Prediction of Stature Based on Foot Dimensions Among the Living Egyptians

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ABSTRACT

Identification of an unknown body who died in mass disaster, wars, homicides, suicide or accidental deaths is a very important task in the fields of physical anthropology and forensic medicine. Sometimes, complete foot or part of it is brought in for postmortem examination. In such a situation, estimation of stature becomes equally important along with other parameters like age, sex, race, etc. The present work attempts to estimate stature from various anthropometric measurements of foot of Egyptians. The study was carried out on 150 living Egyptian individuals comprising 75 males and 75 females; their age was between 19 and 23 years. The results revealed that there was a significant positive correlation between stature and foot length and breadth in males, females and both sexes. Simple linear regression analysis was done for all data in all cases and introduced regression equation formulae for estimation of the stature of any individual from foot dimensions. These formulae are helpful in the estimation of stature of the deceased from foot length, breadth or both of them when foot is the only portion available for examination.
INTRODUCTION

Identification of an individual from dismembered, mutilated and fragmentary remains is a challenge to forensic experts. The problem is encountered in cases of mass disasters, explosions, and assault cases where the body is dismembered to conceal the identity of the victim (Kanchan et al., 2008). The determinations of sex as well as the reconstruction of stature are, apart from the estimation of age, most important for identifying unknown bodies, parts of bodies or skeletal remains. It is commonly accepted that anthropometric standards vary among different populations and have to be constantly renewed to cope with temporal change (Mall et al., 2001).

A person’s height (i.e. stature) is one identifying characteristic that is often used (Sorg, 2005). The stature prediction occupies relatively a central position both in the anthropological research and in the identification necessitated by the medical jurisprudence or by the medico-legal experts (Jasuja and Singh, 2004).

Over a decade, a close relationship between stature and dimensions of various body segments is reported and the results are frequently used in anthropometric studies of body proportions, physical growth and development of children, medico-legal investigations and personal identification in forensic examinations by several scientists all over the world (Krishan and Vashisht, 2002). In forensic anthropology, a common method of estimating stature of victims is to measure the long bone length and extrapolating the data (Sorg, 2005). Measurements of other body parts such as lower leg length, arm span, and hand span can also be used (Oommen et al., 2005 & Ozaslan et al., 2006). There are some other attempts for identifying the person by hand measurements (Rastogi et al., 2008), vertebral column length (Nagesh and Kumar, 2006), leg length (Ozaslan et al., 2003) and footstep length (Jasuja et
(al., 1997) in alive person. Besides, there are some studies on the stature estimation from cephalo-facial dimensions in school-age children (Krishan and Kumar, 2007). Height estimation by measurement of various long bones has been attempted by several workers with variable degree of success. Each worker has derived his own formula for calculating the stature from long bones. However, foot measurement has not frequently been used for this (Patel et al., 2007).

It is important to remember that the anatomic structure of the foot shows ethnical and regional variations by congenital, climatic factors, physical activities, nutrition and used shoe type. Anthropometric measurements which are made to determine these differences give us the specific data about the population. These measurements also help us see the difference among the populations (Krishan, 2007). Consequently, the purpose of this study was to find out correlation of foot measurements (foot length and breadth) with stature in living Egyptians.

SUBJECTS AND METHODS

Subjects:

In the present work, 150 living adult Egyptians comprising 75 males and 75 females of age range from 19-23 years were chosen from the students of faculty of Medicine, Benha University. All the subjects included in this study were healthy and free from any apparent symptomatic deformity of the foot and above the age of 18 years. Above this age, most people attain their maximum growth and therefore their maximum foot length and breadth. Owing to the diurnal variation of stature (Krishan and Vij, 2007), all subjects were measured approximately at the same time (between 2.00 to 4.30 p.m.) and by the same person to avoid personal error in methodology.

After informed oral consent, every individual was subjected to measurements of his/her stature, foot length and foot breadth.
Methods:

Measurements are all taken from the left side according to the procedure described by the International Biological Program (Davis, 1994). All subjects were barefoot and measured for the following:

1. **Stature (S):** The stature was measured in centimeters by asking the individual to stand barefoot on the baseboard of a standard metric height measuring stand, both feet in close contact with each other, trunk braced along the vertical board with eyes looking forwards (standard anatomic position). The face was adjusted to keep the lateral palpebral commissure and the tip of the auricle in a horizontal plane parallel to that of the feet. The measurement was taken in centimeters by bringing the projecting horizontal sliding bar to the vertex.

