CHAPTER 9

RESULTS - SEX DETERMINATION

9.1 Introduction

Seven measurements were recorded on each of the hand bones, the details of which are set out in the chapter on materials and methods. These measurements included the length dimension, anteroposterior (ap) and mediolateral (ml) head dimensions, anteroposterior (ap) and mediolateral (ml) midshaft dimensions, anteroposterior (ap) and mediolateral (ml) base dimensions.

In the present study, discriminant function analysis using a stepwise and direct approach, was conducted on the pooled data which was based on results from the descriptive analysis. From this, canonical discriminant function coefficients for the stepwise and direct procedures as well as sexing accuracies were obtained. The canonical discriminant coefficients will be discussed in detail with the metacarpals where examples will be given on how to incorporate these values into the equation to estimate sex. For the phalanges, reference will be made to the table. The calculations for the phalanges are exactly the same as that for the metacarpals.

In the first step, the stepwise discriminant function procedure is performed using Wilk's lambda with F=3.84 to enter and F=2.71 to remove. In other words, Wilk's lambda determines the order in which the variables are selected to enter into the function. Multivariate analysis of variance (MANOVA) is used to compare the group means on a combination of variables. In the present study, the groups would be male and female while the variables are the seven dimensions of each hand bone. The value of interest in the results generated by the computer is Wilk's lambda. These values are arranged from the highest to the lowest confidence scores. Lambda can be described almost as an inverse measure. In other words, if its values are near zero then it denotes a high discrimination between the groups. If the values are further away from zero, then it denotes a low discrimination between the groups. In addition to the Wilk's lambda scores, the values for the exact F-ratio are also provided. These values are also

graded from the highest to the lowest and interpreted in the same manner as the Wilk's lambda. Thus, the Wilk's lambda will be described for each series of hand bones.

Wilk's lambda is also used to test the significance of the discriminant function as a whole. The larger the lambda value the more likely that the discriminant function is significant. A significant lambda means that one can reject the null hypothesis that two groups have the same discriminant function score. One can therefore conclude that the variable entered is discriminating. In other words, either one or all seven hand bone dimensions are significantly different between males and females.

The stepwise discriminant function analysis generates the output in a stepwise manner. Stepwise selects the one parameter that provides the best discrimination first, and then sees what has not already been "covered" by that parameter, thereby selecting the second best discriminator until it has chosen the best possible combination of variables.

In the present study, the (model) stepwise Wilk's lambda was run initially to generate the discriminant functions that would yield the highest lambda scores for each series of hand bones and to list them in a stepwise manner. Lambda varies from zero to one, with zero indicating a difference in the group mean values. A value of one indicates all the group means are the same. The F test of lambda shows which variable has a significant contribution.

In order to carry out the direct Wilk's lambda analysis, the discriminant function with the highest lambda score from the stepwise procedure was used. The reason for doing this is that a vast number of combinations of all variables are possible. In other words, the statistics would become overwhelming considering that there are seven dimensions for each hand bone and that there are four hand bone series, namely, metacarpals, proximal, middle and distal phalanges.

For practical reasons, a stepwise analysis was carried out firstly, using all measurements per hand bone. Secondly, the direct analysis was run using the "best" measurement per hand bone only.

In the statistical analysis there is an F- test of significance of the ratio between two Wilk's lambdas. The second lambda is divided by the first lambda where there are fewer

predictors, and an approximate F value for this ratio is calculated (Tabachnick & Fidell 2007). This F- ratio also assesses the improvement in classification when using sequential discriminant analysis. In the present study, the Wilk's lambda will be reported with comments on the level of significance.

In the second output, canonical discriminant function coefficients are generated. Canonical analysis is a multivariate technique that determines the relationship between groups of variables in a data set. In this analysis, values for the unstandardized and standardized coefficients as well as the structure coefficients are given. The sum of the unstandardized discriminant coefficients and the constant with the observations yields the discriminant scores. Unstandardized discriminant function coefficients and standardized discriminant coefficients are partial coefficients that are used to assess the relative classifying importance of the independent variables (e.g. seven hand bone dimensions).

The group centroids are the mean discriminant scores of each dependent variable categories (e.g. male and female) for each of the discriminant scores (e.g. seven hand bone dimensions). A two-group discriminant analysis will have two centroids, one for each group. The indication that the discriminant function is clearly discriminating is when the mean values are distinctly different. If the mean values are close to each other, the likelihood of more errors of classification exists. The midpoint between the two centroids is the sectioning point.

In the third output, discriminant analysis with cross-validation, which is done only for those cases in the analysis, is then used to assess classification accuracy. In cross-validation, each case is classified by the functions derived from all cases other than that case.

The ultimate goal in this chapter is to develop discriminant function formulae using metacarpals, proximal, middle, and distal phalanges for the South African population. This information will contribute to existing data on different parts of the skeleton recorded by other researchers on the South African population. Each series of hand bones will be reported on independently.

9.2 Metacarpals (Tables 9.1 to 9.3)

The results of the discriminant function analysis of metacarpals are shown in Table 9.1). When all seven variables were entered for metacarpal 1, only five variables were selected in a stepwise manner and two were excluded. The order of selection was mediolateral (ml) midshaft, mediolateral (ml) head, mediolateral (ml) base, anteroposterior (ap) midshaft and length variables. The variable with the largest Wilk's lambda score was the mediolateral (ml) midshaft dimension. This variable will yield a high sexing accuracy with the least amount of error. The variable with the lowest Wilk's lambda score was the length dimension. This variable, on the other hand, will yield a low sexing accuracy and have a high error. The variable with the largest Wilk's lambda score also had the largest univariate F-ratios. The range of F-ratios for first metacarpals was from 38.88 to 125.78. Results for the first metacarpal were highly significant ($p<0.01$). To run the direct analysis, only the mediolateral midshaft dimension was entered into the computer. The results also indicated a high Willk's lambda score for this variable, similar to that of the computed with the stepwise procedure.

Stepwise discriminant function analysis for the second metacarpal selected three variables. The order of their selection were anteroposterior (ap) base, anteroposterior (ap) midshaft and mediolateral (ml) base dimensions. The variable with the highest Wilk's lambda score and exact F-ratio was the anteroposterior (ap) base dimension. In other words, this variable has a high sexing accuracy with the least amount of error. The mediolateral (ml) base has the lowest Wilk's lambda score and is expected to have the highest error in sexing accuracy. While the univariate F-ratio's for second metacarpals were slightly less (range = 53.41 to 87.16) than those of the first metacarpal, they were statistically significant ($p<0.01$). A direct discriminant analysis using the anteroposterior (ap) base dimension yielded a high Wilk's lambda score and exact F-ratio with a lambda value close to the same variable computed through the stepwise analysis.

An analysis in a stepwise manner for the third metacarpal showed that the first two out of the three variables selected are exactly the same as those selected for the second metacarpal. These are the anteroposterior (ap) base which had the highest Wilk's lambda

score, followed by the anteroposterior (ap) midshaft dimension. The variable with the lowest Wilk's lambda score and exact F-ratio was the anteroposterior (ap) head dimension. The range recorded for the univariate F-ratio's was 53.90 to 116.972. The direct discriminant analysis for the anteroposterior (ap) base dimension generated a Wilk's lambda score close to that of the same variable generated in the stepwise analysis. All results were highly significant ($p<0.01$).

Results for the fourth metacarpal also yielded three variables similar to that of the second and third metacarpals. These variables are the anteroposterior (ap) and mediolateral (ml) base and anteroposterior (ap) midshaft dimensions. The first selected variable with the highest lambda score and F-ration was the anteroposterior (ap) base. The variable with the lowest Wilk's lambda score was the anteroposterior (ap) midshaft dimension. Univariate F-ratio's recorded for fourth metacarpals ranged from 42.958 to 108.914.

The last bone in the series yielded five variables in the stepwise analysis. Except for the anteroposterior (ap) head dimension, all the dimensions selected are similar to those of the first metacarpal. The sequence of the selection, however, differs from that of the first metacarpal. The variable with the highest Wilk's lambda score and F-ratio in the fifth metacarpal is the anteroposterior (ap) head dimension. As is the case of the first metacarpal, the variable with the lowest Wilk's lambda score is length. The range for the univariate F-ratio's is recorded from 33.940 to 97.384.

An overview of the metacarpal results indicate that the base is the preferred dimension for metacarpals two, three, and four while the midshaft and head are the dimensions selected for the first and fifth metacarpals respectively. Moreover, anteroposterior rather than mediolateral width dimensions are considered the best sex determinants in the metacarpal series. The lengths of metacarpals do not have a role in sexing accuracies.

In the second part of the discrimant analysis, canonical discriminant coefficients produced by the stepwise and direct analyses are generated (Table 9.2). The output reflects the values for the unstandardized coefficients, standardardized coefficients, structure coefficients and group centroids. The unstandardized (raw) coefficients are used to calculate the discriminant function formulae. The standard coefficient provides information on the

contribution of that variable to the overall classification, while the structure coefficient assesses the product-moment correlation between the variables and the discriminant function respectively. The sectioning point is the midpoint between the two centroids and is calibrated to zero if the samples are of equal size. If the calculated value falls below the sectioning point, the bone is female. On the other hand, if the value is above, then the bone is male.

9.3 Calculation of discriminant scores

Before calculating a discriminant score the following steps need to be followed:

1) The hand bone/s must first be identified
2) Seven dimensions must be recorded on each hand bone
3) A discriminant function analysis must then be run on the data
4) A stepwise and direct analysis must be carried out
5) Look for the variable with the highest Wilk's lambda value and establish in the output the significance level. A high lambda is indicative of the best discriminator for sex
6) Analyze the output with the canonical discriminant function coefficients as these will be entered into the following formula:

DS = unstandardized (raw) coefficient x dimension + c

[Where DS=discriminating score, c=constant]

7) Calculate the sectioning point
8) Compare the discriminating score to the sectioning point to confirm whether the bone is male or female
9) Establish sexing accuracies for the original and cross-validated samples

Example

The hand bone of an unknown individual was found and identified as the second metacarpal. The following measurements are obtained for this hand bone:

VARIABLE	MEASUREMENT
mediolateral (ml) head	= 15.67 mm
anteroposterior (ap) head	= 15.16 mm

mediolateral (ml) midshaft = 13.46 mm

anteroposterior (ap) midshaft = 9.40 mm

mediolateral (ml) base = 15.96 mm

anteroposterior (ap) base = 15.08 mm

length = 46.97 mm

Discriminant score (DS) = (unstandardized coefficient x base ap) + (unstandardized coefficient x midshaft ap) + (unstandardized coefficient x base ml) + constant (see Table 9.2)

DS = (0.3046 x 15.08) + (0.5284 x 9.40) + (0.2756 x 15.96) + (-14.5365)

DS = 4.593368 + 4.96696 + 4.398576 – 14.5365

DS = -0.577596 (This value is smaller than the sectioning point, indicating a female)

While the results thus far have been reported for an intact bone, it may happen that only a fragment of a hand bone is available. The first step in such cases would be to identify the hand bone to which this fragment belongs. Following the stepwise procedures for the descriptions of hand bones, let us say that the fragment was the base of a second metacarpal. This variable with its dimension is then entered into the direct discriminant analysis.

DS = (unstandardized coefficient x base ap) + constant

DS = (0.7002 x 15.08) + (-11.5789)

DS = 10.559016 – 11.5789

DS = -1.019884 (This value is smaller than the sectioning point, indicating a female)

However, because only one dimension is available, a demarking point rather than the discriminating score can be used to make assessment easier. The demarking point is obtained from the group means. In this example, it would be the mean value between the two group means. The mean value of the male and female is added and then divided by two. For example:

ap base dimension mean value in males = 17.4763

ap base dimension mean value in females = 15.5860

then, 17. 4763 + 15.5860 = 33.0623 / 2 = 16.53115 (= demarking point)

The ap base measurement of 15.08 mm is smaller than the demarking point, thus also indicating a female. The accuracies of the discriminant functions are shown in Table 9.3.

Metacarpal results for classification accuracy are seen in Table 9.3. For metacarpal one, 85 males and females out of a total original sample of 100 and 99 in the stepwise analysis were correctly classified. In the cross-validated sample, which is based on the “leave one out” classification, 84 males and 85 females out of a sample of 100 and 99 were correctly classified. The results indicate that only one case in the male was dropped in the cross-validation analysis. In the direct analysis, using a single variable, the percentage accuracy was reduced. Seventy five males and 78 females out of a total sample of 100 and 99 respectively, were assigned to the correct sex. The cross-validated results indicate no difference in accuracy when compared to the results of the original sample.

In general, the analyses with multiple variables exhibited better classification accuracies than those of single variables. The rows marked “original” refers to the percentage of individuals predicted to belong to either the male or female group; whereas the cross-validation classification test determines the accuracy of assignment of a bone to either a male or female category. This was achieved by re-classifying each case to see whether that individual case was attributed to the same group membership as during the first classification. Subsequently, the test allows an observation of the number of specimens classified versus the number of specimens in the sample. When using multiple variables, the average range of accuracies is from 76.0 – 85.9% and 83.8 – 86.7% for males and females respectively. This drops to 71.0 – 78.0 % and 78.8 – 86.7% for males and females when single variables are used. The sexing accuracy for metacarpals was thus fairly high in both the original (correct group membership) and cross-validation testing.

