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SYSTEMATIC REVIEW

Stature estimation in the South-East Asian population: A systematic review

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Abstract

Introduction: Stature estimation is population dependent, and population-specific regression equations should be generated for accurate anthropological assessments. Nevertheless, stature estimation data was inaccessible and limited in some of the South-East Asian countries. The systematic review was conducted to analyse the regression equations of stature estimations developed in South-East Asian region. *Materials and Methods:* A systematic literature search was performed through SCOPUS database and Google Scholar from January till March 2018. All published articles which developed stature estimation from different types of bone, methods and type of statures (i.e. living stature, forensic stature and cadaveric stature) were included in this study. Risks of biases were also assessed. Population studies with no regression equations were excluded from the study. *Results:* Seven studies that met the inclusion criteria were identified. In the South-East Asia region, regression equations for stature estimation were developed in Thailand and Malaysia. In these studies, bone measurements were done either by radiography, direct bone measurement, or palpation on body surface for anatomical bony prominence. All of these studies used various parts of bones for stature estimation. *Conclusion:* The most widely used regression equations for stature estimation in South-East Asian population were from the Thailand population. Further research is recommended to develop regression equations for other South-East Asian countries.

Keywords: Stature estimation, regression equations, forensic anthropology

INTRODUCTION

Asia is the largest Continent on earth with a complex diversity of cultures and ethnicity. In South-East Asia region (Indonesia, Malaysia, Brunei, Singapore, Thailand, Myanmar, Laos, Philippines, Vietnam and Cambodia), most countries do not have their own reliable regression equations for stature estimation. Earlier publications on stature estimation had started and well developed in most western countries, whereby nearly all have population-specific regression equations for stature estimation. Different methods and types of bone measurements had resulted in several regression equations in multiple categories in the same population, which further strengthened the data for stature estimation. Several countries were updating their regression equations periodically to avoid the effect of secular changes.[1-4]

Limited studies were published on regression equations for stature estimation in the South-East Asia region. Formerly, forensic anthropologist would use regression equations from the Hispanic samples based on out-dated regression equations such as Trotter and Gleser's regression equations using Mongoloid samples.[5] However, with the arising awareness of updated and accurate population-specific equations for stature estimation, more studies were conducted to derive with better equations for routine use.[1,6,7]

In Malaysia, Forensic anthropologist was having difficulty in getting dry bones for research study.[8] Particularly in stature estimation's research, direct bone measurement is not an option due to unavailability of enough samples.

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Moreover, skeletal donations is not a practice in the Malaysian culture for various reasons such as cultural, religious and traditional issues. Lack of willingness and acceptability of the family to give consent to bone donation may hamper such practices. Further, skeletal collections are quite limited in the Hospital Kuala Lumpur and Universiti Kebangsaan Malaysia Medical Centre.[9]

In a survey conducted among the forensic anthropologists and pathologists in Malaysia, it was found that there were no standardised procedures by which regression equations may be used on skeletal remain to estimate stature.[10] Results showed that the forensic anthropologists and pathologists had applied regression equations by Trotter and Gleser[5] and Mahakkanukrauh, *et al*.[1] Based on the respondents and their experience in such applications, the accuracy of the equations was slightly more accurate when applied in the Malaysian population. However, there was no comparison study were conducted to support the finding.

In Malaysia, more recent researches have been done to develop regression equations for stature estimation.[6,10-12] Meanwhile in Thailand, further research was conducted to enhance and expand on the existing regression equations.[13] Thus far, other countries were still lacking in developing equations for stature estimation. Hence, this study was conducted to identify regression equation for stature estimation found or practiced in the South-East Asian population. It is important for the forensic team from other parts of the world to identify victims from South-East Asia region, as they are population specific.[14]

MATERIALS AND METHODS

Data sources and Searches

A systematic literature search was conducted between January till March 2018 using the Scopus database (published between 1969 and March 2018). In order to consider additional literature, Google Scholar search was screened for relevant additional titles. Additional studies were identified through a bibliographic search of eligible studies. The search strategy involved a combination of the following two sets of keywords i.e. "stature estimation" and "South-East Asian". The name of the individual country also was searched to avoid missing of any relevant articles. The name of the countries was Malaysia, Indonesia, Brunei, Myanmar, Thailand, Singapore, Vietnam, Philippines, Laos and Cambodia.