2. **Foot Length (FL):** Subject stand erect with left foot forward than right foot with whole weight of body falling on left foot. Then, measure the straight distance between acropodian (the extreme point of the longest toe) and pternion (the extreme point of the heel) when the foot is fully stretched and placed on flat surface. This measurement excluded any nail extending over the end of the toe.

3. **Foot Breadth (FB):** It is measured as a straight distance between the surfaces of the 1st and 5th metatarsal bone heads.
All measurements for stature, foot length and foot breadth were obtained in centimeters and recorded on the Data Collection Form for statistical computation. Data were analyzed using a statistical package for Social Sciences SPSS (Version 14).

**Statistical analysis:**

Statistical analysis of the data was done by calculation of the mean, standard deviation (± S.D.), standard error (± S.E.), range (minimum and maximum) and the student’s t-test with its P-value of significance for each parameter. Also, linear correlation coefficient (r) was determined.

According to **Knapp and Miller (1992)**, linear regression analysis was performed to derive the estimate of stature from one variable; foot length or foot breadth separately and multiple regression analysis to create the estimate of stature from both variables; foot length, breadth and sum of them. Regression equation formulae have been derived for both sexes separately to calculate the stature from foot dimensions.
The equation used for stature estimation was: \( Y = a + b \ (x) \pm S.E. \)
when one variable was used and the equation \( Y = a + b_1 \ (x_1) + b_2 \ (x_2) \pm S.E. \) when two variables were examined.

Here, \( Y \) is the dependent variable (the stature), \( a \) (the intercept) is the point of crossing between the regression line and the \( Y \)-axis, \( b \) is the slope of the regression line (\( b_1 \) is foot length and \( b_2 \) is foot breadth), \( x \) is the independent variable (\( x_1 \) is foot length and \( x_2 \) is foot breadth) and S.E. is the standard error of estimate.

**RESULTS:**

The data obtained including the stature, foot length and foot breadth was analyzed for their range, mean and standard deviation which are represented in table (1). The Egyptian male individuals have a mean stature of 171.590 cm, mean foot length of 27.064 cm and mean foot breadth of 11.274 cm. At the same time, the results denoted that the Egyptian female individuals have mean stature of 160.132 cm, mean foot length of 25.030 cm and mean foot breadth of 10.513 cm. Moreover, it is found that the Egyptian individuals of both sexes have mean stature of 165.861 cm, mean foot length of 26.047 and mean foot breadth of 10.894 cm. It was obvious that all measurements in males were higher than in females.

Table (2) represents a comparison between the mean values of different measured parameters in males and females. It is evident that the stature, foot length and breadth are significant in male than in female group.

Correlation coefficient \( (r) \) of foot length and that of foot breadth for stature estimation are shown in tables (3, 4). In all samples of an adult living Egyptians, the correlation \( (r) \) between stature and foot length and between stature and foot breadth for males, females, and both sexes together were found to be statistically significant. The correlation \( (r) \)
between stature and foot length and between stature and foot breadth for males were (0.578) and (0.548) respectively and for females were (0.500) and (0.538) respectively, and for both sexes were (0.639) and (0.564) respectively. From (table 5), it is obvious that the correlation coefficient of sum of foot length and foot breadth for stature is significant either in males (0.540), females (0.506) or both sexes (0.639). Hence, stature is observed to be dependent on foot length, foot breadth or both of them. Therefore, the regression equation formulae to estimate stature from foot dimensions are available.

