

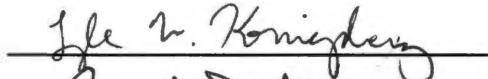
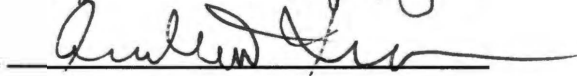
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I am submitting herewith a dissertation written by Erin H. Kimmerle entitled "Biological and Statistical Variation in Age Estimation from Pubic Symphyseal Morphology with Regard to Individual Identification and Demographic Profiling". I have examined the final paper copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Anthropology.

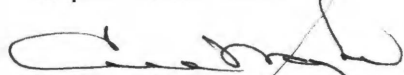


Richard L. Jantz, Major Professor

We have read this dissertation  
and recommend its acceptance:


Accepted for the Council:



Vice Chancellor and Dean of  
Graduate Studies

**Biological and Statistical Variation in Age Estimation from Pubic Symphyseal  
Morphology with Regard to Individual Identification and Demographic Profiling**

A Dissertation  
Presented for the  
Doctor of Philosophy  
Degree  
University of Tennessee, Knoxville

Erin H. Kimmerle  
December, 2004

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2004b  
.K57

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This dissertation is dedicated to Michael and Sean Boland.

## ACKNOWLEDGMENTS

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## ABSTRACT

Population variation in the morphological aging process of the pubic symphysis has generated much debate. The question of whether age parameters derived from an American population will reliably estimate age-at-death for East European skeletal populations is important since the ability to accurately estimate an individual's age-at-death hinges on what *standard* is used. Consequently, successful age estimation, individual identification, and demographic profiling rests on the ability to correctly define the skeletal parameters of age-at-death.

The purpose of this study is to assess the aging process of American and East European populations and to determine what age parameters should be applied to estimate the ages-at-death for unidentified victims. A reference sample of identified individuals with known ages-at-death from Kosovo, Bosnia, and Croatia (n=861) is used to determine the age structure of victims and serves as the informed prior in the Bayesian analysis. Skeletal data comes from a subset of the Balkan reference sample and a comparative American sample. Balkan male (n=212) and female (n=84) pubic symphyses were scored in both the manners of Todd (1920 and 1924) and Suchey-Brooks (Katz and Suchey, 1986; Suchey *et al.*, 1986). Further, repeat observations were completed by four observers for the entire Balkan sample. American male (n=1,560) and female (n=518) pubic symphyses were scored in the manner of Todd (1920 and 1921). The American data were converted from the Todd ten-phase system to the Suchey-Brooks six-phase system, as recommended by Katz and Suchey (1986) for comparative purposes.

First, the affect of inter-observer variation on the reliability of estimating age-at-death parameters from the pubic symphyses is investigated. Pearson's *r* correlation coefficients among

observers for the Todd system are all significant ( $p < 0.01$ ) and strongly correlate among females. The correlation coefficients among males are more varied and not as strong as the female sample, ranging from  $r = 0.309 - 0.738$ . Correlation coefficients among observers for the Suchey-Brooks method are more consistent and higher than those for the Todd method, ranging from  $r = 0.866 - 0.939$  among females and from  $r = 0.710 - 0.844$  among males. Wilcoxon signed ranks tests demonstrate significant differences among observers for both methods.

Second, population variation in the aging processes of American and East European populations is tested using proportional odds probit regression. An analysis of deviance is calculated using an improvement chi-square to test the adequacy of the model. No significant association between the aging process of pubic symphyses and population is found ( $df = 1$ , *chi-square likelihood ratio* = 3.209,  $p = 0.10$ ). However, when males and females are treated separately, there is a significant association among females and the population ( $df = 1$ , *chi-square likelihood ratio* = 15.071,  $p = 0.001$ ).

Finally, a Bayesian statistical analysis is utilized to establish accurate age parameters. The ages-of-transition for each phase are calculated using an unrestrictive cumulative probit model for the Balkan males and the log-age cumulative probit model for the Balkan females. The probability density functions (PDF) for the posterior distributions of age at each symphyseal phase are calculated. The age estimates are based on the calculated age distribution from the Gompertz-Makeham hazard analysis and the ages-of-transition. To estimate the age-at-death for an individual, the *highest posterior density regions* for each Symphyseal phase is calculated and four different regions are provided (95%, 90%, 75%, and 50%).

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## LIST OF ABBREVIATIONS

|        |                                                           |
|--------|-----------------------------------------------------------|
| ANOVA  | Analysis of Variance                                      |
| BiH    | Bosnia-Herzegovina                                        |
| FAC    | Forensic Anthropology Center, The University of Tennessee |
| FDB    | Forensic Data Bank, The University of Tennessee           |
| GM     | Gompertz-Makeham Hazard Model                             |
| ICC    | International Criminal Court                              |
| ICMP   | International Commission for Missing Persons              |
| ICRC   | International Committee for the Red Cross                 |
| ICTY   | International Criminal Tribunal for the Former Yugoslavia |
| ICTR   | International Criminal Tribunal for Rwanda                |
| JV     | Yugoslav National Army                                    |
| KLA    | Kosovo Liberation Army                                    |
| KM     | Kaplan-Meier Survivorship Model                           |
| MLE    | Maximum Likelihood Estimate                               |
| MNI    | Minimum Number of Individuals                             |
| NATO   | North Atlantic Treaty Organization                        |
| OSCE   | Office for Security and Cooperation in Europe             |
| PDF    | Probability Density Function                              |
| PHR    | Physicians for Human Rights                               |
| TPO    | Trans-Pacific Organization                                |
| UN     | United Nations                                            |
| UNMIK  | United Nations Mission in Kosovo                          |
| UNAMIR | United Nations Assistance Mission in Rwanda               |
| UT     | The University of Tennessee                               |
| VRS    | Bosnian Serb Army                                         |

## CHAPTER 1

### INTRODUCTION

#### The Importance of Demographic Profiles in Human Rights Cases

Forensic anthropologists play a leading role in collecting and analyzing evidence in human rights cases. Primary among the various tasks performed by anthropologists is the creation of victim demographic profiles. Specifically, this evidence is critical in the prosecution of those indicted for violations of international humanitarian law, as the demography of victims provides evidence of the types of crimes committed, as well as the overall pattern of crimes. It is important to accurately determine the age and sex of victims to aid in identification. Equally important is determining the circumstances leading to death, such as whether the victims were civilians or military combatants. The case of *The Prosecutor of the Tribunal against Radislav Krstic* (Case No. IT-98-33) underscores the importance of this type of evidence. In this case, the defense argued that during the conflict in Bosnia only enemy soldiers were targeted, not the elderly, women and children, or non-combatants. The indictment against Krstic alleged:

“...units of the Drina Corps of the Bosnian Serb Army (VRS) shelled the Srebrenica ‘safe area’ and ...either expelled or killed most of the members of the Bosnian Muslim population of the Srebrenica enclave. As a result of these actions, VRS forces virtually eliminated the presence of any Bosnian Muslims in the Srebrenica enclave area, thus continuing an ethnic cleansing campaign which had begun in the Spring of 1992”.  
[Case fact index, ICTY, United Nations]

Krstic had ordered the attack on Srebrenica, the greatest massacre of the Balkan genocide, which resulted in the disappearance and murder of an estimated 7,000 to 8,000 men in a four day period. Krstic was convicted and sentenced to forty-six years of imprisonment for genocide, crimes against humanity, and violations against the laws or customs of war.

The Krstic case was a landmark court case because it was the first conviction of genocide in Europe and relied heavily on forensic evidence and the work of anthropologists. During the Krstic trial, the need for population-specific aging standards and improved identification methodology became apparent. The methods used to construct the demographic profiles of victims based on American and Balkan reference samples were questioned in court. The defense team questioned the anthropological expert witness (Baraybar in courtroom testimony of the *Prosecutor v. Radislav Krstic* May 30, 2000) as to why American (Iskan et al., 1984, 1985; Katz and Suchey, 1986; Suchey et al., 1986; Brooks and Suchey, 1990) and Balkan (Simmons et al., 1999) adult aging methods differ, whether the two populations age differently, and which methods are the most reliable for use in the former Yugoslavia. During trial, Krstic's defense lawyer, Tomislav Visnjic, asked the question:

"Generally speaking, bearing in mind the standard established by this investigation in 1999 and the standards that you refer to in your studies – I'm not quite sure whether they are American standards – anthropologically speaking, can it be said of the Bosnian population that they develop earlier or quicker? Or let me put it this way: What is the difference between the two standards? Is it of substantive significance?" [Court Testimony in *Prosecutor v. Radislav Krstic* May 30, 2000:44]

Visnjic asked specific questions regarding the actual ages and age-at-death estimations of the individuals in the graves. The question of the *minimum number of individuals (MNI)* was also an

important issue in the Krstic trial. Krstic was charged with not only creating mass graves, but in digging up those graves and moving the bodies to new and different locations (*secondary sites*) in order to thwart investigators. Questions were raised as to the identities of who were in the graves - whether they were civilians or military personal, fighting or captured, and their sex and ages-at-death. Consequently, much rests on the ability to correctly define the skeletal parameters of identity. The success of defining these parameters has been challenged by statistical limitations in the current methodology and a lack of diverse reference collections heightening the need for a comprehensive study based on a set of Bayesian statistical methods.

### **Population Standards in Aging Methodology**

Forensic anthropologists working in different geographic regions have applied American standards to other populations with varying success (Ferlini, 1999; Komar 2003; Baraybar and Kimmerle, 2003; Sarajlic, 2003). Consequently, the difficulty in applying one set of aging methods to diverse populations has lead to the revision of many of the American and European standards (i.e. Hanihara, 1952; Bocquet-Appel and Masset, 1982; Loth and Iscan, 1989; Zhang et al., 1989; Kemkes-Grottenthaler, 1996; Galera et al., 1998; Ferlini, 1999; Simmons et al., 1999; Hoppa, 2000; Jackes, 2000; Cho et al., 2002; Monzavi et al., 2003). For example, Ferlini (1999;296)

found that applying American standards of sexing criteria to Rwandan skulls was problematic due to differences in sexual dimorphism between the two populations:

“...in the morphological analysis, Rwandan male skulls exhibited marked frontal eminences, which are considered to be a female trait in Western skeletal samples. Additionally, craniometric analysis was applied to the skulls in question... the measurements obtained being fed into the *Fordisc* computer program, which produces a statistical probability of the sex based on the measurements taken. The results would at times contradict the morphological analysis. As a result, the morphological analysis was considered to be the more reliable method.”

Consistent with Ferlini's experience, Komar (2003) found that applying American aging standards to Bosnia was problematic due to biological variation among populations. Komar (2003;714) found that only 42.2% of the known ages from identified cases fell within the anthropological age “ranges” estimated by anthropologists working for Physicians for Human Rights in Bosnia, and that known *ante-mortem* stature fell within the estimated range in 29.4% of cases. Komar (2003;715) wrote: “...the application of standards derived from North American skeletal samples to European contexts may have contributed to the error rate reported in this study.” Komar (2003;716) acknowledged the need for research that tests population variability in her statement: “... the use of standards that were created on North American samples and have not been adequately tested on Eastern European populations...”.

While the estimated age-at-death interval was based on numerous criteria from a variety of skeletal traits, the determination of individual age parameters was not standardized among investigators. Anthropologists weighed methods differently, depending on the context or their experiences and preferences. This source of error may be overcome using Bayesian statistical

analysis to estimate age parameters (Hoppa, 2000; Boldsen et al., 2002) or with the use of multi-trait approaches that rely on statistical modeling to cumulate parameters from various techniques, such as Boldsen and co-workers (2002).

The matter of how to age skeletons and create a demographic profile of a skeletal population is not new to the field of physical anthropology, however the Krstic case was the first time this question was raised in a court of law and directly challenged the methods of forensic anthropologists. Therefore, when working with diverse populations, a highly reliable and statistically accurate model is needed.

### **Accuracy in Assessing Age-at-Death Estimation in the Former Yugoslavia**

The standard American protocol used for adult age assessment in the countries of the former Yugoslavia relies on dental metric regression coefficients (Lamendin et al., 1992) and point estimates from categorical or discrete traits (Iskan et al., 1984, 1985; Katz and Suchey, 1986; Suchey et al., 1986; Brooks and Suchey, 1990). Point estimates from categorical or phase methods consist of the mean age-at-death and 95% confidence interval around the mean of each phase. It is the accuracy of these specific methods, as applied to East European populations, that has been called into question (Komar, 2003; Simmons et al., 1999).

In the case of Bosnia, Simmons and co-workers (1999) presented a study which re-calibrated the age parameters of the Suchey-Brooks pubic symphysis and Iscan sternal rib methods for estimating age at the annual meeting of the American Academy of Forensic Sciences, entitled, *Evaluating age estimation in a Bosnian forensic population: "Age-at-Stage": via Probit*

**Analysis.** Simmons and co-workers utilized a modern Bosnian forensic sample and used probit analysis which measures the relationship between the known ages-at-death and the proportion of cases that exhibit each phase, given a particular age, by regressing phase on age. However, it has not to date been published or made available in its entirety for clarification or for peer review. Further, the age parameters provided for use to the ICTY anthropologists included only descriptive statistics (e.g. the mean age of each phase) rather than maximum likelihood or probability statistics that typically are associated with probit analysis. The continued use of the original Suchey-Brooks and Iscan methods, as well as the revised Simmons and co-author's calibration has lead to confusion about the biological and statistical variation between American and Balkan populations. Consequently, this has lead to questions about the reliability of these methods in Court as previously addressed. A comparison between these methods is further explored in the literature review of Chapter 2: *A review of previous research on aging methods*.

To assess the accuracy of the aging protocol currently used in the former Yugoslavia, the estimated anthropological age "ranges" are compared to the actual identified ages for 730 individuals identified from Kosovo (Figure 1.1). The difference between identified and estimated ages are calculated as the number of years the identified age falls in either direction above or below the estimated age "range". The known ages of 24.1% of identified cases from Kosovo fall outside of the estimated anthropological age intervals constructed by anthropologists working for the ICTY in Kosovo during the field season of 2000. As in the Komar example, the age "ranges" were not standardized, rather they were constructed by averaging the estimates of each method (i.e. rib phase and dental metrics) at the time of the initial investigation. The estimated age intervals varied in length from just under one year among infants to seventy-year intervals for

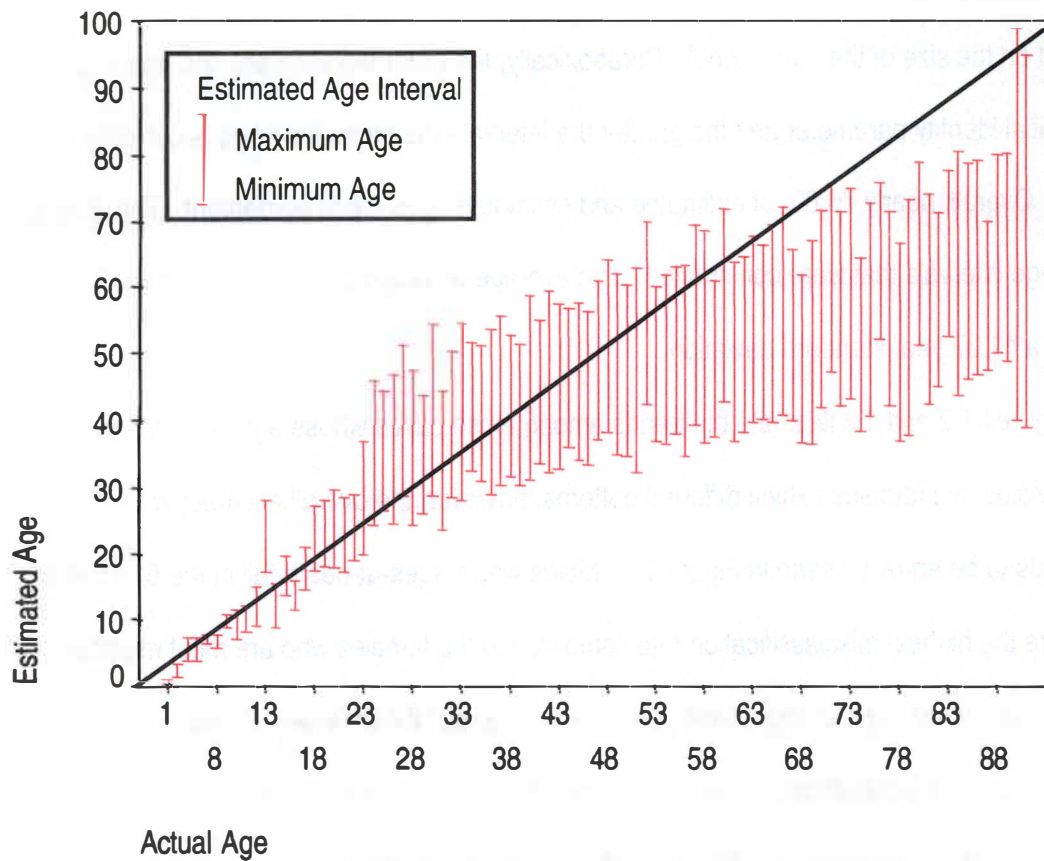


Figure 1.1. Accuracy of age estimation in Kosovo. The actual ages of identified individuals are plotted against the estimated anthropological age intervals. Note that subadults under 18 years, tend to be *under-aged*, adults under the age 50 tend to be *over-aged*, and adults over the age of 50 years tend to be *under-aged*.

incomplete adult remains. Note that there are fewer females than males in this sample, yet, there is < 2.0% difference between males and females in terms of successful age estimation.

There are also a high number of individuals (83.7%) accurately aged in spite of not knowing the sex of the individual at the time of the analysis. The accuracy of the estimated age is dependent on the size of the age "range". Paradoxically, the wider the estimate, the less useful it is as an initial identity parameter and the greater the interval - the more likely age is correctly classified. Overall, nearly 76.0% of estimated and estimated ages are in agreement. This is due to the large age intervals that were constructed. The average anthropological age interval is 23.0 years with a 11.37 year standard deviation.

Figures 1.2 and 1.3 illustrate the trends among those cases whose ages are misclassified (n=177). Males and females exhibit different patterns, however, the overall accuracy rate for both groups tends to be equal as seen in Figure 1.2. Males who's ages-at-death fall in the 51-75 year cohort score the highest misclassification rate compared to the females who are most misclassified in the >76 year cohort. The youngest individuals in the sample, those under 30 years of age, score the second highest misclassification rate, approximately 25.0%, among both males and females. Finally, misclassified cases among individuals whose sex was indeterminate at the time of autopsy are in the youngest age cohort and are biased within five years.

Eighty-five individuals (almost half of the sample, 48.3%) are misclassified by less than five years (Figure 1.3). This finding suggests that with improved methodology for constructing standard age intervals, the misclassification rate should decrease. The high misclassification rate among younger aged individuals likely results from narrow age intervals. Consequently, misclassification tends to be biased by only one to two years. Older aged adults are typically misclassified when the

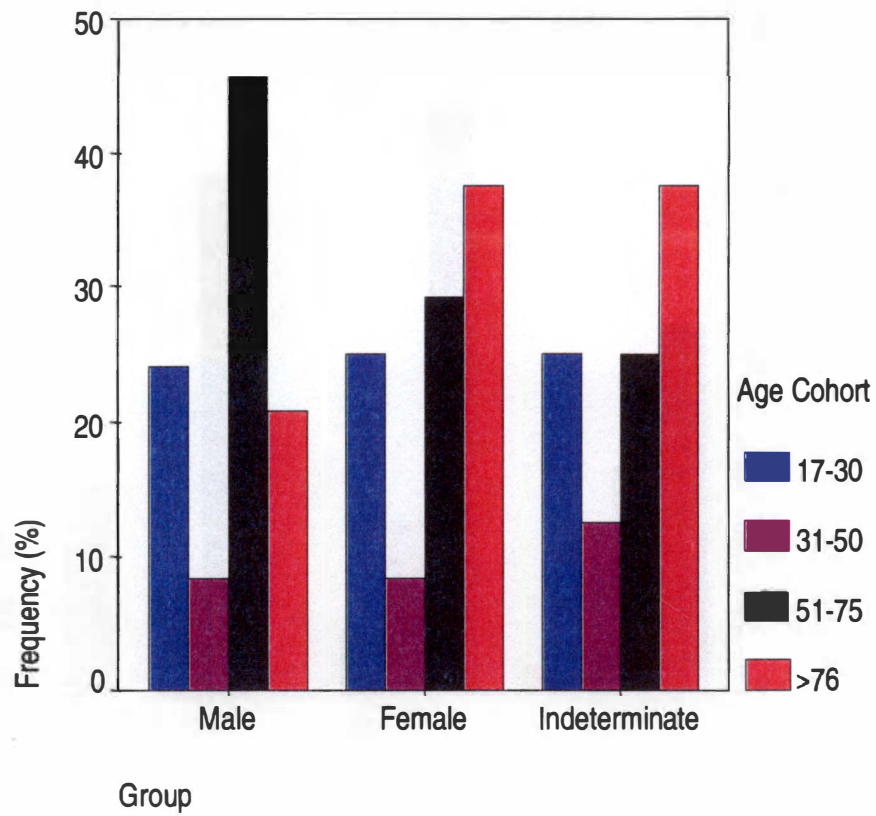


Figure 1.2. Frequency of individuals whose actual identified ages-at-death do not fall within the estimated anthropological age intervals for the Kosovar sample. Frequencies are summarized by identified age cohorts (years).

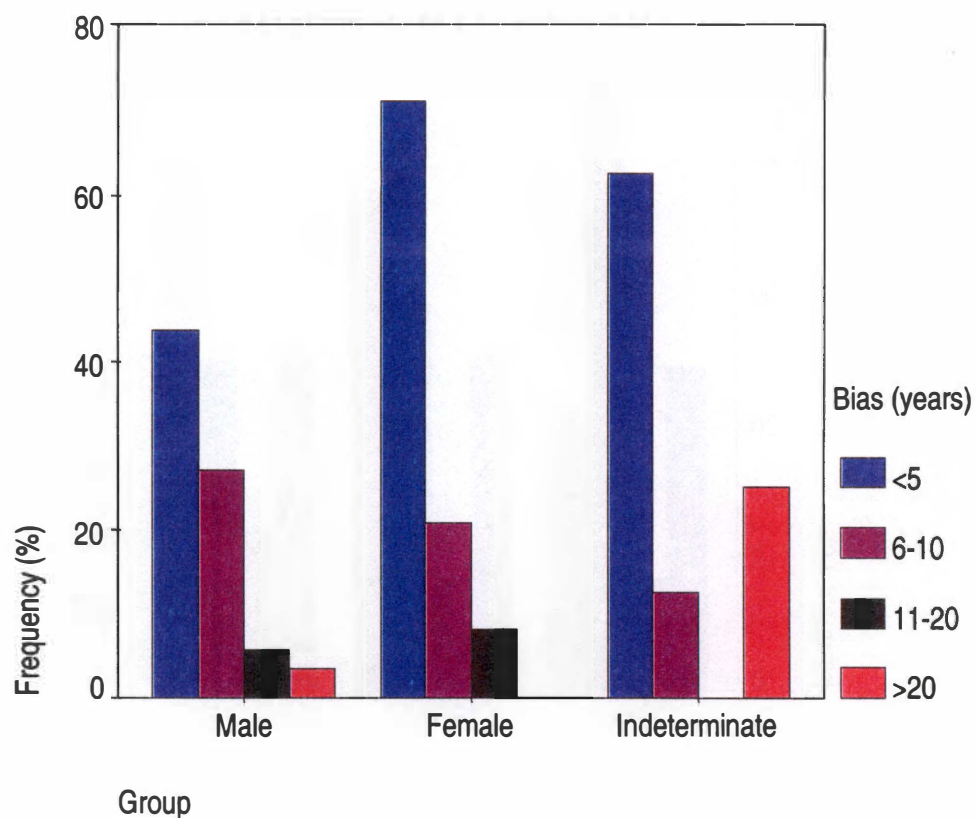


Figure 1.3. Frequency of individuals whose actual identified ages-at-death do not fall within the estimated anthropological age intervals for the Kosovar sample. Frequencies are summarized into intervals representing the number of years the estimated ages differ from the actual ages (Bias).

upper bound of the range is provided, such as 50-70 years old, rather than left open-ended, such as 50+ years.

Review of the Kosovar sample demonstrates there is greater accuracy in estimating skeletal ages-at-death than that reported by Komar (2003) for Bosnia. Further, differences between the age distributions of the Bosnian sample (based on missing persons) and the Kosovar sample (human remains actually recovered) indicate differences in the demographic profiles of missing and recovered persons. The actual ages-at-death are within the anthropological age interval in 75.9% of cases from Kosovo, compared with 42.2% of cases from Bosnia (Komar, 2003). Further, investigation into inter-observer error, population variation in the aging processes of the pubic symphysis, and differences in the age distributions of reference samples may explain these findings and increase the accuracy of aging methods for East European populations.

### **Problem Statement**

The continued use of the original Suchey-Brooks and Iscan methods, as well as the revised Simmons and co-author's calibration of these methods has raised questions about the biological and statistical variation between American and Balkan populations. Consequently, this has led to questions about the reliability of these methods in Court (*The Prosecutor of the Tribunal against Radislav Krstic*, Case No. IT-98-33). Additionally, the accuracy rates of the Bosnian data presented by Komar (2003) and the Kosovar data presented in Chapter 1 demonstrates variation in the success of current age methods for use in the Balkans.

Leaders within the ICTY such as Jose Pablo Baraybar (former Chief Forensic Anthropologist) recognized the methodological problems in assessing skeletal age and the need for published scientific studies that address these problems for the region of the former Yugoslavia. By 1996, the Office of the Prosecutor requested that the standard methods used for constructing a biological profile and determining victim identity be studied and improved for Balkan populations, thereby ensuring the most scientifically accurate and precise means of establishing the demographic profile of victims and individual identification be achieved. To fulfill that request, skeletal biosamples were routinely collected from the ICTY autopsies. Initial analysis of population variation in aging methods was undertaken by Jose Pablo Baraybar and myself during the field season of 2000. Subsequently, the Forensic Anthropology Center (FAC) at The University of Tennessee (UT) began a collaborative relationship with the ICTY and United Nations Mission in Kosovo (UNMIK) on analysis of the current methods used to construct the biological profile of victims to determine what standards should be used in the Balkans and to re-calibrate the age parameters of traditional aging methods (Kimmerle, Jantz, and Konigsberg; *in press*). Subsequently, this analysis was undertaken to assess the current methods used to construct the age-at-death profiles of victims using pubic symphyseal phase methods and to determine what age parameters should be used in the Balkans, thereby establishing new criteria for creating age-at-death intervals from skeletal remains recovered in the former Yugoslavia that meets the standards used by the ICTY for the presentation of scientific evidence in court (American case law, *Daubert v. Merrell Dow Pharmaceuticals*, 509 US 579, 1993).

The purpose of this study is to determine whether the process of aging as observed in the pubic symphysis differs among American and East European populations and consequently, what methodological standards should be applied to estimate the age-at-death parameters for

unidentified victims. To accomplish this task, three important areas of age estimation are investigated. First, the presence of inter-observer variation is investigated. Second, variation in the aging processes of East European and American populations is tested. Third, a Bayesian analysis is used to establish accurate age parameters for unidentified victims in the former Yugoslavia through the use of maximum likelihood estimates for the probability of age, given a particular phase and probability density functions for estimating the age-at-death distribution derived from the Gompertz-Makeham hazard parameters estimated from a Balkan reference sample for whom the actual ages-at-death are known.

