



UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

**AGE RELATED CHANGES IN THE POST-CRANIAL HUMAN
SKELETON AND ITS IMPLICATION FOR THE DETERMINATION
OF SEX**

by

Veronica L.W. Vance

Submitted in fulfillment of the requirements for the degree PhD Anatomy

In the faculty of Health Sciences

University of Pretoria

Pretoria

December 2007



Declaration

I declare that the dissertation that I am hereby submitting to the University of Pretoria for the PhD degree in Anatomy degree is my own work and that I have never before submitted it to any other tertiary institution for any degree.

A handwritten signature in black ink, appearing to read 'Veronica L.W. Vance', written over a horizontal line.

Veronica L.W. Vance

1 day of December 2007



Table of Contents

| | |
|---|-----------|
| List of Tables | xii |
| List of Figures | xviii |
| List of Appendices | xxix |
| Abstract | xxxii |
| Abstrak | xxxiii |
| Acknowledgements | xxxv |
| CHAPTER 1: INTRODUCTION | 1 |
| CHAPTER 2: LITERATURE REVIEW | 5 |
| 2.1 Manifestation of sexual dimorphism in the human skeleton | 6 |
| 2.2 Other factors that influence sexual dimorphism in a population | 10 |
| 2.3 Previous research in age-related changes in sexual dimorphism | 14 |
| 2.4 Non-metric techniques for determining sex in the postcranial skeleton | 20 |
| 2.5 Metric techniques for determining sex in the postcranial skeleton | 22 |
| 2.6 Geometric morphometric techniques for determining sex from the postcranial skeleton | 24 |
| CHAPTER 3: MATERIALS AND METHODS | 29 |
| 3.1 Sample | 29 |
| 3.2 Data Collection | 31 |



| | | |
|--|--|-----------|
| 3.2.1 | Data collection of non-metric information | 31 |
| 3.2.2 | Data collection of non-metric information from the humerus | 32 |
| 3.2.3 | Data collection of non-metric information from the pelvis | 33 |
| 3.2.4 | Data collection of metric information from long bones | 34 |
| 3.3 | Statistical analysis of metric and non-metric data | 35 |
| 3.4 | Data collection for geometric morphometric analysis | 39 |
| 3.4.1 | Image capture of the EPI view of the humerus | 41 |
| 3.4.2 | Image capture of the OL view of the humerus | 44 |
| 3.4.3 | Image capture for the SUB view of the os coxa | 46 |
| 3.4.4 | Image capture of the SCI view of the os coxa | 48 |
| 3.5 | Statistical analysis of geometric morphometric data | 49 |
| CHAPTER 4: RESULTS of METRIC ANALYSIS | | 74 |
| 4.1 | Comparison of postcranial metric data: all populations | 75 |
| 4.1.1 | Comparison of postcranial metric data between sexes and populations | 76 |
| 4.2 | Comparison of female postcranial data between populations and age | 76 |
| 4.2.1 | Metric changes in long bone measurements with the onset of age: black females | 79 |
| 4.2.2 | Metric changes in long bone measurements with the onset of age: white females | 79 |



| | | |
|-------|---|----|
| 4.3 | Comparison of male postcranial data between populations and age groups | 80 |
| 4.3.1 | Metric changes in long bone measurements with the onset of age: black males | 81 |
| 4.3.2 | Metric changes in long bone measurements with the onset of age: white males | 82 |
| 4.4 | Implications of metric changes with age between males and females: long bone measurements | 82 |
| 4.4.1 | Statistically significant long bone changes in black females with age | 83 |
| 4.4.2 | Statistically significant long bone changes in white females with age | 84 |
| 4.4.3 | Statistically significant long bone changes in black males with age | 87 |
| 4.4.4 | Statistically significant long bone changes in white males with age | 89 |
| 4.4.5 | Summary | 90 |
| 4.5 | Comparison of pelvic metric data between sexes | 90 |
| 4.5.1 | Comparison of pelvic metric data between sexes and population | 91 |
| 4.6 | Comparison of female pelvic data between populations and age groups | 92 |
| 4.6.1 | Metric changes in pelvic measurements with the onset of age: black females | 93 |
| 4.6.2 | Metric changes in pelvic measurements with the onset of age: white females | 93 |
| 4.7 | Comparison of male pelvic data between populations and age groups | 94 |
| 4.7.1 | Metric changes in pelvic measurements with the onset of age: black males | 95 |

| | | |
|--|---|------------|
| 4.7.2 | Metric changes in pelvic measurements with the onset of age: white males | 95 |
| 4.8 | Implications of metric changes with age between males and females: the pelvis | 96 |
| 4.8.1 | Statistically significant pelvic changes in black males with age | 97 |
| 4.8.2 | Statistically significant pelvic changes in white males with age | 97 |
| 4.9 | Visual summary of metric results | 98 |
| CHAPTER 5: RESULTS of NON-METRIC ANALYSIS | | 134 |
| 5.1 | Results of non-metric data from the humerus | 134 |
| 5.1.1 | Sex determination from epicondylar symmetry (all males and females) | 135 |
| 5.1.2 | Sex determination from trochlear extension (all males and females) | 136 |
| 5.1.3 | Sex determination from olecranon fossa shape (all males and females) | 136 |
| 5.1.4 | Sex determination from the angle of the medial epicondyle (all males and females) | 136 |
| 5.1.5 | Final estimated sex from the distal humerus (all males and females) | 137 |
| 5.2 | Removal of inaccurate trait (s) and the improvement in classification accuracy for the distal humerus | 138 |
| 5.3 | Comparison of non-metric data from the humerus: females | 139 |
| 5.3.1 | Classification accuracy for black females vs. white females | 140 |
| 5.3.2 | Classification accuracy for young black females vs. old black females | 141 |
| 5.3.3 | Classification accuracy for young white females vs. old white females | 141 |

