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Estimation of the femur length from its proximal measurements in Anatolian Caucasians by artificial neural networks

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Femora are a well preserved section of the skeleton after death. Therefore, they are commonly used in the field of forensic sciences, physical anthropology and anatomy. In addition, femur morphometry is helpful in finding sex or side (left or right) differences. The femur also shows characteristics of certain populations. Femur length is important for calculation of individual stature. In this study, the artificial neural network method was used to estimate femur length. In total, 230 femora exemplar were used. The three input parameters of the method were the distance between trochanter major top point and trochanter minor bottom point, the diameter of caput femoris and the diameter of collum femoris. By using these parameters, the artificial neural network estimation on femur length was performed. The results show that the method is capable of performing this estimation. In addition, sex discrimination was performed and achieved with 82% accuracy. As well as the identification of sex or side differences, morphometry of the proximal femur is necessary and important for surgical procedures.

Keywords: femur; morphometry; sexual dimorphism; artificial neural network

1. Introduction

Skeleton components differ metrically among populations. These differences are related to environmental and genetic factors. Therefore, variations in the skeleton system can help determine the racial characteristics of populations. Anthropometric skeleton measurements are helpful for indication of regional differences among the same population or different populations. Moreover, skeleton measurements and shape of the bone can guide a clinician in the determination of risk factor for fractures1–3. Skeleton remains have great importance for the forensic pathologist and physical anthropologist in identification of the deceased. Osteometry is important in medico-legal searches for estimating height, which is part of estimating sex, stature, race, body weight, body build and age at the time of death4.

The femur is longest and strongest bone in the human body. It has a shaft, proximal femur and distal femur5. Long bones form the largest part of stature. The femur and tibia are more useful than the humerus and ulna. Measurement of femur fragments can be used in estimation of stature6. An intact femur has the highest correlation in stature estimation. But in most forensic cases, a fragment of the femur is used because of

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absence of the entire femur. The entire weight of the body is supported by the femoral heads, suggesting that the morphometry of the proximal femur can contribute to femoral neck strength. The biomechanical properties of the proximal femur depend on the length and width of the femoral neck. Hip fractures have high morbidity and mortality rates for people. They are generally seen in elderly.

In recent years, the artificial neural network (ANN) method has been used in the clinical biomechanics fields. Several examples can be given for such works as the neural network prediction of lower extremities’ movement by angle-angle diagrams, the neural network approach for bone fracture healing assessment, classification of gender-specific dynamic gait patterns by using the artificial neural network method, artificial neural network usage for assessing parameters of gait symmetry, and determination of patellar position by neural network method. The ANN method is a mathematical model that mimics the human brain functionality. In the method, there is no need for any relationship between the input and desired output data. The method is also successful for highly non-linear data. In the current work, three measurements belonging to the femur proximal were used as input parameters of the ANN. The main task was to obtain femur length \( L \) according to the given inputs. After performing three applications, it was seen that the ANN method is appropriate for prediction of this length. Our goal is to contribute to the forensic sciences by estimation of the entire length of the femur from proximal femur measurements.

2. Materials and methods

2.1. Samples and measurements

In this study, 230 well-preserved intact femur samples were used. These femurs belong to the adults of the republic period of Anatolian region. These bones are in the anatomy laboratory of the Faculty of Medicine at Aydın Adnan Menderes University in Turkey. Ninety of the samples belong to females and the rest are male. All female femora are in two separate sets: 38 belong to the right and 52 to the left. In addition, there are 55 right male femora and 85 left male femora. We indicated six different anatomic points \( a, b, c, d, e, f \) on the femur proximal. Point \( a \) is the trochanter major top point; point \( b \) is the collum femoris top point; point \( c \) is the caput femoris centre; point \( d \) is the transverse diafiz top lateral point; point \( e \) is the trochanter minor bottom point; and point \( f \) is the trochanter major lateral point. Furthermore, the diameter of caput femoris \( \text{cap} \), the diameter of collum femoris \( \text{col} \) and the femur length \( L \), i.e. the distance from caput femoris to medial condyles, were measured (Figure 1). \( de \) is the distance between the transverse diafiz top lateral point and trochanter minor bottom point, \( fc \) is the distance between the trochanter major lateral point and the caput femoris centre, \( ce \) is the distance between the caput femoris centre and the trochanter minor bottom point, \( be \) is the distance between the collum femoris top point and the trochanter minor bottom point and \( ae \) is the distance between the trochanter major top point and the trochanter minor bottom point. The measurements were performed using slide calliper with 1/50 sensibility by the same anatomist. Also, the student t-test was used in the measurements (SPSS).