This study impacts anthropologists who are working in the Balkans and globally by providing new and reliable aging criteria specifically for that region. It meets the requirements for the presentation of scientific evidence in court and provides insight into long-standing anthropological questions about population variation in aging. This study further contributes to our understanding of the effects of individual inter-observer variation in the formulation of new methodology and successful identification.

## CHAPTER 2

### A REVIEW OF PREVIOUS RESEARCH ON PUBIC SYMPHYSEAL AGING

The question of whether there are substantial population differences in the morphological aging process of the pubic symphysis is important since the ability to accurately estimate age hinges on the issue of what *standard* to use. The following chapter reviews research on this issue and is divided into several sections: *Pubic Symphyseal Methodology with Regard to Sex and Ethnic Differences*, *Anthropological Methods and Population Variation*, *Method Accuracy and Inter-observer Variation*. The question of reliable reference collections and a discussion of Bayesian statistical procedures used to estimate population and individual age parameters are important areas of discussion in the following chapter.

#### Pubic Symphyseal Methodology with Regard to Sex and Ethnic Differences

American standards developed for determining skeletal ages-at-death from pubic symphyseal morphology began with T. W. Todd in 1920. Todd created a morphological standard based on a ten phase categorical system for American White males (1920). The aging parameters consisted of descriptive statistical information for each phase, such as the mean age-at-death and standard deviation. This method was created from anatomical specimens (n=306 White males) from the Hamann-Todd Anatomical Collection, housed at Western Reserve University in Ohio.

Todd (1920;288) noted: "...the symphysis, once its changing features are properly understood, forms one of the most stable and satisfactory guides to the age of the individual". The consistent *metamorphosis* of the pubic symphysis, as it is related to age through the adult life span, was described in earlier anatomical literature and reviewed by Todd (i.e. Bonn, 1777; Aeby 1858; Henle, 1872; Cleland, 1889). In comparing these earlier works, Todd observed that the pubic symphysis does not grow after the age of twenty-one but that the age related changes are due to *metamorphosis* or degenerative age changes and that aging becomes unreliable after the age of forty years. Todd (1920;291) wrote: "disease, habits and use" affect the development process and "... that there are certain phases of *metamorphosis* which the bone normally undergoes and that these phases may be passed through with regularity, but we shall also see that progress may be accelerated, retarded or possibly even inhibited at any stage".

Subsequently in a 1921 publication, Todd compared the pubic aging morphology of White females (n=47) aged from 16-74 years, Black males (n=90) aged from 17-45 years, and Black females (n=22) aged from 16-45 years to determine whether individual standards were needed for each group. He noted that there were no racial differences in the aging process of the pubic symphysis but did comment on individual cases which exhibited variation from the Todd (1921) White male series. For example, individual cases among Black males, represented by the later phases, varied in age by one-two years, particularly in phase VI (Todd, 1921). Further, five cases of Black females also exhibited variation, which Todd (1921;46) wrote about in detail and described as having "irregularities". The variation he observed for Black females was similar to that of White females. Females from both groups differed from Black and White males. Accordingly, the variation that Todd observed were among males and females, not between racial

groups. However, Todd did not believe the variation was great enough to warrant separate age parameters for each group. Therefore, cases exhibiting variation were omitted from his study, a point of criticism later raised by Katz and Suchey (1986).

Differences between males and females had also been noted in the earlier anatomical literature described by Todd. For example, Aeby (1858) attributed the accelerated age changes observed for females to regular periods of "congestion" in the female pelvis or pregnancy. Todd's (1921) differences between males and females were only one to two years. In contrast to Aeby, the primary difference Todd noted was that females appeared to be delayed not accelerated in phases 3 and 6 compared to their male counterparts. In particular, the ventral aspect of the pubic symphysis was initially delayed among females but then extended in these phases one-two years longer than males. Further, Todd found no differences between males and females in phases greater than VII. As previously stated, Todd described individual cases exhibiting morphological variation however, his small comparative samples differed from the male sample in their age distributions, making it difficult to directly compare the morphology of some age cohorts. Finally, contrary to Aeby, Todd found no difference in the aging patterns of females who had given birth (parity) versus those who had not.

Since Todd's study, numerous researchers have questioned the applicability and reliability of his method (Brooks, 1955; Stewart, 1957; McKern and Stewart, 1957; Meindl et al, 1985; Katz and Suchey, 1986; Brooks and Suchey, 1990). Difficulty distinguishing between ten phases has been the primary criticism. Also questioned are the actual ages of the reference sample and that the age parameters are too low due to a reference sample that is too young and homogeneous. To overcome these problems, several new methods based on Todd's work

followed (McKern and Stewart, 1957; Acsádi and Nemeskéri, 1970; Gilbert and McKern, 1973; Hanihara and Suzuki, 1978; Meindl et al., 1985; Katz and Suchey, 1986; Brooks and Suchey, 1990).

In a recent review of the literature, Kemkes-Grottenthaler (2002) noted that most research on pubic Symphyseal aging reports substantial differences between males and females, particularly among the oldest aged individuals. Kemkes-Grottenthaler (2002;63) also suggested that age assessments for females were less reliable than those for males and suggested that if sex specific standards were not accounted for, females were "under-aged". For example, Brooks (1955) used a sample of American Indians from California to test Todd's method on a non-American population and the correlations between symphyseal phases and cranial suture closure. Brooks' sample consisted of approximately 470 skeletal remains from the University of California, Museum of Anthropology and had a mean age of less than thirty years (Brooks, 1955;569). Brooks selected ten pubic symphyses she thought represented each of Todd's phases, which became known as Brooks' model (1955;569). She applied this model to her archaeological sample and to Todd's original data and found a ten year age difference between the two methods for females and a five to eight year difference for males (Brooks 1955;569). Using regression coefficients, she reported a high association among male individuals in both samples, greater variation among females than males, and that the regression model greatly under-aged skeletons in the archaeological sample (Brooks 1955;576). Based on the regression analysis of both samples, she reported that her model performed better on Todd's original sample than the archaeological sample, as it correctly predicted age for only 54% of males and 31% females of

unknown age (Brooks 1955;581). However, by modifying the age parameters of Todd's method by 3.5 years, the percentage of correct age estimations increased 60-70% (Brooks 1955;581).

Stewart (1957) also found substantial differences between males and females and attributed those differences to parity. Gilbert and McKern (1973) reported that the morphological features of the pubic symphyses of females appeared older than males of the same age by ten years, particularly among older aged individuals. To explain differences between the sexes, they also investigated the issue of parity, but found no difference in morphology between females who had given birth versus those who had not. They attributed their findings to racial or environmental differences (e.g. nutrition) among populations.

Meindl and co-workers (1985) reported that correlations between estimated and actual ages were higher among females than males. However testing differences among males, females, and various ethnic groups through an analysis of variance, they reported no significant differences among any groups (Meindl et al., 1985;31).

In contrast, Klepinger and co-authors investigated a variety of pubic symphyseal methods, reporting that racial differences were present and that associated age parameters should be modified for various racial groups. They reported that all methods performed better for American Blacks than Whites, including the unisex and race-specific standards (Klepinger et al., 1992;767). They also found significant differences among the Suchey-Brooks and Gilbert-McKern methods for estimating age among females. Overall, there was greater accuracy for males than for females with regard to LA County sample.

Hoppa (2000) investigated the issue of sex differences using data on parity and found no association between parity and pubic symphyseal morphological changes associated with aging.

Hoppa (2000) found that the female pubic symphyses appeared younger than males after the age of forty years in several different populations but that females did not exhibit greater variation than males. Hoppa attributed these findings to differences in the aging processes of the various samples used and pointed out that one reference sample does not work for estimating age in all populations (Hoppa, 2000). More recently, Schmitt and co-workers (2002) found that age related changes were not different for males and females and also suggested that any apparent differences were likely due to different age distributions among comparative samples.

Modifications to Todd's technique, using Brooks' model (1955), developed into what is known as the Suchey-Brooks method (Katz and Suchey, 1986; Suchey et al, 1986; Brooks and Suchey, 1990). Katz and Suchey (1986) compared Todd's sample with a modern forensic sample obtained from the Los Angeles County Medical Examiner's Office. This sample consisted of 739 males. The majority of individuals from the LA Medical Examiner's Office were born in the United States, however, fifty-five were born in Europe, Asia, or South America (Katz and Suchey, 1986). Additionally, 65.8% of their sample was classified as "White" while the remaining portion of the sample included "Blacks", "Mexicans", "Orientals", and "Others" (Katz and Suchey, 1986;429). Differences among ethnic groups were noted however according to Katz and Suchey, the sample sizes were too small to fully investigate population differences. Katz and Suchey (1986;430) suggested that since the sample was a large, multi-racial sample it was applicable to any population.

Katz and Suchey (1986) found that the problems with the original Todd method were that it over estimated the ages-at-death for most individuals, particularly those under the age of forty years; did not account for individual variation; and did not accurately age older individuals. The

Suchey-Brooks six phase system for estimating age from the pubic symphysis was directly based on the Todd ten phase system, as they condensed the ten phases into six phases in an attempt to clarify differences among the stages (Katz and Suchey, 1986).

Brooks and Suchey (1990) later provided separate age parameters for males and females. Regression analysis (Katz and Suchey, 1986; Brooks and Suchey, 1990) was used to test method reliability, but not to establish age parameters. As with the Todd method, the age parameters for the six phase system were based on descriptive statistics for each symphyseal phase such as the mean age-at-death and standard deviation. Later, Katz and Suchey (1989) provided separate aging parameters for American Whites, Blacks, and Mexicans, arguing that significant racial differences exist as a result of genetic and environmental factors.

The modified Suchey-Brooks (1990) six phase system has been shown to be a more accurate estimator than the original Todd method (Gillet, 1991; Galera et al., 1995; Kemkes-Grottenthaler, 2002). While both methods are still used, the Suchey-Brooks method has become the *standard* for estimating age from the pubic symphysis internationally (e.g. the ICTY forensic anthropology protocol). However, the introduction and use of this method has not ended the controversy over age estimation in terms of variation among males, females, or various populations; inter-observer repeatability; accuracy; or method reliability.

## **Anthropological Methods and Population Variation**

In most international forensic investigations, an American based anthropological protocol is applied for the collection of skeletal data to estimate demographic profiles and to establish victim identification (i.e. Bass, 1987; Brooks and Suchey, 1990; Jantz and Moore-Jansen, 1988; Ubelaker, 1989; Buikstra and Ubelaker, 1994). Yet, a growing body of research suggests that population specific standards are warranted (e.g. Hanihara, 1952; Zhang et al., 1989; Narasaki, 1990; Ferlini, 1999; Hoppa, 2000; Katzmarzyk, 2001, 2002, and 2003; Sarajlic, 2001; Cho et al., 2002; Schmitt et al., 2002; Baraybar and Kimmerle, 2002; Komar, 2003; Alunni-Perret et al., 2003; Monzavi et al., 2003; Slaus et al., 2003; Jantz and Kimmerle, 2004). For example, Ferlini (1999;296) found that applying American *standards* of sexing criteria to Rwandan skulls was problematic due to differences in sexual dimorphism between the two populations. As reviewed in the previous section, there is even debate among researchers regarding the need for separate aging parameters among various groups within the American population, i.e. American Whites and Blacks.

The matter of population variation and the anthropological protocol is not limited to aging methods. Regional modifications to American methods for sex and stature estimation have been developed for various populations and implemented by forensic anthropologists when available. For example, the reliability of the Trotter and Gleser (1952) method for stature was reviewed and new formulae developed for populations in Korea (Choi et al., 1997), Turkey (Sagir, 2000; Duyar and Pelin, 2002; Pelin and Duyar, 2003), India (Mohanty, 1998), Spain (Muñoz et al., 2001), Portugal (De Mendonca, 2000), and the countries of the former Yugoslavia (Sarajlic, 2001; Jantz

and Kimmerle, 2004). Moreover, metric evaluation of sexual dimorphism has also lead to a variety of biostatistical studies for determining sex among populations throughout the world. Some examples include: South Africa (De Villiers, 1968; Bidmos and Asala, 2003), Nigeria (Asala et al., 1998), Croatia (Slaus et al., 2003; Jantz and Kimmerle, 2004), Scotland (Mac Laughlin and Bruce, 1985), Spain (Trancho et al., 1997), Finland (Kajanoja, 1996), France (Alunni-Perret et al., 2003), Japan (Tagaya, 1987; Iscan et al., 1995), China (Tan, 1973; Wu, 1989), India (Singh and Singh, 1972), Sri Lanka (Katzmarzyk, 2001, 2002, and 2003), and Thailand (King et al., 1998).

To account for population variation in the aging process, American methods have been revised using archaeological and non-American samples (e.g. Brooks, 1955; Pal and Tamankar, 1983; Sinha and Gupta, 1995; Kemkes-Grottenthaler, 1996; Simmons et al., 1999; Schmitt et al., 2002; Hoppa, 2002; Hoppa and Vaupel, 2002; Atmadja et al., 2004). Specific population standards for estimating age have been created for American Blacks (Todd, 1921; Iscan et al., 1987; Loth and Iscan, 1989; Katz and Suchey, 1989; Galera et al., 1998), Norway (Solheim and Sundnes, 1980), Chile (Ericksen, 1998), Japan (Hanihara, 1952; Narasaki, 1990); Iran (Monzavi et al., 2003), India (Pal and Tamankar, 1983; Sinha and Gupta, 1995), the Phillipeans (Atmadja et al., 2004), China (Zhang, 1982; Zhang et al., 1989), and the countries of the former Yugoslavia (Simmons et al., 1999; Berg et al., 2004; Kimmerle et al., 2004; Prince and Konigsberg, 2004; Stuart and Konigsberg, 2004). Population differences have also been found in age related bone remodeling rates by several researchers (Richman et al., 1979; Pollitzer and Anderson, 1989; Nelson et al., 1991; Stout and Lueck, 1995).

Most studies investigating population variation offer new aging parameters based on descriptive statistics for various geographic regions. However, several recent studies have shown

that such apparent population differences may be statistical artifacts due to differences in the age distribution of the samples compared (i.e. Hoppa 2000; Hoppa and Vaupel, 2002; Schmitt et al., 2002). For example, Hoppa compared two known samples, the Suchey-Brooks reference data from a modern forensic sample and archaeological data from the Spitalfields Cemetery in England (data attributed to Molleson et al., 1993, In: Hoppa, 2000). The distributions of age and symphyseal phase among these samples were investigated. The reference sample was significantly younger than the archaeological sample. Further, the mean ages of the six symphyseal phases differed among the two populations. Hoppa (2000;190) noted that the question was not a matter of whether one group 'under' or 'over' aged the other group, rather the whole age distribution of the sample must be taken into account. He concluded that individual variation has a large impact on establishing the demographic profile of the population and that differences appear between reference and target samples due to differences in the age distributions (Hoppa, 2000;190).

Schmitt and co-workers (2002) also applied Bayesian analysis to investigate population variation in the pubic symphysis and auricular surface. They argued that there is a need for population specific aging standards, reporting significantly different aging processes among Asian and African samples compared to groups from Europe (Schmitt et al., 2002;1207). Interestingly, the variation among different populations within Europe were consistent with one another (Schmitt et al., 2002;1207).

Simmons and co-workers (1999) revised the age parameters for the Suchey-Brooks method in an attempt to account for population variation when applying this method in Bosnia. This study utilized a modern Bosnian forensic sample (n=24 males, n=52 females) to estimate age

parameters and probit analysis which measured the relationship between the known ages-at-death and the proportion of cases exhibiting each phase, given a particular age by regressing phase on age. While the form of association used in probit analysis was based on classic regression, the age structure of the sample was not taken into account. The age parameters provided for use to the ICTY anthropologists included only descriptive statistics or "point estimates" (e.g. the mean age of each phase) rather than the maximum likelihood or probability statistics that typically are associated with probit analysis.

Methods that set age parameters based on "point estimates" establish age intervals that are constant and no report of level error (Milner et al., 2000;477). Problems with using this type of aging parameters have also been noted by Konigsberg and Holman (1999) and Konigsberg and Frankenberg (2002;307) who wrote; "Substituting point estimates neglects the fact that ages are estimated rather than known, and gives the analysis false power in tests."

Alternatively, in a Bayesian model, phase ( $i$ ) is regressed onto age ( $f$ ):  $f = a + b * i$ . Phase is assumed to be dependent on age to calculate the maximum likelihood estimate of age conditional on phase:  $\Pr(\text{age} | \text{phase})$ . Hoppa and Vaupel (2002;2) point out that the probability of being a certain age, given a particular skeletal characteristic  $\Pr(\text{age} | \text{phase})$ , must be calculated from the probability of obtaining the characteristic, given a particular age,  $\Pr(\text{phase} | \text{age})$ . Hoppa and Vaupel (2002;2) wrote; "Even the most experienced and intelligent osteologists cannot make this calculation in their heads. Pencil and paper or a computer is required, as well as information concerning  $f(a)$ , the probability distribution of ages-at-death (i.e., life span) in the target population of interest". A Bayesian approach requires the distribution of age,  $f(\text{age})$ , which must be estimated or taken from a reference sample of identified age.

The continued use of the original Suchey-Brooks age parameters, as well as the revised Simmons and co-authored parameters, have lead to confusion about the biological and statistical variation between American and Balkan populations. Consequently, this has lead to questions about the reliability of these methods in Court as previously addressed in the introductory chapter of this volume. Table 2.1 compares the two pubic symphyseal methods used in the former Yugoslavia. Note that among males, Americans have a lower mean age for phases 1-5. American females have a lower mean age in all six phases. Further, the mean age of phase 3 among Bosnian females (46.9 years) is higher than the mean age of phase 4 (44.2 years).

Questions raised during the Krstic trial focused on why American and Balkan methods differed and whether the Bosnian population aged 'quicker' than the American population. Research into similar questions, for a variety of aging methods and populations, have focused on primarily three areas. First, it has been argued that different populations grow, develop, or age differently from one another due to environmental and genetic factors, such as, the quality of nutrition, the presence of infectious diseases, general health care throughout adulthood, or population genetic history (Todd, 1920; Katz and Suchey, 1986; Galera, et al., 1995; Jackes, 2000; Kemkes-Grottenthaler, 2002). These factors are collectively referred to as *biological variation*.

Kemkes-Grottenthaler (2002) points out that apparent population differences may be the result of extrinsic factors such as material culture (i.e. health care access, nutrition, or cultural behaviors) that affect bone density or degeneration, particularly among older aged individuals. Recent research on aging suggests that the skeletal remains of females (including the pubic

**Table 2.1. Comparison of age parameters from the two pubic symphyseal methods used in the former Yugoslavia\***

| <b>American Males(n=739)</b> |                 |           |              | <b>Bosnian Males (n=24)</b> |           |              |
|------------------------------|-----------------|-----------|--------------|-----------------------------|-----------|--------------|
| Phase                        | Mean<br>(years) | Std. Dev. | 95%<br>Range | Mean<br>(years)             | Std. Dev. | 95%<br>Range |
| 1                            | 18.5            | 2.1       | 15 - 23      | 19.3                        | 2.8       | 13 - 25      |
| 2                            | 23.4            | 3.6       | 19 - 34      | 29.1                        | 10.0      | 9 - 49       |
| 3                            | 28.7            | 6.5       | 21 - 46      | 35.4                        | 11.7      | 13 - 57      |
| 4                            | 35.2            | 9.4       | 23 - 57      | 43.7                        | 14.2      | 15 - 71      |
| 5                            | 45.6            | 10.4      | 27 - 66      | 48.9                        | 11.2      | 27 - 71      |
| 6                            | 61.2            | 12.2      | 34 - 86      | 57.6                        | 15.2      | 28 - 88      |

| <b>American Females (n=273)</b> |      |      |         | <b>Bosnian Females (n=52)</b> |      |         |
|---------------------------------|------|------|---------|-------------------------------|------|---------|
| 1                               | 19.4 | 2.6  | 15 - 24 | 21.5                          | 4.0  | 14 - 30 |
| 2                               | 25.0 | 4.9  | 19 - 40 | 29.0                          | 0    | 0       |
| 3                               | 30.7 | 8.1  | 21 - 53 | 46.9                          | 13.7 | 19 - 75 |
| 4                               | 38.2 | 10.9 | 26 - 70 | 44.2                          | 13.2 | 18 - 70 |
| 5                               | 48.1 | 14.6 | 25 - 83 | 56.6                          | 14.4 | 29 - 85 |
| 6                               | 60.0 | 12.4 | 42 - 87 | 66.9                          | 13.7 | 39 - 95 |

\* Figures presented here come from the original studies (Brooks and Suchey, 1990; Simmons et al., 1999).

symphysis) may appear older in some populations due to a loss of bone mineral density (Kemkes-Grottenthaler, 2002). Kemkes-Grottenthaler (2002;64) provide a brief review of various studies that have found significant population variation in “biologically induced differences in the aging mechanisms”. These biological differences are believed to affect the metabolic rate which in turn influences the aging process (Plato et al., 1994; Belkin et al., 1998; Kemkes-Grottenthaler, 2002).

Second, apparent population differences may result as statistical artifacts depending on the reference population or particular statistical methodology that is used as previously discussed (Bocquet-Appel and Masset, 1982; Konigsberg *et al.*, 1994; Hoppa, 2000; Hoppa and Vaupel, 2001; Boldsen et al., 2002; Schmitt et al., 2002; Konigsberg and Frankenberg, 2002). Through the use of Bayesian statistical analyses, the need for population specific standards and reliable reference samples have become apparent. Researchers have argued that one reference sample does not provide accurate age parameters for populations with different age distributions (Bocquet-Appel and Masset, 1982; Hoppa, 2000; Boldsen et al., 2002; Schmitt et al., 2002). The problem with the two sets of aging criteria currently used in the former Yugoslavia is that neither take the age structure of the reference population into account, although the age distributions are substantially different from another as evidenced by the descriptive statistics listed (refer again to Table 2.1).

Hoppa and Vaupel (2002) argue that linking skeletal morphology to age is based on the reference sample and requires the distribution of age to be calculated. The issue of primary concern is the reliability of that age distribution. Numerous other researchers (Konigsberg and Frankenberg, 1992; Wood et al., 1997; Milner et al., 2000; Hoppa and Vaupel; 2002) have also argued that to achieve the most reliable distribution, the probability of age, based on a skeletal

trait, must be estimated using Bayes' Theorem. For example, Buikstra and co-workers (2003) applied "transition analysis" to estimate the age of a single individual from Pakal, Mexico. Their estimate was based on a prior taken from Seventeenth Century Danish mortuary data. They estimated age from the maximum likelihood, at 80.9 years. The older age was consistent with all other skeletal indicators, however, such an age estimate would not have been possible based on the aging parameters associated with traditional methods (Buikstra et al., 2003).

A third potential source of bias in the creation of population specific standards may be method reliability and inter-observer variation (Hoppa and Vaupel, 2002; Schmitt et al., 2002). The accuracy and reliability of aging methods vary (Schmitt et al., 2002). Further, the association between age and pubic symphyseal morphology is not linear and varies among different populations, therefore through the use of Bayes' theorem, method reliability should increase (Schmitt et al., 2002). Refer to the following section for a more thorough review method reliability and inter-observer variation.

### **Method Accuracy and Inter-observer Variation**

Method repeatability and accuracy has been widely investigated producing conflicting results due to small sample sizes and different statistical approaches (Suchey, 1979; Lovejoy et al., 1985; Meindl et al., 1985; Suchey et al., 1986; Klepinger et al., 1992; Saunders et al., 1992; Aiello and Molleson, 1993; Bedford et al., 1993; Galera et al., 1995; McKeown et al., 1997;

Buccino et al., 1999). However, most researchers have found that the level of experience is an important factor and that researchers working together should calibrate with one another.

Kemkes-Grottenthaler (2002;55-56) suggested that high correlations among aging characteristics (i.e. pubic Symphyseal phase) and age are an important measure of method reliability. Katz and Suchey (1986) report correlation coefficients between the Todd phases and age of  $r = 0.64$  for females,  $r = 0.57 - 0.85$  for males, and  $r = 0.57$  for a combined unisex sample. The correlation coefficients among the multi-component systems of McKern-Stewart (1957) and Gilbert-McKern (1973) are lower ranging from  $r = 0.37 - 0.72$ . Bocquet-Appel and Masset (1982) and Lovejoy and co-authors (1985) suggested that a method should be considered inaccurate if this correlation is less than  $r = 0.9$  or  $r = 0.7$ , respectively. Kemkes-Grottenthaler (2002;56) pointed out the problem with this type of correlation is that traits are non-linear and therefore it is statistically not informative.

Meindl and colleagues (1985) suggested using the correlation coefficients between the estimated and actual ages. They investigated a variety of aging methods including Todd (1920, 1921), McKern-Stewart (1957), Hanihara and Suzuki (1978), and Suchey-Brooks (Katz and Suchey, 1986), using the Hammond-Todd collection ( $n=96$ ). Through an three-way analysis of variance (ANOVA), the level of error in each method was measured. Meindl and co-workers (1985) found that the Todd method was the most reliable, but that all methods produced parameters that were lower than the true ages-at-death. The correlations ranged from  $r = 0.57$  for males to  $r = 0.64$  for females (Meindl et al., 1985). To increase the accuracy of Todd's method they suggested the use of a new five phase system derived from the original ten phases. The conclusions drawn by Meindl and co-workers differ from Brooks (1955), who originally tested the

accuracy of Todd's method on an archaeological sample of known age. Brooks (1955) found that Todd's method estimated age higher than the actual age.

Klepinger and co-workers (1992) tested the McKern-Stewart (1957), Gilbert-McKem (1973), and Suchey-Brooks (Katz and Suchey, 1986) aging methods using the modern forensic cases from Suchey's original collection from the Los Angeles County Medical Examiner's Office in California and from the Miami Medical Examiner's Office in Dade County, Florida. Through the use of *paired t-tests*, they measured the number of cases that fell outside of two standard deviations of the estimated age intervals (Klepinger et al., 1992;766). Overall, they reported poor accuracy and precision among all of the pubic symphyseal methods (Klepinger et al., 1992;767). However, of these methods they found that the Suchey-Brooks method performed the best since it produced the largest age intervals. Consequently, most cases fell within one standard deviation (Klepinger et al., 1992;766). Further, all methods performed better on younger aged individuals.

McKeown and researchers (1997) investigated the accuracy of 224 cases submitted to the Forensic Data Bank (FDB) at the University of Tennessee (refer to Chapter 4: *Materials and Methods* for a summary of the Forensic Data Bank). They found the correlation coefficients among the actual ages of identified individuals and the estimated anthropological ages were highest for males using the Todd method  $r=0.934$ , followed by McKern-Stewart  $r = 0.822$ , Gilbert-McKem  $r = 0.723$ , and Suchey-Brooks  $r = 0.760$  (for males). Further, accuracy increased when the methods were averaged together for multi-trait estimation, to  $r = 0.868$  (for males).

