Sex determination using anthropometric measurements from multi-slice computed tomography of the 12th thoracic and the first lumbar vertebrae among adult Egyptians

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Abstract

Introduction: Identification of the dismembered and skeletal remains has been a challenge for forensic anthropologists.

Aim: Therefore, the aim of the present study was to assess the sexual dimorphism from the 12th thoracic and the first lumbar vertebra measurements data obtained from reformatted images of multi-slice computed tomography (MSCT) and to derive equations for sex determination in the Egyptian population.

Subects and methods: The study was conducted on 120 adult Egyptian patients (54 males and 66 females) with a mean age of 37.1 ± 6.01. Twenty-four linear measurements were taken from the 12th thoracic and L1 vertebrae and then four ratios were calculated. The data was analyzed by the statistical package for social sciences (SPSS) version 20. Accuracies and regression equations for sex determination were then derived.

Results: Fourteen measurements out of the 24 linear measurements showed significant sex differences when using the 12th thoracic vertebra. As regards to the first lumbar vertebra, only seven linear measurements and one ratio of the posterior height of the vertebral body/anterior height of the vertebral body (VBHp/VBHa) were sexually dimorphic. The percentage of accuracy of the 12th thoracic vertebra was found to be 93.1%, while that of the first lumbar was 68.0%. When combining the two vertebrae the accuracy increased to above 95% (96.3%).

Conclusion: Finally, it was concluded that the 12th thoracic vertebra is more accurate for sex determination than the first lumbar vertebra in the Egyptian population, which means that bone dimensions are population specific.

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1. Introduction

Identification of the dismembered and skeletal remains has been a challenge for forensic anthropologists especially in cases of mass disaster and high intensity explosions, when severe fragmentation, burning or commingling of human remains has occurred.

The determination of sex is an important starting point in developing a biological profile for human skeletal remains as it reduces the number of possible matches by 50%.

Forensic scientists and physical anthropologists have traditionally employed morphological and anthropometric methods for the estimation of sex from bone samples. The pelvis and skull exhibiting prominent sexually dimorphic characters are reliable indicators of sex estimation in cases where a complete skeleton is available for identification. In the presence of complete skeleton, sex could be assessed with nearly 100% accuracy. This estimation rate is 98% for the pelvis and the skull together and 95% for the pelvis only.

Physical anthropologists are frequently asked to provide a reliable estimation of the sex of unknown individuals represented by only a few bones or when several bones are missing or are broken due to the effect of carnivores and environmental conditions. Therefore, exploration of sex differences in less commonly used bones is also needed. Many previous studies have attempted to determine sex by metric analysis of femur, humerus, patella, talus, calcaneus, metacarpals, metatarsals, tarsals, phalanges, clavicle, scapula and sternum.

The first cervical and the second cervical vertebrae can be used to correctly classify sex with nearly the same level of accuracy as the other traditionally used bones.

In studies conducted by Pastor et al. and Yu et al. it was found that the 12th thoracic and the first lumbar vertebrae presented significant sex differences and could be used in the determination of sex from the fragmentary remains.

The vertebral column is comprised of a combination of outer dense cortical bone and an inner cancellous bone that assist in the weight bearing function of the vertebrae. In addition, the structural integrity of the vertebrae is maintained throughout the taphonomic process. The 12th thoracic vertebra is easily identifiable in a disarticulated skeleton because of its unique morphology. Its place as a transitional vertebra results in the morphological characteristics between both thoracic and lumbar vertebrae.

Over the past decade, modern cross-sectional imaging techniques have revolutionized forensic medicine. Virtual anthropology obtained by the 3D imaging techniques such as computer tomography (CT) and magnetic resonance imaging (MRI) allow us to visualize almost every anatomical and pathological structure with high resolution and quality. Magnetic resonance (MR) imaging and especially multi-slice computed tomography (MSCT) are becoming more and more widely used for post-mortem examinations.