Study Selection

All published articles on stature estimation from different populations, types of bones, methods and statures (i.e. living stature, forensic stature and cadaveric stature) were included in this study. Studies with no regression equations developed to estimate stature within the population were excluded. Only publications in the South-East Asian population and, articles that are written in English were included.

Managing References

Each reference obtained from the searches was exported into the reference management software, Endnote X7.0.1. All duplicates were identified and inspected individually, to prevent error of deleting the relevant studies. The selection of studies involved two researchers (NAI and SNAB), and the titles and abstracts were reviewed for suitability. Any discrepancies were discussed and rectified by a third researcher (FMN). Subsequently, full-text articles for the list of potential studies were obtained and reviewed, according to the inclusion and exclusion criteria.

Data Extraction

Data reporting involved a descriptive summary, study appraisal, and systematic reviews. A report of the study was prepared according to PRISMA guidelines.

RESULTS

Selection and Characteristics of Studies

There was a total of 364 articles retrieved from different databases and six articles were retrieved through bibliographic search. Of these numbers, 350 articles remained after removing all the duplicates. There were 17 potentially eligible studies for full-text review. However, ten articles did not meet the inclusion criteria resulting of only seven studies in a final inclusion. Fig. 1 summarised the selection process.

Table 1 displayed the list of publications, which developed regression equations on stature estimation. The list was arranged according to countries namely, Malaysia (4) and Thailand (3).