Galera and co-workers (1995) performed inter-observer tests on the Todd (1920, 1921), McKern-Stewart (1957), Acsádi and Nemeskéri (1970), Gilbert-McKem (1973), and Suchey-Brooks (Katz and Suchey, 1986) aging methods for individuals ( $n=10$ ) with known ages from the

Robert J. Terry Collection, housed at the Smithsonian Institution in Washington, D.C. For the Todd and McKern-Stewart methods, they found no agreement among any of the three observers. The most agreement they reported for the Suchey-Brooks method was that three observers agreed on 3 out of 10 pubic symphyses and two observers agreed on 5 out of 10 cases (Galera et al., 1995). In contrast, they reported more agreement among observers using the Acsádi and Nemeskéri (1970) method, where there was only one case where all three observers disagreed. Overall, agreement among observers occurred in the rank order for the Acsádi and Nemeskéri, McKern-Stewart, Suchey-Brooks, Gilbert-McKern, and finally Todd methods. Galera and co-authors attributed the order of method repeatability to the number of Symphyseal phases in each method, arguing that methods which offer a greater number of choices exhibit more observer variation. Overall, Galera and co-workers found that all of the methods were easy to apply and that no statistical differences were found among observers using a non-parametric *Kruskal-Wallis* test.

Buccino and co-workers (1999) investigated the reliability of various aging methods, the effect of inter-observer error, the role of each investigator's experience in producing accurate results. The need to incorporate a composite of many techniques in the determination of age, rather than a single method was also explored. Buccino and co-authors (1999) studied a variety of methods including dental metric techniques, phase methods based on the morphology of the fourth rib and pubic symphyseal face, and femoral cortical thickening. Their sample was a modern forensic sample (n=19) from France. Buccino and colleagues found that the level of experience among observers plays an important role in the success of accurately estimating the age-at-death. Further, they suggested that investigators practice and conduct repeatability tests. As with earlier

studies, Buccino and colleagues also noted that all aging techniques were more reliable when working with younger individuals (< 54 years). They further demonstrated that the 'Lamendin' method based on dental metrics was the best single method for age estimation, but that employing multiple methods rather than a single method increased accuracy.

## **CHAPTER 3**

### **A BRIEF OVERVIEW OF FORENSIC ANTHROPOLOGY IN HUMAN RIGHTS INVESTIGATIONS**

The enforcement of human rights requires that all individuals who perpetrate crimes against humanity be held accountable for violations through a legitimate court of justice. Therefore, physical evidence acquired through medico-legal death investigations must be systematically collected and presented before a judicial body. Anthropology plays an important role in the overall investigation, serving as the cornerstone to determining what past events transpired (Snow et al., 1984; Tedeschi, 1984; Thompsen et al., 1989; Jimenex, 1996; Primorac et al., 1996; Burns, 1998; Ferlini, 1999; Fondebrider, 2002; Haglund, 2002; Schmitt, 2002; Doretti and Snow, 2003; Koff, 1996 and 2004; Kimmerle, 2004a,b). The armed conflict in the former Yugoslavia (1991-1999), and the resulting crime scenes, provide a practical example of the usefulness and importance of anthropological evidence, such as the biological profile constructed from skeletal analysis and victim age-at-death estimates. The following chapter provides an overview of the role of anthropology in the investigation of violations of international humanitarian law and the variety of crime scenes uncovered in the region of the former Yugoslavia.

## **A Historical Perspective of International Tribunals**

Throughout American history, warfare has been bounded by cultural values. The International Committee of the Red Cross (ICRC) cites “over 500 cartels, codes of conduct, covenants and other texts designed to regulate hostilities” since the “beginning of warfare to the advent of contemporary humanitarian law” (Handbook of ICRC, 2001). The humanitarian laws that currently exist have a long history beginning with the first Geneva Convention (1864). This convention was established by the Swiss government which organized a conference to address the rights of soldiers wounded in combat, victims of conflicts, and the necessity of ensuring immunity for medical workers (Handbook of ICRC, 2001). At this summit, sixteen states adopted the first Geneva Convention which drew on the Lieber Code (Handbook of ICRC, 2001). The Lieber Code (1863), canonized the laws and customs of war, and was used to establish a code of conduct for Union soldiers fighting in the American Civil War (Handbook of ICRC, 2001). The first Geneva Convention (1864) was a multilateral attempt to enter these laws into a convention that all states would be subject to follow.

The Nuremberg Trial (1945) and Tokyo Military Tribunal (1946-1948) were the first international criminal proceedings against individuals for violations of treaty-based international law, specifically the Versailles Treaty and the Kellogg-Briand Pact. These international tribunals, established by the Allied Powers of WWII, investigated *crimes against peace* (violating international peace by initiating a war of aggression), *crimes against humanity* (i.e., murder, extermination, enslavement, deportation, inhumane treatment before or during the war), *war*

*crimes* (i.e., murder, ill-treatment or deportation of slave labor of civilians, killing hostages, plundering private or public property), and *conspiracy to wage war* (conspiracy against peace).

While the atrocities that occurred during WWII would today be classified as genocide, this term was not a legal concept until introduced by Raphael Lemkin in 1946 in his statement that; "...genocide means any of the following acts committed with the intent to destroy in whole or in part, a national, ethnical, racial or religious group..." (*United Nations, Convention on the Punishment and Prevention of the Crime of Genocide, 1946*). This convention was adopted by the United Nations (UN) in 1947 but was not ratified into law by the United States of America until 1986. Therefore, it was not until the atrocities that occurred in Rwanda (1994) and Yugoslavia (1991-1999) that official charges of genocide were formally lodged during the criminal proceedings of the International Criminal Tribunals of Rwanda (ICTR) and the former Yugoslavia (ICTY).

At time of the Nuremberg Trial, there was no international case law to draw on for rules of procedure or evidence. Therefore, the court adopted its rules of procedure and evidence from the Allied forces (United States, England, France, and Soviet Union). Many other denazification trials followed (1945-1963), including the US Military Commission, a variety of European military tribunals, and various national and supreme courts throughout Europe (Tutorow, 1986). These courts relied on the set of procedures used by the Nuremberg and Tokyo Military Tribunals, as well as some of the domestic rules established within the various European judicial systems (Tutorow, 1986).

The bulk of evidence presented during these various trials was in the form of written documents and witness testimony. However, forensic evidence of mass killings was used at the Nuremberg trial. This evidence comes from the mass grave associated with the Katyn massacre

during WWII and is summarized by Haglund (2002). Over 11,000 Polish prisoners were murdered in 1941 and buried together in a grave that was later excavated in 1943 by the German government (Fitzgibbon, 1977; Abarinov, 1993; Haglund, 2002). Evidence from the excavation and post-mortem examinations of more than 4,000 human remains was collected by the German authorities who worked to circumvent accusations that they were responsible for committing the atrocity (Fitzgibbon, 1977; Haglund, 2002). The Germans issued a report attributing the massacre to the Soviet Union. Later that year, the Soviet Army re-occupied the region and launched its own investigation that concluded the Germans were responsible for the massacre (Haglund, 2002). Ultimately, the massacre was listed in the indictment against Nazi defendants at the Nuremberg Trial; however, it was not included in the verdict due to controversy over who was responsible for the killings (Haglund, 2002). It is now known through historical documentation that the Soviet Army was in fact responsible for committing the Katyn atrocity (Fitzgibbon, 1977; Abarinov, 1993; Haglund, 2002).

Since Nuremberg, judicial bodies investigating violations of international humanitarian law have rarely been in the form of international tribunals. Notable exceptions include the ICTY, ICTR and the recently formed International Criminal Court (ICC). In 1993, the War Crimes Commission became the ICTY through UN Security *Resolution 1995/82*. Their mission was "to prosecute persons responsible for serious violations of international humanitarian law committed in the territory of Yugoslavia since 1991" (UN Security Council *Resolution 1993/827*). Specifically, this body had a mandate to investigate *grave breaches against the 1949 Geneva Convention* (Article 2), *violations of the laws or customs of war* (Article 3), *genocide* (Article 4), and *crimes against humanity* (Article 5). To date, 102 people have appeared in court proceedings before the tribunal,

fifty of whom have received trial chamber judgment including thirty-four convictions (UN, ICTY Tribunal at a Glance).

It should be noted that like the denazification trials following WWII that adopted rules of procedure from the Allied forces, the ICTY adopted its rules from NATO countries. Specifically, the rule for the presentation of scientific evidence in court was adopted from the American case, *Daubert v. Merrell Dow Pharmaceuticals* 509 US 579 (1993). This standard requires “relevance and reliability” of a scientific theory or process, inclusion of measures of precision and error in all estimates, peer reviewed standards, and wide professional acceptance of scientific methods:

“the Court recognized that general acceptance by the scientific community was a relevant factor in determining the admissibility of expert testimony based on a scientific theory or technique (113 S.Ct. at 2797). But that acceptance, the essential ingredient of the Frye Principle is not the sole test. The Court thought relevant the question whether the theory or technique can be or has been tested (113 S.Ct. at 2796-2797). Peer review and publication of the theory or process is pertinent but also not an indispensable predecessor of admissibility (641 N.E.2d 1349)”. [West Group 1999].

Some of the current methods used in forensic anthropology, including those adopted by the forensic teams working in the former Yugoslavia, have been peer reviewed and accepted by the professional community; however, levels of precision are rarely reported by investigators.

Following the formation of the ICTY, the United Nations established the International Criminal Tribunal for Rwanda (ICTR) in 1994 to investigate the genocide of Tutsis by Hutus that occurred in Rwanda earlier that year. The ICTR issued its first indictment against eight people in

1995 (UN, ICTR Tribunal at a Glance). To date, there have been twelve convictions, including Jean Kambanda, who served as Prime Minister of the Rwandan government during the genocide (UN, ICTR Tribunal at a Glance). Kambanda was the first head-of-state to be convicted of genocide, leading the way for indictments against other high ranking officials such as: General Augusto Pinochet of Chile, former President Hissein Habre of Chad, former President Slobodan Milosevic of Serbia and the former presidents of Peru; Alan Garcia, Fernando Belaunde, and Alberto Fujimori (UN, ICTR Tribunal at a Glance). In addition to the first conviction of genocide, the judicial branch of the ICTR has created a large body of case law that is being used by ICTY and will serve as a foundation for the International Criminal Court (UN, ICTR Tribunal at a Glance). The International Criminal Court (ICC) was recently established by the 120 member states of the United Nations participating in the "United Nations Diplomatic Conference of Plenipotentiaries" in 1998 (ICC at a Glance). The purpose of the ICC is to preside over gross violations of international humanitarian law globally. Burns (1998) provides a thorough review of the laws and international protocols employed by various judicial systems.

Overall, the formation of international tribunals is relatively rare as courts are more often organized in the form of domestic truth commissions, military tribunals, or are held within the standing judicial systems of various countries. A recent example of a domestic truth commission is the *Truth and Reconciliation Commission* established in Peru (2001) to investigate human rights violations, including mass atrocities and the disappearance of over 5,500 people from 1980-1992 (Fraser, 2004). The Peruvian Presidential administrations of former leaders Garcia, Belaunde, and Fujimori, as well as the activities of the political group, *The Shining Path*, are currently under

investigation for committing these atrocities (Fraser, 2004). Similar judicial examples can be found throughout the world (e.g. South Africa, Guatemala, and Panama).

### **The Use of Anthropological Evidence**

Former Argentine President Raul Alfonsin established a domestic court in 1985 that issued nine indictments against former military leaders who were responsible for the abduction and murder of more than 30,000 Argentinians during the years 1976-1982 (Snow et al., 1984; Burns, 1998). Dr. Clyde Snow, an American forensic anthropologist, provided testimony in Argentina in 1985 against the nine military leaders which was the first time an anthropologist provided evidence in an international human rights case. As a result of this trial, there were five convictions. There are several thorough reviews of this case (Snow et al., 1984; Joyce and Stover, 1991; Burns, 1998).

Snow used the story of the abduction and murder of one woman, Liliana Pereyra (Joyce and Stover, 1991), to represent the hundreds of the pregnant women who had been abducted and executed by the government. Snow was able to demonstrate the pattern and extent of crimes committed through the skeletal analysis and identification of one set of remains. This is an important example of how forensic evidence is sometimes used in cases of mass victims. Due to the large scale of an atrocity, time and efficiency often prohibit detailing of every individual death in court. The extent of the crime is accounted for through the use of summaries and demographic profiles. A similar strategy has been adopted by ICTY and ICTR.

The field work and anthropological protocol for the collection of evidence was initially established in the Balkans by Snow who was working with the non-governmental organization, Physicians for Human Rights (PHR). In 1992, Physicians for Human Rights (PHR) investigated a hospital massacre of more than 300 patients in Vukovar, Croatia. The mass grave associated with this atrocity laid the foundation for investigations in the Balkans by ICTY anthropologists. Early in this process, forensic reports were submitted by other agencies working on behalf of the Tribunal such as PHR and the American Federal Bureau of Investigation. Later, the ICTY developed its own forensic and investigative teams.

The ICTY relies heavily on the work of forensic anthropologists. Forensic teams exhumed graves and completed examinations of bodies and skeletal remains throughout Croatia, BiH and Kosovo from 1996-2001. Physical evidence enabled conclusions to be drawn regarding the extent and patterns of crimes committed and to provide the Tribunal with data to aid in the prosecution of individuals indicted for violations against international humanitarian law. Anthropological evidence, including the demographic profile and *cause of death* of victims was summarized and combined to establish the general patterns of crimes. This was similar to Snow's strategy in Argentina. The use of summaries and demographic profiles was necessary because in these investigations hundreds-of-thousands of victims were involved. There are several in depth reviews of international forensic casework and anthropology (Burns, 1998; Ferlini, 1999; Fondebrider, 2002; Haglund, 2002; Schmitt, 2002; Doretti and Snow, 2003; Koff, 1996 and 2004; Kimmerle, 2004a,b).

## **Crime Scene Variation in the Former Yugoslavia**

To discuss crime scene variation throughout the former Yugoslavia and its implications for collection sampling, a brief overview of the conflict is needed. In 1991, the provinces of Slovenia, Croatia, Kosovo, and Macedonia declared independence from Yugoslavia. Slovenia was the first province to declare independence. An armed conflict ensued as the Yugoslav National Army (JNA) entered Slovenia, resulting in a brief ten day war with minimal casualties. During this time, the JNA collaborated with ethnic Serbs' in Croatia to seize land for Serbia (Scharf, 1997;230). The Serb's attacks against the Croats, such as at the Vukovar hospital where 300 patients were killed, were the first reports of "ethnic cleansing" in the area (Scharf, 1997;230). During the first seven months of the conflict in Croatia, over 10,000 people were killed and over half a million people were forced from their homes (Power 2002:247). In September of 1991, the UN Security Council passed *Resolution 1991/713* which implemented an international arms embargo against all provinces in the region (Scharf, 1997;231). This embargo was done at the request of the Serbian government and contributed to the genocide by limiting the means Bosniaks, Croats, and Kosovars had to defend themselves against the JNA and Serbian militia forces.

Bosnia also declared independence from Yugoslavia in 1992. However, then-president, Slobodan Milosevic, refused to relinquish territory and escalated his forces to regain control of the region. Yugoslavia and Montenegro united to create the Federal Republic of Yugoslavia and remained in control of the JNA. The JNA laid siege to Sarajevo and began a campaign to "ethnically cleanse" the region of Bosniak Muslims in an effort to gain control of, and ultimately reunite with Bosnia. While officially Serbia was trying to crush the armed resistance of rebellion

forces, in fact the country's "intellectuals, musicians and professionals" were killed (Power 2002:249). Additionally, various "cultural and religious sites" were destroyed (Power 2002:249). War between the Bosnian and Croatian governments also occurred as Croatia attempted to annex part of Bosnia (Scharf, 1997;232). This same year, the UN passed Security Council *Resolution 1992/780* that called for a War Crimes Commission to investigate violations of international humanitarian law. The conflict rose to its peak following the Serbian take-overs of UN Safe Havens, Srebrenica and Zepa.

The violence, mass atrocities, and genocide continued until NATO air raids in 1994 began to force the Serbian forces to withdraw. The signing of the Dayton Peace Accord later in 1995 turned the province of Bosnia into the Federation of Bosnia-Herzegovina (BiH) consisting of three regions (Serbian, Bosniak Muslim, and Croatian Catholic components).

The genocide committed in Bosnia-Herzegovina 1992-1995 resulted in the creation of numerous mass graves, the total number is still not known. The ICTY has exhumed mass graves since 1996 but has uncovered only a fraction of the total amount believed to exist. Single mass grave sites have contained over 200 individuals. The most recent and largest grave found to date, near the town of Zvornik, is a *secondary site* associated with the Srebrenica massacre and is currently under exhumation by the Bosnian Commission for Missing Persons in cooperation with the ICMP (CNN World Report, 2003). The Srebrenica massacre of 1995 is one of the most notorious atrocities of the Balkan war. Approximately 7,000 - 8,000 men were killed in a four day period. These men were held in warehouses and then shot. Additionally, grenades and other explosives were thrown into the warehouses. Subsequently, a series of mass graves were created

with backhoes and the bodies were trucked to these remote sites. In *A Problem from Hell: America and the Age of Genocide*, Samantha Power wrote (2002, pp. 407):

“Muslim men of Srebrenica belonged to one of four categories: those alive and trying to escape through the woods; those killed on that journey; those who had surrendered to the Serbs and had already been killed; those who had surrendered and who would soon be killed.”

As the Tribunal's investigations progressed, the Serbian Army acted to thwart the investigation through the destruction of evidence. For example, it exhumed the mass graves that it had created only to rebury the remains in new, undisclosed locations in an effort to stay ahead of and avoid investigators and possible prosecution. Upon excavation of these sites, physical structures such as building materials from the warehouses were recovered in the graves. Also present were impressions in the dirt of the backhoes and machinery used to originally create the graves. Physical evidence such as this corroborated other documentary forms of evidence that the atrocities took place. The efforts to ethnically cleanse and commit genocide in Bosnia resulted in large mass graves, *secondary sites* (graves that were dug up and moved to new locations ), and the well preserved, but incomplete recovery of many individuals. Today there are still an estimated 40,000 individuals missing (Power 2000;440).

The events that occurred later in Kosovo may be contrasted to those which occurred in Bosnia. The human rights abuses and armed conflict that had occurred since Kosovo asserted its

independence escalated into an attempted genocide. Power wrote (2002:445):

“The tide turned in March 1998, when the KLA [Kosova Liberation Army] gunned down several Serbian policemen and Milosevic struck back so violently that popular support for the KLA soared. Serbian forces swept through the region of Drenica and murdered some fifty-eight relatives of KLA strongman Adem Jashari, including women and children.”

Unlike the atrocities that already occurred in Bosnia, human rights abuses and war crimes were executed differently in Kosovo, which resulted in the two countries having very different crime scenes. In Kosovo, many victims unable to take refuge in the forests or mountains were killed in or near their homes. Consequently, surviving family members, neighbors, or the Roma passing through the area often buried victims. As a result, the international community knew who many of the victims were and suspected what events had occurred. The International Red Cross (IRC) compiled a long list of the names of the disappeared. Once the conflict ended, the Transcultural Psychosocial Organization (TPO) collected ante-mortem information from survivors to create a database of missing persons to aid in victim identification. Survivors later gave permission to the TPO and ICTY to exhume and autopsy the bodies. In many cases, families wanted confirmation of identity to establish closure and some measure of justice. The ICTY also had jurisdiction to exhume the victims who were unidentified to gain a complete picture of the atrocities and alleged crimes that occurred. Many of the families who gave permission, as well as those who were still searching for the disappeared, joined archaeologists in the field to witness exhumations. Families also looked through personal objects such as clothing or jewelry to aid in the identification process.

Once the bodies were lifted from the ground and families had the opportunity for viewing, they were transported to the morgue for examination.

Crime scenes differed in Kosovo from BiH as a tactical response to the criminal forensic investigations that occurred previously. The Serbian army sought to outflank investigators by changing how victims were disposed. Instead of mass graves, victims were killed, but often not buried. Additionally, victims were abducted and transported to Serbia where they were later killed and buried in mass graves (OSCE report 1999a,b). The attempted genocide continued in Kosovo (1998-1999) as war crime investigations were on-going in Bosnia and Croatia. The Serbian army made every effort to posture that they were defending their national security through the extermination of "guerrilla terrorists" (Maass 1996) rather than committing genocide and the forced expulsion or the *ethnic cleansing* of Albanian Muslims from the Kosovar province.

By 1995, the ICTY was fully operational and issued indictments against four Serbian officers of the JNA who were responsible for the Vukovar massacre in Croatia (refer to the UN, ICTY, Tribunal at a Glance for the specific indictments and judgements). Later in 1996, PHR assisted the ICTY anthropologists in the excavation of mass graves associated with the Srebrenica massacre in Bosnia (Haglund, 2002). That same year, the International Commission for Missing Persons (ICMP) was established to aid in the location and identification of missing persons in the former Yugoslavia. Forensic investigations using anthropologists for exhumations and post-mortem examinations continued through 2001. Investigations are still underway by the Bosnian Commission (sponsored by the BiH government), ICMP and UNMIK.

## CHAPTER 4

### MATERIALS AND METHODS

A reference sample comprised of individuals with known ages-at-death from Kosovo, BiH, and Croatia (n=861) was used to determine the age structure of genocide victims in the Bayesian analysis. The Balkan skeletal data came from a subset of this reference sample. Balkan male (n=212) and female (n=84) pubic symphyses were scored in both the manners of Todd (1920, 1921) and Suchey-Brooks (Katz and Suchey, 1986; Suchey et al, 1986). Data from the Balkan sample were collected by this author (Observer 1). Additionally, repeat observations were completed by three other observers for the entire Balkan sample to test for inter-observer variation.

Additionally a comparative American sample was used. American male (n=1,560) and female (n=518) pubic symphyses were scored in the manner of Todd (1920, 1921). Data from this sample were collected by several different researchers on numerous forensic and anatomical collections and are listed in the subsequent discussion. Several cases from the Forensic Data Bank included data for both Todd and Suchey-Brooks methods. Otherwise, all of the American data was converted from the Todd ten-phase system to the Suchey-Brooks six-phase system, as recommended by Katz and Suchey (1986) for comparative purposes. A comparison of these methods revealed no difference between using the original Todd ten phases or the converted Suchey-Brooks six phases for this investigation.

The following chapter includes a description of the skeletal materials, how the samples were obtained, and a summary of the statistical methods used. First, the skeletal and demographic samples from the United States and the former Yugoslavia are discussed.

Second, the set of statistical methods used in this investigation are described in the sections; *Testing for Inter-observer Variation, Models for Determining the Ages-of-Transition, Testing for Population Variation, Bayes' Theorem, Hazard Analysis, and Estimating Individual Ages-at-Death.* In addition, American and Balkan histograms illustrating the age-at-death distributions of each sample by pubic symphyseal phase are presented in Appendix A.

### **American Skeletal Samples**

Pubic symphyseal data were collected for a large American sample (n=2,078) consisting of White and Black males (n=1,560) and females (n=518), ranging in age from 15-102 years. The age-at-death distributions of American male (Figure 4.1) and female (Figure 4.2) skeletal samples are illustrated by histograms. This sample came from numerous American forensic and anatomical reference collections including The University of Tennessee Forensic Data Bank (FDB), Gilbert-McKern skeletal data, McKern-Stewart Korean War Dead data, Los Angeles County Medical Examiner's Office forensic skeletal materials, and the Robert J. Terry Anatomical Skeletal Collection. Table 4.1 lists the frequency of males and females from each of these sources.

*Table 4.1. Sample size and sex distribution of comparative American and Balkan samples*

| Collection                            | Males (n) | Females (n) | Total (n) |
|---------------------------------------|-----------|-------------|-----------|
| <i>Balkan Reference Sample</i>        |           |             |           |
| Kosovo                                | 592       | 97          | 689       |
| BiH                                   | 55        | 1           | 56        |
| Croatia                               | 116       | 0           | 116       |
| Total (n)                             | 763       | 98          | 861       |
| <i>Balkan Skeletal Sample</i>         |           |             |           |
| Kosovo                                | 106       | 83          | 189       |
| BiH                                   | 55        | 1           | 56        |
| Croatia                               | 51        | 0           | 51        |
| Total (n)                             | 212       | 84          | 296       |
| <i>American Skeletal Sample</i>       |           |             |           |
| FDB                                   | 41        | 43          | 84        |
| Gilbert-McKern                        | 0         | 147         | 147       |
| Korean War Dead                       | 258       | 0           | 358       |
| Los Angeles Medical Examiner          | 739       | 0           | 739       |
| Robert J. Terry Anatomical Collection | 422       | 328         | 750       |
| Total (n)                             | 1,560     | 518         | 2,078     |

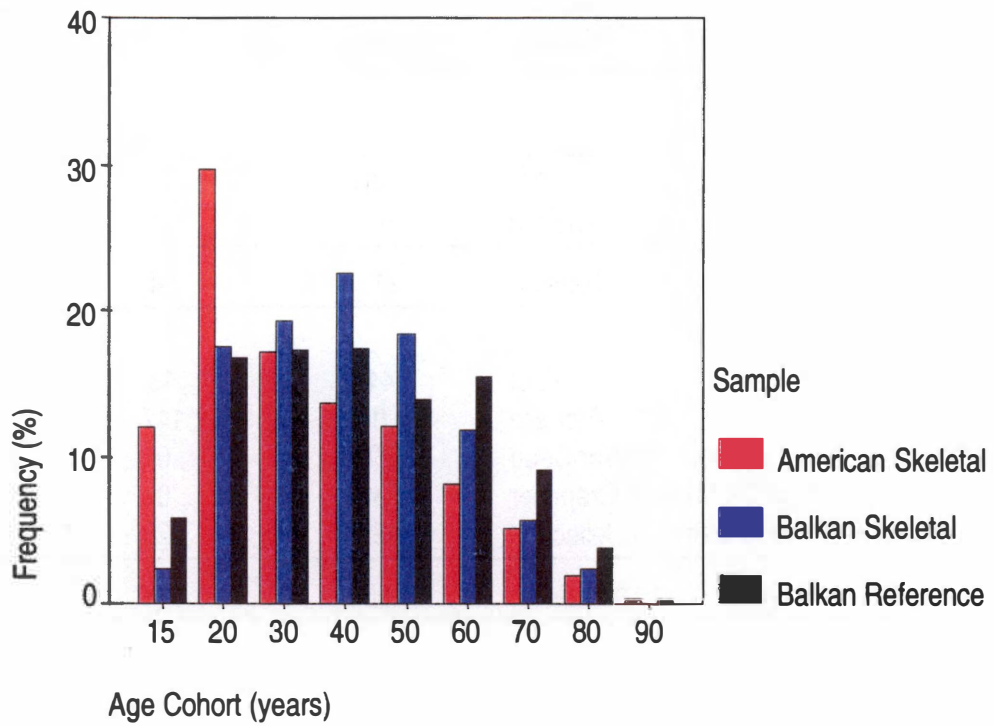


Figure 4.1. The frequency of male individuals in each age cohort represented by sample. The 15-20 year cohort is a five year interval. All other age cohorts are ten year intervals.