9.3 Proximal phalanges (Tables 9.4 to 9.6)

The results of the discriminant function analysis of proximal phalanges are shown in Table 9.4. After entering all seven variables for the first proximal phalanx, three variables were selected in the stepwise procedure. The order of selection was anteroposterior (ap) midshaft, anteroposterior (ap) base and mediolateral (ml) midshaft. The variable with the largest Wilk's lambda score was the mediolateral (ap) midshaft dimension which means that this variable will yield a high sexing accuracy with the least amount of error. While this variable showed the highest lambda score, it was the lowest in the proximal phalangeal series. The range of F-ratios for the first proximal phalanges was 86.5000 to 204.3969. Results for these hand bones were highly significant ($p<0.01$). To run the direct analysis, only the anteroposterior (ap) midshaft dimension was entered into the computer. While the results also indicated a high Willk's lambda score for this variable, similar to that of the computed with the stepwise procedure, it was the lowest in the first proximal phalangeal series of bones.

Stepwise discriminant function analysis for the second proximal phalanx also selected three variables. The order of their selection was midshaft mediolateral (ml), midshaft anteroposterior (ap) and base anteroposterior (ap) dimensions. The variable with the highest Wilk's lambda score and exact F-ratio was the midshaft mediolateral (ml) dimension. While the univariate F-ratio's for second proximal phalanges were slightly less (range = 63.0925 to 148.1646) than those of irst proximal phalanges, they were nonetheless, statistically significant ($p<0.01$). A direct discriminant analysis using the midshaft mediolateral (ml) dimension yielded a high Wilk's lambda score and exact F-ratio with a lambda value equivalent to that for the same variable computed through the stepwise analysis.

Two variables were selected in the stepwise procedure for the third and fourth proximal phalanges, namely, anteroposterior (ap) base and mediolateral (ml) midshaft dimensions, while midshaft (ml) and base (ap) were selected for the fifth proximal phalanx. The unstandardized, standard and structure coefficients as well as the sectioning points are shown in Table 9.5.

The sexing accuracy indicated high percentages for the third proximal phalanx (Table 9.6). An overview of the stepwise procedure for this bone shows that in the original output, 81 cases out of a sample of 100 (81.0%) was correctly assigned as male and 87 out of 98 cases (88.8%) were correctly assigned as female. In the cross-validated analysis, only one case was dropped for both the male and female sample yielding accuracies of 80.0% and 83.8% for male and females respectively. A comparison between the average percentages recorded for the original (84.8%) and cross-validated (83.8%) analysis showed slight differences. Results for the direct analysis using the best selected single variable of the third proximal phalanx, reveals the same values as for the original and cross-validated stepwise analysis. In other words, 82 cases out of a total sample of 100 (82.0%) in males and 86 out of 98 (87.8%) cases in females was the third proximal phalanx correctly assigned. Sexing accuracy averages for the original and cross-validated results was the same, namely, 84.8%.

In general, the analyses with multiple variables provided better classification accuracies than for single variables of the proximal phalangeal series. The average range of accuracies using multiple variables is from 80.6 – 84.0% and 85.9 – 88.8% for male and females respectively. In comparison, these results drops slightly when using single variables with accuracies reported as 74.5 – 85.0% for males while in females the classification accuracies are similar to that for multiple variables, namely, 86.6 – 88.8% (Table 9.6).

An overview of this series of hand bones is that the base and midshaft are the preferred areas of proximal phalanges for sexing a bone. Width measurements of the midshaft and anteroposterior (ap) of the base presented with high lambda scores. The length dimension was not selected for any of the proximal phalanges. Average sexing accuracies for this series of hand bones ranged 81.7% to 86.9% which are fairly high percentages.

9.4 Middle phalanges (Tables 9.7 to 9.9)

Table 9.7 shows the discriminant function analysis for all middle phalanges. While three variables were selected for the second middle phalanx, only two were chosen for the third,

fourth and fifth middle phalanges. The one variable that appears in all middle phalanges is the width of the midshaft. The anteroposterior (ap) dimension of the midshaft is selected for the second, third and fifth middle phalanges. The anteroposterior (ap) dimension of the base is selected for the first and fourth middle phalanges. In terms of priority listing, the highest Wilk's lambda score in the second middle phalanx is the anteroposterior (ap) base dimension (0.5714) in comparison to the mediolateral (ml) midshaft dimension of the third (0.5805), fourth (0.5976) and fifth (0.5831) middle phalanges. The first selected variable generated by the stepwise procedure and entered into the direct analysis, indicates a lambda value similar to that. The lambda value for the fourth middle phalanx, however, was higher than that obtained for the stepwise analysis. This indicates that a single variable can be used to assign sex to a bone. The unstandardized, standard and structure coefficients as well as the sectioning points are shown in Table 9.8.

Classification accuracies for the middle phalangeal series of bones are shown in Table 9.9. For the second middle phalanx 76 out of 98 original cases (77.6%) in males and 82 out of 96 (85.4%) for females, were correctly classified. When the stepwise results are compared to that of the cross-validated output, there was no change in the male group and only one case was dropped in the female group yielding a percentage of 83.3%. The average sexing accuracy was recorded as 81.4% (original) and 80.9% (cross-validated). Entering a single variable for the direct analysis drops the number of cases in males to 71 out of 98 (72.4%) and in females to 80 out of 96 (83.3%) with an average for the two groups being 77.8%.

Average classification accuracies using the third middle phalanx were the highest in the middle phalangeal series and reported as 85.9% using multiple variables and 81.8% using a single variable. Furthermore, none of the cases dropped during cross-validation.

Using multiple variables in the case of the fourth middle phalanx, 77 out of 99 original cases (77.8%) in males and 83 out of 96 cases (86.5%) for females, were correctly classified. There was no change in the cross-validated results with average accuracies reported as 82.1%. These results dropped slightly when single variables were used as 71 out of 99 original cases (71.7%) in males and 82 out of 96 cases (85.4%) for females, were correctly classified.

On cross-validation one case was dropped in males while in females the results stayed the same.

Average classification accuracies using the fifth middle phalanx were the second highest in the middle phalangeal series and reported as 84.8% using multiple variables and 81.7% with single variables.When compared to using multiple variables, the number of cases using single variables dropped to 76 (79.2%) and 80 (84.2%) for males and females respectively with an average accuracy range of 84.3 – 84.8%. When comparing accuracies for the original and cross-validated analysis using single variables, none of the cases were dropped.

In conclusion, using single variables in the middle phalangeal series of bones will reduce the overall sexing accuracy in comparison to using as many variables as possible. However, the computed statistics for the middle phalangeal series of bones indicates that single variables of the third and fifth bones yields fairly high sexing accuracies.

9.5 Distal phalanges (Tables 9.10 to 9.12)

Results of the discriminant analysis for the distal phalangeal series of bones are shown in Table 9.10. For the first distal phalanx, three variables selected in a stepwise manner were, base (ap), length, and midshaft (ap) of which the base (ap) dimension had the highest lambda score (0.59698). Direct analysis on the anteroposterior (ap) base dimension revealed a lambda value (0.5970) close to that given in the stepwise approach. While three variables were also selected for the second distal phalanx, they were slightly different to that of the first bone, namely, midshaft (ap), length and base (ml) dimensions. The midshaft (ap) dimension had the highest lambda score (0.69351) with a corresponding high F-ratio (84.411). This variable was entered into the direct analysis yielding a lambda value (0.6935) close to that reported in the stepwise procedure with a similar F-ratio (84.4112). For distal phalanges 3 and 4, the same three variables were selected, namely, base (ml), length and midshaft (ap) dimensions. The base (ml) dimension had the highest lambda score of 0.65801 (distal phalanx 3) and 0.71977

(distal phalanx 4) and a corresponding high F-ratio of 98.230 (distal phalanx 3) and 72.025 (distal phalanx 4). Entering these variables entered into the direct analysis yielded similar results to that of the direct analysis. Four variables were selected for the fifth distal phalanx, namey, length, base (ml), midshaft (ap), and head (ml). The length dimension had the highest lambda score (0.63854) and F-ratio (101.328). Generally, the lambda scores and F-ratios using multiple and single variables were similar. The unstandardized, standard and structure coefficients as well as the sectioning points are shown in Table 9.11.

Classification accuracies using distal phalanges are shown in Table 9.12. For the first distal phalanx, 84 out of 100 males (84.0%) and 84 out of 99 females (84.8%) were correctly sexed. On cross-validation, only one case was dropped for males resulting in 83.0% sexing accuracy with no change in the number of female cases. Average accuracies with multiple variables were 84.4% (original) and 83.9% (cross-validated). When using a single variable the number of cases in males dropped in that 81 out of 100 cases (81.0%) were correctly classified while the numbers of female cases increased slightly in that 86 out of 99 (83.9%) females were correctly classified. Average accuracies for multiple and single variables was 84.4% and 83.9% respectively.

For the second distal phalanx, 76 out of 97 males (78.4%) and 80 out of 96 females (83.3%) were correctly assigned. On cross-validation, one case was dropped in males (77.3%) and in females (82.3%). Average accuracies for multiple variables were 80.8% (original) and 79.8 (cross-validated). The number of cases dropped slightly when using single variables as compared to multiple variables. In other words, 71 out of 96 (73.2%) male and 75 out of 96 (78.1%) female cases were correctly assigned. No cases were dropped on cross-validation with single variables. The average accuracy reported for single variables was 75.6%.

In the third distal phalanx, 77 of 96 cases in males (80.2%) and 80 out of 95 cases for females (84.2%) were correctly assigned. On cross-validation, one case was dropped in males (79.2%) and two in females (82.1%). The average sexing accuracies were 82.2% (original) and 80.6% (cross-validated). When only a single variable is entered, the results indicate a drop in accuracies in that 74 cases (77.1%) in males and 74 cases (77.1%) in females were only

correctly assigned. On cross-validation, no cases were dropped for either males or females. Average sexing accuracies using single variables was 77.1%.

Sexing accuracies for the fouth distal phalanx indicate that 77 out of 95 males (81.1%) and 74 out of 93 females (79.6%) cases were correctly assigned. On cross-validation, the number of male cases stayed the same while one case was dropped from the female sample (78.5%). Average accuracies were recorded as 80.3% (original) and 79.8% (cross-validated). Using single variables, there is a drop in the number of cases to 73 (76.8%) in males and 73 (79.6%) in females. No cases were dropped on cross-validation when using single variables and average accuracies were reported as 78.2%.

Generally, the fifth distal phalanx gave the highest sexing accuracy. When multiple variables are used, 80 out of 94 (85.1%) males and 73 out of 87 (93.9%) females were accurately sexed. On cross-validation, one case was dropped in males (81.9%) and one in females (82.8%). Average sexing accuracies for males and females was 84.5% (original) and 82.3% (cross-validated). When using single variables, 75 out of 94 (79.8%) males and 70 out of 87 (80.5%) females were correctly assigned. Cross-validated results showed that only one case was dropped in females with an overall average classification accuracy of 79.0 – 80.1%.

In conclusion, the sexing accuracies for distal phalanges are fairly high using multiple and single variables with the fifth distal phalanx as the best selected bone in this series.