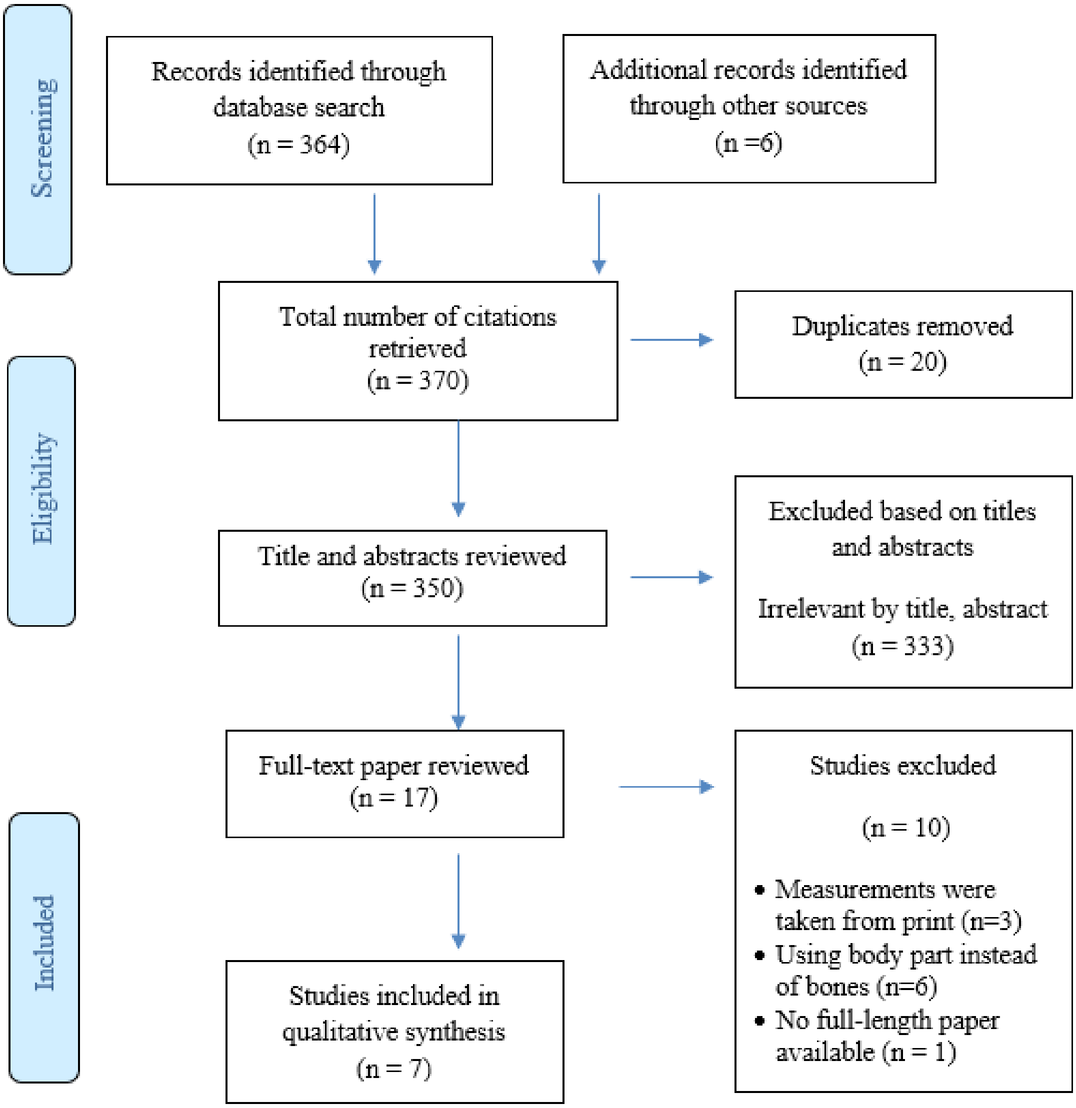

FIG. 1: Flow diagram of study selection.

Assessment of risk of bias

All studies included in this systematic review were conducted to develop regression equations for stature estimation from bone measurements, as in the inclusion criteria. There were 17 studies that developed regression equations but, ten studies were rejected, as the developed regression equations were measured from prints and body dimension and not directly on the bone. Although these regression equations may be useful for identification of living individuals, in fresh forensic cases (mass disaster), biological study and nutritional purposes, but they were not applicable for dead bodies that are usually received by the forensic department. The aforementioned studies had developed regression equations from foot and hand prints (in three studies) and from body parts instead of bone (in six studies). The other one study was rejected due to unavailability of full-length article. Due to these specific reasons, the final number was only seven studies that were conducted to develop regression equations for identification of skeletal remains in the forensic anthropological cases.

DISCUSSION

In Malaysia, researches on stature estimation were conducted in small scale and the results were not convincing enough to be utilised in forensic anthropological cases. Pioneer studies

TABLE 1: Studies on regression equations for stature estimation in South-East Asia.

