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ORIGINAL ARTICLE

CORRELATION OF HEIGHT AND MAXIMUM OVERHEAD REACH: FORENSIC IMPLICATIONS FROM A STUDY OF YOUNG ADULTS IN SRI LANKA

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ABSTRACT

Introduction: Hanging is a common method of suicide encountered in routine forensic practice, and the ability of the victim to access the suspension point is a crucial consideration during the death investigation. Establishing a correlation between an individual's height and maximum overhead reach (MOR) can provide supportive evidence when determining the circumstances of death in suspected hanging cases.

Objectives: This study aimed to establish a correlation between height and MOR in a cohort of Sri Lankan young adults.

Methods: A cross-sectional study was conducted among 189 university students (86 males, 103 females) aged 22–26 years, selected through simple random sampling. Standing height was measured barefoot from heel to vertex using a stadiometer. MOR was measured by marking the highest point attained when the participant, standing on tiptoes on one foot, extended the opposite arm overhead to 180°. Measurements were recorded thrice and averaged. A regression equation was formulated to assess the relationship between height and MOR.

Results: The mean height was 168.9 cm for males and 157.1 cm for females, with corresponding mean MORs of 228.9 cm and 213.6 cm. A strong positive correlation was observed between height (H) and MOR in both sexes (Pearson's r=0.922 in males, 0.895 in females, $p<0.001$). Regression models demonstrated high predictive accuracy: MOR=1.493H−23.270 (males, $R^2=0.850$) and MOR=0.931H+67.492 (females, $R^2=0.800$). A multiple regression model incorporating height and age (A) yielded the equation MOR=1.240H−0.604A+33.678 (adjusted $R^2=0.891$, $p<0.001$).

Conclusion: The regression models derived can aid forensic practitioners in assessing whether a victim could reach the suspension point in cases of hanging, although findings should be interpreted alongside circumstantial and autopsy evidence.

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INTRODUCTION

Hanging is a common presentation in routine forensic practice, with self-suspensions being the commonest[1]. The circumstances of death will be suicidal in most cases, but the possibility of postmortem suspension, accidental hanging, and homicidal hanging needs to be excluded[2,3]. It was the preferred method of suicide in Sri Lanka before 1960, but was overtaken later by agrochemical poisoning[4,5].

In cases of suicidal hanging, the person's height and the height from the ground level to the point of suspension are important factors to determine if the person was able to reach the point where the ligature is suspended from. In a typical case, the victim would be using a ligature such as a rolled bed sheet or saree, a wire, string, belt, necktie, or other rope-like objects[1]. One end of the ligature will be attached to a higher point, like a ceiling beam or a ceiling fan, while the other end will be placed around the victim's neck, formed into a fixed loop or slip knot. The victim would use a supporting surface, such as a chair or desk, to reach the point where the upper end of the ligature is attached, and subsequently, would jump off or kick the supporting surface away, as in the case of a chair. Ideally, the height to the point of suspension from the ground level needs to be equal to or less than the sum of the height of the support and the maximum overhead reach (MOR) of the person. Otherwise, a suspicion of postmortem suspension or homicidal hanging may arise.

OBJECTIVES

This study aimed to derive regression relationships between the height (H), age (A), and MOR in a Sri Lankan young adult population.

METHODS

The ethical approval for this study was granted by the Ethics Review Committee of the Faculty of Medicine, University of Peradeniya, Sri Lanka (2021/EC/48). In this study, a simple random sampling technique was used to recruit voluntary young adults, with informed written consent, among the undergraduates of the University of Peradeniya, Peradeniya, Sri Lanka. Individuals with musculoskeletal deformities or growth disorders, a history of trauma to long bones or vertebrae, absence of toes or fingers or any other condition/disease that may affect the stature and MOR were excluded.