Table 9.1: Discriminant function analysis of metacarpals 1 to 5 for South Africans

Function	Step	Variable	Wilk's lambda	Exact F-ratio	d.f
Metacarpal 1					
Stepwise	1	midshaft ml	0.610	125.780	1.197
	2	head ml	0.563	75.929	2.196
	3	base ml	0.537	56.142	3.195
	4	midshaft ap	0.514	45.769	4.194
	5	length	0.498	38.878	5.193
Direct	1	midshaft ml	0.610	125.780	1.197
Metacarpal 2					
Stepwise	1	base ap	0.693	87.165	1.197
	2	midshaft ap	0.590	68.004	2.196
	3	base ml	0.549	53.409	3.195
Direct	1	base ap	0.693	87.165	1.197
Metacarpal 3					
Stepwise	1	base ap	0.627	116.972	1.197
	2	midshaft ap	0.575	72.568	2.196
	3	head ap	0.547	53.900	3.195
Direct	1	base ap	0.627	116.972	1.197
Metacarpal 4					
Stepwise	1	base ap	0.643	108.914	1.196
	2	base ml	0.547	53.611	3.194
	3	midshaft ap	0.529	42.958	4.193
Direct	1	base ap	0.641	110.344	1.197
Metacarpal 5					
Stepwise	1	head ap	0.667	97.384	1.195
	2	midshaft ml	0.592	66.738	2.194
	3	base ml	0.570	48.479	3.193
	4	midshaft ap	0.550	39.220	4.192
	5	length	0.530	33.940	5.191
Direct	1	head ap	0.667	97.384	1.195

ap=anteroposterior, ml=mediolateral, df-degrees of freedom

Table 9.2: Canonical discriminant function coefficients of metacarpals (MC) 1 to 5 for South Africans

Function	Step	Variable	Unstandardized coefficient	Standard coefficient	Structure coefficient	Group centroids
MC1 Stepwise	1	midshaft ml	0.2861	0.3016	0.7962	M=0.9935
	2	head ml	0.2566	0.3384	0.6470	F=-1.0036
	3	base ml	0.2121	0.2879	0.5766	
	4	midshaft ap	0.3822	0.3239	0.6573	
	5	length	0.0982	0.2730	0.5938	
		(Constant)	-18.3415			
		Sectioning point	-0.00505			
Direct	1	midshaft ml	0.9485	1	1	M=0.7910
		(Constant)	-11.5287			F=-0.7990
		Sectioning point	-0.0040			
		Demarking point	Males>12.15>Females			
MC2 Stepwise	1	base ap	0.3046	0.4350	0.7338	M=0.8974
	2	midshaft ap	0.5284	0.5153	0.7301	F=-0.9064
	3	base ml	0.2756	0.4294	0.7093	
		(Constant)	-14.5365			
		Sectioning point	-0.00450			
Direct	1	base ap	0.7002	1	1	M=0.6585
		(Constant)	-11.5789			F=-0.6652
		Sectioning point	-0.0033			
		Demarking point	Males>16.53>Females			
MC3 Stepwise	1	base ap	0.3324	0.4219	0.8462	M=0.9015
	2	midshaft ap	0.4283	0.3942	0.7375	F=-0.9106
	3	head ap	0.4124	0.4216	0.8353	
		(Constant)	-15.5067			
		Sectioning point	-0.00455			
Direct	1	base ap	0.7879	1	1	M=0.7628
		(Constant)	-13.1813			F=-0.7705
		Sectioning point	-0.0038			
		Demarking point	Males>16.72>Females			
MC4 Stepwise	1	base ap	0.4163	0.4200	0.8003	M=0.9174
	2	base ml	0.4627	0.4861	0.6529	F=-0.9361
	3	midshaft ap	0.5275	0.4849	0.7145	
		(Constant)	-14.5196			
		Sectioning point	-0.00935			
Direct	1	base ap	0.9935	1	1	M=0.7409
		(Constant)	-12.2514			F=-0.7484
		Sectioning point	-0.0037			
		Demarking point	Males>12.33>Females			
MC5 Stepwise	1	midshaft ml	0.3723	0.3096	0.7072	M=0.9291
	2	base ml	0.2954	0.3909	0.6371	F=-0.9386
	3	midshaft ap	0.4857	0.4411	0.7288	
	4	length	0.1157	0.3786	0.5560	
		(Constant)	-16.4791			
		Sectioning point	-0.00475			
Direct	1	midshaft ml	1.1567	1	1	M=0.6995
		(Constant)	-13.7773			F=-0.7067
		Sectioning point	-0.0036			
		Demarking point	Males>11.91>Females			

ap=anteroposterior, ml=mediolateral

Table 9.3: Sexing accuracy of metacarpals 1 to 5 of South Africans. Percentage of correct group membership and cross-validation

Function		N (Total)	Male Count	%	Female Count	%	Average Accuracy
Metacarpal 1							
Stepwise	Original	199	85/100	85.0	85/99	85.9	85.4
	Cross-validated	199	84/100	85.0	85/99	85.9	84.9
Direct-MC1 midshaft ml	Original	199	75/100	75.0	78/99	78.8	76.9
	Cross-validated	199	75/100	75.0	78/99	78.8	76.9
Metacarpal 2							
Stepwise	Original	199	76/100	76.0	83/99	83.8	79.9
	Cross-validated	199	76/100	76.0	82/99	82.8	79.4
Direct-MC2 base ap	Original	199	71/100	71.0	80/99	80.8	75.9
	Cross-validated	199	71/100	71.0	80/99	80.8	75.9
Metacarpal 3							
Stepwise	Original	199	80/100	80.0	83/99	83.8	81.9
	Cross-validated	199	79/100	79.0	83/99	83.8	81.4
Direct-MC3 base ap	Original	199	72/100	72.0	84/99	84.8	78.4
	Cross-validated	199	72/100	72.0	83/99	83.8	77.9
Metacarpal 4							
Stepwise	Original	198	80/100	80.0	85/98	86.7	83.3
	Cross-validated	198	77/100	77.0	85/98	86.7	81.8
Direct-MC4 base ap	Original	199	78/100	78.0	79/99	79.8	78.9
	Cross-validated	199	78/100	78.0	79/99	79.8	78.9
Metacarpal 5							
Stepwise	Original	197	78/99	78.8	84/98	85.7	82.2
	Cross-validated	197	78/99	78.8	84/98	85.7	82.2
Direct-MC5 head ap	Original	199	76/99	76.8	82/98	83.7	80.2
	Cross-validated	199	76/99	76.8	82/98	83.7	80.2

Table 9.4: Discriminant function analysis of proximal phalanges 1 to 5 for South Africans

Function	Step	Variables	Wilks lambda	Exact F-ratio	d.f
Proximal Phalanx 1					
Stepwise	1	midshaft ap	0.4895	204.3969	1.196
	2	base ap	0.4426	122.7989	2.195
	3	midshaft ml	0.4278	86.5000	3.194
Direct	1	midshaft ap	0.4895	204.3969	1.196
Proximal Phalanx 2					
Stepwise	1	midshaft ml	0.5682	148.1646	1.195
	2	midshaft ap	0.5169	90.6562	2.194
	3	base ap	0.5049	63.0925	3.193
Direct	1	midshaft ml	0.5682	148.1646	1.197
Proximal Phalanx 3					
Stepwise	1	base ap	0.5423	165.3920	1.196
	2	midshaft ml	0.4696	110.1276	2.195
Direct	1	base ap	0.5423	165.3920	1.196
Proximal Phalanx 4					
Stepwise	1	base ap	0.5503	160.1438	1.196
	2	midshaft ml	0.5005	97.2858	2.195
Direct	1	base ap	0.5503	160.1438	1.196
Proximal Phalanx 5					
Stepwise	1	midshaft ml	0.5405	161.5076	1.190
	2	base ap	0.4808	102.0623	2.189
Direct	1	midshaft ml	0.5398	163.6591	1.192

ap=anteroposterior, ml=mediolateral, df=degrees of freedom

Table 9.5: Canonical discriminant function coefficients of proximal phalanges (PP) 1 to 5 for South Africans

Function	Step	Variable	Unstandardized coefficient	Standard coefficient	Structure coefficient	Group centroids
PP1 Stepwise	1	midshaft ap	0.8641	0.4899	0.8830	M=1.1391
	2	base ap	0.4285	0.3820	0.8268	F=-1.1624
	3	midshaft ml	0.3856	0.3132	0.8035	
		(Constant)	-13.8089			
		Sectioning point	-0.0116			
Direct	1	midshaft ap	1.7640	1	1	M=1.0058
		(Constant)	-10.9009			F=-1.0263
		Sectioning point	-0.0102			
		Demarking point	Males>6.18>Females			
PP2 Stepwise	1	midshaft ml	0.6104	0.5261	0.8802	M=0.9903
	2	midshaft ap	0.5790	0.3634	0.8017	F=-0.9803
	3	base ap	0.3790	0.2980	0.8241	
		(Constant)	-13.9989			
		Sectioning point	-0.0050			
Direct	1	midshaft ml	1.1601	1	1	M=0.8717
		(Constant)	-11.0219			F=-0.8628
		Sectioning point	-0.0044			
		Demarking point	Males>9.50>Females			
PP3 Stepwise	1	base ap	0.8285	0.6526	0.8643	M=1.0468
	2	midshaft ml	0.6094	0.5457	0.7989	F=-1.0681
		(Constant)	-16.4649			
		Sectioning point	-0.01065			
Direct	1	base ap	1.2695	1	1	M=0.9048
		(Constant)	-15.9796			F=-0.9232
		Sectioning point	-0.0092			
		Demarking point	Males>12.59>Females			
PP4 Stepwise	1	base ap	0.9061	0.6504	0.9049	M=0.9839
	2	midshaft ml	0.5638	0.4959	0.8297	F=-1.0039
		(Constant)	-15.7711			
		Sectioning point	-0.0100			
Direct	1	base ap	1.3931	1	1	M=0.8903
		(Constant)	-16.2481			F=-0.9085
		Sectioning point	-0.0091			
		Demarking point	Males>11.66>Females			
PP5 Stepwise	1	midshaft ml	0.8834	0.6898	0.8872	M=1.0338
	2	base ap	0.6148	0.5019	0.7732	F=-1.0338
		(Constant)	-13.3100			
		Sectioning point	0.0000			
Direct	1	midshaft ml	1.2839	1	1	M=0.9185
		(Constant)	-10.2171			F=-0.9185
		Sectioning point	0.0000			
		Demarking point	Males>7.96>Females			

ap=anteroposterior, ml=mediolateral

Table 9.6: Sexing accuracy using the proximal phalanges 1 to 5. Percentage of correct group membership and cross-validation

Function		N (Total)	Male Count	%	Female Count	%	Average Accuracy
Proximal phalanx 1							
Stepwise	Original	198	84/100	84.0	87/98	88.8	86.4
	Cross-validated	198	84/100	84.0	86/98	87.8	85.9
Direct midshaft ap	Original	198	85/100	85.0	87/98	88.8	86.9
	Cross-validated	198	85/100	85.0	87/98	88.8	86.9
Proximal phalanx 2							
Stepwise	Original	197	79/98	80.6	85/99	85.9	83.2
	Cross-validated	197	79/98	80.6	85/99	85.9	83.2
Direct midshaft ml	Original	197	73/98	74.5	88/99	88.9	81.7
	Cross-validated	197	73/98	74.5	88/99	88.9	81.7
Proximal phalanx 3							
Stepwise	Original	198	81/100	81.0	87/98	88.8	84.8
	Cross-validated	198	80/100	80.0	86/98	87.8	83.8
Direct base ap	Original	198	82/100	82.0	86/98	87.8	84.8
	Cross-validated	198	82/100	82.0	86/98	87.8	84.8
Proximal phalanx 4							
Stepwise	Original	198	81/100	81.0	86/98	87.8	84.3
	Cross-validated	198	80/100	80.0	86/98	87.8	83.8
Direct base ap	Original	198	77/100	77.0	85/98	86.7	84.8
	Cross-validated	198	77/100	77.0	85/98	86.7	83.3
Proximal phalanx 5							
Stepwise	Original	193	81/97	83.5	83/96	86.5	85.0
	Cross-validated	193	81/97	83.5	83/96	86.5	85.0
Direct midshaft ml	Original	194	78/97	80.4	84/97	86.6	83.5
	Cross-validated	194	77/97	79.4	84/97	86.6	83.0

Table 9.7: Discriminant function analysis of middle phalanges 2 to 5 for South Africans

Function	Step	Variables	Wilk's lambda	Exact F-ratio	d.f
Middle Phalanx 2					
Stepwise	1	base ap	0.5714	143.9917	1.192
	2	midshaft ml	0.5252	86.3415	2.191
	3	midshaft ap	0.5132	60.0775	2.190
Direct	1	base ap	0.5714	143.9917	1.192
Middle Phalanx 3					
Stepwise	1	midshaft ml	0.5805	141.6487	1.196
	2	midshaft ap	0.5169	91.1227	2.195
Direct	1	midshaft ml	0.5805	141.6487	1.196
Middle Phalanx 4					
Stepwise	1	midshaft ml	0.5976	129.3029	1.192
	2	base ap	0.5475	78.9273	2.191
Direct	1	midshaft ml	0.6325	112.1567	1.193
Middle Phalanx 5					
Stepwise	1	midshaft ml	0.5831	135.1478	1.189
	2	midshaft ap	0.5227	85.8365	2.188
Direct	1	midshaft ml	0.5831	135.1478	1.189

ap=anteroposterior, ml=mediolateral, df=degrees of freedom

Table 9.8: Canonical discriminant function coefficients of middle phalanges (MP) 2 to 5 for South Africans

Function	Step	Variable	Unstandardized coefficient	Standard coefficient	Structure coefficient	Group centroids
MP2						
Stepwise	1	base ap	0.8555	0.5134	0.8892	M=0.9589
	2	midshaft ml	0.5193	0.3896	0.8262	F=-0.9789
	3	midshaft ap	0.6306	0.2810	0.7887	
		(Constant)	-14.8327			
		Sectioning point	-0.0100			
Direct	1	base ap	1.6665	1	1	M=0.8527
		(Constant)	-15.2669			F=-0.8705
		Sectioning point	-0.0089			
		Demarking point	Males>9.16>Females			
MP3						
Stepwise	1	midshaft ml	0.7944	0.6022	0.8794	M=0.9522
	2	midshaft ap	1.1185	0.5509	0.8539	F=-0.9716
		(Constant)	-12.4827			
		Sectioning point	-0.4761			
Direct	1	midshaft ml	1.3192	1	1	M=0.8373
		(Constant)	-11.0683			F=-0.8544
		Sectioning point	-0.0086			
		Demarking point	Males>8.39>Females			
MP4						
Stepwise	1	midshaft ml	0.8256	0.6140	0.9027	M=0.8951
	2	base ap	0.8356	0.5181	0.8602	F=-0.9138
		(Constant)	-14.4151			
		Sectioning point	-0.0094			
Direct	1	midshaft ml	1.2843	1	1	M=0.7468
		(Constant)	-10.1807			F=-0.7702
		Sectioning point	-0.0117			
		Demarking point	Males>7.93>Females			
MP5						
Stepwise	1	midshaft ml	0.9311	0.6168	0.8849	M=0.9456
	2	midshaft ap	1.2454	0.5374	0.8451	F=-0.9556
		(Constant)	-11.5301			
		Sectioning point	-0.0050			
Direct	1	midshaft ml	1.5095	1	1	M=0.8368
		(Constant)	-10.3340			F=-0.8456
		Sectioning point	-0.0044			
		Demarking point	Males>6.85>Females			

ap=anteroposterior, ml=mediolateral, df=degrees of freedom

Table 9.9: Sexing accuracy of middle phalanges 2 to 5 of South Africans. Percentage of correct group membership and cross-validation