| | | |
|-------|---|-----|
| 5.4 | Comparison of non-metric data from the humerus: males | 142 |
| 5.4.1 | Classification accuracy for black males vs. white males | 142 |
| 5.4.2 | Classification accuracy for young black males vs. old black males | 143 |
| 5.4.3 | Classification accuracy for young white males vs. old white males | 143 |
| 5.4.4 | Classification accuracy from the distal humerus: summary | 144 |
| 5.5 | Results of non-metric data from the pelvis | 145 |
| 5.5.1 | Sex determination from the subpubic concavity (all males and females) | 145 |
| 5.5.2 | Sex determination from the subpubic angle (all males and females) | 146 |
| 5.5.3 | Sex determination from the ischio-pubic ramus width (all males and females) | 146 |
| 5.5.4 | Sex determination from the width of the greater sciatic notch (all males and females) | 147 |
| 5.5.5 | Estimated sex (all males and females) | 147 |
| 5.6 | Comparison of non-metric data from the pelvis: females | 148 |
| 5.6.1 | Classification accuracy for black females vs. white females | 148 |
| 5.6.2 | Classification accuracy for young black females vs. old black females | 148 |
| 5.6.3 | Classification accuracy for young white females vs. old white females | 149 |
| 5.7 | Comparison of non-metric data from the pelvis: males | 150 |
| 5.7.1 | Classification accuracy for black males vs. white males | 150 |
| 5.7.2 | Classification accuracy for young black males vs. old black males | 151 |

| | | |
|--|--|-----|
| 5.7.3 | Classification accuracy for young white males vs. old white males | 152 |
| 5.8 | Repeatability for non-metric characteristics of the humerus and pelvis | 152 |
| CHAPTER 6: RESULTS OF GEOMETRIC MORPHOMETRIC ANALYSIS | | 177 |
| 6.1 | Sexual dimorphism in the distal humerus: EPI perspective | 177 |
| 6.1.1 | Results from the EPI perspective between females and males | 178 |
| 6.1.2 | Results from the EPI perspective: black females vs. males | 180 |
| 6.1.3 | Results from the EPI perspective: white females vs. males | 182 |
| 6.1.4 | Sexual dimorphism and the onset of age: EPI perspective | 184 |
| 6.1.5 | Sexual dimorphism and the onset of age: black females and males | 185 |
| 6.1.6 | Sexual dimorphism and the onset of age: white females and males | 187 |
| 6.2 | Sexual dimorphism in the distal humerus: OL perspective | 189 |
| 6.2.1 | Results from the OL perspective between females and males | 190 |
| 6.2.2 | Results from the OL perspective: black females vs. males | 193 |
| 6.2.3 | Results from the OL perspective: white females vs. males | 194 |
| 6.2.4 | Sexual dimorphism and the onset of age: OL perspective | 195 |
| 6.2.5 | Sexual dimorphism and the onset of age: black females and males | 196 |
| 6.2.6 | Sexual dimorphism and the onset of age: white females and males | 198 |
| 6.3 | Sexual dimorphism in the pelvis: SUB perspective | 201 |

| | | |
|------------------------------|---|------------|
| 6.3.1 | Results from the SUB perspective between females and males | 202 |
| 6.3.2 | Results from the SUB perspective: black females vs. males | 204 |
| 6.3.3 | Results from the SUB perspective: white females vs. males | 206 |
| 6.3.4 | Sexual dimorphism and the onset of age: SUB perspective | 207 |
| 6.3.5 | Sexual dimorphism and the onset of age: black females and males | 208 |
| 6.3.6 | Sexual dimorphism and the onset of age: white females and males | 211 |
| 6.4 | Sexual dimorphism in the pelvis: SCI perspective | 214 |
| 6.4.1 | Results from the SCI perspective between females and males | 215 |
| 6.4.2 | Results from the SCI perspective: black females vs. males | 217 |
| 6.4.3 | Results from the SCI perspective: white females vs. males | 218 |
| 6.4.4 | Sexual dimorphism and the onset of age: SCI perspective | 220 |
| 6.4.5 | Sexual dimorphism and the onset of age: black females and black males | 221 |
| 6.4.6 | Sexual dimorphism and the onset of age: white females and males | 223 |
| CHAPTER 7: DISCUSSION | | 267 |
| 7.1 | Research sample | 269 |
| 7.2 | Metric analysis | 272 |
| 7.2.1 | Metric changes in females with the onset of age | 272 |

| | | |
|--------|---|-----|
| 7.2.2 | Metric changes in males with the onset of age | 278 |
| 7.3 | Non-metric Analysis | 284 |
| 7.3.1 | Non-metric changes in females with the onset of age | 286 |
| 7.3.2 | Non-metric changes in males with the onset of age | 291 |
| 7.4 | Geometric Morphometric Analysis | 295 |
| 7.4.1 | Sexual dimorphism of the EPI perspective | 297 |
| 7.4.2 | The EPI perspective: changes in females with the onset of age | 300 |
| 7.4.3 | The EPI perspective: changes in males with the onset of age | 302 |
| 7.4.4 | Sexual dimorphism of the OL perspective | 304 |
| 7.4.5 | The OL perspective: changes in females with the onset of age | 305 |
| 7.4.6 | The OL perspective: changes in males with the onset of age | 307 |
| 7.4.7 | Sexual dimorphism of the SUB perspective | 309 |
| 7.4.8 | The SUB perspective: changes in females with the onset of age | 310 |
| 7.4.9 | The SUB perspective: changes in males with the onset of age | 312 |
| 7.4.10 | Sexual dimorphism of the SCI perspective | 314 |
| 7.4.11 | The SCI perspective: changes in females with the onset of age | 316 |
| 7.4.12 | The SCI perspective: changes in males with the onset of age | 318 |
| 7.4.13 | Geometric morphometric analysis: summary | 320 |