In certain cultural circles where a conventional autopsy is stigmatized or even forbidden, a virtual autopsy would allow sound medicolegal practice without violating religious prohibitions or personal reservations.

Despite the evidence of sexual dimorphism in the last thoracic and the first lumbar vertebrae according to these previously published studies, the validity of these two bones for sex determination has not been explored in the Egyptian population. The objective of the present investigation was to assess the sexual dimorphism from the 12th thoracic and the first lumbar vertebra measurements data obtained from the reformatted images of multi-slice CT and also to derive equations for sex determination in the Egyptian population.

2. Subjects and methods

2.1. Sample

The present study was performed on 120 adult Egyptian patients (54 males and 66 females), who presented to the Diagnostic and Interventional Radiological Department, Faculty of Medicine, Alexandria University for multi-slice computerized tomography (MSCT) of the chest and the abdomen.

The Ethics Committee of Alexandria Faculty of Medicine approved this study, and all the patients included in the study signed an informed consent document.

The following exclusion criteria were used to ensure normal bone evaluation: skeletal immaturity, fracture, pathological lesions such as congenital developmental dysplasia, metabolic bone diseases or surgery, tumors and osteoarthritis.

2.2. MSCT protocol for image acquisition

Computer tomographic (CT) scanning was performed using a helical CT scanner imaging machine. Linear measurements were taken in the three dimensional models of the 12th thoracic and the 1st lumbar vertebrae.

CT imaging was performed using a helical CT scanner imaging machine (SOMATOM Definition AS, Siemens, Germany). The patients lay supine on the scanner. The scanning procedure was performed to acquire 0.625 mm computer tomographic (CT) slices. The 12th thoracic vertebra and the first lumbar vertebra could be recognized by the 12th rib or by counting the lumbar vertebrae. The three dimensional (3D) models of the 12th thoracic and the first lumbar vertebrae could be rotated, cut, clipped, and measured.

The protocol used for scan acquisitions was identical for all patients to avoid technical variations in length measurements.

All the measurements were taken twice during two different periods with an interval of 4 weeks. The average values were calculated for further analysis. All measurements were taken by the same radiologist.

2.3. Reconstruction and post-processing considerations

Reconstruction of high quality 3D models using the surface shaded display and the volume rendering technique was performed on the workstation using commercially available software (Syngo 3D).

2.4. Measurements on the vertebrae 3D-CT images

Twenty-four linear measurements were taken from each of the 12th thoracic and L1 vertebrae and then four ratios were calculated. These measurements followed Yu et al. and Zheng et al. studies Table 1.
The ratios used in this study:

1. Upper end plate width/upper end plate depth (EPWu/EPDu).
2. Lower end plate width/lower end plate depth (EPWl/EPDl).
3. Posterior height of vertebral body/anterior height of vertebral body (VBHp/VBHa).
4. Foramen diameter width/Foramen diameter depth (FDc/FDs).
5. Landmarks and measurements used in the present study are illustrated in Fig. 1.

2.5. Statistical analysis

The data was subjected to statistical analysis using the statistical package for social sciences (SPSS) version 20 and the following were calculated:

- Means and standard deviations for each of the measurements.
- Student’s t-test to establish that a significant difference exists between males and females.
- Unstandardized coefficient.
- The cut off point was calculated. A measured value higher than the cut off point classifies an individual as a male and a lower value classifies an individual as a female.
- Linear regression analysis was performed in which individual variables of the vertebral measurements were regressed for sex discrimination.
- The level of significance was set at $P$ value < 0.05.

3. Results

The age and sex distribution of the studied subjects is shown in Table 2.

Descriptive statistics for the 12th thoracic and L1 vertebrae (Mean, standard deviations and $p$ values) is presented in Tables 3 and 4, respectively. It is apparent that most of the measurements of the 12th thoracic and L1 vertebrae were larger in males than in females. Fourteen measurements out of the 24 linear measurements used showed significant sex difference when using the 12th thoracic vertebra. As regards to the first lumbar vertebra, only seven linear measurements and one ratio of the posterior height of vertebral body/anterior height of vertebral body (VBHp/VBHa) were sexually dimorphic.