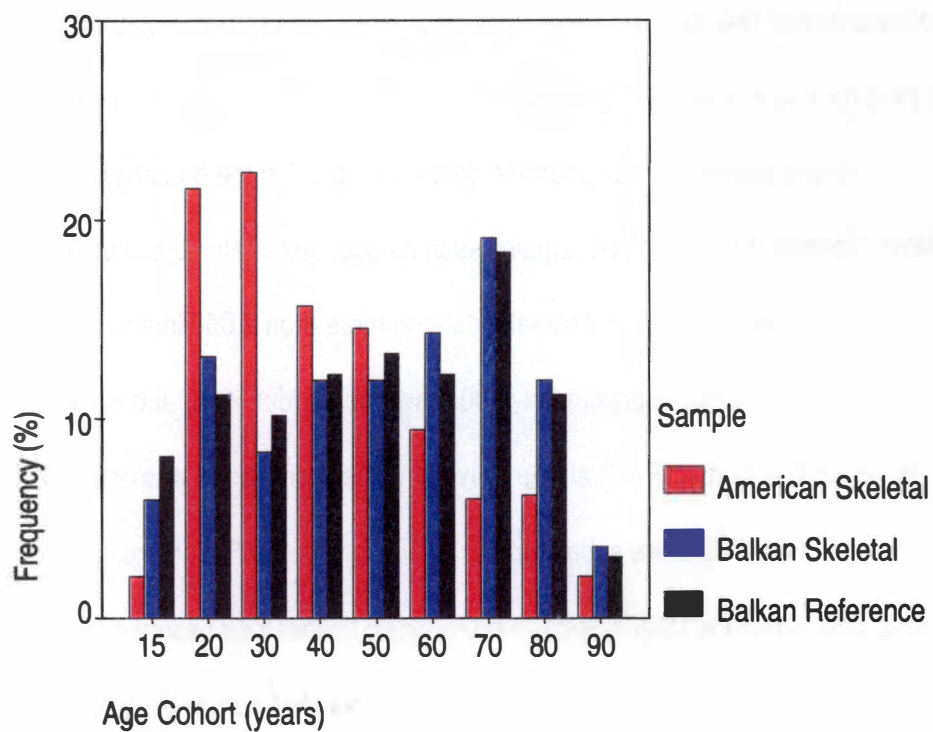


Figure 4.2. The frequency of female individuals in each age cohort represented by sample. The 15-20 year cohort is a five year interval. All other age cohorts are ten year intervals.

### Forensic Data Bank

Pubic symphyseal data from the Forensic Data Bank (FDB) consists of the known ages-at-death from eighty-four (84) forensic cases, including forty-one (41) males and forty-three (43) females, ranging in age from 17-87 years (Table 4.2). The FDB was initiated by Dr. Richard Jantz to serve as a reference collection for anthropologists and to aid in the process of determining biographical information from skeletal remains such as age, sex, stature, and ancestry. The FDB currently consists of ante-mortem and skeletal data on more than 2,000 individuals from throughout the United States, approximately 500 of whom are identified, and is maintained by the Forensic Anthropology Center (FAC) at The University of Tennessee in Knoxville (UT).

The data in the FDB were submitted by various forensic anthropologists from universities and morgues throughout the United States who routinely submit their casework to the FAC for inclusion into the FDB database. The eighty-four cases included here were selected for use based on the following criteria. First, the individuals had been positively identified and therefore the actual chronological ages of the individuals were known. Second, data for either the Suchey-Brooks or Todd methods were available.

### Gilbert-McKern Data

The Gilbert and McKern (1973) data included in this study consists of pubic symphyseal data and the known ages-at-death of White (n=137) and Black (n=10) females, ranging in age

**Table 4.2. Descriptive statistics for the American skeletal sample**

| Collection                   | Mean<br>(years) | Std. Error | 95% CI Mean | Std. Dev. | Observed<br>Range |
|------------------------------|-----------------|------------|-------------|-----------|-------------------|
| <i>Forensic Data Bank</i>    |                 |            |             |           |                   |
| Males                        | 44.8            | 3.03       | 38.6 - 50.9 | 19.399    | 19 - 78           |
| Females                      | 40.4            | 2.62       | 35.1 - 45.7 | 17.206    | 17 - 87           |
| <i>Gilbert-McKern Data</i>   |                 |            |             |           |                   |
| Males                        | 0               | 0          | 0           | 0         | 0                 |
| Females                      | 33.4            | 0.95       | 31.5 - 35.3 | 11.751    | 16 - 66           |
| <i>Korean War Dead</i>       |                 |            |             |           |                   |
| Males                        | 24.1            | 0.32       | 23.5 - 24.8 | 5.952     | 17 - 50           |
| Females                      | 0               | 0          | 0           | 0         | 0                 |
| <i>LA Medical Examiner</i>   |                 |            |             |           |                   |
| Males                        | 40.2            | 0.66       | 38.9 - 41.5 | 17.977    | 14 - 92           |
| Females                      | 0               | 0          | 0           | 0         | 0                 |
| <i>R.J. Terry Collection</i> |                 |            |             |           |                   |
| Males                        | 47.4            | 0.84       | 45.8 - 49.0 | 17.232    | 17 - 98           |
| Females                      | 52.1            | 1.10       | 49.9 - 54.3 | 19.969    | 16 - 102          |
| <i>Total</i>                 |                 |            |             |           |                   |
| Males                        | 38.6            | 0.45       | 37.7 - 39.5 | 17.939    | 18 - 98           |
| Females                      | 45.8            | 0.86       | 44.1 - 47.5 | 19.631    | 16 - 102          |
| American Sample              | 40.4            | 0.41       | 39.6 - 41.2 | 18.634    | 15 - 102          |

from 16-66 years (Table 4.2). These data were scored by Dr. Lyle Konigsberg from both casts and skeletal material housed at the National Museum of Natural History, Smithsonian Institution in Washington, D.C.

#### McKern-Stewart Korean War Dead Data

The McKern-Stewart Korean War data (McKern and Stewart, 1957) included in this study consists of pubic symphyseal data and the known ages-at-death from 358 White and Black males, ranging in age from 17-50 years (Table 4.2). These data came from American soldiers who were killed during the American-Korean War. The chronological ages-at-death were obtained from birth certificates and military records. Data were scored from casts housed at the National Museum of Natural History, Smithsonian Institution in Washington, D.C. by Drs. Danny Wescott, Nick Herrman, and Lyle Konigsberg.

#### Los Angeles County Medical Examiner Data

Pubic symphyseal data from the Los Angeles County Medical Examiner's Office came from 739 males, ages 15-92 years (Table 4.2). Fifty-five individuals (0.07%) were born in foreign countries throughout Europe, Asia or South America (Katz and Suchey, 1986). Of the American born portion of the sample, 65.8% were classified as "White" while the remaining portion of the sample included "Blacks", "Mexicans", "Orientals", and "Others" (Katz and Suchey, 1986:429). The chronological ages were all established by legal documentation of birth and death dates (Katz and

Suchey, 1986). These data were originally collected by Dr. Judy Suchey for the initial creation of the Suchey-Brooks pubic symphyseal aging method and were provided by Drs. Lyle Konigsberg and Robert Hoppa.

#### Robert J. Terry Anatomical Skeletal Collection

Data on 750 White individuals (Table 4.2), including 422 males and 328 females, came from the Robert J. Terry Anatomical Skeletal Collection, located at the National Museum of Natural History, Smithsonian Institution in Washington, D.C. The chronological ages were obtained from birth certificates or reported by family members at the time the remains were donated. These data were scored by Drs. Nick Herrman, Danny Wescott, and Lyle Konigsberg.

Beginning in 1910, Dr. Robert Terry of the Anatomy Department at Washington University, St. Louis, Missouri began collecting skeletons from cadavers. These cadavers were from Washington University's Medical School anatomy courses and were obtained from hospital and institutional morgues throughout St. Louis. In 1941 Dr. Mildred Trotter took over curation of the Robert J. Terry Anatomical Skeletal Collection and continued to add to the collection as individuals were willed to the medical school. Currently, the collection consists of 1,728 specimens.

Table 4.3 provides descriptive statistical information for each symphyseal phase for the combined American skeletal samples. Figures 4.3 and 4.4 illustrate the age distributions by phase for the American male and female samples.

**Table 4.3. Descriptive statistics for each Suchey-Brooks symphyseal phase, American sample**

| Suchey-Brooks Phase | n   | Mean Age (Years) | SE (Mean) | 95% CI (Mean Age) | Standard Deviation | Observed Age Range |
|---------------------|-----|------------------|-----------|-------------------|--------------------|--------------------|
| <b>Males</b>        |     |                  |           |                   |                    |                    |
| 1                   | 318 | 19.9             | 0.19      | 19.6 - 20.4       | 3.462              | 15.0 - 65.0        |
| 2                   | 215 | 26.6             | 0.57      | 25.5 - 27.7       | 8.364              | 17.0 - 78.0        |
| 3                   | 95  | 31.5             | 1.00      | 29.5 - 33.5       | 9.772              | 22.0 - 70.0        |
| 4                   | 386 | 40.4             | 0.65      | 39.1 - 41.7       | 12.726             | 20.0 - 88.0        |
| 5                   | 399 | 51.7             | 0.76      | 50.2 - 53.2       | 15.140             | 21.0 - 98.0        |
| 6                   | 145 | 61.3             | 1.19      | 58.9 - 63.6       | 14.361             | 23.0 - 92.0        |
| <b>Females</b>      |     |                  |           |                   |                    |                    |
| 1                   | 46  | 21.9             | 0.65      | 20.6 - 23.2       | 4.435              | 16.0 - 40.0        |
| 2                   | 79  | 31.7             | 1.19      | 29.4 - 34.1       | 10.603             | 18.0 - 74.0        |
| 3                   | 24  | 36.5             | 2.39      | 31.5 - 41.5       | 11.739             | 20.0 - 66.0        |
| 4                   | 146 | 44.3             | 1.09      | 42.1 - 46.4       | 13.223             | 22.0 - 95.0        |
| 5                   | 110 | 55.7             | 1.74      | 52.2 - 59.1       | 18.210             | 22.0 - 101.0       |
| 6                   | 113 | 59.8             | 1.94      | 56.0 - 63.7       | 20.619             | 21.0 - 102.0       |
| <b>Total</b>        |     |                  |           |                   |                    |                    |
| 1                   | 364 | 20.2             | 0.19      | 19.8 - 20.6       | 3.647              | 15.0 - 65.0        |
| 2                   | 294 | 28.0             | 0.54      | 26.9 - 29.0       | 9.286              | 17.0 - 78.0        |
| 3                   | 119 | 32.5             | 0.95      | 30.6 - 34.4       | 10.343             | 20.0 - 70.0        |
| 4                   | 532 | 41.5             | 0.56      | 40.3 - 42.6       | 12.968             | 20.0 - 95.0        |
| 5                   | 509 | 52.5             | 0.71      | 51.2 - 53.9       | 15.920             | 21.0 - 101.0       |
| 6                   | 258 | 60.6             | 1.08      | 58.5 - 62.8       | 17.360             | 21.0 - 102.0       |

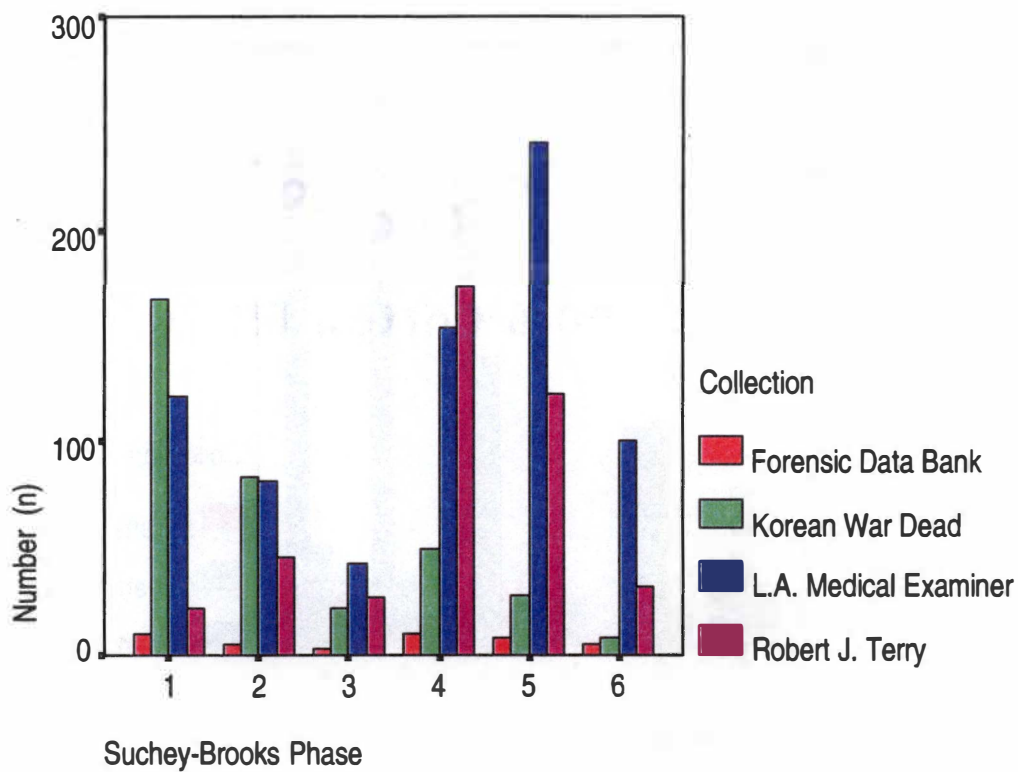


Figure 4.3. The number of cases in each Suchey-Brooks phase for American males, represented by collection.

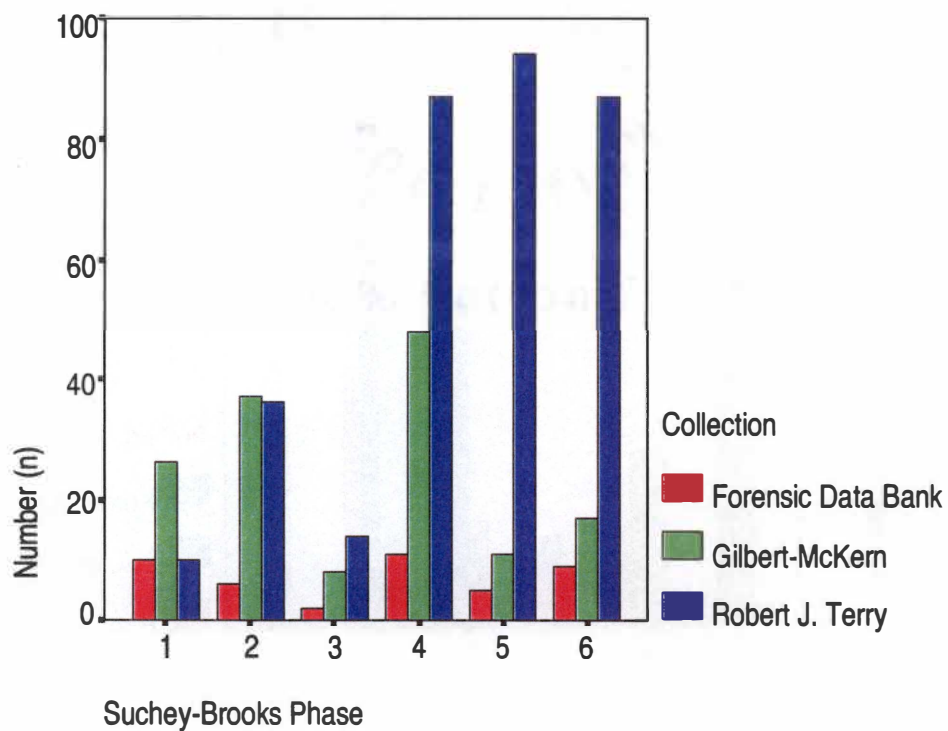


Figure 4.4. The number of cases in each Suchey-Brooks phase for American females, represented by collection.

## **Balkan Reference and Skeletal Samples**

The Baraybar Forensic Biosample Collection consists of two components, a reference sample of identified genocide victims with known ages-at-death from Kosovo, BiH, and Croatia (n=861) and a subset consisting of skeletal biosamples. As discussed in the introductory chapter of this volume, this collection was the result of forensic investigations into crimes against international humanitarian law in the former Yugoslavia by the ICTY.

Beginning in 1995, the ICTY established a protocol for its forensic investigations which outlined the anthropological methods to be used in the osteological analysis of human remains recovered through exhumations by the Tribunal's investigators. The protocol incorporated a list of biological samples, including the pubic symphysis, to be collected at the time of autopsy. The skeletal sample consists of a variety of elements from both known and unknown individuals, representing males and females of all ages from Kosovo, BiH, and Croatia. All of the biological samples were collected at the time of the ICTY autopsies from 1995-2000 and were subsequently shipped to The University of Tennessee (UT) for cleaning, morphological and metric assessment, and photography. The remains are currently housed at UT until completion of the collaborative ICTY-UT project as described in the introductory chapter of this investigation. Upon completion, these remains will be being returned for final identification, repatriation and reburial. This identification process is currently underway by such international organizations as the UNMIK and ICMP.

Over 75.0% of this collection came from Kosovo. The reason that so many positive identifications were made at the time of autopsy in Kosovo was due to the events that unfolded during the conflict that besieged that Province between 1998-1999. Unlike BiH and Croatia where numerous individuals were buried in mass graves, victims in Kosovo were often killed by Serbian authorities in or near their homes. Subsequently, family members or neighbors who returned to

the area would later bury the dead. As a result, the majority of graves exhumed and autopsied by the ICTY were of identified individuals located in single interment graves within pre-existing cemeteries. Therefore, the ICTY was able to obtain permission from families for exhumation and subsequent investigations including autopsy prior to analysis. Once the post-mortem examination was complete, remains were repatriated to families who subsequently held funerals and buried the remains.

The small number of cases from BiH (n=55) and Croatia (n=51) came from mass grave sites (refer again to Table 4.1). These remains were positively identified in the field at the time of the investigation and subsequently returned to surviving family members for burial.

#### *Balkan Reference Sample*

The distribution of known ages-at-death for the reference sample (n= 861) consists of males and females ranging in age from 15-98 years. A Bayesian analysis was used to determine the likelihood of obtaining an observed pubic symphyseal phase given a particular age if an identification is correct, versus the likelihood of it coming from the population at large (Kimmerle and Konigsberg, 2004). Of the 603 individuals from Kosovo that were tested, 510 or approximately 85.0%, had a likelihood ratio greater than 1.0, indicating that the identifications are consistent and not randomized (Kimmerle and Konigsberg, 2004). Therefore, the identified ages of the reference sample are reliable. In actuality, positive identifications are based on many factors other than symphyseal phase, therefore, this example does not imply that identifications with a likelihood ratio less than 1.0 are incorrect. Table 4.4 provides summary information on the Balkan reference and skeletal samples.

**Table 4.4. Descriptive Statistics for the Balkan reference and skeletal samples**

| Sample                                | Mean<br>(years) | Std.<br>Error | 95% CI<br>Mean | Std. Dev. | Observed<br>Range |
|---------------------------------------|-----------------|---------------|----------------|-----------|-------------------|
| <b><i>Balkan Reference Sample</i></b> |                 |               |                |           |                   |
| Males                                 | 46.40           | 0.670         | 45.0 - 47.7    | 18.523    | 15 - 90           |
| Females                               | 53.59           | 2.257         | 49.1 - 58.1    | 22.341    | 15 - 96           |
| Total                                 | 47.22           | 0.652         | 45.9 - 48.5    | 19.119    | 15 - 96           |
| <b><i>Balkan Skeletal Sample</i></b>  |                 |               |                |           |                   |
| Males                                 | 45.14           | 1.096         | 42.9 - 47.3    | 15.966    | 17 - 85           |
| Females                               | 55.16           | 2.400         | 50.4 - 59.9    | 21.996    | 17 - 96           |
| Total                                 | 47.98           | 1.070         | 45.9 - 50.1    | 18.410    | 17 - 96           |

### **Balkan Skeletal Sample**

Skeletal data were collected on 296 individuals from the Baraybar Forensic Biosample Collection. These data come from identified remains in Kosovo, BiH, and Croatia and include 212 males and eighty-four (84) females, ranging in age from 17-96 years. A histogram illustrates the distributions of Balkan males and females (Figure 4.5) by symphyseal phase. Pubic symphyseal data were collected by four observers: Erin Kimmerle, Gregory Berg, Jaime Stuart, and Debra Prince. The data used throughout this investigation were collected by Kimmerle. Data collected by the other three observers were used for comparison to test observer variation. The skeletal sample consists of data for both the corresponding right and left skeletal elements, however no difference was noted between sides, indicating the symmetrical progression of aging components between the corresponding pubic symphyses. Consequently, data from only one side (predominately the right side unless it was not observable) were used in this investigation.

Table 4.5 provides descriptive statistics for the Balkan skeletal sample by symphyseal phase. Note that among females, only one case was classified as phase 2. Consequently, the descriptive statistics associated with this phase were limited. Further implications for this finding will be discussed in *Chapter 5: Results*.

### **Pubic Symphyseal Morphology with Regard to Scoring**

Throughout this investigation, differences were noted between males and females in the morphology of the symphyseal face. Variation in pubic symphyseal morphology among males

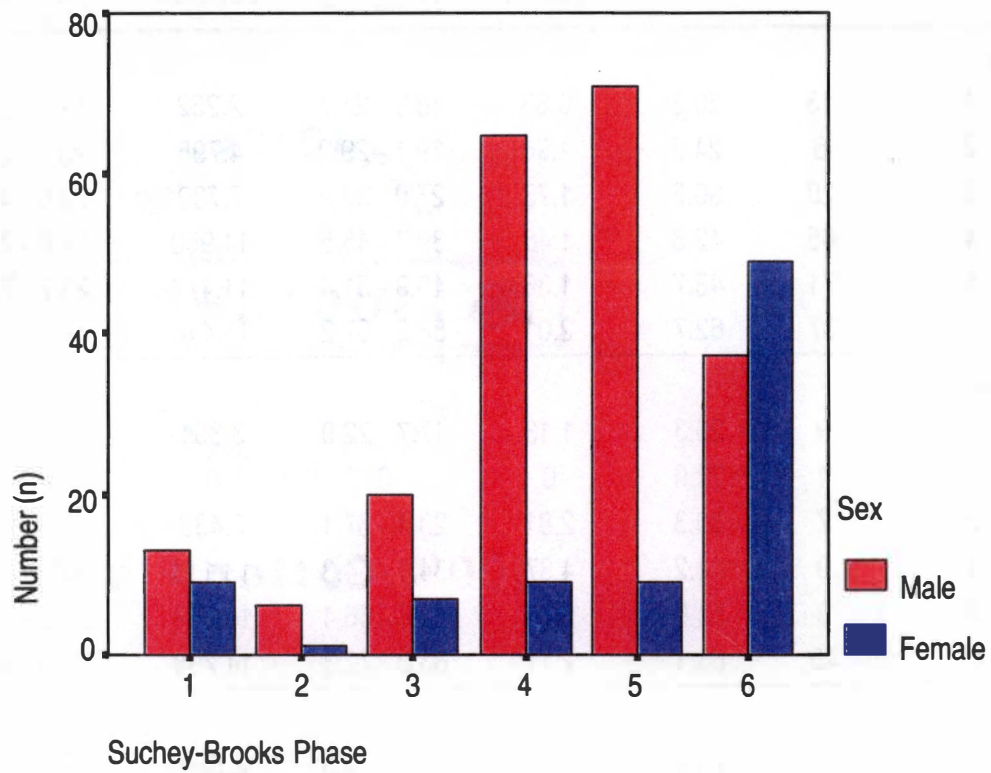


Figure 4.5. The number of cases in each Suchey-Brooks phase for Balkan males and females.

**Table 4.5. Descriptive statistics for each Suchey-Brooks symphyseal phase, Balkan skeletal sample**

| Phase          | n  | Mean Age<br>(Years) | SE<br>(Mean) | 95% CI<br>Mean Age | Standard<br>Deviation | Observed Age<br>Range |
|----------------|----|---------------------|--------------|--------------------|-----------------------|-----------------------|
| <b>Males</b>   |    |                     |              |                    |                       |                       |
| 1              | 13 | 20.3                | 0.63         | 18.9 - 21.7        | 2.252                 | 17.0 - 25.9           |
| 2              | 6  | 24.2                | 1.96         | 19.1 - 29.2        | 4.795                 | 20.0 - 33.0           |
| 3              | 20 | 30.5                | 1.73         | 27.0 - 33.9        | 7.739                 | 22.0 - 45.0           |
| 4              | 65 | 42.6                | 1.48         | 39.7 - 45.5        | 11.950                | 24.0 - 74.0           |
| 5              | 71 | 48.7                | 1.36         | 45.9 - 51.4        | 11.477                | 23.7 - 74.0           |
| 6              | 37 | 62.7                | 2.01         | 58.2 - 67.2        | 13.416                | 34.0 - 85.0           |
| <b>Females</b> |    |                     |              |                    |                       |                       |
| 1              | 9  | 20.3                | 1.13         | 17.7 - 22.9        | 3.391                 | 17.0 - 28.0           |
| 2              | 1  | 22.0                | 0            | 0                  | 0                     | 22.0                  |
| 3              | 7  | 30.3                | 2.81         | 23.4 - 37.1        | 7.432                 | 21.0 - 44.0           |
| 4              | 9  | 44.2                | 4.37         | 34.1 - 54.3        | 13.113                | 26.0 - 65.0           |
| 5              | 9  | 53.6                | 5.55         | 40.8 - 66.4        | 16.659                | 27.0 - 79.0           |
| 6              | 49 | 68.1                | 2.11         | 63.8 - 72.3        | 14.798                | 33.0 - 96.0           |
| <b>Total</b>   |    |                     |              |                    |                       |                       |
| 1              | 22 | 20.3                | 0.58         | 19.1 - 21.5        | 2.698                 | 17.0 - 28.0           |
| 2              | 7  | 23.9                | 1.69         | 19.8 - 28.0        | 4.457                 | 21.0 - 33.0           |
| 3              | 27 | 30.4                | 1.45         | 27.6 - 33.3        | 7.511                 | 21.0 - 45.0           |
| 4              | 74 | 42.8                | 1.40         | 40.0 - 45.5        | 12.013                | 24.0 - 74.0           |
| 5              | 80 | 49.2                | 1.36         | 46.5 - 51.9        | 12.133                | 23.7 - 79.0           |
| 6              | 86 | 65.8                | 1.55         | 62.7 - 68.8        | 14.390                | 33.0 - 96.0           |

and females aged 81-86 years old are illustrated in Figure 4.6. Differences appear in the presence and amount of porosity, weight, and bone density. These differences were observed consistently and do not reflect examples of isolated variation. Such differences have also been noted in throughout the literature and may provide insight into inter-observer variation (refer to Chapter 2: *A Review of Previous Research on Pubic Symphyseal Aging* for a full discussion).

### **Statistical Methodology**

The purpose of this study was to determine whether the process of aging as observed in the pubic symphysis differs among American and East European populations and consequently, what methodological standards should be applied to estimate the age-at-death parameters for unidentified victims in the former Yugoslavia. The affect of inter-observer variation on the reliability of estimating age-at-death parameters from skeletal remains was also investigated. The section, *Testing for Inter-observer Variation* describes the statistical methods used. The presence of variation in the aging processes of East European and American populations was tested. The methods used are described in the section, *Testing for Population Variation*. Finally, a Bayesian analysis was used to establish accurate age parameters for unidentified victims in the former Yugoslavia through the use of maximum likelihood estimates for the probability of age, given a particular phase and probability density functions for estimating the age-at-death distribution derived from the Gompertz-Makeham hazard parameters estimated from a Balkan reference sample for whom the actual ages-at-death were known. The statistical models used in the Bayesian analysis are described in the sections, *Models for Determining the Ages-of-Transition*, *Bayes' Theorem*, *Hazard Analysis*, and *Estimating Individual Ages-at-Death*.

