Sugatha, Venkata Ramana. Assessment of time since death using forensic autopsies based on the presence of rigor mortis—a cross-sectional study. International Journal of Contemporary Medical Research. 2019;6(4):D11-D14.
19. D'Souza DH, Harish S, Rajesh M, Kiran J. Rigor mortis in an unusual position: Forensic considerations. International journal of applied and basic medical research. 2011 Jul;1(2):120-122.