Table 5 represents the cut off value in correct sex classification for males and females using the 12th thoracic vertebra. Numbers above this value represent males and numbers below it represent females.

The accuracy percentage for the most significant measurements of the 12th thoracic & L1 vertebrae is presented in Tables 5 and 6. The remaining measurements showed considerable overlap among males and females which make the calculation of the cut off value difficult.
Table 7 demonstrates the unstandardized coefficients and the accuracy of the 12th thoracic vertebra; where the accuracy ranged from 49% to 85%, the lower end plate depth (EPDl) shows the highest accuracy of 85.0%, while the upper end plate depth (EPDu) shows the highest accuracy of 79.0% in the first lumbar vertebra (Table 8).

Table 9 represents the regression equations for sex determination using different vertebral measurements. The accuracy of the 12th thoracic vertebra was found to be 93.1%, and when adding the first lumbar vertebra to the equation the accuracy increased above 95% (96.3%).

The average accuracies of classification found in this study were compared to those found by other researchers (Table 10).

4. Discussion

Sexually dimorphic features of the skeleton are of fundamental importance when constructing a biological profile from unidentified human remains. In actual forensic cases, we often encounter parts of bones that are broken. Different bones of the upper and lower limbs, skull and pelvic bones have been used in attempts to formulate equations for sex determination.

MSCT represents the latest breakthrough in CT technology. It has transformed the CT from a transaxial cross-sectional technique into a truly three-dimensional imaging modality with a variety of clinical applications mainly in musculoskeletal imaging. Moreover, it allows studying the anatomy and macroscopic content while preserving the integrity of the remains. In addition, the images are very similar to the original images of the bone shape that need to be measured, in any axis and in rapid manner.

Traits that are sexually dimorphic in one population may be much less in another. This spatial variation within and between populations makes it necessary to reevaluate the diagnostic value of sexually dimorphic traits each time when a new population is studied.
To the best of my knowledge, there is no published literature on sex determination from anthropometric measurements of the 12th thoracic and first lumbar vertebrae among the Egyptian population using Multi-Slice CT.

In the present study, the overall mean values collected from the vertebrae of males are greater than that of females; this indicates the presence of sexual dimorphism in the measurements of Egyptian vertebrae.

In the present study 14 measurements out of the 24 linear measurements showed significant sex differences when using the 12th thoracic vertebra, and the predictive accuracy ranged from 49.0% to 85.5%, with 3 variables having more than 80% predictive accuracy: lower end plate depth (EPDu), upper end plate width (EPWu) and superior vertebral length (VLs), while the articular process distance (APD) was the least accurate (49%). In the study conducted by Yu et al. for the first lumbar vertebra, only seven measurements and one ratio showed sexual dimorphism with a predictive accuracy ranging from 47% to 79.0%. Only the upper end plate depth (EPDu) showed an accuracy above 75% (79.0%). This is lower than the reported results of Zheng et al. for the 12th thoracic vertebra.

Variations between results of different researches could be explained by the use of different methodological approaches either radiological or osteological.
In the study conducted by Zheng et al. on the Chinese population; 25 out of 34 traits were sexually dimorphic with 5 variables having a predictive accuracy more than 80%. These different results may be due to the difference in the sample size.

The sex was correctly assigned using cut off values for the 12th thoracic vertebrae alone which encourages the use of these vertebrae for sex determination especially in cases of fragmentary forensic assemblages. By a combination of the 12th thoracic and L1 vertebrae, only five variables occurred in the equation that predicted sex with a high level of accuracy (96.3%).

The level of accuracy obtained by the 12th thoracic vertebra alone is near that obtained by the 12th thoracic & L1 combined; this means that the 12th thoracic vertebra could be used as a single bone for sex determination especially in cases of fragmentary forensic assemblages.