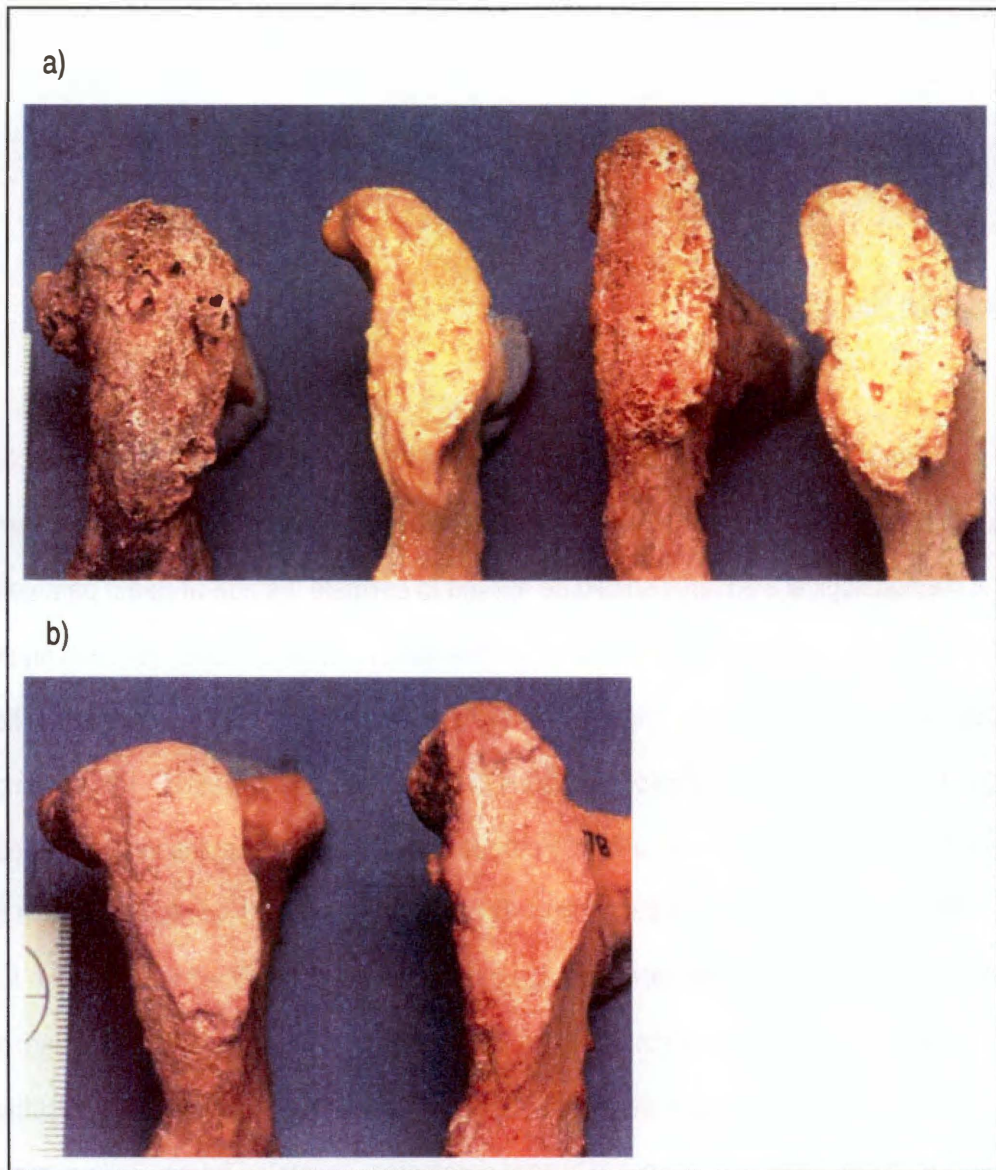


Figure 4.6. Variation in pubic symphyseal morphology; a) female ages range from 81-85 years and b) male ages range from 81-86 years.

Statistical models used to establish the ages-of-transition were run in the Fortran based program *Nphases* developed by Dr. Lyle Konigsberg (2003, <http://konig.la.utk.edu>). Descriptive statistics and general data management were run in SPSS (Systat, 1998). All other statistical procedures were run in the statistical program "R" (<http://www.r-project.org>).

### Testing for Inter-observer Variation

It should be noted that considerable effort was made prior to analysis among the four observers to calibrate with one another. Several test samples were scored and the results compared. Discussion among the observers over definitions and what traits constituted which phase was conducted. Once this initial calibration took place, no discussion was made among the observers regarding scoring so that the symphyses were scored independently.

Two non-parametric tests were used to investigate inter-observer variation, *Pearson's r correlation coefficients* and the *Wilcoxon signed ranks test*. Pearson's *r* correlation coefficients were used to investigate the presence and pattern of inter-observer variation. Pearson's *r* correlation coefficients were used as a measure of the linear association between the four observers and as a measure of how the ranked order of pubic symphyseal phases by each of the observers were related (Pagano and Gauvreau, 1993). Further, the Wilcoxon signed ranks test measures differences among observers by ranking them from low to high and placing a sign based on the direction of that difference (Zar, 1984). These ranked differences are then used to analyze the distributions of scores among observers (Zar, 1984).

### Models for Determining the Ages-of-Transition

The models used to calculate the mean, standard deviation, log-likelihood, and standard error of the ages-of-transition for each phase were the *unrestrictive cumulative probit model* for the Balkan male skeletal sample and the *log-age cumulative probit model* (also known as *proportional odds probit analysis*) for the Balkan female skeletal sample (Boldsen *et al.*, 2002). The ages-of-transition, or what Boldsen and co-workers (2002;74) refer to "*transition analysis*" is, "an estimation procedure that allows inferences about the timing of transition from one stage to another". These statistics were used to calculate the chi-square for population variation and the probability density functions for estimating individual age. Ideally, the unrestrictive cumulative probit model would have been used for both males and females however, the sample size of one ( $n=1$ ) for phase 2 among females prohibited its effective use. Unlike the unrestrictive cumulative probit model; the log age cumulative probit model assumes a constant standard deviation on the log scale for all transition distributions.

### Testing for Population Variation

A *proportional odds probit regression* analysis and an *improvement chi-square test* were used to test for variation among American and East European populations in the morphological aging process of the pubic symphysis. Proportional odds probit regression analysis was used to compare the aging processes of two populations by measuring the association between the proportion of cases that exhibited a particular pubic symphyseal phase and age for each population (Fox, 2002). The population (American or Balkan sample) was used as a dichotomous

dummy variable (0=American population, 1=Balkan population). The symphyseal phase was regressed onto the log-age, population, and the interaction between the log-age and population. The model was run twice, once with the interaction term and once without the interaction term, for the total sample, males, and females. An analysis of deviance is used to test the adequacy of the model (Fox, 2002). In the manner of Fox (2002), the analysis of deviance is calculated using an improvement chi-square based on the two models. This test compares the observed frequencies of pubic symphyseal phases from both the American and Balkan samples to ascertain whether they contained the same proportion of pubic symphyseal phases conditional on age. The degrees of freedom is calculated as the difference in the number of parameters for the two models.

### Bayes' Theorem

The probability that an individual is an exact age at the time of death,  $\Pr(\text{age} | \text{phase})$ , is estimated from a particular phase conditional on age,  $\Pr(\text{phase} | \text{age})$  using *Bayes Theorem* (Lucy et al., 1996; Boldsen et al., 2002; Konigsberg and Frankenberg, 1994 and 2002):

$$f(\text{age} | \text{phase}) = \frac{\Pr(\text{phase} | \text{age}) * f(\text{age})}{\int \Pr(\text{phase} | \text{age}) * f(\text{age})d(\text{age})}$$

The Bayesian approach to estimate age is based on "classic regression" and thereby avoids the problem of "regression to the mean" (Konigsberg and Frankenberg, 2002). The phase is assumed to be dependent on age in order to calculate the likelihood estimate of age conditional on phase:  $\Pr(\text{age} | \text{phase})$ . The distribution of age,  $f(\text{age})$ , is a probability density function (PDF)

for individuals with ages 15-100 years. The PDF is derived from a Gompertz-Makeham hazard model (Konigsberg and Frankenberg, 2002).

### Hazard Analysis

*Kaplan-Meier (KM) survivorship analysis* is a non-parametric method of calculating life tables that estimates the survival function from ages-at-death. Two parametric models, the *Exponential* and *Gompertz-Makeham (GM)* mortality models (Wood et al., 1992; Konigsberg and Frankenberg, 2002), were used to estimate the age-at-death distributions and were compared to the Kaplan-Meier survivorship curve to determine which hazard model was the most useful for estimating  $f(\text{age})$  in the Bayesian analysis. Kaplan-Meier survivorship, plotted with the Exponential and Gompertz-Makeham mortality distributions for males and females were calculated from the Balkan reference samples. The shape estimate of the Gompertz-Makeham hazard parameters were defined by three parameters ( $\alpha_1, \alpha_2, B$ ) and were expressed as:

$$h(t) = \alpha_1 + \alpha_2 \exp(Bt)$$

and

$$s(t) = \exp(-\alpha_1 / \alpha_2 (1 - \exp(-Bt)))$$

where  $h$  = the hazard rate,  $t$  = age, and  $s$  = survivorship (Konigsberg and Frankenberg, 2002).

The 95% confidence intervals were placed around the KM survivorship curves of known ages for each sample. These parameters were used to calculate the distribution of age,  $f(\text{age})$ .

### Estimating Individual Ages-at-Death

A Bayesian approach requires that the distribution of age,  $f(\text{age})$ , be estimated. This distribution is the probability density function (PDF). Therefore, the results from a Bayesian analysis are not “point estimates”, but rather the posterior distribution. As more cases become available, the posterior distribution changes. However, individual estimates can be obtained from the distribution, and are known as the *highest posterior density regions*. To estimate the age-at-death for an individual, the *highest posterior density region* for each symphyseal phase were calculated (Königsberg and Frankenberg, 2002). These age estimates were based on the GM hazard parameters and the ages-of-transition between one pubic symphyseal phase to the next. The PDF was calculated by multiplying the rate of survivorship to the hazard rate:  
 $f(\text{age})=h(\text{age})\cdot s(\text{age})$ ; where  $f(\text{age})$ =PDF,  $s(\text{age})$ =survivorship, and  $h(\text{age})$ =hazard rate.

## CHAPTER 5

### RESULTS

The purpose of this study is to determine whether the process of aging, as observed in the pubic symphysis, differs among American and East European populations and consequently what methodological standards should be applied to estimate the age-at-death parameters for unidentified victims in the Balkans. To accomplish this task, three important areas of age estimation were investigated. First, the affect of inter-observer variation on the reliability of estimating age-at-death parameters from skeletal remains was investigated. Second, the presence of biological variation in the aging processes of East European and American populations was tested. Third, a Bayesian analysis was used to establish accurate age parameters for unidentified victims in the former Yugoslavia.

The results from this investigation are presented in the following sections. First, the results from several tests that investigated the presence of observer variation and its affect on method reliability are presented in the section, *Testing for Inter-observer Variation*. Descriptive statistics and significance tests are presented including Pearson's  $r$  correlation coefficients and the Wilcoxon signed ranks test.

Second, unrestricted and log-age cumulative odds probit models are presented in the section, *Modeling Pubic Symphyseal Ages-of-Transition*, to calculate the ages-of-transition from one pubic symphyseal phase to the next. The mean ages-of-transition, standard deviations, and log-likelihoods are used to test population variation and calculate probability density plots for individual age estimation.

Third, proportional odds probit regression and an improvement chi-square test are used to test for variation among the populations and are presented in the section, *Testing for Population Variation*. This section addresses the issue of variation in the pubic symphyseal aging process of East European and American populations.

The fourth section, *Hazard Analysis*, presents two parametric models, the Exponential and Gompertz-Makeham (GM) hazard models to estimate the age-at-death distributions. The GM hazard model is shown to accurately estimate population parameters,  $f(\text{age})$ , for the Balkan reference sample.

Finally, to estimate the age-at-death for an individual, the *highest posterior density region* for each symphyseal phase is calculated. These results are presented in the section, *Estimating Individual Ages-at-Death*.

### **Testing for Inter-observer Variation, Todd Method**

Since the American data was collected using the Todd ten phase system and later reduced to the Suchey-Brooks six phase system, observer variation is tested for both methods. Table 5.1 lists the Pearson's  $r$  correlation coefficients of the Todd method among the four observers. The total Balkan sample and male and female sub-groups are analyzed separately. All of the correlations are significant at the  $p < 0.01$  level.

**Table 5.1. Inter-observer variation for the pubic symphysis, Todd method**

|                             | Observer 1 | Observer 2 | Observer 3 |
|-----------------------------|------------|------------|------------|
| <b>Total Sample (n=206)</b> |            |            |            |
| Observer 2                  | 0.785*     |            |            |
| Observer 3                  | 0.738*     | 0.316*     |            |
| Observer 4                  | 0.674*     | 0.549*     | 0.811*     |
| <b>Males (n=124)</b>        |            |            |            |
| Observer 2                  | 0.738*     |            |            |
| Observer 3                  | 0.538*     | 0.398*     |            |
| Observer 4                  | 0.493*     | 0.309*     | 0.735*     |
| <b>Females (n=82)</b>       |            |            |            |
| Observer 2                  | 0.843*     |            |            |
| Observer 3                  | 0.929*     | 0.827*     |            |
| Observer 4                  | 0.906*     | 0.812*     | 0.906*     |

\* Correlation is significant at the 0.01 level.

Correlation coefficients ranged from  $r = 0.316 - 0.811$  for the total sample, from  $r = 0.309 - 0.738$  among the male subgroup, and from  $r = 0.812 - 0.906$  among the female subgroup. Note that the correlations are the strongest among females.

Table 5.2 presents the results of the Wilcoxon signed ranks test. Observer 3 is significantly ( $p < 0.05$ ) different from the other three observers. Observer 4 is also marginally significantly different from observers 1 and 2 and highly significantly different from observer 3. The two observers who appear to be in agreement, with no statistical differences among their scores, are observers 1 and 2. Therefore, out of four observers only two are statistically consistent.

**Table 5.2. Wilcoxon signed ranks test statistics, Todd method**

|             | Obs. 1-2 | Obs. 1-3 | Obs. 1-4 | Obs. 2-3 | Obs. 2-4 | Obs. 3-4 |
|-------------|----------|----------|----------|----------|----------|----------|
| Z           | -0.791** | -4.828*  | -1.995*  | -4.468*  | -1.907*  | -3.906** |
| Asymp. Sig. | 0.429    | <0.001   | 0.046    | <0.001   | 0.057    | <0.001   |

\* Based on positive ranks, \*\* Based on negative ranks.

### **Testing for Inter-observer Variation, Suchey-Brooks Method**

Table 5.3 lists the Pearson's  $r$  correlation coefficients among both methods and the actual age-at-death. The Suchey-Brooks method ( $r = 0.786$ ) has a slightly stronger correlation with age than does the Todd method ( $r = 0.751$ ) for the total sample. However, when males and females are treated separately, the Todd method has the strongest correlation to age among females ( $r = 0.818$ ).

Table 5.4 compares the pattern of observations between observer 1 and observers 2, 3, and 4 for the Suchey-Brooks method. Note that there was total agreement among all observers for phase 1. There are similar patterns for phase 6 among observers 1 and 2 and observers 1 and 3, however there are greater differences among observers 1 and 4 for this phase. In contrast, phases 4-5 show considerable variation among all observers.

**Table 5.3. Correlation coefficients (n) among estimated phase and known age**

| Method         |               | Age          | Suchey-Brooks |
|----------------|---------------|--------------|---------------|
| <i>Total</i>   | Suchey-Brooks | 0.786* (296) |               |
|                | Todd          | 0.751* (206) | 0.833* (206)  |
| <i>Males</i>   | Suchey-Brooks | 0.702* (212) |               |
|                | Todd          | 0.611* (124) | 0.679* (124)  |
| <i>Females</i> | Suchey-Brooks | 0.789* (84)  |               |
|                | Todd          | 0.818* (82)  | 0.914* (82)   |

\* Correlation is significant at the 0.01 level.

**Table 5.4. Frequency of Suchey-Brooks phases comparing Observer 1 scores to those of Observers 2-4**

|                   |    | Observer 1 |         |         |         |         |         |
|-------------------|----|------------|---------|---------|---------|---------|---------|
|                   |    | Phase 1    | Phase 2 | Phase 3 | Phase 4 | Phase 5 | Phase 6 |
| <b>Observer 2</b> |    |            |         |         |         |         |         |
| Phase 1           | 17 | 0          | 0       | 0       | 0       | 0       | 0       |
| Phase 2           | 0  | 4          | 1       | 0       | 0       | 0       | 0       |
| Phase 3           | 0  | 2          | 5       | 4       | 0       | 2       |         |
| Phase 4           | 0  | 0          | 4       | 23      | 11      | 8       |         |
| Phase 5           | 0  | 0          | 1       | 8       | 24      | 17      |         |
| Phase 6           | 0  | 1          | 1       | 4       | 7       | 63      |         |
| <b>Observer 3</b> |    |            |         |         |         |         |         |
| Phase 1           | 15 | 2          | 0       | 0       | 0       | 0       | 0       |
| Phase 2           | 0  | 4          | 0       | 0       | 0       | 0       | 0       |
| Phase 3           | 0  | 2          | 3       | 1       | 5       | 2       |         |
| Phase 4           | 0  | 0          | 4       | 26      | 8       | 8       |         |
| Phase 5           | 0  | 0          | 0       | 15      | 28      | 7       |         |
| Phase 6           | 0  | 0          | 1       | 2       | 15      | 58      |         |
| <b>Observer 4</b> |    |            |         |         |         |         |         |
| Phase 1           | 16 | 1          | 0       | 0       | 0       | 0       | 0       |
| Phase 2           | 0  | 4          | 0       | 0       | 0       | 0       | 0       |
| Phase 3           | 0  | 2          | 5       | 1       | 0       | 5       |         |
| Phase 4           | 0  | 0          | 9       | 13      | 10      | 14      |         |
| Phase 5           | 0  | 1          | 1       | 6       | 14      | 28      |         |
| Phase 6           | 0  | 1          | 2       | 3       | 4       | 66      |         |

The Wilcoxon signed ranks test for observer variation using the Suchey-Brooks method shows a slightly different pattern than that observed for the Todd method, although significant differences are again present among observers (Table 5.5). A significant difference is present among observers 1 and 2 ( $p = 0.032$ ), whereas with the Todd method no difference is noted. As with the Todd method, observer 4 significantly differs from the other three observers. Differences among observers 1 and 4 ( $p = 0.001$ ), observers 2 and 4 ( $p = 0.015$ ), and observers 3 and 4 ( $p = 0.015$ ) are evident. Observer 3 is consistent with observers 1 and 2 in that no statistical differences are noted.

Table 5.6 lists the Pearson's  $r$  correlation coefficients of the Suchey-Brooks method among the four observers. Again, the total Balkan sample and male and female subgroups are analyzed separately. All of the correlations are significant at the  $p = 0.01$  level. Correlations among observers are higher for Suchey-Brooks method than the Todd method (refer again to Table 5.1). Correlations among the total sample range from  $r = 0.787 - 0.857$ , males range from  $r = 0.710 - 0.844$  and females range from  $r = 0.866 - 0.939$ . As with the Todd method, the correlations are the strongest among females.

*Table 5.5. Wilcoxon signed ranks test statistics, Suchey-Brooks method*

|             | Obs. 1-2 | Obs. 1-3 | Obs. 1-4 | Obs. 2-3 | Obs. 2-4 | Obs. 3-4 |
|-------------|----------|----------|----------|----------|----------|----------|
| Z           | -2.141*  | -1.224*  | -3.265*  | -0.994*  | -1.812*  | -2.427*  |
| Asymp. Sig. | 0.032    | 0.221    | 0.001    | 0.320    | 0.070    | 0.015    |

\* Based on negative ranks.

**Table 5.6. Inter-observer variation for the pubic symphysis, Suchey-Brooks method**

|                       | Observer 1 | Observer 2 | Observer 3 |
|-----------------------|------------|------------|------------|
| <b>Total (n=206)</b>  |            |            |            |
| Observer 2            | 0.845*     |            |            |
| Observer 3            | 0.843*     | 0.837*     |            |
| Observer 4            | 0.787*     | 0.857*     | 0.821*     |
| <b>Males (n=124)</b>  |            |            |            |
| Observer 2            | 0.765*     |            |            |
| Observer 3            | 0.771*     | 0.742*     |            |
| Observer 4            | 0.715*     | 0.844*     | 0.710*     |
| <b>Females (n=82)</b> |            |            |            |
| Observer 2            | 0.924*     |            |            |
| Observer 3            | 0.907*     | 0.935*     |            |
| Observer 4            | 0.867*     | 0.866*     | 0.939*     |

\* Correlation is significant at the 0.01 level.

### **Modeling Pubic Symphyseal Ages-of-Transition**

The unrestrictive cumulative probit model is used to calculate the mean ages-of-transition for Bosnian males. Each line in Figure 5.1 represents the normal distribution of one phase transitioning into the next. The varying dispersion of each distribution indicates that the standard deviation for each transition is not constant, reflecting the age variation among phases. The considerable overlap among the phases reflects the wide range of observed ages for each phase.

An attempt to use the unrestrictive cumulative probit model to calculate the mean ages-of-transition for Balkan females was made (Figure 5.2). However, because there was only a one case in phase 2, the distributions involving this phase were omitted. Therefore, the log-age cumulative probit model is used to calculate the mean ages-of-transition for Bosnian females (Figure 5.3). This model produces a constant standard deviation in the log scale.

Table 5.7 provides descriptive statistics, including the mean ages-of-transition, standard deviations, and standard errors for each transitional distribution among the total sample and males, using the unrestrictive cumulative probit model.

Table 5.8 provides descriptive statistics, including the mean ages-of-transition, standard deviations, and standard errors for each transitional distribution among the females using the log-age cumulative probit model. Note that the parameters are in log-scale.

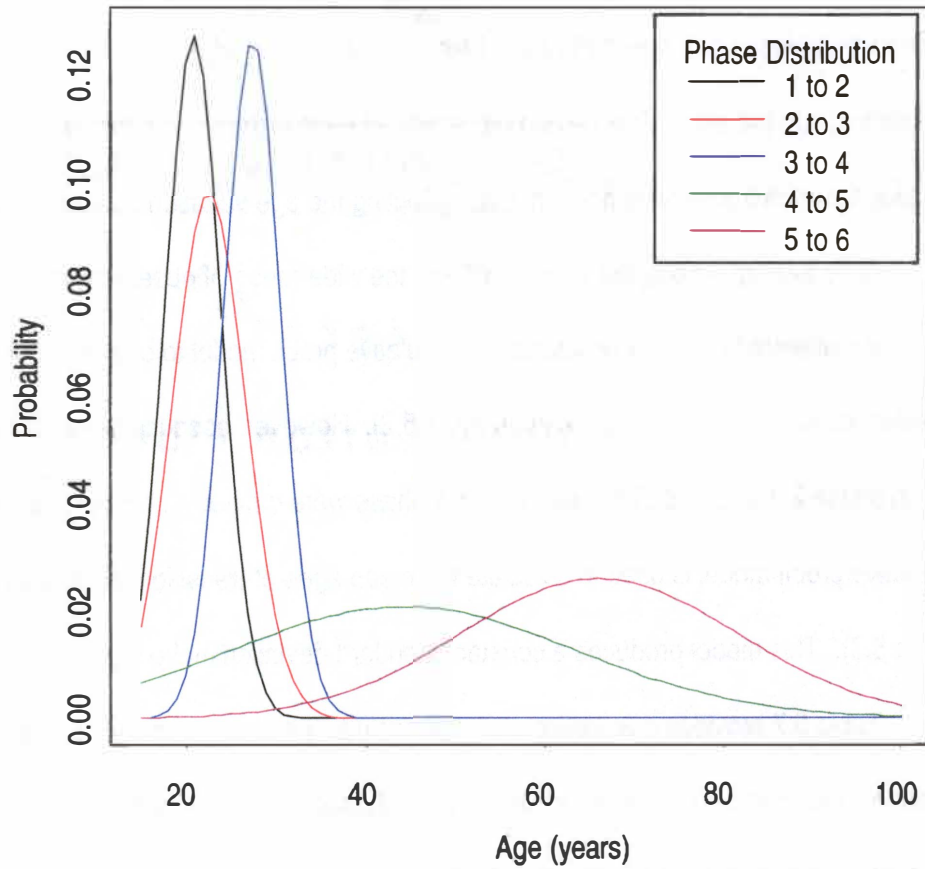


Figure 5.1. Age-of-transition distributions derived from the unrestrictive cumulative probit model for Suchey-Brooks phases among Balkan males.

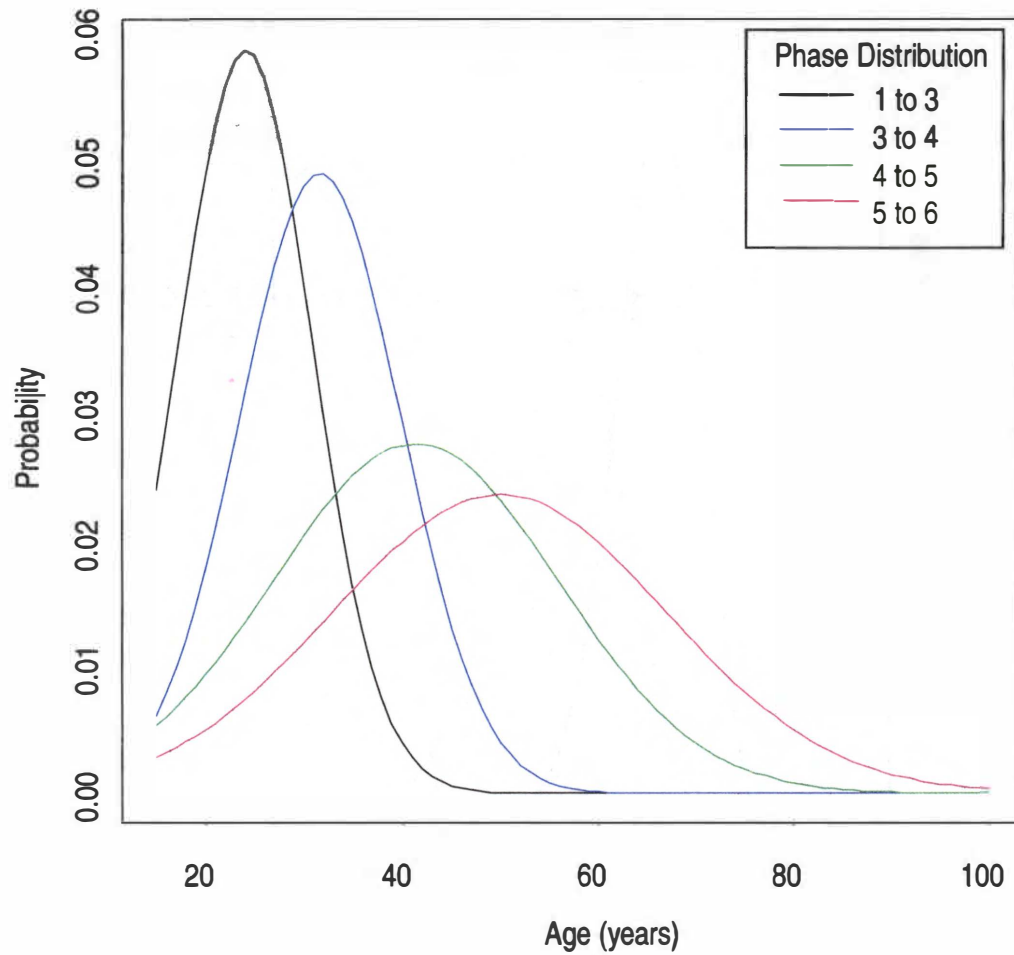


Figure 5.2. Age-of-transition distributions derived from the unrestrictive cumulative probit model for Suchey-Brooks phases among Balkan females. Note that the distribution for phase 2 to 3 is absent as a result of the small sample size of phase 2.