7.4.14 Geometric morphometric analysis: advantages and disadvantages

322

CHAPTER 8: CONCLUSIONS

325

List of Tables

| | | |
|------------|---|-----|
| Table 3.1 | Frequency distribution of males and females in total sample size | 54 |
| Table 3.2 | Non-metric distal humerus characteristics for males and females | 54 |
| Table 3.3 | Non-metric pelvic characteristics for males and females | 55 |
| Table 3.4 | Descriptions of measurements taken on postcranial elements | 56 |
| Table 4.1 | Means, standard deviations, and univariate F-ratios for postcranial measurements of males and females | 99 |
| Table 4.2 | Means, standard deviations, and univariate F-ratios for postcranial measurements of black males and black females | 100 |
| Table 4.3 | Means, standard deviations, and univariate F-ratios for postcranial measurements of white males and white females | 101 |
| Table 4.4 | Means, standard deviations, and univariate F-ratios for postcranial measurements of black females and white females | 102 |
| Table 4.5 | Statistical comparison of size differences between black and white females in the postcranial skeleton | 103 |
| Table 4.6: | Means, standard deviations, and univariate F-ratios for postcranial measurements of young black females and old black females | 104 |
| Table 4.7 | Means, standard deviations, and univariate F-ratios for postcranial measurements of young white females and old white females | 105 |
| Table 4.8 | Means, standard deviations, and univariate F-ratios for postcranial measurements of black males and white males | 106 |
| Table 4.9 | Statistical comparison of size differences between black and white males in the postcranial skeleton | 107 |

| | | |
|------------|---|-----|
| Table 4.10 | Means, standard deviations, and univariate F-ratios for postcranial measurements of young black males and old black males | 108 |
| Table 4.11 | Means, standard deviations, and univariate F-ratios for postcranial measurements of young white males and old white males | 109 |
| Table 4.12 | Means, standard deviations, and univariate F-ratios for pelvic measurements of males and females | 110 |
| Table 4.13 | Means, standard deviations, and univariate F-ratios for pelvic measurements of black males and black females | 110 |
| Table 4.14 | Means, standard deviations, and univariate F-ratios for pelvic measurements of white males and white females | 110 |
| Table 4.15 | Means, standard deviations, and univariate F-ratios for pelvic measurements of black females and white females | 111 |
| Table 4.16 | Means, standard deviations, and univariate F-ratios for pelvic measurements of young black females and old black females | 111 |
| Table 4.17 | Means, standard deviations, and univariate F-ratios for pelvic measurements of young white females and old white females | 111 |
| Table 4.18 | Means, standard deviations, and univariate F-ratios for pelvic measurements of black males and white males | 112 |
| Table 4.19 | Means, standard deviations, and univariate F-ratios for pelvic measurements of young black males and old black males | 112 |
| Table 4.20 | Means, standard deviations, and univariate F-ratios for pelvic measurements of young white males and old white males | 112 |
| Table 4.21 | Classification of age groups for comparison of means with the advancement of age | 113 |
| Table 5.1: | Distribution of classification, all males and females, medial epicondylar symmetry | 154 |
| Table 5.2: | Distribution of classification, all males and females, trochlear extension | 154 |

| | | |
|-------------|---|-----|
| Table 5.3: | Distribution of classification, all males and females, olecranon fossa shape | 154 |
| Table 5.4: | Distribution of classification, all males and females, medial epicondylar angle | 155 |
| Table 5.5: | Distribution of classification, all males and females, estimated sex | 155 |
| Table 5.6: | Distribution of classification and chi square significance, all males and females | 155 |
| Table 5.7: | Distribution and classification changes with “medial epicondylar symmetry” trait removed | 156 |
| Table 5.8: | Distribution of classification, all males and females, estimated sex with the removal of epicondylar symmetry | 157 |
| Table 5.9: | Distribution of classification and chi square significance, black females and white females | 157 |
| Table 5.10: | Distribution of classification and chi square significance for young black females vs. old black females | 157 |
| Table 5.11: | Distribution of classification and chi square significance for young white females vs. old white females | 158 |
| Table 5.12: | Distribution of classification and chi square significance for black males vs. white males | 158 |
| Table 5.13: | Distribution of classification and chi square significance for young black males vs. old black males | 159 |
| Table 5.14: | Distribution of classification and chi square significance for young white males vs. old white males | 159 |
| Table 5.15: | Distribution of classification for all males and females, subpubic concavity | 160 |
| Table 5.16: | Distribution of classification for all males and females, subpubic angle | 160 |