### 5. Conclusions

In conclusion, the sexual dimorphism is present in different regions of the vertebral column. The accuracy of its assessment can vary among populations. A large number of variables were assessed to counteract the problems related to damage of the bone material. It was observed that the 12th thoracic vertebra provides a better determination of sex among Egyptians than the first lumbar vertebra. So the first lumbar vertebra should not be used alone in sex estimation in forensic caseworks. The percentage accuracy increases when the two vertebrae are used together which encourages the use of these parameters and equations as predictors in sex determination problems.

### 6. Recommendations

- Further researches for Egyptians must be done using a larger number of subjects with more age groups.
- Further researches for other populations using CT for vertebrae are recommended.
- The current study has used only the last thoracic and the first lumbar vertebrae for sex determination; therefore more studies should be done on other vertebrae.
- Accurate and reliable modern imaging techniques such as MSCT should pioneer postmortem investigations.

### Table 6

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Cut off point</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPDl</td>
<td>Female &lt; 1.28 &lt; Male</td>
</tr>
<tr>
<td>EPDl</td>
<td>Female &lt; 33.5 &lt; Male</td>
</tr>
<tr>
<td>VBHa</td>
<td>Female &lt; 28.1 &lt; Male</td>
</tr>
<tr>
<td>FDs</td>
<td>Female &lt; 23.5 &lt; Male</td>
</tr>
<tr>
<td>APD</td>
<td>Female &lt; 30.8 &lt; Male</td>
</tr>
<tr>
<td>TDM</td>
<td>Female &lt; 68.1 &lt; Male</td>
</tr>
<tr>
<td>VL sup</td>
<td>Female &lt; 75.3 &lt; Male</td>
</tr>
<tr>
<td>VBHp/VBHa</td>
<td>Male &lt; 1.28 &lt; Female</td>
</tr>
</tbody>
</table>

### Table 7

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Unstandardized coefficient</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPDl</td>
<td>.018</td>
<td>75.0</td>
</tr>
<tr>
<td>EPDl</td>
<td>-.129</td>
<td>85.5</td>
</tr>
<tr>
<td>EPWu</td>
<td>.049</td>
<td>82.5</td>
</tr>
<tr>
<td>EPWl</td>
<td>-.157</td>
<td>78.5</td>
</tr>
<tr>
<td>VBHa</td>
<td>.018</td>
<td>76.8</td>
</tr>
<tr>
<td>FDS</td>
<td>.0154</td>
<td>62.5</td>
</tr>
<tr>
<td>FDc</td>
<td>.053</td>
<td>69.8</td>
</tr>
<tr>
<td>APH right inferior</td>
<td>.059</td>
<td>61.8</td>
</tr>
<tr>
<td>APH left inferior</td>
<td>-.114</td>
<td>79.8</td>
</tr>
<tr>
<td>APD</td>
<td>.022</td>
<td>42.6</td>
</tr>
<tr>
<td>SPH</td>
<td>.305</td>
<td>74.2</td>
</tr>
<tr>
<td>SPL</td>
<td>-.142</td>
<td>74.5</td>
</tr>
<tr>
<td>VL superior</td>
<td>-.007</td>
<td>80.0</td>
</tr>
<tr>
<td>VL inferior</td>
<td>.006</td>
<td>75.8</td>
</tr>
</tbody>
</table>

### Table 8

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Unstandardized coefficient</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPDl</td>
<td>-.040</td>
<td>78.5</td>
</tr>
<tr>
<td>EPDl</td>
<td>-.008</td>
<td>75.2</td>
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<tr>
<td>VBHa</td>
<td>-.031</td>
<td>58.8</td>
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<tr>
<td>FDS</td>
<td>-.031</td>
<td>68.9</td>
</tr>
<tr>
<td>APD</td>
<td>-.087</td>
<td>52.5</td>
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<tr>
<td>TDM</td>
<td>.034</td>
<td>45.5</td>
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<tr>
<td>VL sup</td>
<td>-.346</td>
<td>65.5</td>
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<tr>
<td>VBHp/VBHa</td>
<td>-.005</td>
<td>65.1</td>
</tr>
</tbody>
</table>