Function		N (Total)	Male Count	%	Female Count	%	Average Accuracy
Middle phalanx 2							
Stepwise	Original	194	76/98	77.6	82/96	85.4	81.4
	Cross-validated	194	76/98	77.6	81/96	84.4	80.9
Direct base ap	Original	194	71/98	72.4	80/96	83.3	77.8
	Cross-validated	194	71/98	72.4	80/96	83.3	77.8
Middle phalanx 3							
Stepwise	Original	198	85/100	85	85/98	86.7	85.9
	Cross-validated	198	85/100	85	85/98	86.7	85.9
Direct midshaft ml	Original	198	79/100	79	83/98	84.7	81.8
	Cross-validated	198	79/100	79	83/98	84.7	81.8
Middle phalanx 4							
Stepwise	Original	195	77/99	77.8	83/96	86.5	82.1
	Cross-validated	195	77/99	77.8	83/96	86.5	82.1
Direct midshaft ml	Original	195	71/99	71.7	82/96	85.4	78.5
	Cross-validated	195	70/99	70.7	82/96	85.4	77.9
Middle phalanx 5							
Stepwise	Original	191	80/96	83.3	82/95	86.3	84.8
	Cross-validated	191	79/96	82.3	82/95	86.3	84.3
Direct midshaft ml	Original	191	76/96	79.2	80/95	84.2	81.7
	Cross-validated	191	76/96	79.2	80/95	84.2	81.7

Table 9.10: Discriminant function analysis of distal phalanges 1 to 5 for South Africans

Function	Step	Variables	Wilk's lambda	Exact F-ratio	d.f
Distal phalanx 1					
Stepwise	1	base ap	0.59698	132.992	1.197
	2	length	0.53326	85.777	2.196
	3	midshaft ap	0.49236	67.017	3.195
Direct	1	base ap	0.5970	132.9919	1.197
Distal phalanx 2					
Stepwise	1	midshaft ap	0.69351	84.411	1.191
	2	length	0.59236	65.377	2.190
	3	base ml	0.56810	47.895	3.189
Direct	1	midshaft ap	0.6935	84.4112	1.191
Distal phalanx 3					
Stepwise	1	base ml	0.65801	98.230	1.189
	2	length	0.61597	58.604	2.188
	3	midshaft ap	0.59285	42.808	3.187
Direct	1	base ml	0.6551	100.0504	1.190
Distal phalanx 4					
Stepwise	1	base ml	0.71977	72.025	1.185
	2	length	0.66666	46.001	2.184
	3	midshaft ap	0.63901	34.460	3.183
Direct	1	base ml	0.7216	71.7534	1.186
Distal phalanx 5					
Stepwise	1	length	0.63854	101.328	1.179
	2	base ml	0.56018	69.877	2.178
	3	midshaft ap	0.52757	52.833	3.177
	4	head ml	0.51527	41.392	4.176
Direct	1	length	0.6385	101.3285	1.179

ap=anterposterior, ml=mediolateral, df=degrees of freedom

Table 9.11: Canonical discriminant function coefficients of distal phalanges (DP) 1 to 5 for South Africans

Function	Step	Variable	Unstandardized coefficient	Standard coefficient	Structure coefficient	Group centroids
DP1 Stepwise	1	length	0.2945	0.4485	0.7397	M=1.0052
	2	base ap	0.6361	0.4965	0.8092	F=-1.0154
	3	midshaft ap	0.6961	0.4094	0.6508	
		(Constant)	-15.1960			
		Sectioning point	-0.0051			
Direct	1	base ap	1.2811			M=0.8134
		(Constant)	-11.3104			F=-0.8216
		Sectioning point	-0.0207			
		Demarking point	Males>8.83>Females			
DP2 Stepwise	1	length	0.4210	0.5314	0.7431	M=0.86291
	2	base ml	0.3684	0.3565	0.7196	F=-0.8719
	3	midshaft ap	1.1747	0.4572	0.7624	
		(Constant)	-15.2461			
		Sectioning point	-0.0045			
Direct	1	midshaft ap	2.5693			M=0.6579
		(Constant)	-9.2838			F=-0.6648
		Sectioning point	-0.0035			
		Demarking point	Males>3.61>Females			
DP3 Stepwise	1	length	0.2943	0.3765	0.6887	M=0.8201
	2	base ml	0.6481	0.5843	0.8699	F=-0.8287
	3	midshaft ap	0.7872	0.3381	0.6874	
		(Constant)	-15.4935			
		Sectioning point	-0.0043			
Direct	1	base ml	1.1106			M=0.7219
		(Constant)	-12.2026			F=-0.7219
		Sectioning point	O			
		Demarking point	Males>10.99>Females			
DP4 Stepwise	1	DP4 length	0.3288	0.4263	0.7213	M=0.7357
	2	DP4 base ml	0.5743	0.5568	0.8302	F=-0.7597
	3	DP4 midshaft ap	0.7003	0.3606	0.6384	
		(Constant)	-14.8560			
		Sectioning point	-0.0120			
Direct	1	DP4 base ml	1.0328			M=0.6113
		(Constant)	-11.2036			F=-0.6244
		Sectioning point	-0.0066			
		Demarking point	Males>10.85>Females			
DP5 Stepwise	1	length	0.4142	0.5236	0.7757	M=0.9279
	2	base ml	0.6993	0.5631	0.7731	F=-1.0026
	3	head ml	-0.3525	-0.3005	0.4865	
	4	midshaft ap	1.2803	0.4415	0.6901	
		(Constant)	-15.2340			
		Sectioning point	-0.0374			
Direct	1	length	0.7911			M=0.7198
		(Constant)	-12.8945			F=-0.7777
		Sectioning point	-0.0289			
		Demarking point	Males>16.30>Females			

ap=anteroposterior, ml=mediolateral

Table 9.12: Sexing accuracy of distal phalanges 1 to 5 of South Africans. Percentage of correct group membership and cross-validation

Function		N (Total)	Male Count	%	Female Count	%	Average Accuracy
Distal phalanx 1							
Stepwise	Original	199	84/100	84	84/99	84.8	84.4
	Cross-validated	199	83/100	83	84/99	84.8	83.9
Direct base ap	Original	199	81/100	81	86/99	86.9	83.9
	Cross-validated	199	81/100	81	86/99	86.9	83.9
Distal phalanx 2							
Stepwise	Original	193	76/97	78.4	80/96	83.3	80.8
	Cross-validated	193	75/97	77.3	79/96	82.3	79.8
Direct midshaft ap	Original	193	71/96	73.2	75/96	78.1	75.6
	Cross-validated	193	71/96	73.2	75/96	78.1	75.6
Distal phalanx 3							
Stepwise	Original	191	77/96	80.2	80/95	84.2	82.2
	Cross-validated	191	76/96	79.2	78/95	82.1	80.6
Direct base ml	Original	192	74/96	77.1	74/96	77.1	77.1
	Cross-validated	192	74/96	77.1	74/96	77.1	77.1
Distal phalanx 4							
Stepwise	Original	188	77/95	81.1	74/93	79.6	80.3
	Cross-validated	188	77/95	81.1	73/93	78.5	79.8
Direct base ml	Original	188	73/95	76.8	74/93	79.6	78.2
	Cross-validated	188	73/95	76.8	74/93	79.6	78.2
Distal phalanx 5							
Stepwise	Original	181	80/94	85.1	73/87	83.9	84.5
	Cross-validated	181	77/94	81.9	72/87	82.8	82.3
Direct length	Original	181	75/94	79.8	70/87	80.5	80.1
	Cross-validated	181	75/94	79.8	68/87	78.2	79.0

CHAPTER 10

DISCUSSION

10.1 Introduction

Descriptions of hand bones in anatomical textbooks are of limited value to forensic anthropologists in that insufficient detail with regard to identification and siding on individual bones is given. Instead, these textbooks are designed to assist students studying anatomy to distinguish between different series of hand bones, namely, metacarpals and phalanges. Additional information given in these books, such as details of the base, shaft, and head, allow students to relate attachments of soft tissues or neurovascular structures to these bony landmarks. However, the information given in these textbooks is insufficient with regard to identification and siding of individual hand bones for forensic purposes. Recent studies on adults (Case & Heilman 2006) and juveniles (Scheuer & Black 2000) have provided morphological descriptions of hands for purposes of identification with some features for siding of these bones. The results from the work carried out by these authors were applied to the present study. The detailed description given in this study can be used both for identification and siding purposes and it is hoped that this would be of value to forensic anthropologists.

Stature is an important characteristic used in identifying human remains. Various methods are employed in order to derive an individual's height. While methods used to estimate stature are standard and can be applied to different populations, regression formulae developed by these methods for one population cannot be used on a different group. Regression formulae are thus population specific. Estimation of stature does not only include the more commonly used long limb bones, but hand bones have also been considered in these studies (Scheuer & Elkington 1993). A number of forensic anthropological studies have been carried out on South Africans in order to develop regression formulae specific for this population (e.g., Lundy 1983, 1984, 1985, 1988, Lundy & Feldesman 1987, Dayal 2002, Bidmos & Asala 2005, Bidmos 2006, Chibba & Bidmos 2006, Steyn & Smith 2007, Ryan & Bidmos 2007, Bidmos 2008). Hand bones of the South African population, however, have not

been included in these studies. The present study therefore attempted to fill this gap by regressing the length of each hand bone to that of a long bone. Reasons for adopting this indirect approach will be discussed under stature estimation.

Sexually dimorphic features on various bones of the skeleton are known to be of value in forensic cases (Dwight 1905, Pearson 1917-1919, Reynolds 1947, Washburn 1948, Bainbridge & Genoves 1956, Jit & Singh 1956, Thieme & Schull 1957, Steel 1963, Singh & Singh 1972a,b, Singh & Singh 1974, Singh 1975, Singh & Singh 1976, Black 1978, Flander 1978, Kelly 1978, DiBennardo & Taylor 1979, 1982, Jit *et al*. 1980, Weaver 1980, Kimura 1982a,b, İşcan & Derrick 1984, İşcan & Miller-Shaivitz 1984a,b,c, Dittrick & Suchey 1986, Kieser *et al*. 1992, Steyn & İşcan 1997). This also includes the hand bones (e.g., Scheuer and Elkington 1993, Barrio *et al*. 2006, Falsetti 1995). In the present study, the mediolateral and anteroposterior width of the hand bones displayed greater sexual dimorphism than the length dimension.

Of interest is the age at which a hand bone dimension exhibits sexual dimorphism. Developmental studies have shown that while ossification of the skeleton occurs at about the 6th week of intrauterine development, sexual differentiation is said to be evident at about the 8th week (Komar & Buikstra 2008). The high percentage of correct sex classification for adult hand bones reported in the present study is a further indication of the value of hand bones in establishing sex from an unknown skeleton.

10.2 Research sample

This study was comprised of three aspects, namely, the morphological description of the hand bones, estimation of stature and sex determination. In order to carry out a non-metrical analysis or description of the hand bones, a large enough sample was needed to establish standard criteria that would include key morphological features of each hand bone. An initial sample of 80 sets of hands removed from cadavers allocated to medical and dental students for their dissections were used. These hands were collected over a period of two years as only 48 cadavers are dissected each year by the medical and dental students in the

Department of Anatomy at the University of Pretoria. The mean age for the total sample was 59 years with an average age for males and females recorded as 64 and 55 years respectively. This initial sample was sufficient to identify morphological similarities and differences of bones belonging to one hand and to compare it with those of the opposite hand.

In a descriptive study of bones, one would expect age changes such as osteoporosis to obscure the morphology of a bone. Very few hand bones in this study presented with degenerative changes. Relatively small artefacts were sometimes located on the distal articular surfaces or head region of a bone, but these did not mask bone morphology.

In any osteometric study, the size of the sample is crucial and queries often arise in osteometric and forensic studies as to what constitutes an adequate sample size (St.Hoyme & İşcan 1986, Lundy 1986). In metric studies, if the sample is too small it may not be representative of the population under study (Barrier & L'Abbé 2008) and may not yield the desired results from a statistical analysis. Thus, once a list of key bony landmarks for identification and siding purposes of each hand bone was established in the present study using 80 sets of hand bones, the size of the sample had to be increased. This additional sample was obtained from the Pretoria skeletal collection, bringing the total sample to 200 sets of hand bones with equal numbers of males (50 whites and 50 blacks) and females (50 whites and 50 blacks). A sample size of 50 for each sex and population group was chosen as this best represented an adequate number for statistical analyses. It may be worthwhile mentioning that the Pretoria Bone Collection normally receives more skeletal material of black than white individuals which includes males and females (L'Abbé *et al*. 2005). However, the collection was big enough to randomly select equal numbers of both sexes from the two population groups for this study.