The age and the sex of each subject were documented. The height measurements were recorded in two steps. First, the standing height of the subject was measured from the bare heel flat on the ground to the vertex of the head in centimetres (Figure 1a) using a stadiometer. During this measurement, participants stood barefoot in an upright position with their heels together, back straight, arms relaxed at the sides, and the head positioned in the Frankfurt horizontal plane.

Then the measurement of the point that attained their MOR was marked (Figure 1b). For this measurement, the participant stood adjacent to a vertical wall and was instructed to reach the highest possible point with one hand. The participants were asked to lift from their toes in one foot, bending towards that foot slightly with their hips, extending the opposite arm, ideally the dominant arm, to 180 degrees above their head. The arm was fully extended with the elbow straight, and fingers extended, and the highest point reached by the tip of the middle finger was marked on the wall. Participants were instructed not to jump during this manoeuvre.

The distance from the ground level to the marked point of MOR was measured vertically using a standard 150 cm tailor's tape fixed to a wall. Since the height exceeded the length of the tape, the measurement was taken in two sequential segments and added together to obtain the total distance. Both the standing height and MOR measurements were recorded three times for each participant, and the average value was used for analysis in order to minimize measurement error.

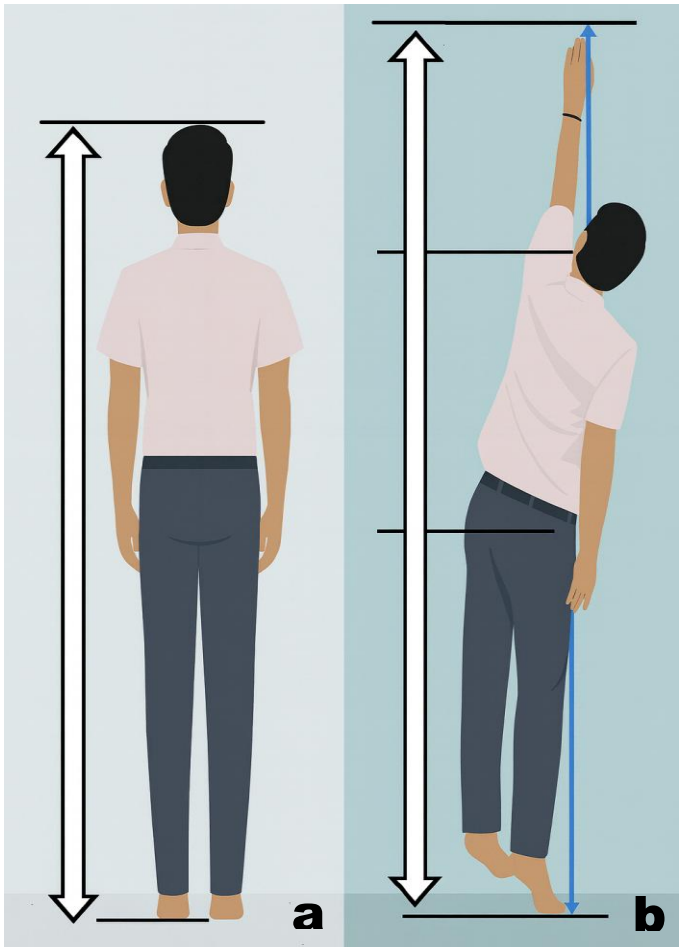

Figure 1: Measurement of the standing height (a) and maximum overhead reach (b).

Collected data was analysed using IBM SPSS Statistics version 26. Normality of the variables was assessed using the Shapiro–Wilk test and visual inspection of histograms and Q–Q plots. Although the Shapiro–Wilk test indicated statistically significant deviations from normality, visual inspection suggested approximate normal distribution. Therefore, Pearson's correlation coefficients were calculated to assess the relationship between MOR, height, and age. Mean MORs were compared using the independent sample t-test. Simple and multiple linear regression analyses were performed to derive predictive equations. Independence of residuals was evaluated using the Durbin–Watson statistic.