### Table 9

<table>
<thead>
<tr>
<th>Vertebra used</th>
<th>Equation</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The 12th thoracic</td>
<td>(Y' = 13.156 - (0.187 \times \text{VL sup}) - (0.10 \times \text{EPDl}) + (0.092 \times \text{EPWl}) + (0.003 \times \text{VL inf}) + (0.025 \times \text{APD}))</td>
<td>93.1</td>
</tr>
<tr>
<td>L1</td>
<td>(Y' = 4.503 - (0.043 \times \text{VL superior}) - (0.023 \times \text{EPDl}) + (0.040 \times \text{VBHa}))</td>
<td>68.0</td>
</tr>
<tr>
<td>The 12th thoracic &amp; L1</td>
<td>(Y' = 13.156 - (0.187 \times \text{VL sup}) - (1.0 \times \text{EPDl}) + (0.092 \times \text{EPWl}) + (0.003 \times \text{VL inf}) + (0.025 \times \text{APD}))</td>
<td>96.3</td>
</tr>
</tbody>
</table>

\(Y = \text{sex (one male, 2 female).} \) Any calculated values using these equations equal to one were classified as male, and those equal to two were classified as female.
Table 10 Comparison of the present study with previously published studies for sex discrimination from the vertebra.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Population</th>
<th>Vertebrae</th>
<th>Research subjects</th>
<th>Number of sample</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present study</td>
<td>Egyptian</td>
<td>The 12th thoracic vertebra &amp; The first lumbar vertebra</td>
<td>CT</td>
<td>120</td>
<td>The 12th thoracic alone 93.1% L1 alone 68.0% T12 &amp; L1 96.3%</td>
</tr>
<tr>
<td>Marino (1995)</td>
<td>American</td>
<td>The first cervical vertebra</td>
<td>Real bone</td>
<td>100</td>
<td>77.8%</td>
</tr>
<tr>
<td>Wescott (2000)</td>
<td>American</td>
<td>The second cervical vertebra</td>
<td>Real bone</td>
<td>400</td>
<td>83%</td>
</tr>
<tr>
<td>Yu et al. (2008)</td>
<td>Korean</td>
<td>The 12th thoracic vertebra</td>
<td>CT</td>
<td>102</td>
<td>90.0%</td>
</tr>
<tr>
<td>Marlow et al. (2011)</td>
<td>UK</td>
<td>The second cervical vertebra</td>
<td>Real bone</td>
<td>153</td>
<td>78.2%</td>
</tr>
<tr>
<td>Zheng et al. (2012)</td>
<td>Chinese</td>
<td>The first lumbar vertebra</td>
<td>CT</td>
<td>210</td>
<td>88.6%</td>
</tr>
<tr>
<td>Yu et al. (2012)</td>
<td>Chinese</td>
<td>The 12th thoracic vertebra</td>
<td>CT</td>
<td>141</td>
<td>94.2%</td>
</tr>
<tr>
<td>Bethard (2013)</td>
<td>American</td>
<td>The second cervical vertebra</td>
<td>Real bone</td>
<td>300</td>
<td>86.7%</td>
</tr>
</tbody>
</table>

- Radiography-based virtual anthropological examination provides an accurate means of making a successful identification in a timely and non-destructive fashion.

Funding

None.

Conflict of interest

None declared.

Informed consent

The Ethics Committee of Alexandria Faculty of Medicine approved this study, and all patients included signed an informed consent document.

Ethical approval

The Ethics committee of Faculty of Medicine, Alexandria University, for human experimentation, approved this work.

References

Sex determination from the 12th thoracic and the first lumbar vertebra measurement data