All osteometric studies using relatively large sample sizes may be influenced by secular trends. This is a tendency towards a change in body size or shape which occurs over a certain time period, as well as through successive generations when compared to past generations (Kieser *et al*. 1987, Garn 1987). This change occurs very slowly throughout time and can present either as a positive or negative secular change. A positive secular trend is an increase

in dimensions as opposed to a negative secular trend, where dimensions are reduced over a certain time period (Tobias 1975, 1985; Tobias & Netscher 1977, Cameron *et al.* 1989). Explanations given for an increase in size include improved nutritional status and optimum medical care for individuals. A healthier environment has a major impact on the size of an individual as it influences growth and development (Henneberg & George 1993, Jantz 2001). A positive secular trend for stature in the American population was noted from 1940 to 1989 which has been attributed to economic recovery (Bogin 1988). According to Cameron *et al.* (1989) environmental factors, which are said to play a key role in positive secular trends, were absent in the mid-20th century.

There are researchers who have documented weak positive trends in stature in the South African population (Henneberg & van den Berg 1990, Steyn & Smith 2007). Studies on the crania and femora, on the other hand, showed a reversal of a positive trend (Tobias & Netscher 1977) which was also documented in the South African population (Tobias 1985). Tobias (1985) presented data on growth and stature from the 20th century for generations that were subjected to deteriorating economic conditions and political unrest. Data on the black South African population of the late 19th century indicated a decline in stature (Tobias 1975). This decrease in stature was associated with a decline in the economic, social, and political environments for black South Africans prior to and during the apartheid era.

The period between 1880 and 1970 showed that South African whites had an increase in mean height of 4.5 mm per decade compared to 2.4 mm per decade for South African blacks (Henneberg & van den Berg 1990). White South Africans were said to be predominantly Dutch in origin which accounted for their increase in stature. However, their increase in stature was still below that of the Dutch population, namely, 15 mm per decade (Bogin 1988). The year 1945 was a period which depicted the end of World War II which was followed by improvements in the industrial sector amongst other changes. This period was considered to be a time when secular trends may have had a great impact on a number of different populations (Henneberg & van den Berg 1990). While Kalichman *et al.* (2008) provided evidence for a secular trend in the size of hand bones in males and females they found this to

be the case only with length dimensions that increased in younger individuals, while midshaft width dimensions remained the same in individuals of different ages.

Dimensions of the cranium and dentition in black South Africans were thought to have shown a positive secular trend (Kieser *et al*. 1987). The finding of a positive secular trend in the dentition is interesting as one would expect a reduction rather than an increase in the size of the teeth. However, these authors reported an increase in the mesiodistal rather than in the buccolingual diameters of the dental arcades of living black South Africans which they compared to that recorded in black crania taken from a skeletal collection.

The Pretoria Bone collection, which houses skeletal material dating from 1987, would also be subjected to the effects of secular trends, either positively or negatively. However, the hand bones that were studied came from the more recent skeletal additions to this collection, and represent the currently living people. It can thus be expected that the influence of secular trend on hand bone dimensions would not be significant.

10.2.1 Non-metric analysis

One of the biggest problems of the descriptive phase of this study was to establish standard identification and siding criteria that could be applied to any bone of the hand. Unfortunately, many of the skeletal elements of the hands that are housed in boxes in the Pretoria Bone Collection were not labelled in terms of hand bone series that they belonged to, namely, metacarpal, proximal, middle, or distal phalanges. In a few boxes the hand bones were not present. As a result of unlabelled and missing hand bones in these skeletal collection boxes, great difficulty was encountered in trying to establish similarities and differences in the bones of the hand. Thus, the only way to describe the bones of the hand as accurately as possible was to use undissected or partially dissected hands. The source for undissected or partially dissected hands was from cadavers assigned to medical and dental students. Removal of the hands from these cadavers had to done only after the students had completely dissected the entire upper limb region. While the sex-population groups were not important for the descriptive aspect of this study, equal numbers of males and females from white and black

South African population groups was necessary to include all possible variations in hand morphology. Both right and left hands were cleaned so that the features of one hand could be compared to that of the other hand.

Once it was decided to start the descriptive part of this study with cadaver material, another problem arose. Separating the hands from the rest of the cadaver's body was not easy. The concern of the technical staff was that the hand bones would not be re-united with the same individual in the Bone Collection at the end of this study. The solution to this problem was to liaise with the technical staff involved with the maceration process. This meant keeping a record of cadaver numbers so that when the maceration process was complete, and the skeleton of each cadaver was ready to be added to the Pretoria Bone Collection, the number assigned to the skeletal box was also kept on record. At the end of the study the hands were re-united with the rest of its skeleton, and all administrative papers had to be signed off by the researcher as well as the clinical anatomy and forensic anthropology technical staff.

Cleaning and careful separation of individual bones of the hand was time-consuming as every effort was made not to mix them. This was crucial as not only was the descriptive part of this study depended on this phase, but the list of key morphological features developed in this phase had to be used to identify and side the hand bones from the collection in order to increase the sample size. Furthermore, in the event of hand bones being recovered from amongst the human remains in a forensic case, these features would need to be accurate in order to correctly assign a hand bone to a digit and a hand.

10.2.2 Metric analysis

A descriptive analysis was run initially on the entire sample to ascertain whether there were statistically significant differences firstly, between whites and blacks, and secondly, between males and females. As the statistical results for the hand bones indicated few statistically significant differences between whites and blacks, the data for these groups were pooled. Additionally, the ancestry will not be known if a sample hand bone is found, therefore it will make little sense to separate the bones of the two ancestral groups. Descriptive statistics

carried out between males and females showed significant differences indicating that hand bone dimensions displayed sexual dimorphism. It was on the basis of these results that all other metric analyses were carried out for males and females.

With the repeatability measurements, the dimension that presented with problems for the second observer was measuring the midshaft area of the smaller hand bones. As some of the hand bones differ in morphology at their proximal and distal ends, trying to visually establish the midshaft region can be difficult. This problem was overcome by measuring the maximum length of the hand bone, and finding the halfway mark which indicated the midpoint between the head and base of the hand bone.

10.3 Morphology of the hand bones

Forensic anthropologists apply osteological techniques to assist them during analyses of decomposed or skeletonized remains known to be human in origin. Their techniques are aimed at providing information that would be useful in identifying these unknown remains, which could also lead to the possible cause of death of an individual. Forensic anthropologists are thus reliant on the knowledge and methods used in the subdisciplines of biological anthropology and archaeology (Brickley & Fellini 2007, Rich *et al*. 2005, Komar & Buikstra 2008, Byers 2005). The bones of the hand are seldomly, if ever, used together with the rest of the skeleton in contributing to the forensic process. Descriptions of hand bones, accompanied by photographs and line diagrams in a number of textbooks are generally aimed at students who need a basic knowledge of hand bones and not designed for forensic purposes (Gray 1959, Bass 1995, Romanes 1991, White 2000). Furthermore, these textbooks do not list sufficient identification and siding criteria which forensic anthropologists could use. This observation is supported by comments made by Case and Heilman (2006), who stated that a superficial description of hand bones as given in anatomical textbooks can only be applied in cases of clinical pathology while anthroplogical, forensic and palaeopathological studies require greater morphological detail. This further emphasizes the need for detailed hand bone descriptions.

In forensic anthropology, the first step when the skeleton or parts thereof is recovered from human remains is the identification of the bones. With regard to the hand bones, osteology textbooks typically classify the metacarpals according to the digit that they belong to which is helpful to some extent in identifying these bones. Phalanges, on the other hand, are classified according to a series, namely, proximal, middle, and distal phalanges. While it may be useful to know where the base, shaft and head of a hand bone is located, this information in textbooks is insufficient should a fragment of the bone be recovered that has to be linked to the correct digit and hand.

According to some authors (Steele & Bramlett 1988, Bass 1995, White 2000), being able to single out a hand bone or a part of it becomes a challenge especially if bones of the feet, in particular, the metatarsals and phalanges, are present. One would assume from this that the morphology of hand and foot bones is similar which would make it difficult to identify them from each other which further emphasizes the need to develop specific standard methods of identification and siding of hand bones. In the present study, this was accomplished.

Researchers have attempted to develop such standard methods. For example, Scheuer and Black (2000) proposed relative length ratios as a guide for correct ray placement of the phalangeal bones. These authors concluded that to carry out an accurate ray placement requires detailed knowledge of hand bone morphology while Smith (1996) suggests that to develop the skill for correct ray placement practice is needed. Thus, the study carried out by Scheuer and Black (2000), which concentrated on ray placement, was not only to identify a bone, but also to side it.

Accuracy in the identification of human hand bones in a forensic investigation is important, as all the findings are of medicolegal significance. In fact, Scheuer and Black (2000) have stated that correct identification of individual hand bones is as critical to a forensic case as are long bones. Once a bone can be successfully identified, the next step would be to side it. This cannot be achieved without prior knowledge of the location or position of the bone (Case & Heilman 2006). Individual metacarpals are far easier to recognise when found isolated

in comparison to the phalanges, because each metacarpal has marked differences that can be easily observed. Phalanges, on the other hand, show similar morphological features that require the presence of all the phalanges as a group (Douglas *et al*. 1997, Kilgore *et al*. 1997), or as a series (Oxenham *et al*. 2005). This was initially also the case with the present study as all the phalanges had to be examined as a group after which they were then separated into their respective series of proximal, middle, and distal phalanges. The distal phalanges, in the present study, were found to be the most difficult of all the phalanges to identify and side.

Additional indicators such as the quality and condition of a bone are also of help in forensic cases (Komar & Buikstra 2008). Distinctive features of bones, which assist in their identification, are said to be related to forces placed on these bones. Age-related studies incorporating the effect of mechanical loading during different developmental periods on the upper limbs, including the hands, of humans and cross-sectional areas of femora from archaeological samples have been investigated (Ruff *et al*. 1994). The femur has been shown to adapt over time to loads of weight bearing by increasing its cortical bone growth and the changes were more marked in the diaphyseal rather than at the articular ends (Ruff *et al*. 1994). While the hands are not subjected to the effects of weight bearing, their functional role in manipulating the environment may bring about subtle morphological changes leaving an imprint or landmark on the bone. One example of such an imprint is the presence of prominent ridges on the palmar aspect of the medial and lateral side of the middle phalanges which serve for the attachment of the flexor digitorum superficialis muscle. The relevance of this information to the present study was that these imprints were used as bony landmarks in the identification and siding process.

The shape of a bone is thought to relay patterns of adaptation, health, activity and life history between past and present human populations (Lazenby 1998). One of the bones of the hand, namely, the second metacarpal, is thought to provide these various patterns of evolutionary changes. Evidence for this is seen in radiogrammetric studies, which have shown that the second metacarpal can be used as a measure of normal and abnormal bone growth, aging and functional asymmetry (Lazenby 1998). With regard to the present study, the shape

of the lateral and medial margins of the shaft depicted certain aspects of the morphology which was used to also identify and side a hand bone.

When siding a hand bone the accuracy of the method used is of importance. Ricklan (1988), in his study on the morphology of the hand bones of early and recent South African hominids, identified asymmetrical features on either side of the midline of the phalangeal bones and scored them. He reported siding accuracies of 83.0% (first proximal phalanx), 82.0% (second proximal phalanx), 80.0% (third proximal phalanx) and 98.0% (fifth proximal phalanx). For the middle phalangeal row, he reported siding accuracies of 93.0% (second middle phalanx) and 85.0% (third middle phalanx). For the distal row he recorded 91.0% (second distal phalanx), 77.0% (third distal phalanx), 57.0% (fourth distal phalanx) and 89.0% (fifth distal phalanx) siding accuracy. Case and Heilman (2006) reported siding accuracies ranging from 88.0-100% for proximal phalanges, 96.0-98.0% for middle phalanges and 52.0-94.0% for the distal phalanges. The second, third and fourth distal phalanges from their studies, however, gave poor results and had to be re-evaluated. While the accuracy of siding was not tested in the present study, emphasis was placed on the method used to describe the hand bones. The only way to carry out this objective was to place all 80 sets of right and left hands out on tables and the descriptions had to done from one view at a time. A feature noted on one bone was then followed through to all other bones, and in each case, similarities and differences were noted. Furthermore, if similar features were observed on bones from both the right and left hands, the surface or margin associated with that specific feature was used also in the siding technique. Thus, although accuracy was not tested formally in the present study, the criteria developed during the initial phase using cadaver material were used to identify and side the hands from the Pretoria Bone Collection. It was felt by the researcher that this could be done accurately. Thus a detailed description accompanied by fully labelled diagrams for each hand bone was accomplished.