RESULTS

A total of 189 individuals participated in the study, with 86 males (45.5%) and 103 females (54.5%). The ages ranged from 22 years to 26 years, with a mean age of 24.0 years. The mean height was 162.4 cm, with the mean height of males being 168.9 cm and 157.1 cm in females. The MOR for males ranged from 200.8 cm to 252.0 cm, with a mean of 228.9 cm. In females, the MOR ranged from 191.8 cm to 232.4 cm with a mean of 213.6 cm. For both sexes, the mean MOR was 220.6 cm. Among the participants, 179 (94.7%) were right-handed while 10 (5.3%) were left-handed.

Table 1: Correlations of height and age with MOR

Variable		Correlation coefficient (Pearson's r)	p-value
Height	Both sexes	0.942	<0.001
	Male	0.922	<0.001
	Female	0.895	<0.001
Age	Both sexes	-0.046	0.532
	Male	-0.110	0.314
	Female	-0.075	0.453

Pearson's correlation analysis (Table 1) demonstrated a strong positive correlation between height and maximum overhead reach (MOR) in both sexes ($r=0.942$, $p<0.001$), as well as in males ($r=0.922$, $p<0.001$) and females ($r=0.895$, $p<0.001$). Age showed weak negative correlations with MOR, which was not statistically significant in the overall sample ($r=-0.046$, $p=0.532$) or when males ($r=-0.110$, $p=0.314$) and females ($r=0.075$, $p=0.453$) were analysed separately.

When the independent sample t-test was used, there was a statistically significant difference in the mean MOR between males and females ($p<0.001$). But between the right- and left-handers, there was no statistically significant difference ($p=0.096$) in mean MOR.

Table 2: Simple regression formulae to calculate MOR from height (H)

Sex	R^2	p-value	Regression formula
Both sexes	0.888	<0.001	1.239H+19.349
Male	0.850	<0.001	1.493H-23.270
Female	0.800	<0.001	0.931H+67.492

Simple linear regression equations were derived to calculate MOR from height (Table 2). When both sexes were considered, simple regression analysis yielded an R^2 value of 0.888, indicating that this model explains 88.8% of the variation of the variable around the mean. When sexes were considered separately, higher R^2 values were observed, with 0.850 for males and 0.800 for females. All the derived models were statistically significant ($p<0.001$).

Furthermore, an attempt was made to formulate a multiple linear regression formula, combining the variables age, sex, handedness, and height to calculate MOR. On analysis, it was revealed that when all variables were considered, the adjusted R^2 was 0.891. Height was the strongest predictor of MOR ($\beta=0.943$, $p<0.001$), while age showed a statistically significant but small negative association ($\beta=-0.059$, $p=0.016$). However, the variables sex ($p=0.159$) and handedness ($p=0749$) did not provide a statistically significant contribution to the model. Therefore, a revised regression model with age and height as independent variables was considered. A multiple regression model incorporating H and A yielded the equation $MOR=1.240H-0.604A+33.678$ (adjusted $R^2=0.891$, $p<0.001$). Residual analysis demonstrated no major violations of linear regression assumptions. Standardized residuals were within acceptable limits. The Durbin–Watson statistic for the main regression model was 1.222, indicating no substantial autocorrelation.

DISCUSSION

Hanging remains one of the most frequently encountered methods of suicide in South Asia and is a major contributor to mortality among young adults worldwide. Globally, suicide ranks as the fourth leading cause of death among individuals aged 15–29 years, with hanging representing a significant proportion of these deaths[6,7]. Sri Lankan data show that 13–34% of suicides are due to hanging, with substantial contributions from the 21–30 year age group[6,8]. The present study focused on young adults within this demographic, a group that accounted for more than one-fifth of suicides by hanging reported nationally in 2022[9].