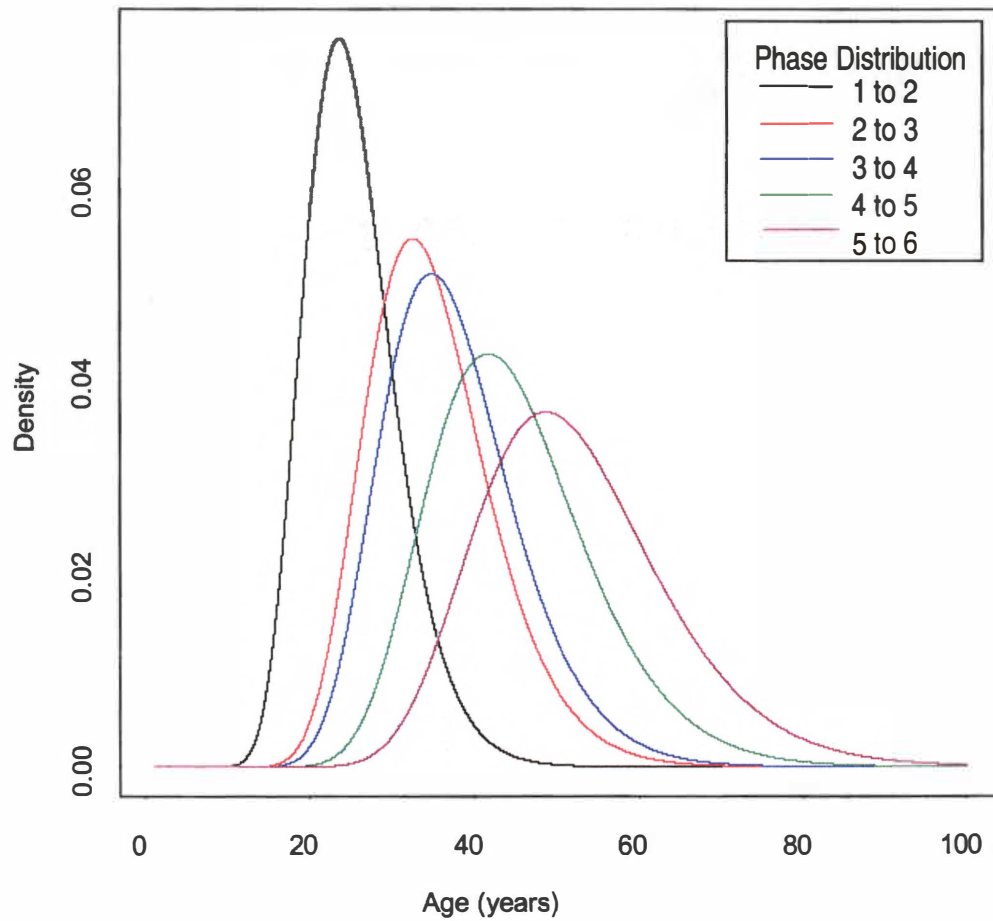


Figure 5.3. Age-of-transition distributions derived from the log-age cumulative probit model for Suchey-Brooks phases among Balkan females.

*Table 5.7. Descriptive statistics for Balkan age-of-transition distributions from one phase to the next for males and the total sample based on the unrestrictive cumulative probit model*

| Phase                    | Mean Age (Years) | SE (Mean) | Std. Dev. |
|--------------------------|------------------|-----------|-----------|
| <i>Males</i>             |                  |           |           |
| 1 to 2                   | 20.94            | 0.81      | 3.13      |
| 2 to 3                   | 22.65            | 0.86      | 4.01      |
| 3 to 4                   | 27.61            | 1.42      | 3.08      |
| 4 to 5                   | 44.33            | 1.85      | 19.16     |
| 5 to 6                   | 66.18            | 2.67      | 15.66     |
| <i>Males and Females</i> |                  |           |           |
| 1 to 2                   | 21.49            | 0.69      | 3.50      |
| 2 to 3                   | 22.99            | 0.70      | 3.97      |
| 3 to 4                   | 28.63            | 1.14      | 8.76      |
| 4 to 5                   | 43.53            | 1.51      | 17.18     |
| 5 to 6                   | 61.12            | 1.61      | 15.22     |

*Table 5.8. Descriptive statistics for Balkan age-of-transition distributions from one phase to the next for females using the log-age cumulative probit model*

| Phase          | Mean Log-Age | SE (Mean) | Std. Dev. |
|----------------|--------------|-----------|-----------|
| <i>Females</i> |              |           |           |
| 1 to 2         | 14.44454     | 1.9893    | 4.564325  |
| 2 to 3         | 15.89327     | 2.1666    | 4.564325  |
| 3 to 4         | 16.20693     | 2.2034    | 4.564325  |
| 4 to 5         | 17.02723     | 2.3080    | 4.564325  |
| 5 to 6         | 17.73458     | 2.3689    | 4.564325  |

## Testing for Population Variation

To test for population variation in the aging process, a proportional odds probit regression analysis and improvement chi-square test are used to compare the aging processes of two populations by measuring the association between the proportion of cases that exhibit a particular pubic symphyseal phase and age for each population (Fox, 2002). The population (American or Balkan sample) is used as a dichotomous dummy variable (0=American population, 1=Balkan population). The symphyseal phase is regressed onto the log-age, population, and the interaction between log-age and population. There is not a significant association between the aging process of pubic symphyses and population when testing the two populations ( $df = 1$ , *chi-square likelihood ratio* = 3.209,  $p = 0.10$ ). However, when males and females are treated separately, there is a significant association among females ( $df = 1$ , *chi-square likelihood ratio* = 15.071,  $p = 0.001$ ), as presented in Table 5.9.

*Table 5.9. Proportional odds probit model used to test population variation among American and Balkan Populations*

| Sample  | df | Likelihood Ratio | <i>p</i> |
|---------|----|------------------|----------|
| Total   | 1  | 3.209            | > 0.10   |
| Males   | 1  | 0.7428           | > 0.10   |
| Females | 1  | 15.071           | < 0.001  |

## Hazard Analysis

Survivorship analysis comparing the Exponential and GM hazard models demonstrate that the GM hazard model accurately estimates the population parameters from the Balkan reference sample. Figures 5.4 and 5.5 illustrate the survivorship from the Exponential model for Balkan males and females, respectively and are plotted against the Kaplan-Meier model. In these figures, the blue lines represent the Exponential survivorship curve. In both examples, the Exponential model does not fit.

Figures 5.6 and 5.7 illustrate the GM hazard models for Balkan males and females, respectively. In these figures, the red lines represent survivorship. As with the Exponential model, the GM hazard curve is plotted against the Kaplan-Meier model. It is demonstrated that the Gompertz-Makeham models are a good fit for both groups. The GM hazard parameters for Balkan males ( $\alpha_1 = 0.012482505$ ,  $\alpha_2 = 0.003543657$ ,  $B = 0.058074052$ ) and Balkan females ( $\alpha_1 = 0.0140656844$ ,  $\alpha_2 = 0.0003480993$ ,  $B = 0.0866711354$ ) are used to calculate the probability density function for estimating individual ages-at-death.

Figures 5.8 and 5.9 plot the same GM hazard curves, estimated from the Balkan reference sample for males and females. In these figures, the red lines represent survivorship, which is plotted against the Kaplan-Meier survivorship of the comparative American sample. These plots demonstrate that the Gompertz-Makeham models, derived from a Balkan reference sample does not estimate the distribution of the American skeletal samples.

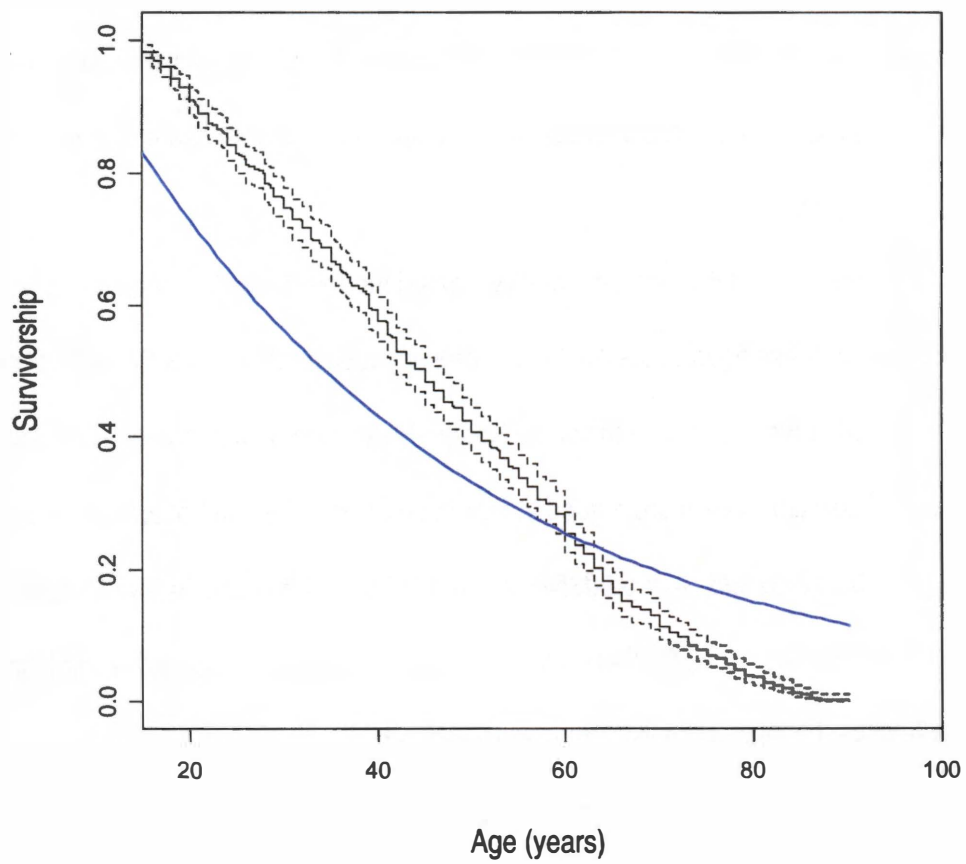


Figure 5.4. Kaplan-Meier survivorship plot for Balkan males. The blue line represents the Exponential survivorship model. Survivorship above 15 years of age.

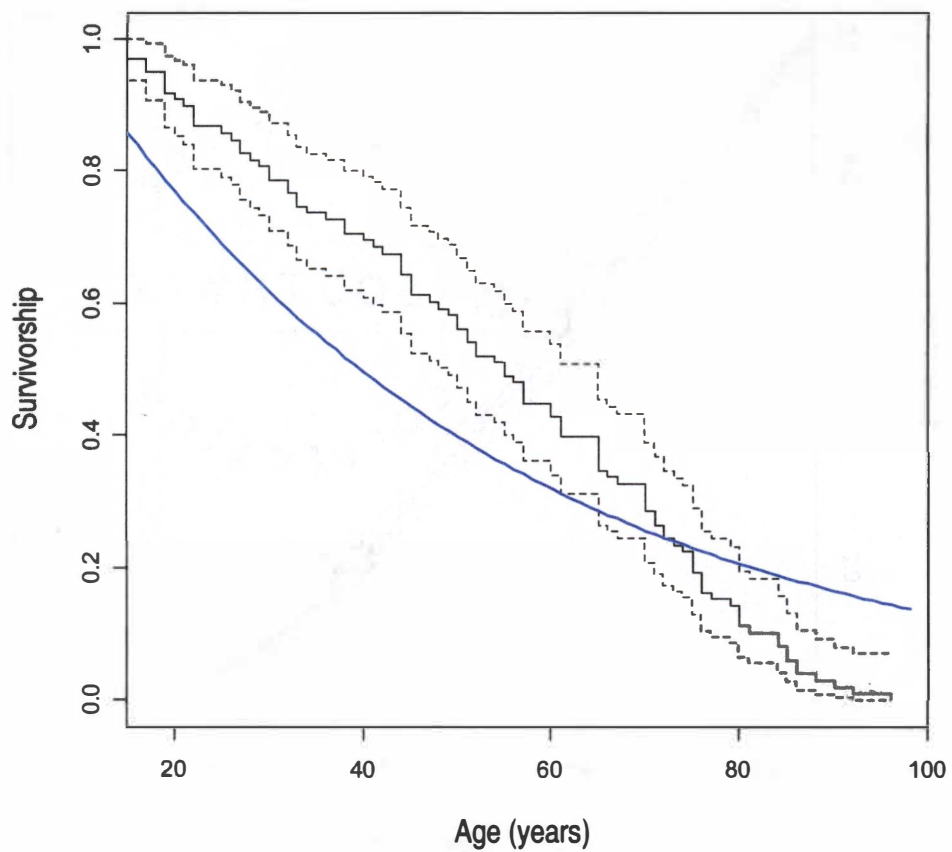


Figure 5.5. Kaplan-Meier survivorship plot for Balkan females. The blue line represents the Exponential survivorship model. Survivorship above 15 years of age.

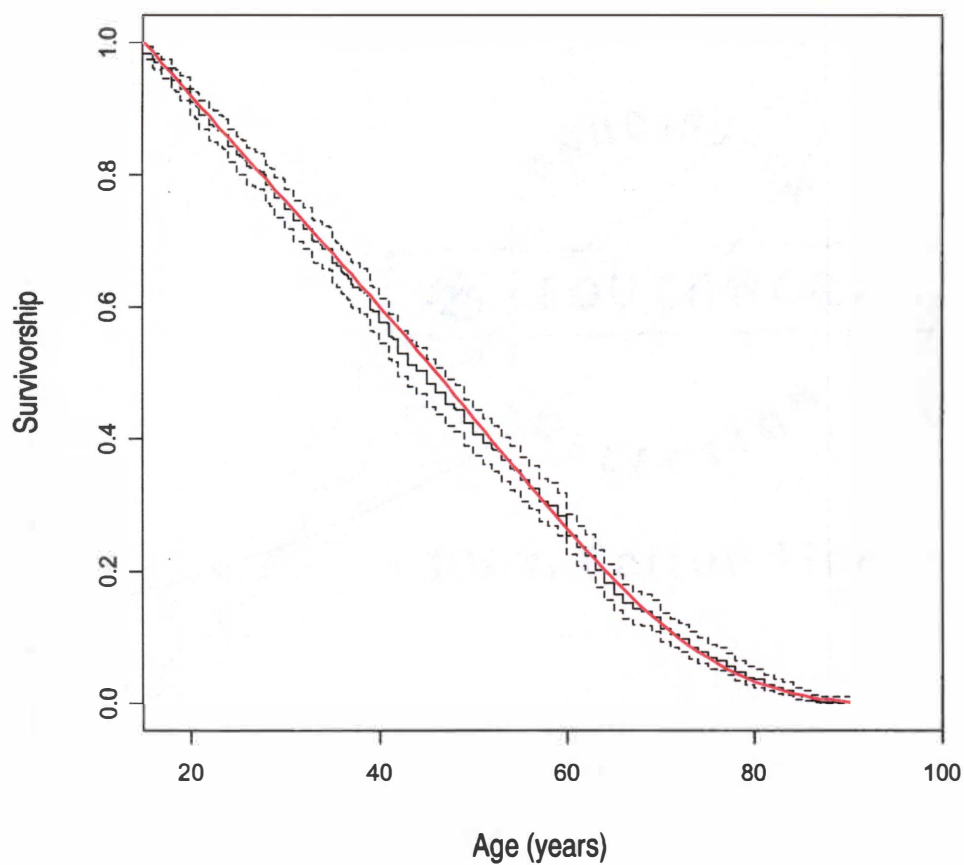


Figure 5.6. Kaplan-Meier survivorship plot for Balkan males. The red line represents the Gompertz-Makeham hazard curve, estimated from the Balkan reference sample. Survivorship above 15 years of age.

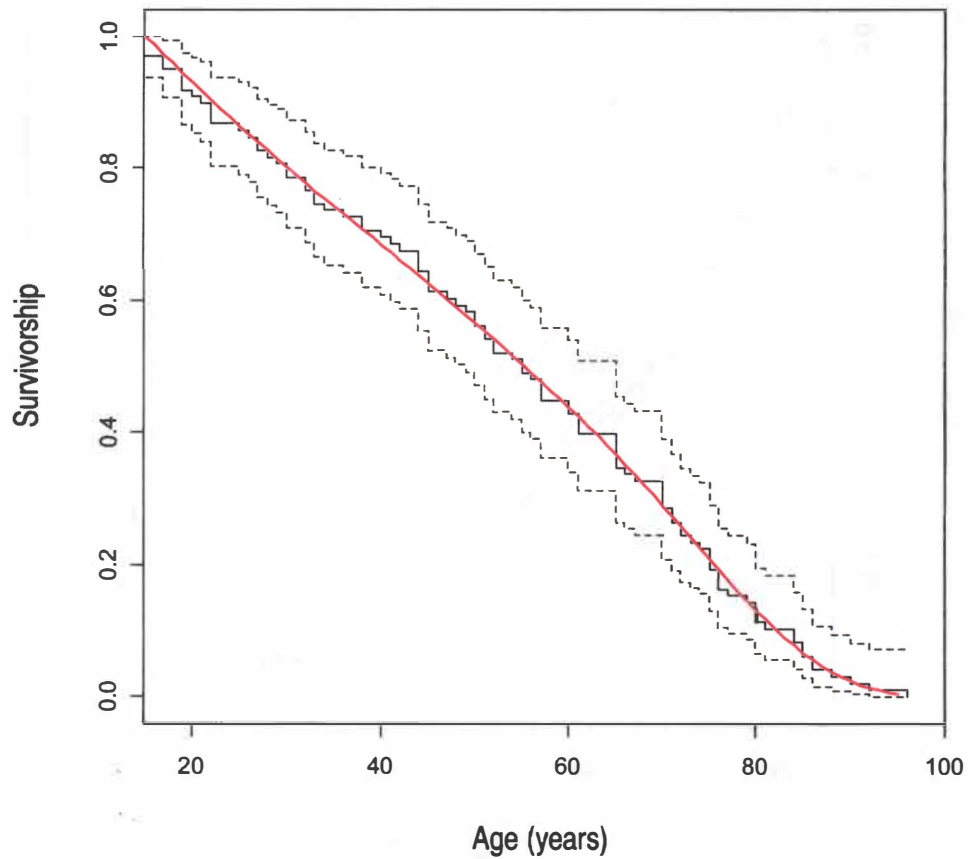


Figure 5.7. Kaplan-Meier survivorship plot for Balkan females. The red line represents the Gompertz-Makeham hazard curve, estimated from the Balkan reference sample. Survivorship above 15 years of age.

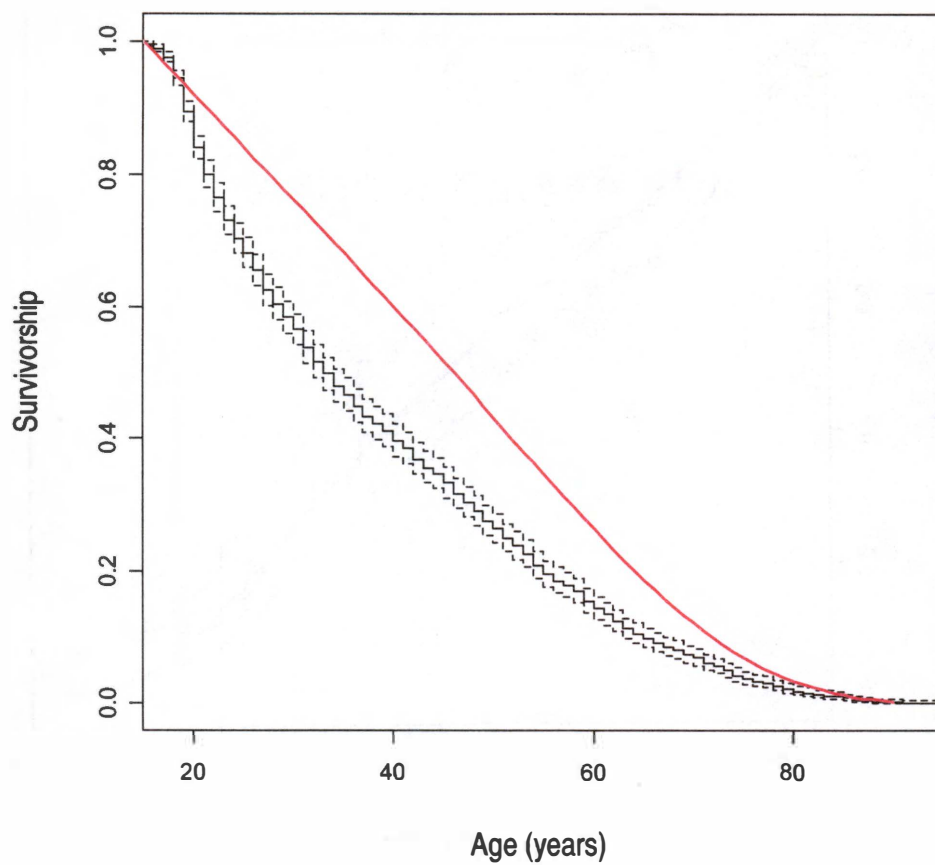


Figure 5.8. Kaplan-Meier survivorship plot for American males. The red line represents the Gompertz-Makeham hazard curve, estimated from the Balkan reference sample. Survivorship above 15 years of age.

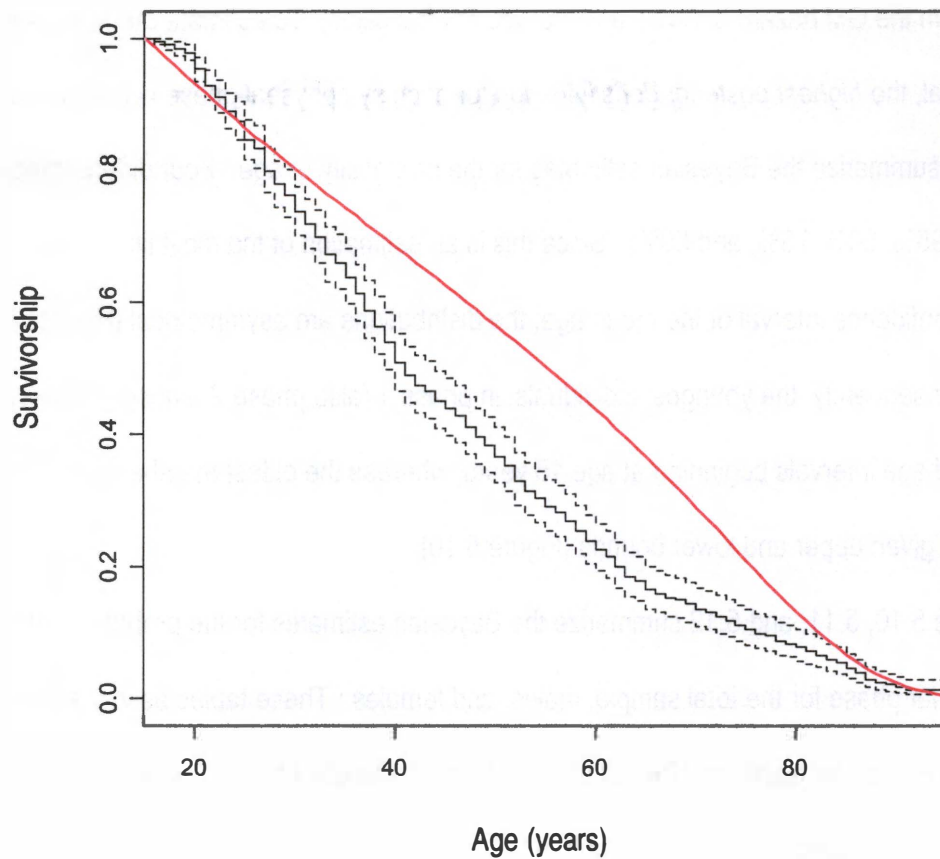


Figure 5.9. Kaplan-Meier survivorship plot for American females. The red line represents the Gompertz-Makeham hazard curve, estimated from the Balkan reference sample. Survivorship above 15 years of age.

## Estimating Individual Ages-at-Death

To estimate age, probability density functions (PDF) for the posterior distributions of age at each symphyseal phase are calculated. The age estimates are based on the calculated age distribution from the GM hazard analysis and the ages-of-transition. To estimate the age-at-death for an individual, the *highest posterior density region* for each symphyseal phase is calculated. These figures summarize the Bayesian estimates for the probability of age. Four different regions are provided (95%, 90%, 75%, and 50%). Since this is an estimation of the most likely age-at-death, not a confidence interval of the mean age, the distributions are asymmetrical (Figures 5.10 and 5.11). Consequently, the youngest individuals, in phase 1 (also phase 2 among females) have truncated age intervals beginning at age 15 years, whereas the oldest members of the group in phase 6 are given upper and lower bounds (Figure 5.10).

Tables 5.10, 5.11, and 5.12 summarize the Bayesian estimates for the probability of age, given a particular phase for the total sample, males, and females. These tables associate with the posterior density plots for each symphyseal phase. Through the use of a PDF, the age distribution of each phase is estimated.