2.2. Method: artificial neural network (ANN)

The mathematical model ANN (artificial neural network) mimics human brain functionality. It consist of several processing units named as neurons. The neurons are
connected to each other via adaptive synaptic weight connections. There are layers in the structure of the ANN. Three main layers are generally used: input, hidden and output layers. The neurons in different layers communicate with each other by weighted connections. The data are transmitted from one to another by these connections. The neurons in the input layer receive data from the environment and the received data transmitted to the hidden neurons. After activation, the results are obtained from the neurons in the output layer. The sigmoid-like hidden layer activation function is commonly used. In this study, tangent hyperbolic \((\text{tanh} x = (e^x - e^{-x})/(e^x + e^{-x}))\) and linear functions were used for hidden and output neurons, respectively. The numbers of hidden layers and their neurons depend on the problem nature. But generally one hidden layer is enough for almost all problems. After several trials, it was seen that, for this problem, the best number of the neurons in the hidden layer is four. We used layered feed-forward ANN in order to estimate the length of the femur \((L)\). The inputs was \(ae\), \(cap\) and \(col\) in the femur (Figure 1). The architecture of the ANN was 3–4–1 (Figure 2). The total number of synaptic weights was 16. No bias was used.

The ANN method is a perfect tool for non-linear function approximation, as in this problem\(^{18}\). The ANN process is composed of two main steps: the training and test steps. In the training step, the weights are modified by known data and ANN is finally

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Figure 1. The distances between anatomic points in femur.
constructed. After the final weights, the constructed ANN is tested over the test data which is not seen before. The total number of femur exemplar was 230 for both sexes. Ninety of these belong to females and 140 to males. In the initial stage of the work, all the data were considered without sex and side separation (the work was deepened by grouping the data for different sex and sides. This will be mentioned in Section 4). All data were partitioned into two separate sets, for training and test steps. In this work, 80% of all data (184 data points) was used for training and 20% (46 data points) was used for testing. If the results are acceptable, it is said that the ANN has generalised the data. In the training stage of this work, a back-propagation algorithm with Levenberg-Marquardt\textsuperscript{19,20} was used for the training of the ANN. The purpose of the training stage is to minimise the difference between the desired and estimated outputs by proper modifications of the synaptic connections. The error function, which measures this difference was the root mean square error (RMSE) given by equation (1).

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{N} (y_i - f_i)^2}{N}}$$ \hspace{1cm} (1)

where $y_i$ and $f_i$ are the neural network and desired outputs, respectively, $N$ is the total number of samples. The RMSE values are about 1.5 for both training and test steps. For details of ANN, we refer the reader to Haykin\textsuperscript{17}.

4. Results and discussion

In this study, proximal femur measurements were used for estimating femur length ($L$) (Table 1). It was seen that $ae$, $cap$ and $col$ give the best results for this estimation. Therefore, we used only these distances in the method although we have more measurements. An ANN software NeuroSolutions v6.02\textsuperscript{21} was used for the calculations. In the initial stage of this study, 230 femora samples were considered as a whole. After training by 184 data including both sex and sides, the test was performed on 46 randomly selected samples which had never been seen before by the network. The average values of the femora length used in the training and test steps were obtained as 42.33 and 42.62 cm, respectively. The corresponding root mean square errors were

![ANN Architecture Diagram](image-url)
1.40 and 1.45 cm. This means that there is an average error of about 3–3.5% in estimation. It is also clear in Figure 3 that the maximum deviations of ANN estimations from real values were 3.08 and 3.04 cm in the test and training data, respectively. The results indicate that the ANN method is a convenient tool for estimating femur length.

After seeing the success of the method, all the data were grouped into four separate sets. The first set belongs to the female right femur and second belongs to the left for the same sex. The third and fourth data groups belong to the male right and male left femora, respectively. In Figure 4, the results for these different groups were shown. As can be clearly seen in the figures, the maximum deviations from measured values were between –2.10 and 1.61. The RMSE values are 0.78, –2.10, –1.87 and –1.49 cm for female right, female left, male right and male left femora. The lowest one between these RMSE values belongs to the female right femur and the largest one is for the female left femur. Given average values of the femur, it is clear that the deviation of the estimations from measurements are between 1.9 and 4.9%.

In the final application of the ANN method, the sex discrimination was practiced. All data belonging to the right femur including both female and male were used for the application. After training of the ANN by this group of data, the test step was applied for discrimination. The same process was implemented for the left femur. In total, 44 (each data group contains 11) data points were used for the test step. According to the results, the constructed ANN recognises the male and female data with 91% and 73% accuracy, respectively. Namely, for a given right femur, the ANN indicated 8 of 11 female femora as female femora and 10 of 11 male femora as male femora. It was seen that the success of the ANN method is higher with male data. In other words, the ANN recognises male data better. Also, it is concluded that 18 of the total 22 right femora were correctly classified. This means that the method has 82% success in discrimination. The same results were taken for the left side.