| | | |
|-------------|---|-----|
| Table 5.17: | Distribution of classification for all males and females, ischio-pubic ramus width | 160 |
| Table 5.18: | Distribution of classification for all males and females, greater sciatic notch width | 161 |
| Table 5.19: | Distribution of classification for all males and females, estimated sex for the pelvis | 161 |
| Table 5.20: | Distribution of classification and chi square significance, all males and females | 161 |
| Table 5.21: | Distribution of classification and chi square significance, all black females and white females | 162 |
| Table 5.22: | Distribution of classification and chi square significance, young black females and old black females | 162 |
| Table 5.23: | Distribution of classification and chi square significance, young white females and old white females | 163 |
| Table 5.24: | Distribution of classification and chi square significance, black males and white | 163 |
| Table 5.25: | Distribution of classification and chi square significance, young black males and old black males | 164 |
| Table 5.26: | Distribution of classification and chi square significance, young white males and old white males | 164 |
| Table 6.1: | Statistical significance between females and males, EPI perspective | 227 |
| Table 6.2: | Percentage of males and females correctly assigned using canonical variates analysis, EPI perspective | 227 |
| Table 6.3: | Percentage of black males and black females correctly assigned using canonical variates analysis, EPI perspective | 227 |
| Table 6.4: | Percentage of white males and white females correctly assigned using canonical variates analysis, EPI perspective | 228 |

| | | |
|-------------|---|-----|
| Table 6.5: | Statistical significance between black females and males, EPI perspective | 228 |
| Table 6.6: | Percentage of young and old black males and females correctly assigned using canonical variates analysis, EPI perspective | 228 |
| Table 6.7: | Statistical significance between white females and males, EPI perspective | 229 |
| Table 6.8: | Percentage of young and old white males and females correctly assigned using canonical variates analysis, EPI perspective | 229 |
| Table 6.9: | Statistical significance between females and males, OL perspective | 230 |
| Table 6.10: | Percentage of males and females correctly assigned using canonical variates analysis, OL perspective | 230 |
| Table 6.11: | Percentage of black males and black females correctly assigned using canonical variates analysis, OL perspective | 230 |
| Table 6.12: | Percentage of white males and white females correctly assigned using canonical variates analysis, OL perspective | 231 |
| Table 6.13: | Statistical significance between black females and males, OL perspective | 231 |
| Table 6.14: | Percentage of young and old black males and females correctly assigned using canonical variates analysis, OL perspective | 231 |
| Table 6.15: | Statistical significance between white females and males, OL perspective | 232 |
| Table 6.16: | Percentage of young and old white males and females correctly assigned using canonical variates analysis, OL perspective | 232 |
| Table 6.17: | Statistical significance between females and males, SUB perspective | 233 |
| Table 6.18: | Percentage of males and females correctly assigned using canonical variates analysis, SUB perspective | 233 |

| | | |
|-------------|---|-----|
| Table 6.19: | Percentage of black males and black females correctly assigned using canonical variates analysis, SUB perspective | 233 |
| Table 6.20: | Percentage of white males and white females correctly assigned using canonical variates analysis, SUB perspective | 234 |
| Table 6.21: | Statistical significance between black females and males, SUB perspective | 234 |
| Table 6.22: | Percentage of young and old black males and females correctly assigned using canonical variates analysis, SUB perspective | 234 |
| Table 6.23: | Statistical significance between white females and males, SUB perspective | 235 |
| Table 6.24: | Percentage of young and old white males and females correctly assigned using canonical variates analysis, SUB perspective | 235 |
| Table 6.25: | Statistical significance between females and males, SCI perspective | 236 |
| Table 6.26: | Percentage of males and females correctly assigned using canonical variates analysis, SCI perspective | 236 |
| Table 6.27: | Percentage of black males and black females correctly assigned using canonical variates analysis, SCI perspective | 236 |
| Table 6.28: | Percentage of white males and white females correctly assigned using canonical variates analysis, SCI perspective | 237 |
| Table 6.29: | Statistical significance between black females and males, SCI perspective | 237 |
| Table 6.30: | Percentage of young and old black males and females correctly assigned using canonical variates analysis, SCI perspective | 237 |
| Table 6.31: | Statistical significance between white females and males, SCI perspective | 238 |
| Table 6.32: | Percentage of young and old white males and females correctly assigned using canonical variates analysis, SCI perspective | 238 |

List of Figures

| | | |
|--------------|--|----|
| Figure 3.1 | Triangular olecranon fossa shape observed in males | 58 |
| Figure 3.2 | Oval olecranon fossa shape observed in females | 58 |
| Figure 3.3 | Angle of the medial epicondyle observed in males | 59 |
| Figure 3.4 | Angle of the medial epicondyle observed in females | 59 |
| Figure 3.5 | Medial epicondylar symmetry observed in males | 60 |
| Figure 3.6 | Medial epicondylar symmetry observed in females | 60 |
| Figure 3.7 | Trochlear extension observed in males | 61 |
| Figure 3.8 | Trochlear extension/ relative symmetry observed in females | 61 |
| Figure 3.9 | Length of the subpubic concavity as observed in males | 62 |
| Figure 3.10 | Length of the subpubic concavity as observed in females | 62 |
| Figure 3.11: | Width of the subpubic angle as seen in males | 63 |
| Figure 3.12 | Width of the subpubic angle as seen in females | 63 |
| Figure 3.13 | Ischiopubic ramus width as seen in males | 64 |
| Figure 3.14 | Ischiopubic ramus width as seen in females | 64 |
| Figure 3.15 | Greater sciatic notch width as seen in males | 65 |
| Figure 3.16 | Greater sciatic notch width as seen in females | 65 |