Tables (6,7) display the regression equation formulae for estimation of stature from foot length (FL) which is 108.661 + 0.334 (x₁) in males, 118.078 + 0.25 (x₁) in females and 95.133 + 0.408 (x₁) in both sexes. It also reveals that the regression equation formulae to estimate stature from foot breadth (FB) is 153.032 + 0.300 (x₁) in males, 130.556 + 0.289 (x₁) in females and 91.643 + 0.318 (x₁) in both sexes. It also denotes that the regression equation formulae to estimate stature when both foot length and breadth are used is 108.884 + 2.317 (x₁) + 0.020 (x₂) in males, 118.078+1.316(x₁)+ 0.867(x₂) in females and 91.643+2.417 (x₁)+ 1.033 (x₂) in both sexes.
Table 1: The measurements of stature, foot length and foot breadth in living Egyptian males, females and both sexes.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Parameters</th>
<th>Stature (S)</th>
<th>Foot length (FL)</th>
<th>Foot breadth (FB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males (n = 75)</td>
<td>Range</td>
<td>157-183</td>
<td>24-30</td>
<td>9-14</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>171.590</td>
<td>27.064</td>
<td>11.274</td>
</tr>
<tr>
<td></td>
<td>±S.D</td>
<td>6.853</td>
<td>1.413</td>
<td>1.032</td>
</tr>
<tr>
<td>Females (n = 75)</td>
<td>Range</td>
<td>143-173</td>
<td>22-27.20</td>
<td>8.50-12.10</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>160.132</td>
<td>25.030</td>
<td>10.513</td>
</tr>
<tr>
<td></td>
<td>±S.D</td>
<td>6.312</td>
<td>2.097</td>
<td>0.803</td>
</tr>
<tr>
<td>Both sexes (n = 150)</td>
<td>Range</td>
<td>143-183</td>
<td>22-30</td>
<td>8.50-14</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>165.861</td>
<td>26.047</td>
<td>10.894</td>
</tr>
<tr>
<td></td>
<td>±S.D</td>
<td>8.727</td>
<td>2.053</td>
<td>0.998</td>
</tr>
</tbody>
</table>

- Measurements shown in cm.
- S.D. is the standard deviation.

Table 2: The comparison between living Egyptian males and females measurements

<table>
<thead>
<tr>
<th>Groups</th>
<th>Parameters</th>
<th>Male (n = 75)</th>
<th>Female (n = 75)</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>±S.D.</td>
<td>Mean</td>
<td>±S.D.</td>
<td></td>
</tr>
<tr>
<td>Stature</td>
<td>171.590</td>
<td>6.853</td>
<td>160.132</td>
<td>6.312</td>
<td>10.698</td>
</tr>
<tr>
<td>Foot length</td>
<td>27.064</td>
<td>1.413</td>
<td>25.030</td>
<td>2.097</td>
<td>6.913</td>
</tr>
<tr>
<td>Foot breadth</td>
<td>11.274</td>
<td>1.032</td>
<td>10.513</td>
<td>0.803</td>
<td>5.319</td>
</tr>
</tbody>
</table>

- Measurements shown in cm.
- S.D. is the standard deviation.
- P is significant if <0.01
Table 3: Correlation coefficient (r) between stature and foot length in living Egyptian males, females and both sexes.

<table>
<thead>
<tr>
<th>Groups</th>
<th>r</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males (n = 75)</td>
<td>0.578</td>
<td>&lt;0.01**</td>
</tr>
<tr>
<td>Females (n = 75)</td>
<td>0.500</td>
<td>&lt;0.01**</td>
</tr>
<tr>
<td>Both sexes (n = 150)</td>
<td>0.639</td>
<td>&lt;0.01**</td>
</tr>
</tbody>
</table>

- *r*: Correlation coefficient.
- Correlation is significant at the 0.01 level.

Table 4: Correlation coefficient (r) between stature and foot breadth in living Egyptian males, females and both sexes.

<table>
<thead>
<tr>
<th>Groups</th>
<th>r</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males (n = 75)</td>
<td>0.548</td>
<td>&lt;0.05*</td>
</tr>
<tr>
<td>Females (n = 75)</td>
<td>0.538</td>
<td>&lt;0.01**</td>
</tr>
<tr>
<td>Both sexes (n = 150)</td>
<td>0.564</td>
<td>&lt;0.01**</td>
</tr>
</tbody>
</table>

- *r*: Correlation coefficient.
- Correlation is significant at the 0.05, 0.01 levels.

Table (5): Correlation coefficient (r) between stature and sum of foot length and foot breadth in living Egyptian males, females and both sexes.

<table>
<thead>
<tr>
<th>Groups</th>
<th>r</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males (n = 75)</td>
<td>0.540</td>
<td>&lt;0.01**</td>
</tr>
<tr>
<td>Females (n = 75)</td>
<td>0.506</td>
<td>&lt;0.01**</td>
</tr>
<tr>
<td>Both sexes (n = 150)</td>
<td>0.639</td>
<td>&lt;0.01**</td>
</tr>
</tbody>
</table>

- *r*: Correlation coefficient.
- Correlation is significant at the, 0.01 levels.
Table 6: Linear regression equation formulae of stature (cm) from each parameter: foot length and foot breadth in living Egyptian males, females and both sexes.