Table 1. Proximal femur and femur length measurements for different sides of females and males.

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Sides</th>
<th>n</th>
<th>Female</th>
<th>N</th>
<th>Male</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>L (cm)</td>
<td>Left</td>
<td>52</td>
<td>41.53 ± 2.54</td>
<td>85</td>
<td>43.40 ± 2.46</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>38</td>
<td>40.57 ± 2.06</td>
<td>55</td>
<td>42.47 ± 2.78</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td>d-e (cm)</td>
<td>Left</td>
<td>52</td>
<td>3.42 ± 0.75</td>
<td>85</td>
<td>3.42 ± 0.32</td>
<td>p&gt;0.05</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>38</td>
<td>3.27 ± 0.23</td>
<td>55</td>
<td>3.30 ± 0.31</td>
<td>p&gt;0.05</td>
</tr>
<tr>
<td>Col (cm)</td>
<td>Left</td>
<td>52</td>
<td>3.01 ± 0.30</td>
<td>85</td>
<td>3.25 ± 0.30</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>38</td>
<td>2.87 ± 0.23</td>
<td>55</td>
<td>3.09 ± 0.34</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td>Cap (cm)</td>
<td>Left</td>
<td>52</td>
<td>4.32 ± 0.36</td>
<td>85</td>
<td>4.55 ± 0.37</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>38</td>
<td>4.12 ± 0.25</td>
<td>55</td>
<td>4.35 ± 0.42</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td>f-c (cm)</td>
<td>Left</td>
<td>52</td>
<td>8.96 ± 0.76</td>
<td>85</td>
<td>9.45 ± 0.74</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>38</td>
<td>8.37 ± 0.69</td>
<td>55</td>
<td>9.02 ± 0.76</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td>c-e (cm)</td>
<td>Left</td>
<td>52</td>
<td>9.06 ± 0.70</td>
<td>85</td>
<td>9.62 ± 0.84</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>38</td>
<td>8.49 ± 0.83</td>
<td>55</td>
<td>9.29 ± 0.71</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td>b-e (cm)</td>
<td>Left</td>
<td>52</td>
<td>6.39 ± 0.61</td>
<td>85</td>
<td>6.93 ± 0.68</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>38</td>
<td>5.94 ± 0.80</td>
<td>55</td>
<td>6.63 ± 0.69</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td>a-e (cm)</td>
<td>Left</td>
<td>52</td>
<td>7.36 ± 0.61</td>
<td>85</td>
<td>7.82 ± 0.57</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>38</td>
<td>7.04 ± 0.53</td>
<td>55</td>
<td>7.65 ± 0.74</td>
<td>p&lt;0.05</td>
</tr>
</tbody>
</table>

L: femur length. de: the distance between transverse diafiz top lateral point and trochanter minor bottom point. col: diameter of collum femoris. cap: diameter of caput femoris. fc: the distance between trochanter major lateral point and is caput femoris centre. ce: the distance between collum femoris top point and trochanter minor bottom point. be: the distance between trochanter major top point and trochanter minor bottom point.
Conclusion

Skeletal remains are helpful in estimation of individual properties. In particular, the femur is frequently used in forensic sciences and physical anthropology. Sometimes an intact femur may not exist. In such cases, individual properties can be estimated by

Figure 3. Difference between measured and estimated values of the femur length ($L$) for test data (upper panel) and training data (lower panel) samples.

Figure 4. Difference between measured and estimated values of the femur length ($L$) for female right (upper-left panel), female left (upper-right panel), male right (lower left panel) and male left (lower right panel) femur.

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femur fragments. In this study, the sex discrimination and full femur length estimation were practised from proximal femur morphometry in Anatolian Caucasians. The method used was ANN. By using the three measurements of the proximal femur, these tasks were completed with acceptable and comparable success. One can confidently use the method with these inputs for estimating femur length for any region, any race, any sex or any group. In addition, in the case of absence of one or more parameters as input, or using another measurement instead of using the specified ones, the method is still useful for this estimation with slightly bigger deviations. The maximum deviation in estimating of the length was 4.9% and the success ratio for the discrimination was 82%. The usage of the artificial neural network method is thought to be new in physical anthropology, forensic and anatomic sciences. Therefore, this study indicates that the method can find a place in these areas. These results are beneficial in forensic cases and anthropologic surveys. The anatomic measurements are useful for the surgeon. For this reason, proximal femur morphometric measurements can guide to surgical procedure in the vascular, metabolic or traumatic reasons.

Conflict of interest
The authors do not have financial or personal relationship with other persons or organisations that might inappropriately influence the work presented therein.

References