| | | |
|-------------|---|-----|
| Figure 3.17 | Measurements of the humerus | 66 |
| Figure 3.18 | Measurements of the ulna | 66 |
| Figure 3.19 | Measurements of the radius | 67 |
| Figure 3.20 | Measurements of the femur | 67 |
| Figure 3.21 | Measurements of the tibia | 68 |
| Figure 3.22 | Measurements of the fibula | 68 |
| Figure 3.23 | Measurements of the pelvis | 69 |
| Figure 3.24 | Measurements used to calculate the ischio-pubic index | 69 |
| Figure 3.25 | Homologous landmarks for the EPI view | 70 |
| Figure 3.26 | Homologous landmarks for the view OL | 71 |
| Figure 3.27 | Homologous landmarks for the view SUB | 72 |
| Figure 3.28 | Homologous landmarks for the view SCI | 73 |
| Figure 4.1 | The relationship between the circumference of the humerus with age in black females and males | 114 |
| Figure 4.2: | The relationship between the humeral head diameter with age in white females and white males | 114 |
| Figure 4.3: | The relationship between the diameter of the humerus at midshaft with age in white females and males | 115 |
| Figure 4.4: | The relationship between the distal epicondylar breadth of the humerus with age in white females and white male | 115 |

| | | |
|--------------|---|-----|
| Figure 4.5: | The relationship between the superior head diameter of the ulna with age in white females and white males | 116 |
| Figure 4.6: | The relationship between the inferior head of the ulna with age in white females and white males | 116 |
| Figure 4.7: | The relationship between the diameter of the ulna at midshaft with age in white females and white males | 117 |
| Figure 4.8: | The relationship between the distal diameter of the ulna with age in white females and white males | 117 |
| Figure 4.9: | The relationship between the olecranon-coronoid diameter with age in white females and white males | 118 |
| Figure 4.10: | The relationship between the head of the radius with age in white females and white males | 118 |
| Figure 4.11: | The relationship between the diameter of the radius at midshaft with age in white females and white males | 119 |
| Figure 4.12: | The relationship between the diameter of the distal radius with age in white females and white males | 119 |
| Figure 4.13: | The relationship between the vertical diameter of the femoral head with age in white females and white males | 120 |
| Figure 4.14: | The relationship between the diameter of the femur at midshaft with age in white females and white males | 120 |
| Figure 4.15: | The relationship between the maximum bicondylar breadth of distal femur with age in white females and white males | 121 |
| Figure 4.16: | The relationship between the bicondylar breadth of the proximal tibia with age in white females and white males | 121 |
| Figure 4.17: | The relationship between the diameter of the tibia at midshaft with age in white females and white males | 122 |

| | | |
|--------------|--|-----|
| Figure 4.18: | The relationship between the diameter of the head of the fibula with age in white females and white males | 122 |
| Figure 4.19: | The relationship between the diameter of the distal fibula with age in white females and white males | 123 |
| Figure 4.20: | The relationship between the diameter of the humerus at midshaft with age in black males and black females | 123 |
| Figure 4.21: | The relationship between the epicondylar breadth of the distal humerus with age in black males and black females | 124 |
| Figure 4.22: | The relationship between the diameter of the superior head of the ulna with age in black males and black females | 124 |
| Figure 4.23: | The relationship between the diameter of the ulna at midshaft with age in black males and black females | 125 |
| Figure 4.24: | The relationship between the diameter of the femur at midshaft with age in black males and black females | 125 |
| Figure 4.25: | The relationship between the bicondylar breadth of the proximal tibia with age in black males and black females | 126 |
| Figure 4.26: | The relationship between the diameter of the head of the fibula with age in black males and black females | 126 |
| Figure 4.27: | The relationship between the diameter of the inferior head of the ulna with age in white males and white females | 127 |
| Figure 4.28: | The relationship between the diameter of the distal radius with age in white males and white females | 127 |
| Figure 4.29: | The relationship between the bicondylar breadth of the proximal tibia with age in white males and white females | 128 |
| Figure 4.30: | The relationship between the ischio-pubic index with age in black males and black females | 128 |

| | | |
|--------------|---|-----|
| Figure 4.31: | The relationship between the pubis length with age in white males and white females | 129 |
| Figure 4.32: | The relationship between the ischio-pubic index with age in white males and white females | 129 |
| Figure 4.33: | Statistically significant measurements that <i>decreased</i> for the black female skeleton from the young age group to the old age group | 130 |
| Figure 4.34: | Statistically significant measurements that <i>increased</i> for the white female skeleton from the young age group to the old age group | 131 |
| Figure 4.35: | Statistically significant measurements that <i>increased</i> for the black male skeleton from the young age group to the old age group | 132 |
| Figure 4.36: | Statistically significant measurements that <i>increased</i> and <i>decreased</i> for the white male skeleton from the young age group to the old age group | 133 |
| Figure 5.1: | Classification accuracy for all males and females, epicondylar symmetry | 165 |
| Figure 5.2: | Classification accuracy for all males and females, trochlear extension | 165 |
| Figure 5.3: | Classification accuracy for all males and females, olecranon fossa shape | 166 |
| Figure 5.4: | Classification accuracy for all males and females, angle of the medial epicondyle | 166 |
| Figure 5.5: | Classification accuracy for males and females, estimated sex | 167 |
| Figure 5.6: | Classification accuracy for males and females with the three-trait combination of features, estimated sex | 167 |
| Figure 5.7: | Classification accuracy for black females vs. white females, estimated sex | 168 |
| Figure 5.8: | Classification accuracy for young black females vs. old black females, estimated sex | 168 |