In forensic practice, assessing the feasibility of self-suspension is a critical component in determining the manner of death in suspected hanging. Reaching the ligature suspension point is essential in suicidal hanging[10], and when the height of the suspension point exceeds MOR, questions may arise regarding postmortem suspension, accidental circumstances, or homicidal involvement. Quantifying MOR, therefore, provides an objective parameter that can aid case interpretation.

The present study demonstrates a strong, statistically significant positive correlation between height and MOR in both males and females. Height accounted for a considerable proportion of the variance in MOR, with sex-specific equations further improving predictive accuracy.

The regression formulae derived in this study can be utilised by forensic investigators when the deceased's height is known, but MOR cannot be measured directly, such as in decomposed or skeletal remains, or cases where direct measurement at the scene is not feasible. When both height and age are available, a multiple regression model provides an alternative equation with similar predictive strength. These formulae, with circumstantial and autopsy evidence, provide a basis for evaluating whether an individual could reasonably have reached the point of ligature suspension.

In a similar study by Sikary et al.[10] in North India, the equation for all participants was MOR=1.46H+0.02, while sex-specific equations were MOR=1.40H+11.22 for males and MOR=1.22H+33.34 for females. The present study also demonstrated similar linear relationships between height and MOR, although the regression coefficients differed slightly. For males, the slope observed in the present study (1.493) was slightly higher than that reported by Sikary et al.[10], whereas the female slope (0.931) was lower. These differences may reflect anthropometric variations between populations or differences in measurement techniques.

Although MOR can be measured directly during autopsy, it is not always practical due to rigour mortis, decomposition, or incomplete remains. In addition, the posture adopted during ligature placement in hanging may involve movements such as standing on tiptoes or reaching with one arm while maintaining balance. The derived regression equations can be used as supportive tools and should be interpreted alongside scene findings, autopsy observations, and circumstantial evidence.

LIMITATIONS

The participants were limited to university students aged 22–26 years, representing a relatively narrow age range of young adults with skeletal maturity. Furthermore, the intercept values observed in the simple regression equations represent theoretical values when the independent variables are zero. These are not physiologically meaningful, as a height of zero is not possible, but are statistical parameters required to achieve the best fit of the regression model within the observed data range. Therefore, the regression equations derived in this study may not be directly generalizable to individuals of other age ranges. The study population consisted of a relatively homogeneous group, which may not fully represent the general population. Although the measurement protocol attempted to simulate a realistic reaching posture, the actual height at which a ligature can be tied in real-life hanging scenarios may vary depending on body posture, balance, and environmental factors. Therefore, the regression equations should be interpreted as approximate estimates rather than precise values.

CONCLUSION

The regression models derived can aid forensic practitioners in assessing whether a victim could reach the suspension point in cases of hanging, although findings should be interpreted alongside circumstantial and autopsy evidence.

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CONFLICTS OF INTEREST

The authors declared no conflicts of interest.

DISCLOSURE

ANV and EMKBE are members of the Editorial Board of the Sri Lanka Journal of Forensic Medicine, Science & Law. Therefore, they did not participate in any way in the publication/decision-making process of this submission, as per journal policy.

ETHICAL ISSUES

The ethical approval for this study was granted by the Ethics Review Committee, Faculty of Medicine, University of Peradeniya, Sri Lanka (Ref. No: 2021/EC/48). The study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments.

SOURCES OF SUPPORT

None

AUTHOR CONTRIBUTIONS

KGCSC: Conception and design of the work; the acquisition, analysis, and interpretation of data for the work; drafting the work or revising it critically for important intellectual content; final approval of the version to be published; and agreement to be accountable for all aspects of the work in ensuring that questions related to

the accuracy or integrity of any part of the work are appropriately investigated and resolved. **ANV:** Conception and design of the work; the acquisition, analysis, and interpretation of data for the work; drafting the work or revising it critically for important intellectual content; final approval of the version to be published; and agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. **EMKBE:** Analysis and interpretation of data for the work; drafting the work or revising it critically for important intellectual content; final approval of the version to be published; and agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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