	Study/ Population	Methods	Bones	Stature	Outcomes
1	Stature approximation of Malay, Chinese and Indian in Malaysia using radiograph of femur, tibia and fibula [7] Malaysian	X-ray	- Lower limbs - The parameters were maximum length of femur, tibia and fibula	Living Stature	- Pioneer study with limited sample size of 32 adult males aged 25-45. - Malay (n=14), Chinese (n=8) and Indian (n=10). - Six regression equations were derived; three regression equations for a single bone, a formula of unknown race, a formula for the Malays and a formula for the Indians - Not practically suitable to be used due to high SEE (standard error) (11.36 – 23.53 cm).
2	Estimation of stature by using lower limb dimensions in the Malaysian population [15] Malaysian	Palpation on body surface	- Lower extremities - The parameters were thigh length, lower leg length, leg length, foot length, foot height and foot breadth.	Cadaver Stature	- Sample size of 100: 69 males, 31 females, aged 20-90. - Measurements were taken from the left side. - Six single regressions for each category for male, female and combined sex - Four multiple regressions for male, female and combined sex. - The mean difference between known stature and estimated stature was 0.86 cm in males, which ranged from 1.1 cm to 2.4 cm. The mean difference between known stature and estimated stature was 1.96 cm in females, which ranged from 4.4 cm to 5.1 cm - SEE ranged from 4.49-8.53 cm. - This study had confirmed the usefulness of lower leg parameters for stature estimation in the Malaysian population.
3	Stature estimation from lower limb anthropometry using linear regression analysis: A study on the Malaysian population [16] Malaysian	Palpation on body surface	- Lower extremities - The parameters were thigh length, lower leg length, leg length, foot length, foot height and foot breadth	Cadaver stature	- Sample size of 87: 81 males, six females - All measurements were done on the left side - Six regression equations were developed from each measurement - SEE ranged from 4.2 to 6.85 cm - SEE obtained in this study were lower than the study done by previous researchers[15] by using similar technique and parameters
4	Stature estimation in Malaysian population from radiographic measurements of upper limbs [6] Malaysian	X-ray	- Upper limbs - The parameters were maximum length of humerus, radius and ulna	Living Stature	- Sample size of 90 adults, 50 males and 40 females with aged 25-47. - The mean stature of male (168.24 cm), and female (155.69 cm). - Measurements were taken from the left side. - Eight regression equations were developed, of which three for single bone and one in combination of three bones in males and females - The best parameters were ulna (in male) and humerus (in female). - The maximum difference between true and estimated stature in both single linear and multiple regression equations showed large differences i.e. 8.96 and 9.33 cm, respectively. - Not practically suitable to be used due to high SEE (10.33 – 15.99 cm). - However, this study showed a great effort to develop regression equations for the Malaysian population.
5	Estimation of stature of Thai and Chinese from the length of femur, tibia and fibula[17] Thailand	Fresh bones	- Lower limb bones - The parameters were maximum length of femur, tibia and fibula.	Cadaver Stature	- Sample size of 77 of Thai and Chinese-Thai. - Small sample of females (n = 27), and an unknown mix of Thai and Chinese individuals who died more than 25 years ago. - The resulting equations were never tested on a holdout sample to confirm their accuracy. - The SEE for females in this study were: femur (3.0 cm), tibia (4.6 cm), and fibula (4.4 cm). The SEE for males were: femur (5.4 cm), tibia (5.1 cm), and fibula (4.2 cm). - Results for both sexes were quite high
6	Stature estimation from long bone lengths in a Thai population [1] Thailand	Bones were macerated and dried	- Long bones - The parameters were maximum length of humerus, radius, ulna, femur, and fibula, bicondylar length of the femur, and standard length of tibia. - Two less commonly used measurements of the tibia were also made.	Cadaver Stature	- Sample size of 200 skeleton of Northern Thai modern population. - 132 males and 68 females aged 19-94. - Study sample (117 males, 53 females), and cross validation sample (15 females, 15 males). - Measurements were averaged when available bilaterally. Otherwise, whichever measurement was available for either the left or right side was used to create regression equations. - The reported equations included a correction factor to estimate living stature, which was accomplished by subtracting 2.0 cm from the equation's constant. - The mean stature of male (165.2 cm), and female (153.5 cm). - Fourteen regression equations were developed, of which ten for single bone and four in combination of bones in males and females - The best parameters were fibula (in male) and femur (in female). Femur appeared to be the most accurate single bone for stature estimation among Thai people. The median absolute error when tested on the holdout sample was very small 2.4 cm. - The most popular regression equations used in South-East Asia.

	Study/ Population	Methods	Bones	Stature	Outcomes
7	Estimation of stature using fragmentary femur and tibia lengths in a Thai population [13] Thailand	Direct measure on fresh bones.	Fragments of femur and tibia with seven parameters	Cadaver Stature	- Sample size of 255 adults, 159 males and 96 females aged 26-91 years. - Cross-validation sample: 30 femora and tibiae (16 males and 14 females) - The mean stature of male (165.5 cm), and female (152.6 cm). - Measurements were taken from the left side. - Two analytical methods; i.e. direct 1-step and indirect 2-step. - The direct 1-step method, stature was estimated directly from the measurements of both bones using the equations derived in the present study. - The indirect 2-step method, i.e. the maximum length of femur and tibia were estimated first by linear regression equations derived from the present study, then the values were applied in regression equations based on equations by Mahakkanukrauh et al.'s (2011) study.[1] - Eight regression equations were developed, of which three for single bone and one in combination of three bones in males and females - Results showed that the upper breadth of femur from males and maximum anteroposterior diameter of lateral condyle from females were the best estimators of stature. - Comparing between two purposed methods, standard errors obtained from the indirect 2-step method produced higher errors in all the femur and tibia measurements. - The maximum difference between true and estimated stature in both single linear and multiple regression equations showed large differences i.e. 8.96 and 9.33 cm, respectively. - The present study suggested that measurements taken from damaged bones can be used for stature estimation.

by Amal Hayati *et al*.[7] and Ismail *et al*.[6] were developed with high SEE (standard error) that lead to inaccuracy. It was the main reason that the Malaysian forensic anthropologist and/or pathologist not able to use the regression equations. Although it was a great start for stature estimation research in Malaysia, more research in this specific area should be taken into consideration to produce a reliable and accurate regression equation for stature estimation.