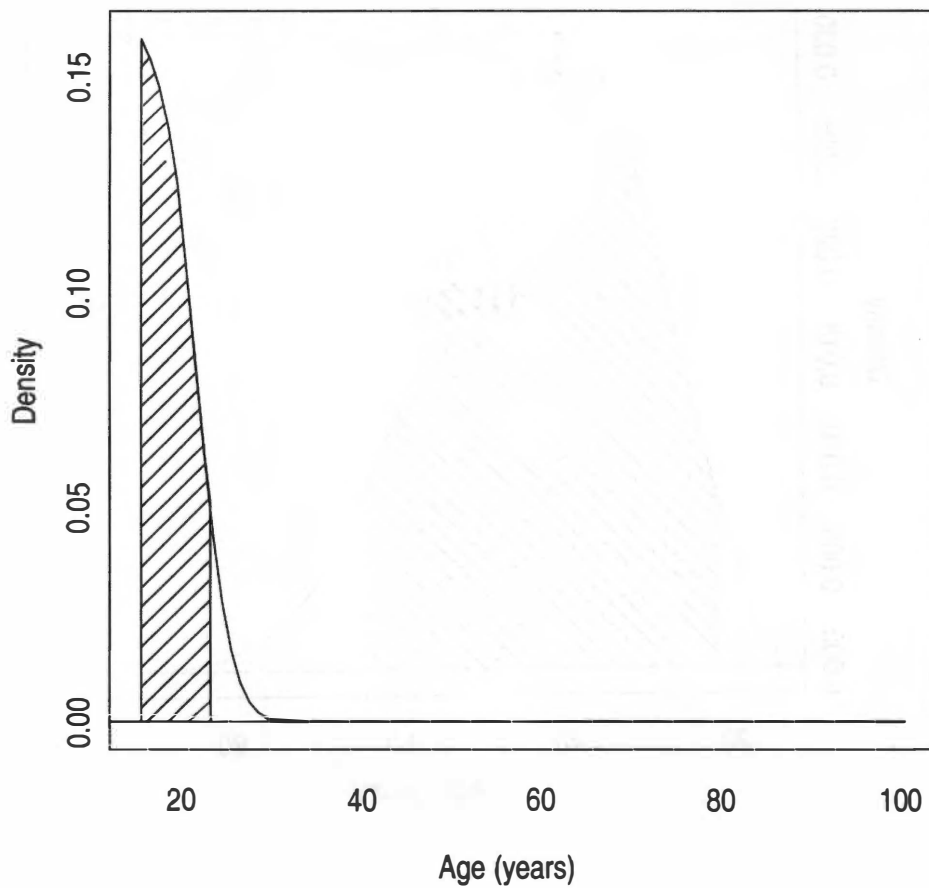


Figure 5.10. Phase 1 maximum density of age-at-death for Balkan males. Note that because survivorship begins at age 15, phase 1 is truncated.

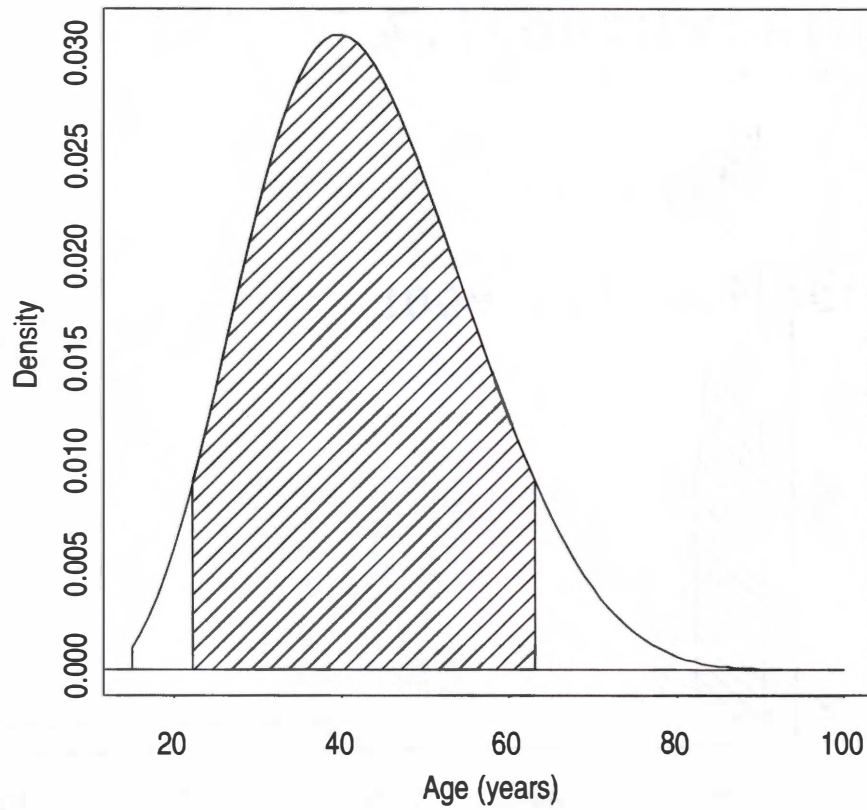


Figure 5.11. Phase 4 maximum density of age-at-death for Balkan males, 39.7 years.

**Table 5.10. Highest posterior density region for each pubic symphyseal phase ~ unisex standard combining males and females**

| Pubic Symphyseal Phase | Posterior Density (years) | CI  | Lower - Upper Bound (years) |
|------------------------|---------------------------|-----|-----------------------------|
| <i>Phase 1</i>         | --                        | 95% | 15.0 - 24.8                 |
|                        |                           | 90% | 15.0 - 23.4                 |
|                        |                           | 75% | 15.0 - 21.1                 |
|                        |                           | 50% | 15.0 - 18.7                 |
| <i>Phase 2</i>         | 23.3                      | 95% | 16.6 - 30.1                 |
|                        |                           | 90% | 17.6 - 29.2                 |
|                        |                           | 75% | 19.2 - 27.4                 |
|                        |                           | 50% | 20.9 - 25.7                 |
| <i>Phase 3</i>         | 28.0                      | 95% | 20.0 - 42.9                 |
|                        |                           | 90% | 20.9 - 39.5                 |
|                        |                           | 75% | 22.6 - 35.7                 |
|                        |                           | 50% | 24.6 - 32.2                 |
| <i>Phase 4</i>         | 39.7                      | 95% | 20.6 - 64.6                 |
|                        |                           | 90% | 23.1 - 61.5                 |
|                        |                           | 75% | 27.4 - 54.8                 |
|                        |                           | 50% | 32.1 - 48.3                 |
| <i>Phase 5</i>         | 50.9                      | 95% | 20.8 - 74.5                 |
|                        |                           | 90% | 25.3 - 71.6                 |
|                        |                           | 75% | 33.1 - 66.2                 |
|                        |                           | 50% | 40.6 - 60.3                 |
| <i>Phase 6</i>         | 67.3                      | 95% | 39.8 - 88.7                 |
|                        |                           | 90% | 44.5 - 85.7                 |
|                        |                           | 75% | 51.8 - 80.7                 |
|                        |                           | 50% | 58.4 - 75.4                 |

*Table 5.11. Highest posterior density region for each pubic symphyseal phase among males*

| Pubic Symphyseal Phase | Posterior Density (years) | CI  | Lower - Upper Bound (years) |
|------------------------|---------------------------|-----|-----------------------------|
| <i>Phase 1</i>         | --                        | 95% | 15.0 - 23.9                 |
|                        |                           | 90% | 15.0 - 22.6                 |
|                        |                           | 75% | 15.0 - 20.5                 |
|                        |                           | 50% | 15.0 - 18.4                 |
| <i>Phase 2</i>         | 23.2                      | 95% | 17.4 - 29.9                 |
|                        |                           | 90% | 18.2 - 28.9                 |
|                        |                           | 75% | 19.6 - 27.0                 |
|                        |                           | 50% | 21.0 - 25.4                 |
| <i>Phase 3</i>         | 27.8                      | 95% | 20.1 - 41.9                 |
|                        |                           | 90% | 20.9 - 39.4                 |
|                        |                           | 75% | 22.5 - 35.4                 |
|                        |                           | 50% | 24.5 - 31.9                 |
| <i>Phase 4</i>         | 39.7                      | 95% | 19.9 - 67.4                 |
|                        |                           | 90% | 22.4 - 63.1                 |
|                        |                           | 75% | 26.8 - 55.9                 |
|                        |                           | 50% | 31.7 - 48.9                 |
| <i>Phase 5</i>         | 52.8                      | 95% | 20.6 - 76.3                 |
|                        |                           | 90% | 25.4 - 73.6                 |
|                        |                           | 75% | 33.7 - 68.3                 |
|                        |                           | 50% | 41.9 - 62.4                 |
| <i>Phase 6</i>         | 69.0                      | 95% | 42.3 - 89.6                 |
|                        |                           | 90% | 47.0 - 86.7                 |
|                        |                           | 75% | 54.0 - 81.9                 |
|                        |                           | 50% | 60.5 - 76.8                 |

*Table 5.12. Highest posterior density region for each pubic symphyseal phase among females*

| Pubic Symphyseal Phase | Posterior Density (years) | CI  | Lower - Upper Bound (years) |
|------------------------|---------------------------|-----|-----------------------------|
| <i>Phase 1</i>         | --                        | 95% | 15.0 - 31.9                 |
|                        |                           | 90% | 15.0 - 28.6                 |
|                        |                           | 75% | 15.0 - 23.9                 |
|                        |                           | 50% | 15.0 - 19.9                 |
| <i>Phase 2</i>         | 22.4                      | 95% | 15.0 - 38.9                 |
|                        |                           | 90% | 15.0 - 35.1                 |
|                        |                           | 75% | 16.3 - 30.6                 |
|                        |                           | 50% | 18.5 - 26.9                 |
| <i>Phase 3</i>         | 26.5                      | 95% | 15.0 - 47.0                 |
|                        |                           | 90% | 16.2 - 43.8                 |
|                        |                           | 75% | 18.7 - 37.8                 |
|                        |                           | 50% | 21.6 - 32.6                 |
| <i>Phase 4</i>         | 35.3                      | 95% | 19.7 - 66.1                 |
|                        |                           | 90% | 21.4 - 60.1                 |
|                        |                           | 75% | 24.7 - 51.2                 |
|                        |                           | 50% | 28.5 - 43.8                 |
| <i>Phase 5</i>         | 44.9                      | 95% | 26.2 - 77.9                 |
|                        |                           | 90% | 28.4 - 72.9                 |
|                        |                           | 75% | 32.2 - 64.3                 |
|                        |                           | 50% | 36.7 - 55.7                 |
| <i>Phase 6</i>         | 74.9                      | 95% | 40.6 - 93.3                 |
|                        |                           | 90% | 45.5 - 91.2                 |
|                        |                           | 75% | 54.5 - 87.5                 |
|                        |                           | 50% | 63.6 - 83.2                 |

## CHAPTER 6

### DISCUSSION AND SUMMARY

The UN High Commissioner for Human Rights recognizes the crucial role forensic science is playing in the enforcement of human rights under international law (*Resolution 998/36*). It is through judicial accountability that justice for victims and their families is achieved. The continued reliance on the forensic sciences, particularly anthropology, is needed to enforce basic rights through the scientific collection of evidence. Evidence includes grave exhumation, skeletal analysis, victim identification, and demographic profiling. Successful victim identification and demographic profiling are contingent upon the anthropological methods used for establishing the parameters of identity. Factors that affect the accuracy and applicability of such methods cross-culturally, such as inter-observer variation, statistical methodology, and biological variation are important considerations.

The Forensic Anthropology Center at The University of Tennessee began a project investigating a variety of methods used to construct the biological profile of victims in the regions of former Yugoslavia to determine what standards should be used. Recommendations from that project will be presented to the ICTY and the United Nations Mission in Kosovo for use in that region. The research conducted for this study will also contribute to that project.

The use of two aging methods based on pubic symphyseal morphology, Brooks and Suchey (1990) and Simmons and co-workers (1999), has lead to confusion about which aging parameters to use for age estimation. Further, the importance of the biological and

statistical differences between those methods has been raised in court proceedings as previously addressed. Specifically, the purpose of this study is to assess the aging processes of American and East European populations to determine what age parameters should be applied to estimate the ages-at-death for unidentified victims. To accomplish this task, the affect of inter-observer variation on the reliability of estimating age-at-death parameters from the pubic symphyses is investigated. Second, population variation in the aging processes of American and East European populations is tested. Finally, a Bayesian statistical analysis is utilized to establish accurate age parameters for unidentified victims in the former Yugoslavia which accounts for the age structure of victims in that region.

Kemkes-Grottenthaler (2002;53) argues that the primary criteria for an age marker is the "strong correlation between biological feature and age". Using a large identified sample from the Balkans, this study found that the Suchey-Brooks and Todd methods have relatively strong correlations with age. Interestingly, when males and females are treated separately, both methods correlate higher with age among females than males. Previous researchers have suggested that pubic symphyseal methods are more reliable for males than females (Brooks, 1955; Gilbert-McKern, 1973; Kemkes-Grottenthaler, 2002) and that females are more variable (Brooks, 1955; Suchey and Brooks, 1998; Kemkes-Grottenthaler, 2002). Hoppa (2000) also found differences in morphological changes among females and males but attributed his findings to differences in the age distributions of each group. Note that differences between males and females are consistent trend found through this investigation.

The correlation coefficients among age and the Suchey-Brooks method ranges from  $r = 0.702$  for males to  $r = 0.789$  for females. The difference between males and females is even

greater for the Todd method which ranges from  $r = 0.611$  for males to  $r = 0.818$  for females.

These associations are generally higher than what has been reported by other researchers. For example, Katz and Suchey (1986) report correlation coefficients among the Todd phases and age at  $r = 0.64$  for females,  $r = 0.57 - 0.85$  for males, and  $r = 0.57$  for a combined sample. Suchey and Katz (1998;433) later reported the association between their six phase method and age for males,  $r = 0.734$ .

The usefulness of correlations among the symphyseal phase and age as a marker of method reliability for age estimation is open to debate (Bocquet-Appel and Masset, 1982). Some researchers, such as Meindl and colleagues (1985), have suggested using the correlation coefficients between the estimated and actual ages. In doing so, Meindl and colleagues (1985) found that estimated and actual ages correlate higher among females than males. However, their recommendation is difficult to apply to this study because age parameters are intervals. The result of choosing either the mean age, median age, or highest posterior density to correlate with age produces different results.

Kemkes-Grottenthaler (2002) suggests that observer repeatability is an important measure of method reliability. Inter-observer variation, investigated here through a series of statistical tests including Pearson's  $r$  correlation coefficients and the Wilcoxon signed ranks test, is significant. Pearson's  $r$  correlation coefficients among observers for the Todd system are all significant and strongly correlate. The correlation coefficients among males are more varied and not as strong as the female sample. Correlation coefficients among observers for the Suchey-Brooks method are more consistent and higher than those for the Todd method. Moreover, the four observers are more highly correlated for the female sample using both methods than for the male samples.

The Wilcoxon signed ranks tests for observer variation demonstrates significant differences using both methods. For the Todd method, two of the four observers are statistically consistent. Testing observer variation for the Suchey-Brooks shows a slightly different pattern, with more observer variation than noted for the Todd method. A significant difference is present among observers 1 and 2, whereas with the Todd method no difference was noted between these observers. Whereas, observer 4 significantly differs from the other three observers using both methods.

Buccino and co-workers (1999) argue that observer experience is an important factor and recommend that investigators conduct repeatability tests. In spite of substantial efforts among the observers to calibrate with another in the collection of data that has been used in this investigation, the Wilcoxon signed ranks test demonstrates significant observer variation for both methods. The differences among observers may have been greater without prior collaboration and repeatability tests. Galera and colleagues (1995) had previously reported substantial but not statistically significant differences among observers and that the Suchey-Brooks method is more reliable than the Todd method. The finding of significant observer variation is important. Overall, there have not been large scale investigations of observer repeatability. Several of the primary studies (Galera et al., 1995; Buccino et al., 1999) used sample sizes of less than twenty individuals. Consequently, the affect of observer variation on individual age estimation is an important issue and subject for continued research in the future.

The morphological variation of the pubic symphysis among older aged adults may, at least in part, explain differences among observers. The morphological characteristics used by investigators to assign each pubic symphysis to a particular "phase" is diverse. The morphology of

a symphyseal surface, at any given age, varies substantially and is likely a contributing factor to the level of observer variation. This observation has been discussed in the literature, particularly by investigators proposing new methods for use (i.e. Suchey and Katz, 1998). Since Brooks' model (1955) first developed from Todd's ten phases, casts or line drawings have been used to represent the *typical* morphology for each symphyseal phase. However, most pubic symphyses do not appear as the prototype due to individual variation or the timing of morphological change. Additionally, there are a variety of features to consider when assigning a phase, such as the formation of the ventral rim or surface porosity. As a result, there is a wide range of variation in the morphology of the pubic symphysis at any particular age. This is further evident by the large observed age ranges reported by Suchey and Brooks (1990), Simmons and co-workers (1999).

A second problem noted by observers who collected data used in this study is over confusion between the formation and degeneration of the ventral rampart of the pubic symphysis. Interestingly, this problem has also been noted by Suchey and Katz (1998;221) who wrote; "Phase III is somewhat problematic; it peaks in the mid to late twenties, but there are outlying cases trailing into the sixties. These outlying cases are probably interpretative errors on the part of Suchey and Brooks who may have confused buildup of the ventral rampart with breakdown of the ventral rampart". This confusion may explain the high number of differences among observers for phases 4, 5, and 6.

The issue of whether American standards for age-at-death estimation will produce reliable aging parameters on an East European population was raised during the legal proceedings of the ICTY, when Krstic's defense lawyer asked whether "could it be said of the Bosnian population that they develop earlier or quicker?" (Court Testimony in *Prosecutor v. Radislav Krstic* May 30,

2000;44). To test for variation in the aging processes of the two populations, proportional odds probit regression is used. Further, an analysis of deviance is calculated using an improvement chi-square to test the adequacy of the model (Fox, 2002). No significant association between the aging process of pubic symphyses and the total population is found. However, when males and females are treated separately, there is a significant association among females and population.

There are two possible explanations for population variation. First, it may be that there are biological differences among the populations that affect the aging process of females. As discussed in Chapter 2: *A Review of Previous Research on Pubic Symphyseal Aging* of this volume, Kemkes-Grottenthaler (2002;64) suggests significant biological variation in the aging processes of various populations resulting from environmental differences that affect the metabolic rate such as caloric intake and osteoporosis. The consistent patterns observed for males and females throughout this investigation suggest these morphological and statistical differences may be attributed to biological factors. Alternatively, population variation may not be a question of populations aging “quicker” or “slower” than one another, rather it may be a question of differing age distributions among the samples, as suggested by Hoppa (2000). Future research into this topic for the Balkan sample may provide further insight into this finding. By using a Bayesian statistical approach to estimate age, the population’s age distribution is taken into account. Therefore, the estimates presented here are reliable for the Balkan populations, regardless of the etiology of population or sex differences.

Schmitt and co-workers (2002;1203) argue that because the accuracy and reliability of pubic symphyseal methods vary, investigators need to account for the level of error in their estimations through a Bayesian statistical approach. The results from a Bayesian analysis are not

"point estimates", but rather age distributions for each symphyseal phase. As more cases become available, these distributions change. Nevertheless, individual estimates may be obtained from the distribution, with upper and lower bounds provided and assigned a probability, known as the *highest probability density regions*. To estimate age, probability density functions (PDF) for the posterior distributions of age at each symphyseal phase are calculated. The age estimates are based on the calculated age distribution from the Gompertz-Makeham hazard analysis and the ages-of-transition. To estimate the age-at-death for an individual, the *highest posterior density region* for each symphyseal phase is calculated and four different regions are provided (95%, 90%, 75%, and 50%).

The first step in the identification process is to establish the initial parameters that limit the pool of potential matches, such as broad age categories. The second step is to make a positive identification based on matching criteria found during the skeletal analysis with information about the missing person such as dental charts or DNA. Within that initial step, the objective of the investigator may vary depending on the context such as, establishing large age cohorts, matching age-at-death estimates with ante-mortem ages for identification, or creating demographic profiles for entire sites. The requirements of the investigator will influence how the age parameters are defined. Therefore, it is left to the discretion of the investigator to decide which level of probability to use when estimating an individual case. This approach differs from typical forensic casework encountered in the United States where anthropologists often work with single victims and have some knowledge of missing persons. Rather, this course reflects the situation of human rights cases internationally where the pool of missing persons includes several thousand victims.

Anthropologists are able to quantify their findings and provide a level of certainty when presenting materials to a court which is important for all scientific standards.

A Bayesian statistical approach does not necessarily narrow the overall age intervals, however, it provides a level of precision through probability estimates that allows investigators to choose parameters with a level of certainty based on context of a case and clarifies the issue of population variation, answering the question of which population ages “quicker”, and what method to use when working with diverse populations. For example, the higher the *probability density region*, the wider the age “interval” and the more overlap between stages, particularly at the lower end of the range. For example, the 95% confidence interval for phase 2 among males is 17.4 - 29.9 years. The 95% confidence interval for phase 5 ranges from 20.6 - 76.3 years. While the overall interval is much wider for phase 5, the lower bound is so young that overlaps with the 95% confidence interval of phases 1-5. The lower *probability density regions* provide narrower age intervals and highlight the problem with using traditional age estimation parameters. For example, the 95% confidence interval for Phase 4 among males ranges from 19.9 to 67.4 years. The tightest range, 31.7 - 48.9 years, incorporates the mean ages of phase 4 as described by both Suchey-Brooks and Simmons and co-workers (35.2 years and 43.7 years, respectively). However, if this region is used there is only a 50% chance of being correct. Using traditional methods where the age interval is built around the mean age of the phase, the same problem occurs, however the level of accuracy is unknown.

The age parameters estimated from the *probability density regions* are not directly comparable to the descriptive statistics provided in the aging methods currently used, i.e. the mean ages of each phase and confidence intervals around the means. Although in using the

parameters derived from a Bayesian analysis, the estimates will generally be younger than either the Suchey-Brooks or Simmons parameters for males and females with few exceptions. Namely, the estimates for phase 6 are older for both males and females than other methods.

Finally, the goal of this study is to provide age-at-death parameters for the regions of the former Yugoslavia. The parameters provided here meet the requirements for the presentation of scientific evidence in court by accounting for a level of precision in the age estimate. A Bayesian approach to estimate age offers investigators various age intervals as an alternative approach for anthropologists currently working in the Balkans. This approach should meet the varying needs of anthropologists working in international settings which differ from American casework due to the thousands of victims to be identified and the need for demographic profiles of entire sites.

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## APPENDIX

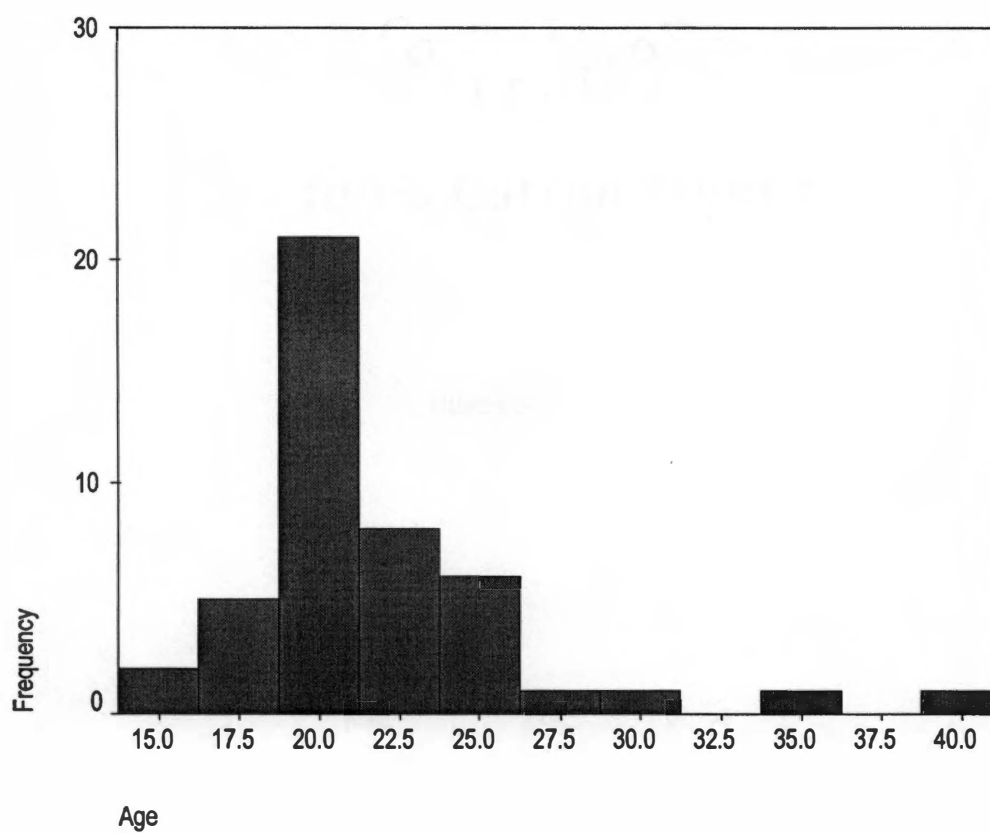


Figure A.1. Histogram of ages-at-death among American females, Suhey-Brooks Pubic Symphyseal Phase 1.

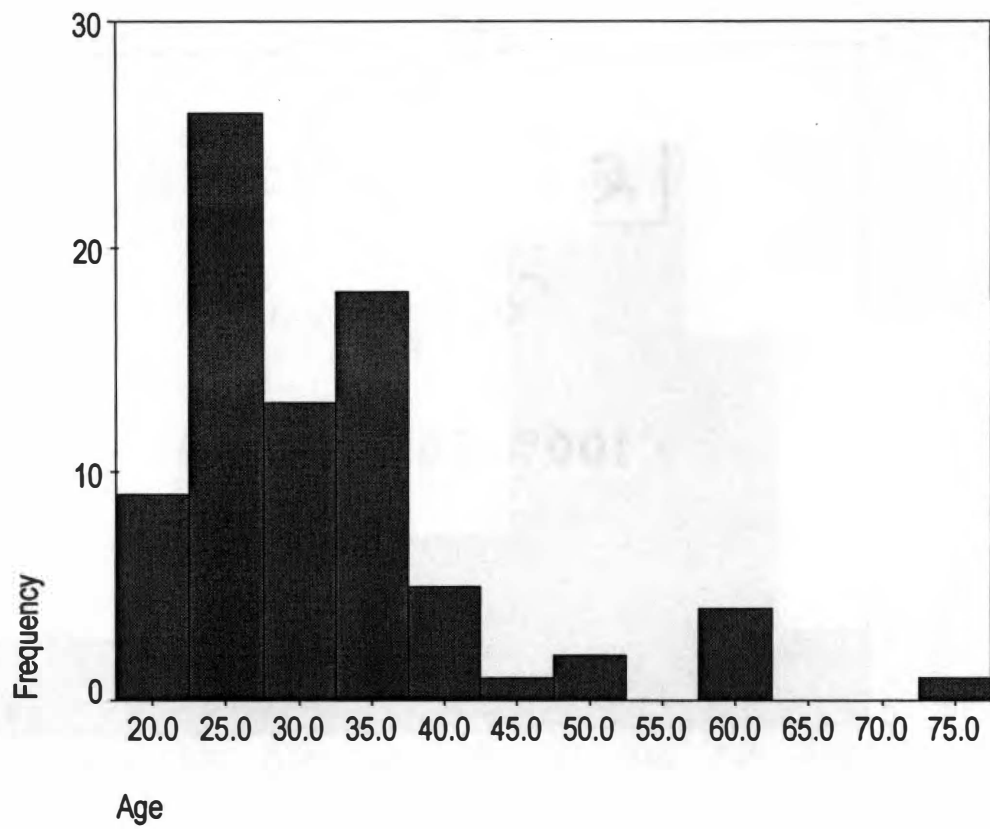


Figure A.2. Histogram of ages-at-death among American females, Suchey-Brooks Pubic Symphyseal Phase 2.