| | | |
|--------------|--|-----|
| Figure 5.9: | Classification accuracy for young white females vs. old white females, estimated sex | 169 |
| Figure 5.10: | Classification accuracy for black males vs. white males, estimated sex | 169 |
| Figure 5.11: | Classification accuracy for young black males vs. old black males, estimated sex | 170 |
| Figure 5.12: | Classification accuracy for young white males vs. old white males, estimated sex | 170 |
| Figure 5.13: | Classification accuracy for all males and females, subpubic concavity | 171 |
| Figure 5.14: | Classification accuracy for all males and females, subpubic angle | 171 |
| Figure 5.15: | Classification accuracy for all males and females, ischio-pubic ramus width | 172 |
| Figure 5.16: | Classification accuracy for all males and females, greater sciatic notch width | 172 |
| Figure 5.17: | Classification accuracy for all males and females, estimated sex | 173 |
| Figure 5.18: | Classification accuracy for black females and white females, estimated sex | 173 |
| Figure 5.19: | Classification accuracy for young black females and old black females, estimated sex | 174 |
| Figure 5.20: | Classification accuracy for young white females and old white females, estimated sex | 174 |
| Figure 5.21: | Classification accuracy for black males and white males, estimated sex | 175 |
| Figure 5.22: | Classification accuracy for young black males and old black males, estimated sex | 175 |
| Figure 5.23: | Classification accuracy for young white males and old white males, estimated sex | 176 |

| | | |
|--------------|--|-----|
| Figure 6.1: | Consensus relative warp analysis of females and males, EPI perspective | 239 |
| Figure 6.2: | Consensus thin-plate spline reference shape of all females and all males from the EPI perspective | 239 |
| Figure 6.3: | Consensus thin-plate spline in deformation mode demonstrating the differences between the reference shape (all females) and all males, EPI perspective | 240 |
| Figure 6.4: | Consensus thin-plate spline (in vector mode) demonstrating the differences between all females and all males, EPI perspective | 240 |
| Figure 6.5: | Consensus thin-plate spline in deformation mode demonstrating the differences between the reference shape (black females) and black males, EPI perspective | 241 |
| Figure 6.6: | Consensus thin-plate spline (in vector mode) demonstrating the differences between black females and black males, EPI perspective | 241 |
| Figure 6.7: | Consensus thin-plate spline in deformation mode demonstrating the differences between the reference shape (white females) and white males, EPI perspective | 242 |
| Figure 6.8: | Consensus thin-plate spline (in vector mode) demonstrating the differences between white females and white males, EPI perspective | 242 |
| Figure 6.9: | Relative warp consensus for eight groups of males and females, EPI perspective | 243 |
| Figure 6.10: | Consensus thin-plate spline (in vector mode) demonstrating the differences between young black females and old black females, EPI perspective | 244 |
| Figure 6.11: | Consensus thin-plate spline (in vector mode) demonstrating the differences between young black males and old black males, EPI perspective | 244 |
| Figure 6.12: | Consensus thin-plate spline (in vector mode) demonstrating the differences between young white females and old white females, EPI perspective | 245 |

| | | |
|--------------|---|-----|
| Figure 6.13: | Consensus thin-plate spline (in vector mode) demonstrating the differences between young white males and old white males, EPI perspective | 245 |
| Figure 6.14: | Consensus relative warp analysis of females and males, OL perspective | 246 |
| Figure 6.15: | Consensus thin-plate spline reference shape of all females and all males from the OL perspective | 246 |
| Figure 6.16: | Consensus thin-plate spline in deformation mode demonstrating the differences between the reference shape (all females) and all males, OL perspective | 247 |
| Figure 6.17: | Consensus thin-plate spline (in vector mode) demonstrating the differences between all females and all males, OL perspective | 247 |
| Figure 6.18: | Consensus thin-plate spline in deformation mode demonstrating the differences between the reference shape (black females) and black males, OL perspective | 248 |
| Figure 6.19: | Consensus thin-plate spline (in vector mode) demonstrating the differences between black females and black males, OL perspective | 248 |
| Figure 6.20: | Consensus thin-plate spline in deformation mode demonstrating the differences between the reference shape (white females) and white males, OL perspective | 249 |
| Figure 6.21: | Consensus thin-plate spline (in vector mode) demonstrating the differences between white females and white males, OL perspective | 249 |
| Figure 6.22: | Relative warp consensus for eight groups of males and females, OL perspective | 250 |
| Figure 6.23: | Consensus thin-plate spline (in vector mode) demonstrating the differences between young black females and old black females, OL perspective | 251 |
| Figure 6.24: | Consensus thin-plate spline (in vector mode) demonstrating the differences between young black males and old black males, OL perspective | 251 |

| | | |
|--------------|--|-----|
| Figure 6.25: | Consensus thin-plate spline (in vector mode) demonstrating the differences between young white females and old white females, OL perspective | 252 |
| Figure 6.26: | Consensus thin-plate spline (in vector mode) demonstrating the differences between young white males and old white males, OL perspective | 252 |
| Figure 6.27: | Consensus relative warp analysis of females and males, SUB perspective | 253 |
| Figure 6.28: | Consensus thin-plate spline reference shape of all females and all males from the SUB perspective | 253 |
| Figure 6.29: | Consensus thin-plate spline in deformation mode demonstrating the differences between the reference shape (all females) and all males, SUB perspective | 254 |
| Figure 6.30: | Consensus thin-plate spline (in vector mode) demonstrating the differences between all females and all males, SUB perspective | 254 |
| Figure 6.31: | Consensus thin-plate spline in deformation mode demonstrating the differences between the reference shape (black females) and black males, SUB perspective | 255 |
| Figure 6.32: | Consensus thin-plate spline (in vector mode) demonstrating the differences between black females and black males, SUB perspective | 255 |
| Figure 6.33: | Consensus thin-plate spline in deformation mode demonstrating the differences between the reference shape (white females) and white males, SUB perspective | 256 |
| Figure 6.34: | Consensus thin-plate spline (in vector mode) demonstrating the differences between white females and white males, SUB perspective | 256 |
| Figure 6.35: | Relative warp consensus for eight groups of males and females, SUB perspective | 257 |