In forensic analysis, the methods employed need to reliable, and if the hand bones are to be incorporated into such cases, then the methods used for hand bone identification should also be as accurate as possible. Thus, while the reported accuracies given by Case and

Heilman (2006) are relatively high, these authors admit that there was no guarantee that all the phalanges came from the same individual. The reason for this was that some of their samples on which their studies were based, came from an anatomical supplier. The method used in the present study is reliable as the sets of right and left hands that were observed came from the same individual. In this way, control was exercised when similarities and differences were noted on these hand bones. Differences described in this study, as well as the methods that were used, now need to be tested on an independent sample in order to determine their accuracy.

The illustrations and key landmarks provided by Ricklan (1988) and Case and Heilman (2006) for the phalanges, were quite useful for the present study. Generally, these authors provided two features (see Tables 2.1 and 2.2) for siding each of the phalangeal rows as seen by different views. The problem with the two features given is that they were not constant for each proximal phalanx. For example, the features for the first three proximal phalanges were described from a palmar view, the fourth phalanx was described from a proximal view and the fifth one from a dorsal view. In the present study, all descriptions were carried out from the same direction, namely, dorsal, palmar, lateral, medial, proximal, and distal views of the shaft, head and base for each hand bone. This was to standardize all descriptions based on the direction in which a bone was held. The descriptions given for the head, shaft and base in the present study, were done so as to be able to identify a hand bone if only a fragment of it was recovered amongst human remains. Thus, a more comprehensive description was attempted with all hand bones in the present study.

Case and Heilman (2006) also referred to a bilateral mass at the base of a proximal phalanx. On closer observations of the hand bones in the present study, the mass was associated with the medial and lateral tubercles and named as such. For the middle phalanges, Case and Heilman (2006) again listed two features (see Tables 2.1 and 2.2 and Figures 2.5 and 2.6) to side each of these bones. These features, amongst others, were also observed in the present study. All illustrations given by these authors for the distal phalanges also showed two distinct features (see Tables 2.1 and 2.2 and Figures 2.5 and 2.6) for the first

to the fourth distal phalangeal bones and a single feature for the fifth distal phalanx. The problem encountered with all the illustrations given by Case and Heilman (2006), is that the figures were not labelled with regard to their orientation. In other words, it is not certain as to what was medial and lateral for right and left hand bones. The diagrams were carefully looked at in conjuction with the individual bones of the hand used in the present study. The orientation with regards to direction is especially crucial when referring to a smaller sized facet at the proximal end, which is used to side the bone. These authors, however, were able to show at least two features on all phalanges which can be used to side these bones. The present study attempted to improve on this list by not only providing a comprehensive description which can be used to identify a bone, but more than two key bony landmarks were also given.

In descriptions of hand bones, nutrient foramina are sometimes also mentioned. The earliest study on the location of nutrient foramina was by Bass (1995) who noted these foramina at the proximal rather than at the distal ends of the shaft of hand bones. On the other hand, studies by Patake and Mysorekar (1977) on nutrient vessels associated with the skeletal system have shown that nutrient foramina are normally present in the midshaft region of metacarpals and concentrated on the medial aspect of the first and second metacarpal and on the lateral side of the remaining metacarpal bones The number of foramina per hand bone also appears to be restricted in that the first metacarpal is reported to have a single foramen (Patake & Mysorekar 1977) while the second metacarpal has two foramina (Singh 1959). The number and location of these nutrient foramina are known to present with numerous variations which explains why they are not used in defining an isolated segment of a bone (Steele 1970). In the present study, the number and location of these nutrient foramina were not constant and although mentioned when present, they were not listed amongst the criteria for identification and siding of hand bones. When nutrient foramina are absent, it has been suggested that the periosteal vessels become the main supply of blood rather than the nutrient artery (Lütken 1950, Mysorekar *et al*. 1967). In a study relating the number of foramina to the length of a long bone, Patake & Mysorekar (1977) found no association between these two variables.

In summary, while descriptions in anatomical textbooks on morphology of the hand bones are far less than those of the rest of the skeleton, some recent research on this subject was published. The present study was also able to show that these bones have more than just a base, shaft and head region. This detail would be of benefit to students and researchers who need more than just a superficial overview of the hand bones. The list of key morphological traits listed at the end of each bone's description, is to provide a quick reference to identify and side a particular hand bone. The different views from which the bones were described as well as the layout of these descriptions under the subsections of head, base and shaft, may assist the forensic anthropologist who recovers either an intact of fragmented hand bone. The photographs provided with each description were done in a way where the main landmarks were emphasized. The layout of the descriptions and photographs could possibly also serve as a field manual. Future research would entail establishing the praticality of using such information in a forensic anthropological setting. In comparison to descriptions of these bones in anatomy textbooks, this research has attempted to provide slightly more detail in a practical manner.

10.4 Stature determination

One of the purposes of the present study was to assess the value of hand bones in the estimation of stature when other long bones are unavailable. This brings into question as to what constitutes an adequate sample size. Generally, a greater sample size tends to yield better results and the regression formulae devised from such a sample best represents the population under study. Sample sizes in hand bone studies vary amongst researchers. For example, Meadows and Jantz (1992) measured metacarpal lengths of right and left hands taken from the same 212 individuals. In contrast, Musgrave and Harneja (1978) recorded metacarpal lengths from 20 left hands and 26 right hands which came from two different female samples. Grieshaber (2001) found statistical calculations problematic with regard to use of the metacarpals in stature estimations and concluded that an original equation for stature estimation from metacarpals could not be devised based on their small sample size

and that these bones were not well preserved. In the present study, the total sample of hands from 200 individuals which included males and females of two South African population groups (whites and blacks), compared well with the sample size recorded by Meadows and Jantz (1992), but is far greater than those of Musgrave and Harneja (1978).

The earliest arguments against the use of the same formulae across populations were recorded by a number of researchers (Pearson 1899, Allbrook 1961). Later studies by Trotter and Gleser (1952, 1958) and Trotter (1970) also stated that regression equations are population and sex-specific and should be limited to the population and sex groups from which the equations were derived. Numerous current studies followed this pattern of thought (Lundy 1983, Lundy & Feldesman 1987, Dayal 2002, Bidmos 2008). Thus, new stature regression equations had to be derived from the bones of the hand specifically for the South African population.

While sample size is crucial, methods used in estimating stature are just as important. Various methods of estimating stature can be used depending on the case under study (Konigsberg *et al*. 1998). One way of reconstructing stature is to use all the skeletal elements from the calcaneus to the skull, according to the anatomical method that was devised by Fully (1956). Although this method is commonly used in anthropological and forensic studies, it does not emphasize explicit methods for carrying out the procedure (Raxter *et al*. 2006). For example, Raxter *et al*. (2006) tested Fully's method for accuracy and applicability and reported that the correction factors used by Fully to convert summed skeletal height to living stature were too small. In using Fully's method, these authors found that stature was underestimated by 2.4 cm. They thus provided new correction factors to account for soft tissue. Nevertheless, this method is tedious and also requires a near complete skeleton. On the other hand, one advantage of the anatomical method is that it measures body proportions accurately (Lundy 1988).

The mathematical method is another way of estimating stature (Lundy 1988). Formulae devised by Lundy and Feldesman (1978) and Dayal (2002) specifically for the South African population, are currently being used by forensic anthropologists doing research in this country.

In forensic anthropology, direct measurements from a complete skeleton of human remains are not always possible. Stature is therefore predicted from the lengths of the long bones, preferably those of the lower limb region (Aiello 1992). In cases where fragments, rather than intact long limb bones are recovered, there are various ways in which stature can be estimated as accurately as possible. The total length of a long bone can also be estimated from its fragments. The estimated length of the long bone can then be inserted into an appropriate regression formula to estimate living height. Wilbur (1998) used metacarpals to estimate femur length, which in turn was used to estimate stature. This indirect method of determining stature was also adopted in the present study, using all hand bones and five long limb bones. The maximum long bone length dimensions of Lundy and Feldesman (1978) and Dayal (2002) were employed for the long limb and hand bones of the present study.

Another indirect approach is where the measured values of long bone fragments are substituted into the regression formula (Simmons *et al*. 1990). Steele and McKern (1969) demarcated segments of the humerus, radius, and tibia as percentages that can then be used to estimate the length of each of these long bones. The calculated length values are then inserted into an appropriate regression formula to get to the final estimated stature.

Parts of the ulna and tibia have been used to determine the entire length of these bones (Mysorekar *et al*. 1984). The distal end of a femur and proximal end of a radius have also been used to determine stature (Mysorekar *et al*. 1984). Mysorekar *et al*. (1984) identified anatomical landmarks at the proximal end of a long bone which they then subtracted from the total length in order to give the length of the distal fragment.

In the present study, while seven dimensions were recorded, only the maximum length, and not the width dimensions at the proximal, distal and midshaft regions, of each hand bone was used to estimate the length of a long limb bone.

Studies estimating adult stature directly from metacarpal bone length (Musgrave & Harneja 1978, Meadows & Jantz 1992, Wilbur 1998), often employ the use of radiographs taken of hands from adult patients (Gupta *et al*. 2000, Himes *et al*. 1977, Musgrave & Harneja 1978) in comparison to the present study where measurements were recorded directly from

the bones of the hand. The problem with radiographic images is that a correction factor needs to be included. Thus a direct approach where measurements can be recorded from the bone itself is advantageous compared to an indirect measurement.

In some anthropological studies, regression formulae are devised for combined groups within the same population. For example, Byers *et al*. (1989) combined data for Afro-American and Euro-American males to derive a common regression equation for males. These authors did the same for their female samples. However, Byers *et al*. (1989) did not provide any descriptive statistics or motivation as to why they combined their ancestral groups.

A study by Bidmos (2008) on an indigenous South African sample, which actually constitutes different “tribes”, was also computed as a single group in the regression analysis. Bidmos’ motivation for combining these “tribes” were as a result of research carried out by De Villiers (1968) and Lundy (1983), who proved that no statistically significant intertribal differences exist in the osteometric dimensions of South African groups.

In the present study, descriptive statistics were provided firstly, for white and black groups (sexes combined) and secondly, for males and females (white and black groups combined). Very few statistically significant differences in hand bone dimensions were noted between the white and black groups in contrast to that obtained for males and females, where most of these differences were statistically significant. Based on these findings, data for the South African population used in the present study, were combined into two groups, namely, males and females rather than into four groups of white males, white females, black males and black females. In other words, all regression analyses were carried out for South African males and females.

When carrying out studies on stature, correlation analyses are also done. This was done in the present study as it was important to assess whether all hand bones are equally correlated to all long limb bones or only to specific long limb bones. Furthermore, correlations between the length of a single long limb bone or combination of bones with stature forms a crucial part in any study concerned with estimating height of an individual. While correlation

values are known to differ depending on the skeletal element used to estimate stature, the best correlation values are those that are close to a value of one.

Lengths of metatarsals have been shown to be significantly correlated with stature in Euro- and Afro-Americans with values ranging from 0.6 to 0.8 (Byers *et al*. 1989). In their study of South African black females, Lundy and Feldesman (1987) reported correlation values of 0.896 (femur), 0.873 and 0.896 (tibia), 0.864 and 0.879 (fibula), 0.816 and 0.803 (ulna), 0.839 and 0.814 (radius), 0.805 and 0.792 (humerus). In summary, their lowest and highest correlation values were 0.538 and 0.956 respectively.

Dayal (2002) carried out her study on South African white males and females and produced correlation coefficients of 0.92 and 0.93 (femur), 0.87 and 0.90 (fibula), 0.83 (ulna), 0.85 and 0.84 (radius), 0.83 and 0.84 (humerus), In summary, the lowest and highest correlation values for Dayal's study were 0.56 and 0.96 respectively.

Correlation values for metacarpals reported by various authors ranged from 0.565 to 0.828 (Meadows & Jantz 1992), and 053 to 067 (Musgrave & Harneja 1978). Correlation values of individual hand bones for males and females in the present study were 0.785 and 0.902 (metacarpals), 0.715 and 0.717 (proximal phalanges), 0.654 and 0.567 (middle phalanges) and 0.567 and 0.507 (distal phalanges) respectively. The lowest and highest correlation values can be summed as 0.567 and 0.785 (males) and 0.507 and 0.902 (females). The metacarpals showed the highest values (0.902) in comparison to the distal phalanges where the correlation values were the lowest (0.507). These results are similar to those reported by Meadows & Jantz (1992) and Musgrave & Harneja (1978).

Correlation values of the long limb bones in the present study for males and females were similar to those given by Lundy and Feldesman (1987) and Dayal (2002) and summarized as 0.678 and 0.713 (humerus), 0.785 and 0.902 (radius), 0.772 and 0.790 (ulna), 0.684 and 0.724 (femur), and 0.745 and 0.771 (tibia). The values for females were slightly higher than those for males which may be an indication that females present with less osteological variation than their male counterparts. The radius was also found to be the best correlated bone in females when compared to the other long limb bones. This is possibly due

to a direct relation of the radius to the wrist and hand bones. The correlation results for males, on the other hand, proved to be inconsistent when compared to those of females in that no single long limb bone was highly correlated to any of the hand bones. In a practical situation, therefore, this means that if any hand bone of a female is recovered, then it could be said with a certain degree of confidence that the radius would be the best bone to select when estimating stature indirectly.