<table>
<thead>
<tr>
<th>Parameters (x)</th>
<th>Groups (n)</th>
<th>Regression equation ( Y = a + b \ (x) )</th>
<th>± S.E.(cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Foot length (FL)</strong></td>
<td>Males (75)</td>
<td>108.661 + 0.334 ((x_1))</td>
<td>6.10</td>
</tr>
<tr>
<td></td>
<td>Females (75)</td>
<td>118.078 + 0.25 ((x_1))</td>
<td>5.51</td>
</tr>
<tr>
<td></td>
<td>Both sexes (150)</td>
<td>95.133 + 0.408 ((x_1))</td>
<td>6.74</td>
</tr>
<tr>
<td><strong>Foot breadth (FB)</strong></td>
<td>Males (75)</td>
<td>153.032 + 0.300 ((x_2))</td>
<td>6.68</td>
</tr>
<tr>
<td></td>
<td>Females (75)</td>
<td>130.556 + 0.289 ((x_2))</td>
<td>5.94</td>
</tr>
<tr>
<td></td>
<td>Both sexes (150)</td>
<td>91.643 + 0.318 ((x_2))</td>
<td>6.71</td>
</tr>
</tbody>
</table>

Table 7: Multiple regression equation formulae of stature (cm) from sum of both parameters: foot length and foot breadth in living Egyptian males, females and both sexes.

<table>
<thead>
<tr>
<th>Parameters (x)</th>
<th>Groups (n)</th>
<th>Regression equation ( Y = a + b_1 \ (x_1) + b_2 \ (x_2) )</th>
<th>± S.E.(cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sum of both parameters</strong></td>
<td>Males (75)</td>
<td>108.884 + 2.317 ((x_1)) + 0.020 ((x_2))</td>
<td>6.06</td>
</tr>
<tr>
<td></td>
<td>Females (75)</td>
<td>118.078+1.316 ((x_1))+ 0.867 ((x_2))</td>
<td>5.51</td>
</tr>
<tr>
<td></td>
<td>Both sexes (150)</td>
<td>91.643+2.417 ((x_1))+ 1.033 ((x_2))</td>
<td>6.71</td>
</tr>
</tbody>
</table>

- S.E.: Standard error of estimate.
DISCUSSION

Based on the fact that population variations in anthropometric dimensions do exist and are attributed to genetic and environmental factors (Gruspier and Pollanen, 2000 & Paley et al., 2000). It is well-known that formulae are population and sex specific due to genetic differences, isolation, differences in bio-cultural history, and other factors (Lundy, 1983). Keeping this in mind, an attempt has been made in the present study tried to create a regression equation which can help in estimation of stature from measurement of foot length and breadth among living Egyptians.

It has long been established that apart from bone material, isolated body parts and body imprints can also be used in forensic identification. The foot, in particular, has proven itself to be a much more significant organ than other parts of the body due to the fact that footprints, upper and lower limb fragments are more likely to be obtained in crime or incident scene investigations, as in some airplane crashes (Fernando and Vanezis, 1998 & Robb, 1999). So, foot measurements were chosen as ossification center and maturation in the foot occurs earlier than the long bones and therefore, during adolescence age, height could be more accurately predicted from foot measurements as compared to that from long bones (Patel et al., 2007). Also Giles and Vallandigham (1991) stated that foot length displays a biological correlation with height that suggests the stature might be estimated from foot length. The foot is also useful in the context of identity, as it is protected by the shoe.

The results of this study revealed that the stature, foot length and foot breadth were significantly greater in males when compared with females. These findings are in agreement with other studies (Ozaslan et al., 2003 & Krishan and Sharma, 2007). Stature is an inherent characteristic and males are constitutionally taller than females. An
association of Y-chromosome with stature has been documented (Yamada et al., 1981). In addition, age of puberty being 2 years later in males as compared with females gives them extra time for growth (Abdel-Malek et al., 1990 & Krishan and Sharma, 2007).

When means of stature, foot length and foot breadth measurements were compared with other studies, differences were found among the communities (Gordon and Buikstra, 1992 & Krishan and Sharma, 2007). These can be affected by variations of stature and foot anatomy due to climate, nutrition, physical activity level and congenital factors (Zeybek et al., 2008).