A research done by Nor *et al*.[15] in the Malaysian population was practically acceptable with SEE in the range of 4.49-8.53 cm), which has been used for routine forensic cases at the Universiti Kebangsaan Malaysia Medical Centre. However, the regression equations maybe limited to fresh bodies only, and may not be applicable to skeletonised remains. This study was succeeded by Abu Bakar *et al*.[16] with a slightly lower SEE (4.2-6.85 cm) by similar method and parameters, albeit on a different set of samples. In contrast with previous study by Nor, *et al*.[15], an improvement was evident in the accuracy of the equations, but was poorly reflected by the correlation value (R). It was stated by the author that one of the limitations might be due to the small sample size in the female samples (81 males and six female cadavers). In brief, this study needs further validation with larger sample size and more parameters to rectify the issue of sample size and correlation coefficient. From the literature search, most studies in the Malaysian population used foot print[18-22], foot anthropometry[23,24], and hand print[25] for stature estimation. These researches are valuable to the forensic anthropology field but could not be used in solving skeletal remains cases. Malaysian researchers had to focus on such research studies for reasons of insufficient samples of human skeletal collection and ethical issues and restriction to conduct research on cadavers.[8]

A different scenario was observed in Thailand, that already has accurate and reliable regression equations for the Thai population, developed by Mahakkanukrauh *et al*.[1] The regression equations have become great significance and value to the South-East Asian population, and were widely used by the neighbouring countries. Four years later, the huge impact from research by Mahakkanukrauh *et al*.[1] had caused an extension of several more regression equations in the Thai population focusing on fragmented bones. The aim of the study was to use the femur and tibia that were highly correlated with stature in developing regression equations to estimate stature, particularly when complete bones are not available.[13] Before the year 2011, Thailand's forensic anthropologists had used regression equations that were developed by Stevenson[26] (Northern China population) and Sangvichien *et al*.[17] (Thai and Chinese-Thai population). However, both regression equations were no longer used for stature estimation in Thailand.

There was documented in Gocha *et al*.[27] that Myanmar had regression equation developed by Taik *et al*. in 1972. However, the publication was not made available online. Further researches are needed from countries like Philippines, Vietnam, Laos, Cambodia, Myanmar, Brunei, Singapore and Indonesia. Recently in 2019, the forensic anthropology field has evolved simultaneously along with the development of virtual autopsy. Recent publications worldwide were focusing on CT scan method.[2,28-31] Meanwhile in South-

East Asia, to the best of the authors' knowledge, there is yet a study to be conducted on stature estimation by using the CT Scan.

The most advanced method in the literature thus far, is to perform Post-Mortem Computed Tomography (PMCT) as it is mainly used in the virtual autopsy. Further studies using this method had been on the increase each year.[2,3,30,32-37] The application of post-mortem CT (PMCT) rather than conventional X-ray allows for better contrast resolution that results in more detailed images of bones and soft tissues, which offers a rapid processing time.[38] Furthermore, PMCT images do not present with image distortion compared to images by conventional X-ray due to the advanced physics that are involved in the design of CT scanners. Although virtual bone measurement takes a slightly longer time in its software training than by direct bone measurement (depending on skills), the time consumed in handling CT is much faster than processing a complete skeleton manually.[39] Bone measurements in CT images were proven to be highly accurate and reliable.[12] Generally, CT scan is more efficient and non-invasive. The use of CT in forensic practice also enlightens the humanitarian and religious stigma.

Nevertheless, there were a few limitations in this study. Firstly, this study was dependent on what has been reported online, and there may be some unpublished researches which were missed out. Next, the literature searching was conducted from January till March 2018 and the available publications outside of this searching period may be missed out. Lastly, according to the exclusion criteria, some studies did not develop any regression equations but was rather comparing the accuracy of regression equations made by different authors. Although the finding was beneficial to the anthropological field, the emphasis was focused only on the developed regression equations.

CONCLUSION

This systematic review exhibited the regression equations for stature estimation that were available in South-East Asian population. In Malaysian population, many regression equations were developed but none was found valid enough to be used for routine practice. Thus far, the widely used regression equations for the South-East Asian population was developed by Mahakkanukrauh *et al.* [1] for the Thailand population. More research should be conducted in this area of interest to derive with reliable regression equations for stature estimations in all South-East Asian countries.

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