| | | |
|--------------|--|-----|
| Figure 6.36: | Consensus thin-plate spline (in vector mode) demonstrating the differences between young black females and old black females, SUB perspective | 258 |
| Figure 6.37: | Consensus thin-plate spline (in vector mode) demonstrating the differences between young black males and old black males, SUB perspective | 258 |
| Figure 6.38: | Consensus thin-plate spline (in vector mode) demonstrating the differences between young white females and old white females, SUB perspective | 259 |
| Figure 6.39: | Consensus thin-plate spline (in vector mode) demonstrating the differences between young white males and old white males, SUB perspective | 259 |
| Figure 6.40: | Consensus relative warp analysis of females and males, SCI perspective | 260 |
| Figure 6.41: | Consensus thin-plate spline reference shape of all females and all males from the SCI perspective | 260 |
| Figure 6.42: | Consensus thin-plate spline in deformation mode demonstrating the differences between the reference shape (all females) and all males, SCI perspective | 261 |
| Figure 6.43: | Consensus thin-plate spline (in vector mode) demonstrating the differences between all females and all males, SCI perspective | 261 |
| Figure 6.44: | Consensus thin-plate spline in deformation mode demonstrating the differences between the reference shape (black females) and black males, SCI perspective | 262 |
| Figure 6.45: | Consensus thin-plate spline (in vector mode) demonstrating the differences between black females and black males, SCI perspective | 262 |
| Figure 6.46: | Consensus thin-plate spline in deformation mode demonstrating the differences between the reference shape (white females) and white males, SCI perspective | 263 |

| | | |
|--------------|---|-----|
| Figure 6.47: | Consensus thin-plate spline (in vector mode) demonstrating the differences between white females and white males, SCI perspective | 263 |
| Figure 6.48: | Relative warp consensus for eight groups of males and females, SCI perspective | 264 |
| Figure 6.49: | Consensus thin-plate spline (in vector mode) demonstrating the differences between young black females and old black females, SCI perspective | 265 |
| Figure 6.50: | Consensus thin-plate spline (in vector mode) demonstrating the differences between young black males and old black males, SCI perspective | 265 |
| Figure 6.51: | Consensus thin-plate spline (in vector mode) demonstrating the differences between young white females and old white females, SCI perspective | 266 |
| Figure 6.52: | Consensus thin-plate spline (in vector mode) demonstrating the differences between young white males and old white males, SCI perspective | 266 |

Appendices

| | |
|---|-----|
| Literature Cited | 328 |
| APPENDIX A: Research Data Sheet used in data collection procedures | 345 |
| APPENDIX B: Specimens used for geometric morphometric analysis – young white females | 346 |
| APPENDIX C: Specimens used for geometric morphometric analysis – young black females | 347 |
| APPENDIX D: Specimens used for geometric morphometric analysis – old black females | 348 |
| APPENDIX E: Specimens used for geometric morphometric analysis – old white females | 349 |
| APPENDIX F: Specimens used for geometric morphometric analysis – old black males | 350 |
| APPENDIX G: Specimens used for geometric morphometric analysis – old white males | 351 |
| APPENDIX H: Specimens used for geometric morphometric analysis – young black males | 352 |
| APPENDIX I: Specimens used for geometric morphometric analysis – young white males | 353 |
| APPENDIX J: Means, standard deviations, and univariate F-ratios for postcranial measurements of males and females, intra-observer results | 354 |
| APPENDIX K: statistical analyses of non-metric humerus characteristics, intra-observer results | 355 |
| Distribution of classification, all males and females, trochlear extension | 355 |

| | |
|--|------------|
| Distribution of classification, all males and females, olecranon fossa shape | 355 |
| Distribution of classification, all males and females, medial epicondylar angle | 355 |
| Distribution of classification, all males and females, estimated sex from the distal humerus | 355 |
| APPENDIX L: statistical analyses of non-metric pelvic characteristics, intra-observer results | 356 |
| Distribution of classification for all males and females, subpubic concavity | 356 |
| Distribution of classification for all males and females, subpubic angle | 356 |
| Distribution of classification for all males and females, ischio-pubic ramus width | 356 |
| Distribution of classification for all males and females, greater sciatic notch width | 357 |
| Distribution of classification for all males and females, estimated sex for the pelvis | 357 |