Also, this work revealed a significant correlation between stature of an individual and foot dimensions (foot length and foot breadth) among adult Egyptian males, females and both sexes. The results of the present study are in agreement with the results of Ozden et al. (2005) & Kanchan et al. (2008) who reported statistically significant correlation coefficients between stature and foot length and stature and foot breadth.

The data of this study revealed that the correlation coefficient of foot length to stature was higher in males (0.578) than in female (0.500). At the same time, the correlation coefficient of foot breadth to stature was higher in males (0.548) than in female (0.538). On the other hand, in a study by Kanchan et al. (2008), the correlation coefficient of foot length to stature was maximum in males, while in females, maximum correlation was exhibited by foot breadth.

Gordon and Buikstra (1992) & Ashizawa et al. (1997) have used foot and/or shoe dimensions in the estimation of stature. All reported significant correlations between stature and foot or shoe length, with appropriate regression equations being derived. Foot or shoe prints as evidence from the crime scene make it possible to not only estimate stature in drawing up a description of a suspect or victim but also to
support height estimates by witnesses (Jasuja et al., 1997 & Ozden et al., 2005).

Linear regression equations for stature estimation were also calculated using foot length and foot breadth by researchers on measurements from Indian populations (Agnihotri et al., 2007 & Krishan and Sharma, 2007 & Kanchan et al., 2008) and also Sanli et al. (2005) have fitted linear regression equations for stature estimation from FL and FB in their study on adult Turkish individuals. All these studies further reported that the regression coefficients were statistically significant, which is in agreement with the results of the present study. The estimation equations which obtained are clearly different from those of other populations and also from Ozden et al. (2005) who developed a formula to estimate the stature of an individual using foot and shoe dimensions. This emphasizes the need for developing separate models for each population on account of racial and ethnic differences in anthropometric measurements (Mohanty et al., 2001).

It has been reported that the estimated height values by using the regression equation formula can never be accepted as the exact value since variations from this are always expected. So, a standard error of estimate must be calculated (Giles and Vallandigham, 1991). However, it must always be kept in mind that precise prediction of stature from an individual’s foot may be an unachievable goal; there would always be an estimation error of a few centimeters (Krishan, 2008). Hence, it is possible to determine the stature of deceased person whose leg is the only portion available by using regression equation formulae derived in this study within standard error of estimate of cross-section of population.

In conclusion, stature is an important parameter in determining the partial identity of unidentified bodies and dismembered remains. Foot dimensions were found to be well correlated to stature in the Egyptian populations. This study indicates that stature can be predicted by linear
regression analysis in males, females and even when gender is unknown, a problem frequently encountered in medico-legal investigations when an individual foot is brought for examination.

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REFERENCES:


الملخص العربي

الاستعراف على أطوال المسماريين الأحياء

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كلية الطب، جامعة بنيا

يعتبر الاستعراف على الجثث المجهولة من أكبر التحديات التي قد يواجهها خبراء الطب الشرعي وخاصة في حالات ضحايا الكوارث، الانفجارات أو ربما نتيجة اعتداء ومحاولة طمس معالم جرمة علن طريقة مخفية وحيلة مع كل ما قد يتوفر لطبيب الشرع ليتمكن الاستعراف من خلاله وعليه، فإن تحديد طول القامة له من الأهمية ما يوازي أهمية تحديد العمر والجنس والعرق البشرى وما إلى ذلك لتم عملية الاستعراف. وبناء على ذلك يهدف هذا البحث إلى دراسة إمكانية تحديد طول القامة في المصريين باستخدام قياس طول القدم أو عرضها أو كلاهما إذا توفر ذلك وقد أجري هذا البحث على 150 فرد مصري من طلبة كلية الطب البشري - جامعة بنيا (75 ذكر و75 أنثى) تتراوح أعمارهم بين 18 و33 سنة وقد تأكدنا من خلوهم من التشوهات أو أي حالة مرضية وقد قمنا بقياس طول القامة، طول القدم وعرضها أو كلاهما لكل فرد مشارك في البحث، وذلك بعد إعلامهم بطبيعة البحث وأخذ موافقة كتابية منهم. وقد تم إجراء تحليل إحصائي لهذه القياسات واستنباط معادلات تحديد القامة في الذكور والإناث المصريين، أيضا كلا الجنسين هذا وقد وجد أن هذه المعادلات ذات فائدة في تحديد طول القامة اعتباراً على قياس طول القدم وعرضها في بعض حالات الاستعراف التي يتم العثور على القدم فقط أو ربما على جزء صغير منها.