In studies on estimation of stature, long limb bones are regressed directly to stature. In comparison, to estimate the height of an individual in the present study, the value obtained for a long limb bone that was calculated from regression of one of seven hand bone dimensions, namely length, would have to be inserted into a second regression formula devised by Lundy and Feldesman (1987) and Dayal (2002). This indirect approach of estimating stature was adopted because the cadaver lengths or antemortem stature found in the skeletal records of the Petoria Bone Collection were either unreliable or not recorded. One disadvantage of the indirect method is that the total skeletal height (TSH) of an individual would have to be calculated by the length of either a single long limb bone or a combination of bones which in turn would have to be calculated from a hand bone. Thereafter, a correction factor for soft tissues would have to be added. Not only is this a longer process, but the standard errors would also be expected to be higher when compared to a direct approach. An indirect approach such as the one adopted in the present study is not new. Wilbur (1998) used metacarpals to estimate femur length which in turn was then used to estimate stature.

It is important in stature estimation that standard errors should be minimal as reliability of a regression equation is based on the standard error of estimates. A low standard error of estimate indicates a high accuracy as opposed to a low accuracy obtained with high standard error of estimate (Ryan & Bidmos 2007, Bidmos 2006). The reason why intact long limb bones are commonly used when estimating stature is because they yield high accuracies and low standard error of estimates (Simmons *et al*. 1990, Holland 1992). Authors have reported standard errors for upper limb bones ranging from 3.3 – 5.0 (Trotter & Gleser 1952, Steele

1970), lower limbs from 3.3 – 6.2 (Trotter & Gleser 1952, Steele 1970), and metatarsals 4.2 – 7.0 (Byers *et al*. 1989).

In their study on estimating stature from metacarpals of a male and female Euro-American sample, Musgrave and Harneja (1978) reported average standard errors ranging from 5.5 to 7.2 cm (metacarpal 1), 4.7 to 5.8 cm (metacarpal 2), 4.7 to 6.6 cm (metacarpal 3), 5.0 to 7.6 cm (metacarpal 4), and 4.7 to 8.3 cm (metacarpal 5). These standard errors are far greater than the rest of the skeleton including those reported by Byers *et al*. (1989) for metatarsals of the foot.

Standard errors recorded for metacarpals and phalanges in the present study were far greater than those reported by the above-mentioned authors. Even when all the metacarpals in the present study were combined, the standard errors were still high. Standard errors obtained where hand bone dimensions were linked to each of the five long limb bones differed for individual bones. Grouped metacarpals showed the lowest standard errors for the radius (5.2 cm), and ulna (5.6 cm) and the highest for the tibia (7.1 cm), humerus (9.2 cm) and femur (10.6 cm). For proximal phalanges, the lowest standard errors were 7.1 cm (radius), 7.3 cm (ulna), and 7.7 cm (tibia) compared to 10.2 cm (humerus) and 12.8 (femur). For the middle phalanges, the lowest standard errors were 7.5 cm (radius) and 7.9 cm (ulna) compared to 9.3 cm (tibia), 10.4 cm (humerus), and 12.4 cm (femur). The lowest standard errors for the distal phalanges were 7.6 cm (radius) compared to 8.1 cm (ulna), 9.9 cm (tibia), 10.0 cm (humerus), and 12.3 cm (femur).

In summary, the lowest standard error of estimates in the present study was above 5.0 cm. This indicates that intact long limb bones still remain the best skeletal components for adult stature estimation as regression equations derived from them have relatively lower standard errors of estimate compared to those obtained from hand bones. Alternatively, if hand bones are the only available skeletal elements, then this study has proposed methods that could be employed to use these hand bones to indirectly estimate stature. This study further emphasizes that the ideal situation would be to use all the hand bones as a group as this would yield better results than only a single hand bone.

There are studies indicating that using a combination of variables results in lower standard errors and therefore higher prediction accuracies (Trotter & Gleser 1952, Lundy 1983, Lundy & Feldesman 1987, Holland 1992, Dayal 2002, Bidmos & Asala 2005). Byers *et al*. (1998) reported that metatarsals 2 and 4 contributed greatly to the accuracy of calculated stature when included with metatarsal 1. The results of the present study indicate that different combinations of hand bones yielded greater prediction accuracies than using only a single hand bone. Ideally, if all hand bones were used, the prediction accuracy would increase. In the present study it was found that in males, for example, a combination of metacarpals 1, 2, 3, and 4, proximal phalanges 2, 3, and 4, middle phalanges 2 and 4 and distal phalanges 1 and 5 were the hand bone combinations selected which increased the accuracy for predicting long limb bones. In females, a combination of all five metacarpals, all proximal phalanges with the exception of the third bone, all middle phalanges with the exception of the second bone and only distal phalanx 1 were selected. While these results indicate great variability between the sexes, the bones of the second (index finger) and fourth (ring finger) digit, with the exception of the distal phalanges, appear to be the best selected hand bones to regress to a long limb bone.

While certain hand bones were selected in the present study as the best predictors for long bone lengths, the standard error of estimates were high, especially for individual rather than for grouped hand bones. Furthermore, the standard error of estimates in males in the present study were slightly higher than for females for the metacarpals and proximal phalanges as a group, while for the middle and distal phalanges, those of females were higher than those of males. If the standard error is higher in one sex, the total skeletal height together with the soft tissue correction factor may lead to a wider range of estimated living statures with the identification process being less accurate.

While the literature has shown that population and individual variation does and will always exist, probable errors will tend to prevail irrespective of how accurate or precise regression equations are devised in order to estimate stature (Sjøvold 2000). All evidence recovered at a site where human remains are uncovered should be investigated, and this

includes the bones of the hand. It has been suggested that the relationship between metacarpals to stature, is far stronger than long bone fragments to stature, which support the use of this series of bones in estimating height of an individual (Musgrave & Harneja 1978). The present study has shown that this is not true. Further support for consideration of hand bones in stature estimation studies would be endorsed by the following quotation given by Sjøvold (2000) “It is self-evident that an undamaged bone facilitates further investigation” (p. 276).

10.5 SEX DETERMINATION

In forensic anthropology, estimation of sex is crucial in that other estimates, such as stature and age, are dependent on it (Scheuer 2002). Determining sex depends greatly on the degree of sexual dimorphism in that specific bone (Novotny *et al*. 1993, Kemkes-Grottenthaler 2001). Sexual dimorphism is defined as observed physical traits, such as size and shape or architecture, within a group that distinguishes males from females (Eckert 1980, Loth & Henneberg 1996, Steyn & İşcan 1999, Loth & İşcan 2000, Asala 2001, Mall *et al*. 2001, Bidmos & Asala 2003, Bidmos & Dayal 2003, Byers 2005). It is generally known that males tend to be relatively larger in overall body dimensions as well as more robust than females. This is attributed to a number of factors that affect the shape and strength of a bone over a certain time period (Ruff 1987, Asala 2001, Byers 2005). In fact, females are said to be 92.0% the size of males, which is a size difference of approximately 8.0% (Byers 2005). Thus, the ability to ascertain the size and shape or architectural differences from skeletal elements greatly contributes to sexing of individuals (Byers 2005).

As shape or architectural differences between males and females are especially evident in the pelvis (Byers 2005, Komar & Buikstra 2008), this bone has been frequently used in sexing individuals (Byers 2005, Komar & Buikstra 2008). In the present study, the measurements recorded on hand bones rather than the shape of these bones, were crucial steps for determining whether the hands, and in particular, the dimensions of each hand bone, could be used by forensic anthropologists to accurately determine sex.

Dimensions of other bones of the skeleton are commonly used in sex determination studies for various population groups. For example, sex differences in the femur and tibia have been documented for American blacks and whites (Black 1978, DiBennardo & Taylor 1982, İşcan & Miller-Shaivitz 1984, Holland 1992), Japanese (Hanihara 1958, İşcan *et al.* 1994), Asian Indians (Singh & Singh 1972, Singh *et al*. 1975), British (Steel 1972), Czechs (Cerny & Komenda 1980), French (Godycki 1957), and Italians (Pettener *et al*. 1980).

Studies on sexual dimorphism in South Africa have steadily increased due to the overwhelming rate of crime in this country. As sexual dimorphism is population specific irrespective of whether metric or non-metric (morphological) methods are used (Novotny *et al.* 1993, İşcan & Shihai 1995), the South African population needed to have its own formulae. The femur and tibia as well as other parts of the human skeleton have thus been used to establish discriminant function formulae. These include the cranium (Ricklan 1987, Steyn & İşcan 1998), mandible (Steyn & İşcan 1998), patella (Dayal 2005), talus (Bidmos & Dayal 2003), humerus (Steyn & İşcan 1999), radius and ulna (Barrier & L'Abbé 2008), calcaneus (Bidmos 2004) and pelvis (Patriquin *et al*. 2005).

As metric variations of different parts of the skeleton are known to occur with time (Borgognini *et al*. 1986, Henneberg 1988), the techniques for establishing sexual dimorphism in a specific population must be derived from a contemporary skeletal collection otherwise this can lead to inaccurate classification of an unknown individual (İşcan 1988). One such study where sexual dimorphism was studied from skeletal material that was not obtained from a contemporary collection was that carried out by Lazenby in 1994. In his observations on second metacarpals, which came from a 19th century skeletal collection, Lazenby (1994) correctly identified the known males, while the females in his sample were misidentified. Conclusions drawn from this is that the source of the skeletal material is crucial as it is known that the bones show a certain degree of sexual dimorphism not only within populations, but also within the same individual (Scheuer & Black 2000). Furthermore, secular changes in populations are known to occur from one generation to the next which can influence results (Bogin 1988, Riggs *et al*. 2004, Marshall *et al*. 2006). The cadaver and skeletal sample used in

the present study came from a contemporary collection and would be expected to truly be representative of the current South African population.

Not only is the source of the sample important but the size of the sample must also be adequate. As explained under the discussion of stature, the white and black population groups were pooled on the basis of the descriptive studies which indicated few statistically significant differences in hand bone dimensions between whites and blacks. The pooled data were thus subjected to discriminant function analysis in this study. The sample size of equal numbers of males (100) and females (100) was appropriate for the statistical analysis. When considering using skeletal elements to discriminate sex, a percentage baseline for assigning individuals to the correct sex must be established. According to Scheuer and Elkington (1993), any method devised to sex individuals using hand bones, can only be useful if it yields an accuracy of 80.0%.

The accuracy in classifying sex from human remains is crucial as it reduces the total number of unknown forensic cases considerably (Loth & İşcan 2000). The degree to which sexing can be accurately carried out also depends on which bone or combination of bones have been selected. Percentage accuracies recorded when an entire skeletion is available is said to be 90.0 - 100%, with pelvis only 90.0 - 95%, skull 80.0 - 90.0% and with long limb bones it reduces to 80.0% (Krogman 1962, Steele 1970, Krogman & İşcan 1986). This information relays the importance of selecting a bone for estimating sex of an individual. However, practical situations and differential preservations may necessitate the use of bones that do not have such high accuracies. The evidence recovered at a crime scene may not necessarily be the bones that are known to be highly sexually dimorphic. While it is known that percentage accuracies drop to 80.0% for lower limbs, one would assume that the upper limbs would have similar percentage accuracies as sex determinants. Barrier and L'Abbé (2008) studied sexual dimorphism in forearm bones of a South African population. Her results for the radius yielded accuracies ranging from 80.0 - 86.0% for males and 82.0 - 88.0% for females, and for the ulna, the accuracies ranged from 76.0 - 87.0% for males and 83.0 - 89.0% for

females. These results indicate that upper limb bones are just as sexually dimorphic as lower limb bones.

Not only is there motivation for the use of forearm bones in contributing to the discriminant process, the use of hand bones is also gaining recognition. For example, metacarpals have been used to establish sex differences (Kimura 1990, Scheuer & Elkington 1993). Scheuer and Elkington (1993) reported that the second metacarpal provided the highest probable correct sexing accuracy (79.0%) and the third metacarpal the lowest (75.0%). In the present study, the first metacarpal for males (85.0%) and females (85.9%) presented with the highest accuracies in the stepwise analysis. These accuracies are slightly higher than those reported by Scheuer and Elkington (1993). It is interesting that the metacarpal of the thumb, rather than the index finger as reported by Scheuer and Elkington, was selected was selected as the most accurate in the present study. The percentages reported for the present study as well as that given by Scheuer and Elkington (1993) are similar to those reported by Barrier and L'Abbé (2008) for the forearm bones which further supports the use of the upper limbs including the hand bones to discriminate sex.

Just as it would be ideal to have a complete skeleton to estimate sex, an intact rather than a fragmented long limb or hand bone is also preferred. However, fragments of bone may be the only remnants recovered during an investigation process. Of interest to the forensic anthropologists in such cases is whether different parts of a hand bone can be used to estimate sex. Most studies have used the proximal and distal ends, such as the head of the humerus and femur, with resultant accuracies equal to or greater than 86.0% (İşcan & Shihai 1995, King *et al*. 1998). Breadth and height of the patella, talus, and calcaneus, although reported to be less accurate than those of the femur and tibia, with percentages ranging from 69.0 - 92.0%, are said to be of value when incomplete or fragmented bones are recovered (Riepert *et al*. 1996, Introna *et al*. 1998, Bidmos & Asala 2003, Asala *et al*. 2004). There are researches who have indicated that only the distal breadth of the radius and ulna is a good indicator for sex discrimination and it is shown to yield classification accuracies ranging from 72.0 - 92.0% (Allen *et al*. 1987; Holman & Benett 1991, Mall *et al*. 2001, Sakaue 2004).