Abstract

The study of skeletal differences between males and females has rarely taken into account the physical change in hard tissue characteristics with the onset of advanced age. Anatomical change through degenerative modification may pose a challenge when diagnosing the sex of an unknown individual, especially if age is unknown. The aim of this study was to establish whether sexual dimorphism changes with age. This issue was addressed by using three types of procedural analyses. Firstly, standard measuring techniques were utilized to determine sex from 593 individuals. Visual (morphological) assessment was then performed on 608 individuals using sexually dimorphic traits in the distal humerus and pelvis. Lastly, over 300 individuals were analyzed with geometric morphometrics using four locations on the postcranial skeleton. Younger females and males (50 years of age and younger) were then compared to older individuals (over 50 years of age) to determine if sexual dimorphism was increasing or decreasing with the onset of age. Long bone measurements of the postcranial skeleton increased with the onset of age in the most osteoporotic sample (South African white females). Males exhibited an increase in size, mainly in the knee and elbow joints, and black females remained static in their measurements with age. Older white females especially can sometimes incorrectly be misclassified as males. Visual techniques indicated that all populations have similar non-metric morphology in the distal humerus and pelvis. Classification accuracies in females decreased when viewing the distal humerus, indicating a decrease in sexual dimorphism at this location. Females appeared static in their pelvic morphology with the onset of age. Males remained sexually dimorphic throughout life in the humerus and pelvis. Geometric morphometrics showed that the morphology of the distal humerus is sexually dimorphic, and does not change with age. Morphometrics also confirmed the marked sexual



dimorphism in the pelvis, and showed virtually no change in sexual dimorphism when comparing young to old groups.

Abstrak

Studies van skeletale verskille tussen mans en vrouens neem selde die fisiese veranderinge in been met toenemende ouderdom in ag. Anatomiese veranderinge as gevolg van degeneratiewe modifikasie kan problematies wees met die bepaling van geslag van 'n onbekende persoon, veral as die ouderdom nie bekend is nie. Die doel van hierdie studie was om te bepaal of seksuele dimorfisme verander met ouderdom. Hierdie probleem is aangespreek deur gebruik te maak van drie metodes van ontleding. Standaard metriese tegnieke is eerstens gebruik om die geslag van 593 individue te bepaal. Visuele (morfologiese) evaluering van seksueel dimorfiese kenmerke van die distale humerus en pelvis is daarna op 608 individue gedoen. Laastens is vier areas op die postkraniale skelet van meer as 300 individue met behulp van geometriese morfometrie ontleed. Jonger mans en vrouens (50 jaar en jonger) is vergelyk met ouer individue (ouer as 50 jaar) om te bepaal of seksuele dimorfisme toeneem of afneem met toename in ouderdom. Langbeenafmetings van die postkraniale skelet neem toe met ouderdom by die mees osteoporotiese groep (wit Suid-Afrikaanse vrouens). Mans toon 'n toename in grootte, hoofsaaklik in die knie en elmboog, en afmetings van swart vrouens was bestendig met toenemende ouderdom. Ouer wit vrouens veral kan soms verkeerdelik geklassifiseer word as mans. Visuele tegnieke dui aan dat alle groepe 'n soortgelyke nie-metriese morfologie in die distale humerus en bekken vertoon. Klassifikasie akkuraatheid in vrouens neem af in die distale humerus, wat dui op 'n afname in seksuele dimorfisme in hierdie gebied. Bekkenmorfologie van vrouens toon geen veranderinge met ouderdom nie. Die humerus en bekken van mans bly seksueel dimorfies deur hul lewe. Geometriese morfometrie wys dat die bou van die distale humerus seksueel dimorfies is, en dat dit nie verander met toename in ouderdom nie. Geometriese morfometrie bevestig ook die kenmerkende seksuele dimorfisme van die



bekken, en wys feitlik geen veranderinge wanneer jong en ouer groepe vergelyk word nie.

Acknowledgements

No scholastic endeavor such as a PhD occurs without the guidance and support of those who have paved the way beforehand. For academic counsel, technical expertise, and the persistent encouragement needed to complete this project, I thank my advisor, Professor Maryna Steyn. Professor Steyn not only served as my extremely erudite academic supervisor, but she and her family made me feel especially welcome in their lovely country. I will treasure the time we spent working and exploring together.

Dr. Ericka L'Abbé was also instrumental in the completion of this project. I thank you for your support and wisdom throughout my academic journey, as well as being a kindred American spirit in an unfamiliar setting. You made my time in South Africa a very memorable one and I will always cherish your kindness.

Marius Loots provided more technical assistance than I could have ever hoped for, and was a pillar of strength when my electronic challenges became overwhelming. All this while providing friendship, entertainment, and many well-crafted meals; thank you so much.

Several fellow students and colleagues made my scholarly experience in South Africa unforgettable. Natalie Keough, Renee Botha, Jolandie Myburgh, Yvette Schultz, Louisa Hutten, Malebo Marabene all provided guidance, support, and friendship throughout my stay in South Africa. These impressive individuals could not have been more accommodating.

My second family deserves distinct recognition and a heart-felt thank you. Dr. Johan Schutte and Lida, Jana and Retha van der Merwe offered me an emotional and intellectual foundation in which I could successfully complete my work. I honour and praise these wonderful people who truly became life-long members of my family. Your

influence and encouragement will always be paramount in my mind when I think back on the fulfillment of this degree.

I would never have started on this academic journey had it not have been for my mentor and colleague, Dr. John Lundy. Dr. John has been a consistent and positive influence in my professional endeavors, and I credit him for instilling a love of forensic anthropology that continues with every case we participate in together. Thank you for your confidence, humor and guidance throughout the years. I look forward to many more.

Finally, I applaud my family, friends and loved ones for their staunch support and confidence in me and my unique choice of careers. Dave, Ski, Greg and Kevin, you have given me the sheer strength to accomplish this- it is through your love that I am who I am today. To all my aunts and uncles, cousins, and second cousins, I truly appreciate your interest and attention to my progress throughout my studies. A special note of thanks goes to my closest friends; you've provided me with much happiness throughout our professional and personal journeys. I share this achievement with all of you.