As far as single measurements are concerned, maximum midshaft dimensions of metacarpals were listed by Scheuer and Elkington (1993,) as the variable with the highest correct sexing accuracy, namely, 76.0% (probability) and 80.0% (actual). Himes and Malina (1977) reported that metacarpal diaphyseal diameters were relatively larger in males than in females. The best discriminators in the present study generally included the measurements recorded at the base (anteroposterior) and midshaft (mediolateral) regions. These results were reported for the stepwise analysis for almost all of the hand bones with sexing accuracies ranging from 75.9 - 84.8% for the base and 75.6 - 86.9% for the midshaft dimensions. For distal phalanges, the base and midshaft measurements were also selected as the best discrimating variables, except that the mediolateral dimension of the base was selected for the third and fourth digits and the anteroposterior variable of the midshaft for the second bone.

An earlier study by Black (1978) showed that the width of a long bone has been reported to be more sexually dimorphic than the length. This was also true for the present study. The length dimension was selected only for the fifth distal phalanx in the stepwise analysis, with a classification accuracy of 85.1% for males and 84.5% for females. These results suggest that length is not as important as the width dimensions in distinguishing between the sexes. There are a number of studies that support the fact that maximum length of a long bone is not necessarily selected as the best discriminating variable (Thieme & Schull 1957, İşcan & Shihai 1995, İşcan *et al*. 1998, King *et al*. 1998; Mall *et al*. 2001, Purkait & Chandra 2002). The study by Barrier and L'Abbé (2008) on forearm bones, reported a 4.0% drop in classification accuracies when the length variable was removed from the male sample. The conclusion drawn by these authors is that the length dimension is only moderately sexually dimorphic.

In the present study, the dimensions of the head (or distal end) of a hand bone, similar to that of length, were also not selected as the best discriminating variable with the exception of the fifth metacarpal. In this bone, the anteroposterior dimension of the head was selected as the best discriminating variable in the stepwise analyses, with a classification accuracy of 76.8% for males and 80.2% for females when used on its own. One can thus conclude that

head dimensions especially the mediolateral width, is a moderate discriminator of sex, similar to that of length. It can be concluded that the statistically significant differences of hand bone dimensions between males and females observed in this study compare well with those reported on other aspects of the skeleton for the South African population (Asala *et al.* 1998, Asala 2001, Bidmos 2006, Patriquin *et al*. 2005).

Barrio and L'Abbé (2008), in their study on a Spanish sample of European origin, used eight metacarpal dimensions. The additional dimension in their study was the epicondylar diameter of the head. It may be argued that the maximum mediolateral dimension which these authors measured excluded the medial and lateral tubercles of the head. Instead, they recorded the distance between these tubercles, namely, epicondylar diameter of the head, as a separate entity. These anatomical landmarks were found to be part of the maximum side to side (mediolateral) dimension in the present study. Furthermore, these authors also reported separate findings for the right and left hand as well as for a pooled sample. Their results, as well as those of other authors (Di Bennardo & Taylor 1979, Ruff 1987), indicate that transverse dimensions are more dimorphic than longitudinal measurements. Barrio *et al*. (2006) also noted differences in transverse measurements for the epiphyses and shaft, with the mediolateral of the former and anteroposterior dimension of the latter displaying the greatest dimorphism.

The accuracies reported by Barrio *et al*. (2006) were higher than that reported by Stojanowski (1999) for two to five variables where a range of 79.0 - 85.0% was obtained and lower than that reported by Falsetti (1995), who gave a range of 84.0 - 92.0% for the metacarpal series as a group. Falsetti (1995) looked at metacarpals two, four and five and reported sexing accuracies in males as 100% for metacarpal five, 84.6% for metacarpal four and 83.3% for metacarpal two. For females the reverse pattern occurred. In other words, 100% accuracy was recorded for metacarpal five, 90.9% for metacarpal two, and 81.8% for metacarpal five. Comparing the results of Falsetti's (1995) study to those of Scheuer and Elkington (1993), it seems the bone of choice in males is the fifth metacarpal while in females it varies between the second and third metacarpals. In the present study, the fourth metacarpal

in males and the first metacarpal in females were the bones selected for the South African population.

Smith (1996) used maximum measurements at the head, base, and midshaft of all the metacarpals, while maximum and interarticular lengths were applied to metacarpals one to three and only the maximum length of four, and five was recorded. Smith (1996) recorded correct classification of metacarpals 86.8% for the right hand and 89.4% for the left hand.

Burrows *et al*. (2003) assessed the validity of metacarpals as sex discriminators by employing the methods proposed by Scheuer and Elkington (1993), Falsetti (1995) and Stojanowski (1999). They concluded that the methods proposed by all three authors were valid and produced high accuracies.

While Scheuer and Elkington (1993) proposed the testing of their equations on other populations, reported results from various other authors indicated that these equations are population specific and should be tested from a sample obtained from the same population. It was on this basis that discriminating equations for metacarpals and phalanges of the human hand for a South African population was derived.

Studies on the use of proximal phalanges as sex discriminators are rare. Scheuer and Elkington (1993) reported an actual correct sexing accuracy for the first proximal phalanx as 78.0%. Smith (1996) results for the various phalangeal rows showed that the designation of individuals to their correct sex and population groups using proximal phalanges was 76.0 - 79.0%, with middle phalanges it was 72.0 - 79.0% and for distal phalanges the percentages were recorded as 81.0 - 83.0%. Smith was able to show that metacarpals displayed higher discriminating values (87.0 - 89.0%) when compared to phalanges.

Percentage accuracies recorded for metacarpals and phalanges in the present study were similar and as high as those reported by Scheuer and Elkington (1993). The phalanges selected as the best discriminators differed for each series. In the proximal phalangeal series, the first proximal phalanx in males and females (84.0% and 88.8% respectively) and third proximal phalanx in females (88.8%) was selected. For the middle phalangeal series, the third middle phalanx for males (85.0%) and females (86.7%) was selected. The fifth distal phalanx

for males (85.1%) and first distal phalanx for females (84.4%) was listed for the distal phalangeal row. Average percentage accuracies for combined data of males and females, listed proximal phalanx one (86.4%), middle phalanx three (85.9%) and distal phalanx five (84.4%) as the three most dimorphic hand bones. These high percentage accuracies recorded for the phalanges may well place these hand bones on the same level as those of, for example, the femur or pelvis, as useful determinants for sex.

Burrows *et al*. (2003) tested three formulae published by Scheuer and Elkington (1993), Smith (1996) and Steele (1970) in order to establish the validity of hand bones, which included the metacarpals and phalanges, as sex determinants. These authors applied the three formulae to a totally different population which yielded poor classification results. They found that the classification accuracies for males were 100%, when compared to that of females of 10%. The study by these authors further emphasizes the fact that hand bones are no different to the rest of the skeleton in that discrimant formulae devised for hands are population specific.

When discriminant functions are tested they generally tend to deviate from the predicted accuracies (Case & Ross 2007). In the case of the study carried out by Burrows *et al*. (2003), the tested accuracies deviated from predicted accuracies by 10.0%. These authors also reported that 60.0% of the discriminant functions deviated by 5.0 - 10.0%. Based on these results, Burrows *et al*. (2003) suggested using single rather than multiple dimensions in order to obtain better predictive accuracies. From this viewpoint, Case and Ross (2007) then based their study on the findings by Burrows *et al*. (2003) and measured the maximum axial length dimension of both right and left sides of hand and foot bones to establish its accuracy as a sex determinant. They reported that the left hand yielded better results than the right hand, and that hands are to be selected rather than feet. They further concluded that the phalanges are better sex discriminators than metacarpals and metatarsals. In the present study, single and combinations of hand bones yielded high classification accuracies. Also, the classification accuracies for each series of hand bones were similar and this includes the metacarpals, proximal, middle and distal phalanges.

With regard to the different phalangeal series of bones, Case and Ross (2007) found that classification accuracies increased in a distal direction meaning that distal phalanges are preferred over those of the proximal and middle rows. These authors also reported that sexing accuracies using phalanges are far better than using metacarpals or metatarsals. One problem which they encountered was the correct siding of the third digit's middle and distal phalanges and suggested that articulated hand bones would be far easier than an isolated phalangeal bone. To overcome this problem, it is hoped that the key identification and siding features listed in the present study would contribute to the methods devised for sexing hand bones.

In the present study, the anteroposterior measurement of the first proximal phalanx in males was the best discriminator (84.0%). In females, the anteroposterior dimension of the first proximal phalanx (88.8%) and the anteroposterior dimension of the base of the third proximal phalanx (88.8%) were the best discriminators. For the middle phalanges, the mediolateral dimension of the third middle phalanx (85.0% and 86.7% for males and females respectively) is the best discriminator. Thus, the percentages for middle phalanges are slightly higher than for proximal phalanges. These results are similar to those reported by Case and Heilman (2006). For distal phalanges, the length of the fifth distal phalanx in males was the best discriminator (85.1%) while in females it was the anteroposterior dimension of the first distal phalanx (84.8%). These results are in agreement with the high percentages reported by Smith (1996). When compared to the findings of the metacarpals in the present study, length was the least selected dimension.

In summary, these results have shown that individual and combination of hand bones are as sexually dimorphic as those of the lower and rest of the upper extremities. The statistically significant differences between males and females observed in this study compare well to those reported on other aspects of the skeleton for the South African population (Asala 2001, Asala *et al.* 1998, Bidmos 2006, Patriquin *et al*. 2005).

Further research on assessing sexual dimorphism of hand bones with age changes may shed light on how the variables selected for accuracy would change, if at all, at different time periods for the South African population. Another aspect for further investigation would be

to perhaps split the South African population into its two groups, namely, whites and blacks, to establish whether the sexually dimorphic variables selected from this study, would also be applicable to these groups.

In summary, Scheuer and Elkington (1993) have proposed that accuracies of discriminant function formulae need to be above 80% to be usable. In this study most of the formulae yielded accuracies above 80%, with all of them being above 75%. It is hoped that the discriminant function tables and formulae that have been devised for the bones of the hand in a South African population, will contribute to the current and ever-growing osteometric standards initiated by various researchers who have already contributed to these standard techniques for South Africans (Washburn 1949, Keen 1950, De Villiers, 1968, Lundy & Feldesman 1987, Macho 1990, Kieser *et al*. 1992, Loth & Henneberg 1996, Steyn & İşcan 1997, İşcan & Steyn 1999, Loth & İşcan. 2000, Oettle & Steyn 2000, Asala 2001, Partriquin *et al*. 2003).

CHAPTER 11

CONCLUSIONS

11.1 Morphology of the hand bones

From the results on descriptions of the hand bones, the following conclusions can be made:

- The bones of the human hand do have specific features which can be used to identify them.
- Some of these features are unique, which makes it possible to assign a metacarpal or phalanx either to the right or the left hand.
- The morphological detail provided for the shaft, body and base of each hand bone can be applied if fragments of hand bones are recovered.

11.2 STATURE DETERMINATION

From the results on determination of stature, the following conclusions can be made:

- It is possible to regress the length of a hand bone to that of a long limb bone.
- Correlation of hand bones to long bone lengths in males varied in that they were not all correlated to one long limb bone whereas in females, all hand bones were highly correlated to the radius length.
- Regression formulae for hand bones of the South African population were created
- Standard errors, however, were high in comparison to those reported for long limb bones.
- In addition, the estimated long bone length would have to be inserted into a second formula, either that of Lundy and Feldesman (1987) or Dayal *et al*. (2008). This, however, may result in an increase in the standard error of estimates which further emphasises the provisional nature of any stature estimate based on the hands.
- Cadaver lengths recorded in the Pretoria Bone Collection, may need to be re-looked with regard to the manner in which they were measured as some of these recorded dimensions were inaccurate or missing.

- Better results may be obtained if the direct method could be used. In other words, the length of a hand bone is regressed directly against cadaver length. This was, unfortunately, impossible since the cadaver lengths are unreliable.

11.3 SEX DETERMINATION

From the results on determination of sex, the following conclusions can be made:

- The hand bones of South Africans are sexually dimorphic for base and midshaft dimensions rather than for head dimensions.
- Width dimensions are more sexually dimorphic than length measurements.
- South African males were more often misclassified than their female counterparts possibly because males display greater variability in the skeleton than females.
- Metacarpals and first proximal phalangeal bones for the South African population are as sexually dimorphic as hand bones and lower limb bones reported in the literature for other populations.
- Classification accuracies using hand bones were moderately high with percentages recorded for metacarpals as 75.9 - 80.2% and 79.9 - 85.4%, proximal phalanges as 81.7 - 86.9% and 83.2 - 86.4%, middle phalanges as 77.8 - 81.8% and 81.4 - 85.9%, and distal phalanges as 75.6 - 83.9% and 80.3 - 84.5% for single and multiple variables respectively. Average accuracies for males and females generally ranged from 75.9 - 86.9%.
- As the hands used in this study came from a contemporary sample, one would expect that secular trends would have a minimal effect.