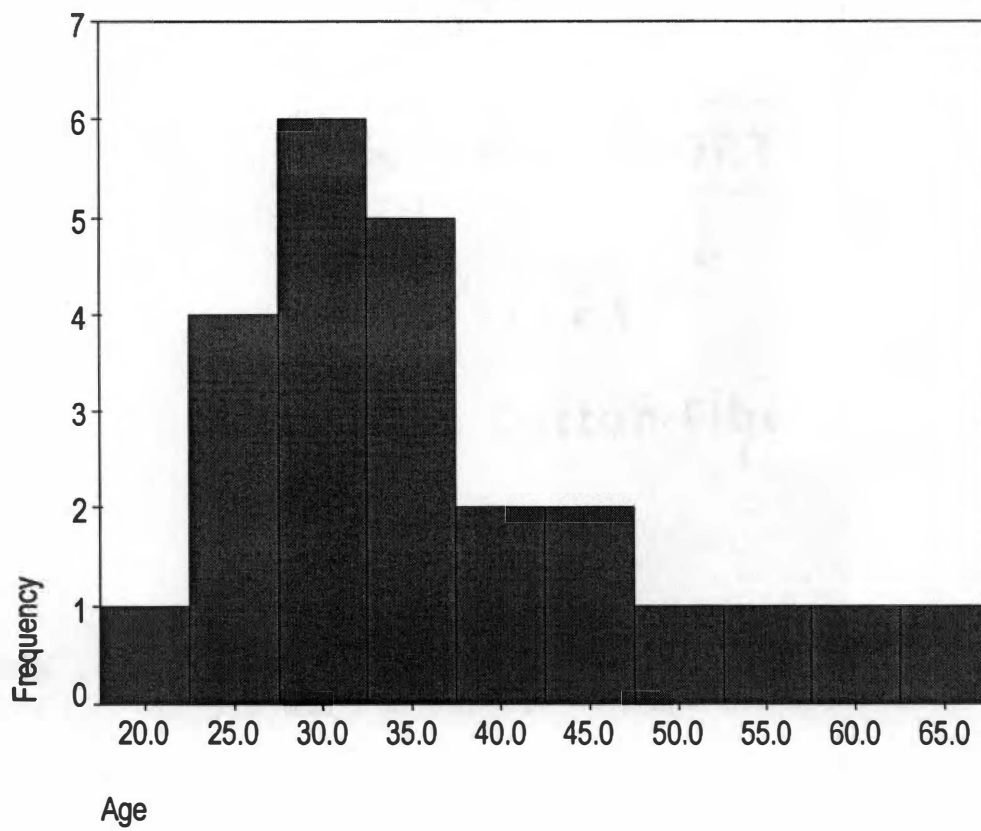


Figure A.3. Histogram of ages-at-death among American females, Suchey-Brooks Pubic Symphyseal Phase 3.

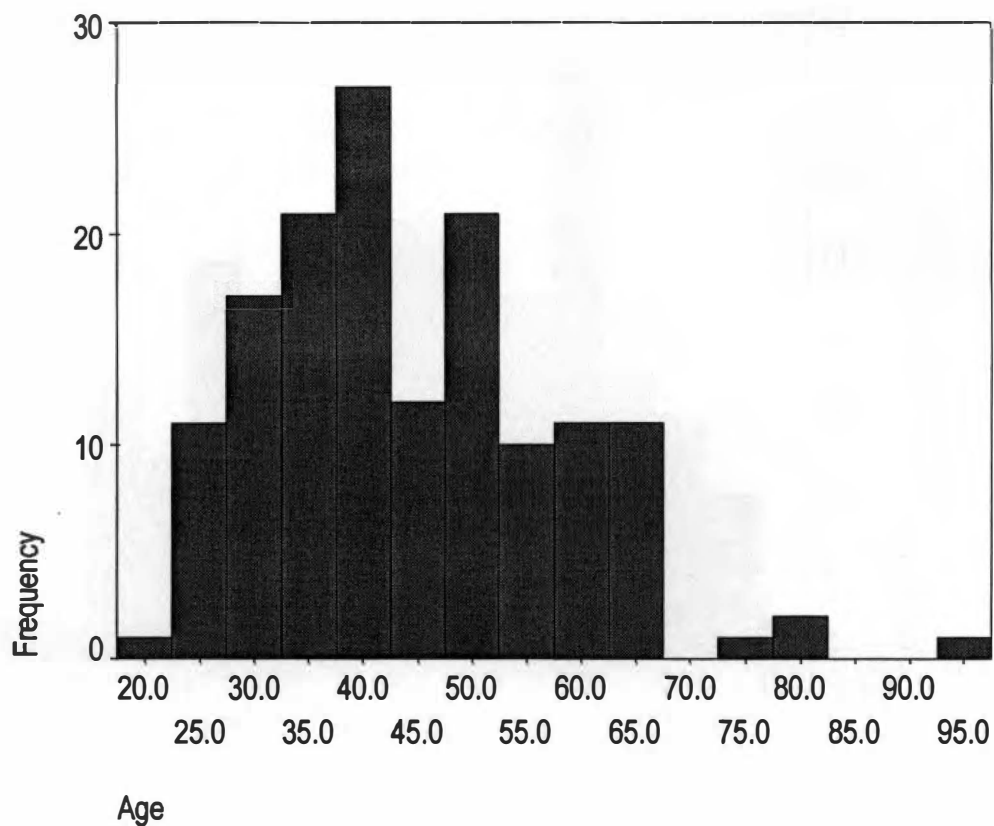


Figure A.4. Histogram of ages-at-death among American females, Suchey-Brooks Pubic Symphyseal Phase 4.

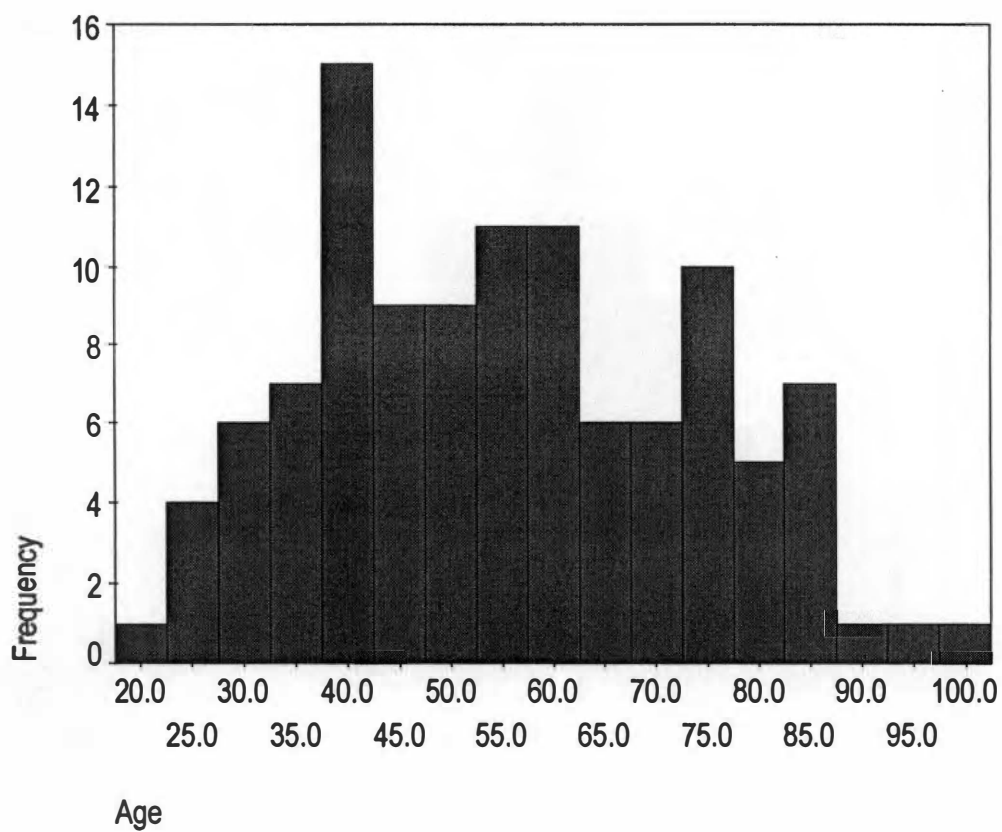


Figure A.5. Histogram of ages-at-death among American females, Suchey-Brooks Pubic Symphyseal Phase 5.

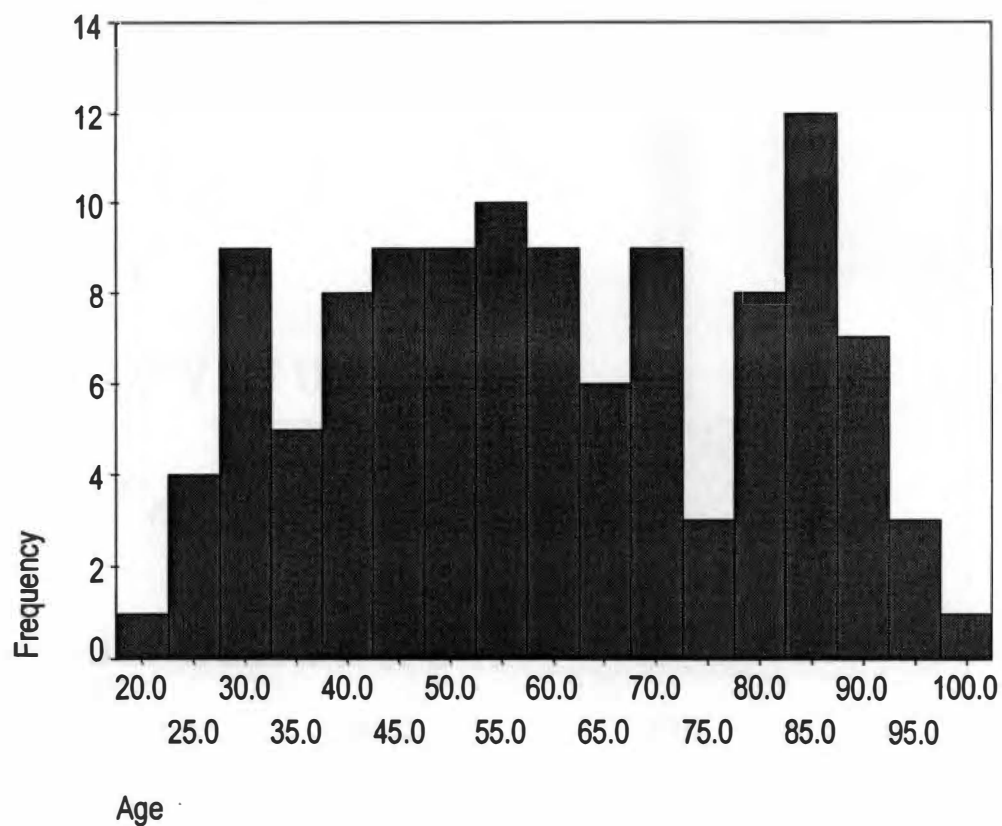


Figure A.6. Histogram of ages-at-death among American females, Suchey-Brooks Pubic Symphyseal Phase 6.

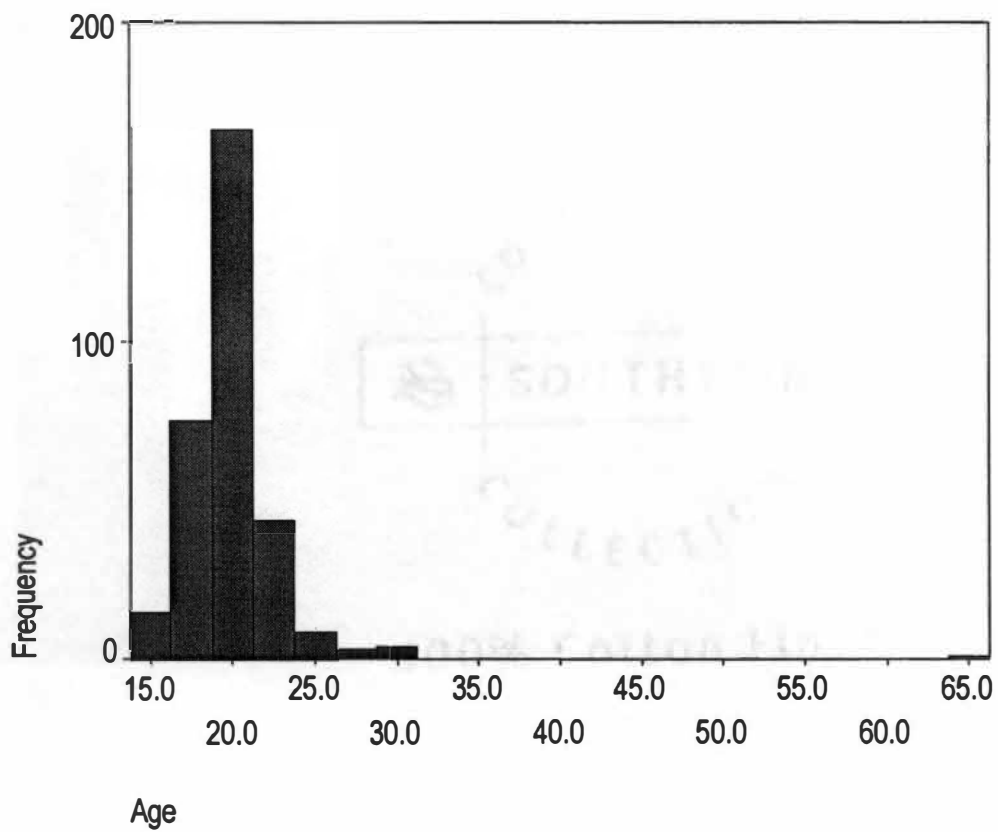


Figure A.7. Histogram of ages-at-death among American males, Suchey-Brooks Pubic Symphyseal Phase 1.

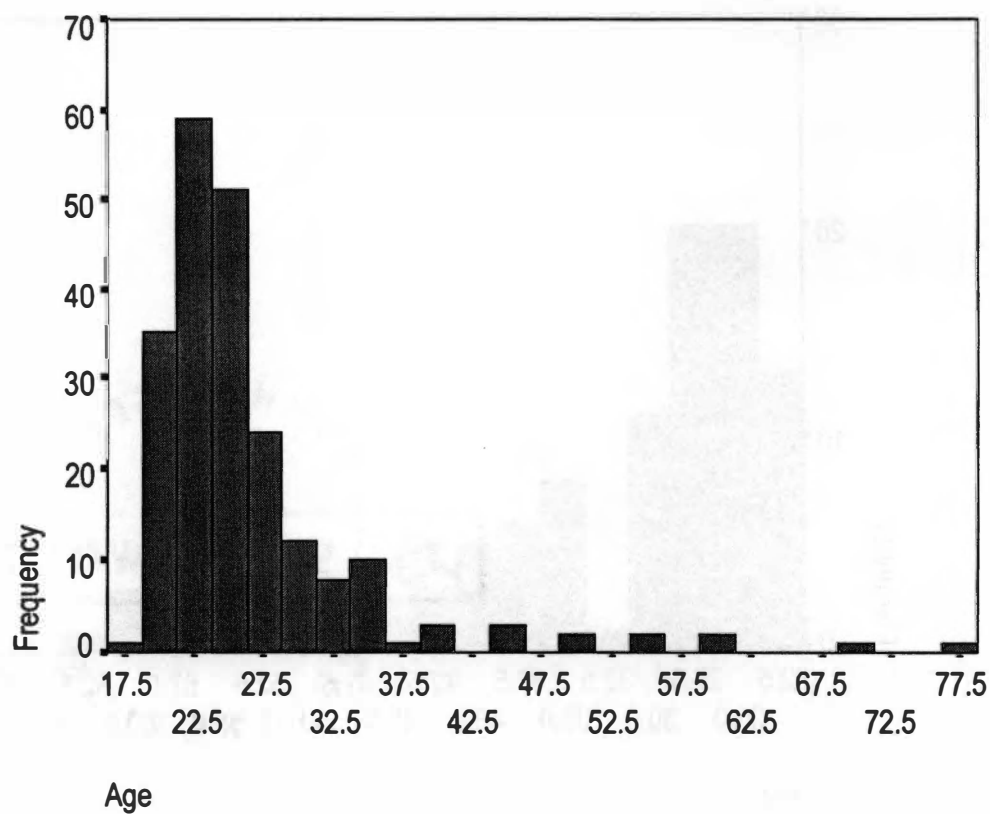


Figure A.8. Histogram of ages-at-death among American males, Suchey-Brooks Pubic Symphyseal Phase 2.

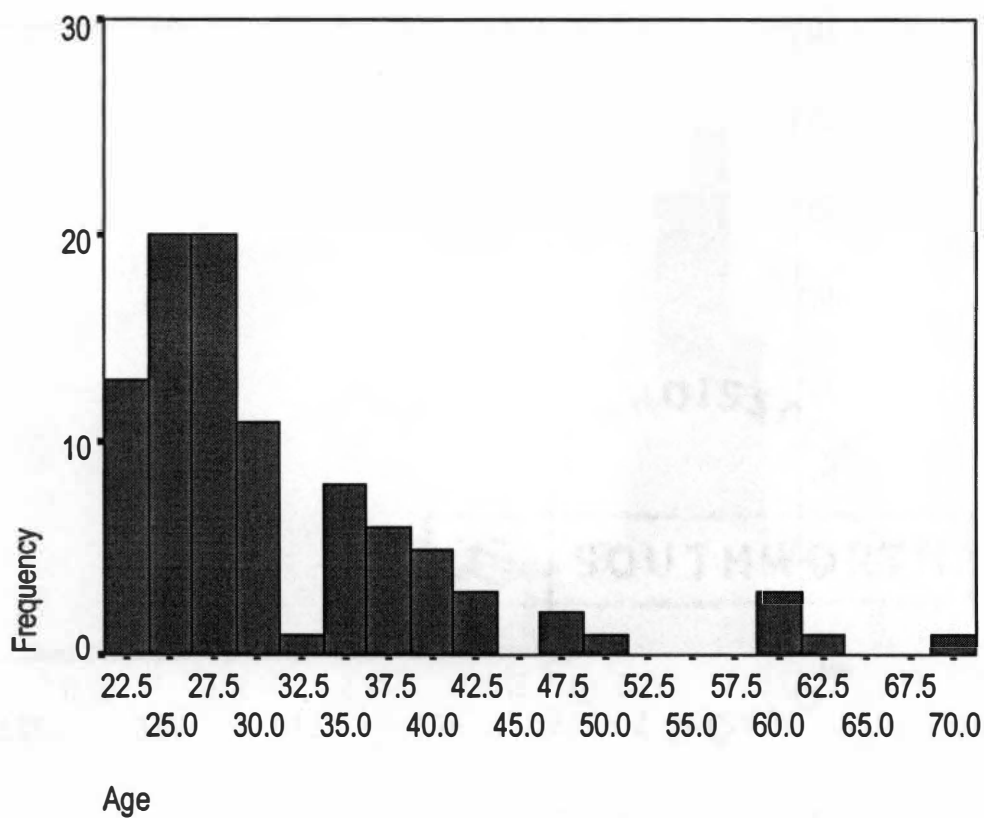


Figure A.9. Histogram of ages-at-death among American males, Suchey-Brooks Pubic Symphyseal Phase 3.

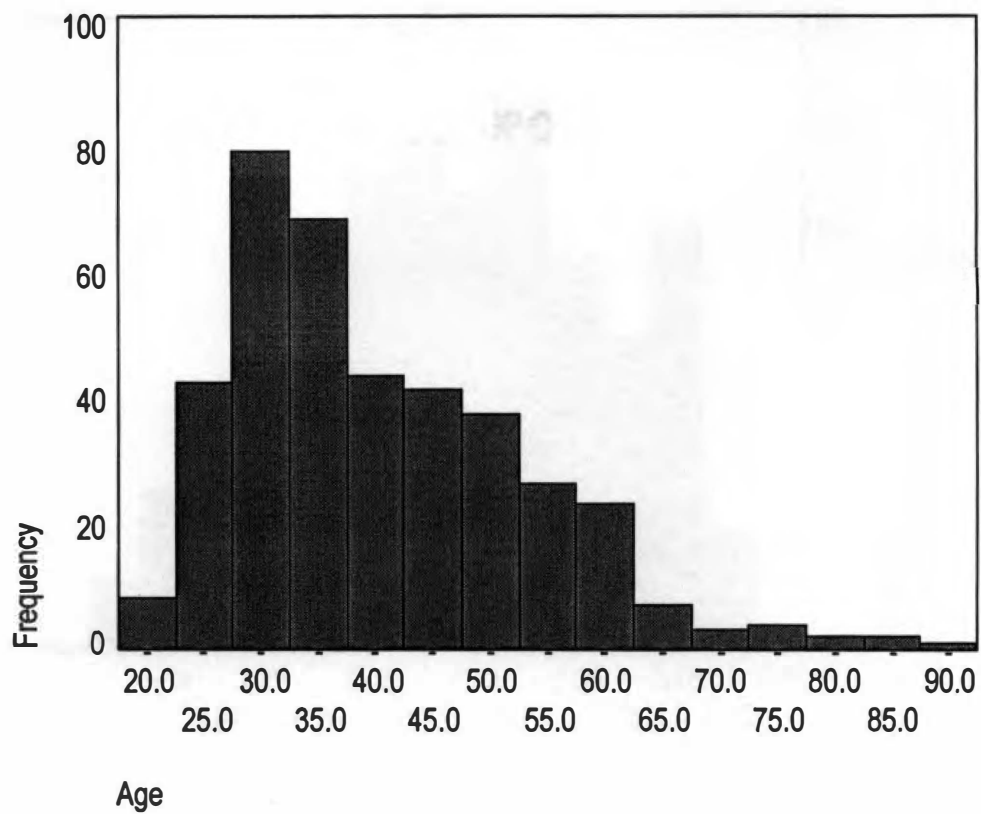


Figure A.10. Histogram of ages-at-death among American males, Suchey-Brooks Pubic Symphyseal Phase 4.

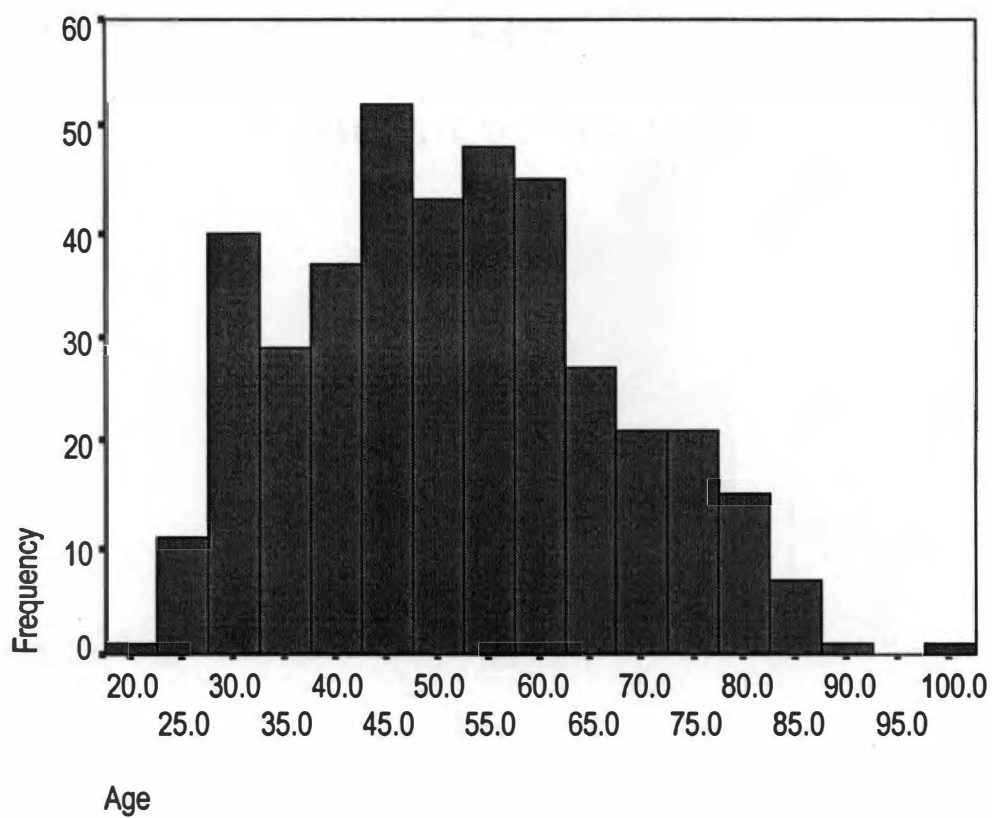


Figure A.11. Histogram of ages-at-death among American males, Suchey-Brooks Pubic Symphyseal Phase 5.

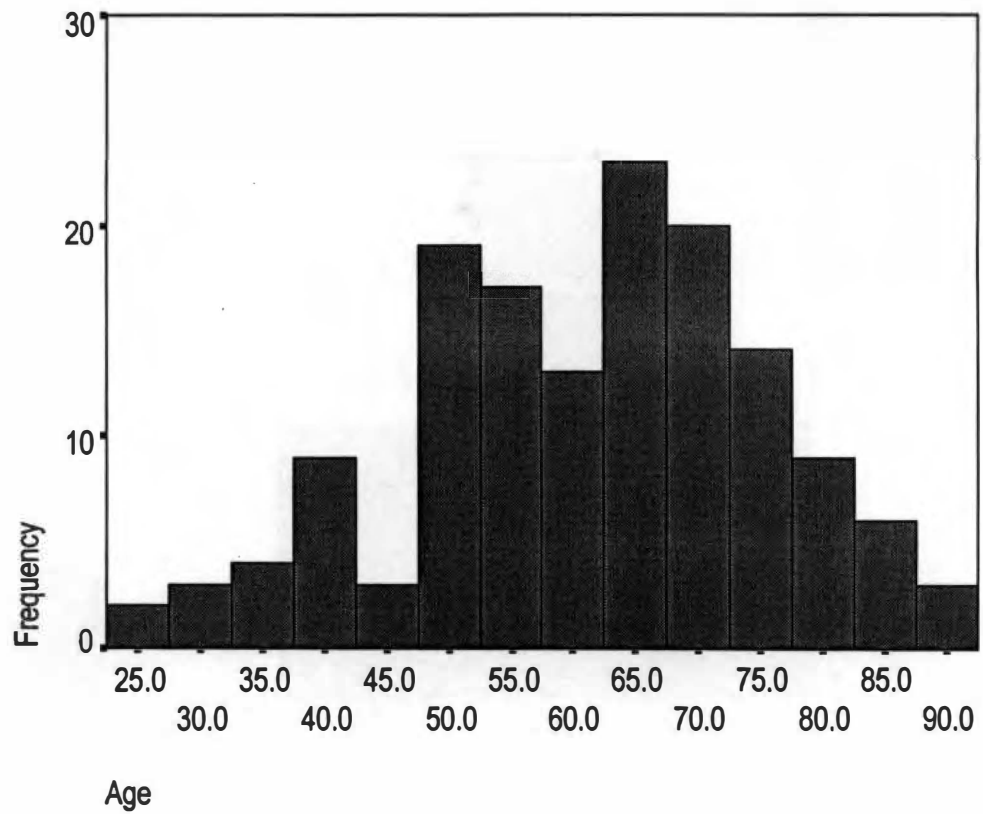


Figure A.12. Histogram of ages-at-death among American males, Suchey-Brooks Pubic Symphyseal Phase 6.

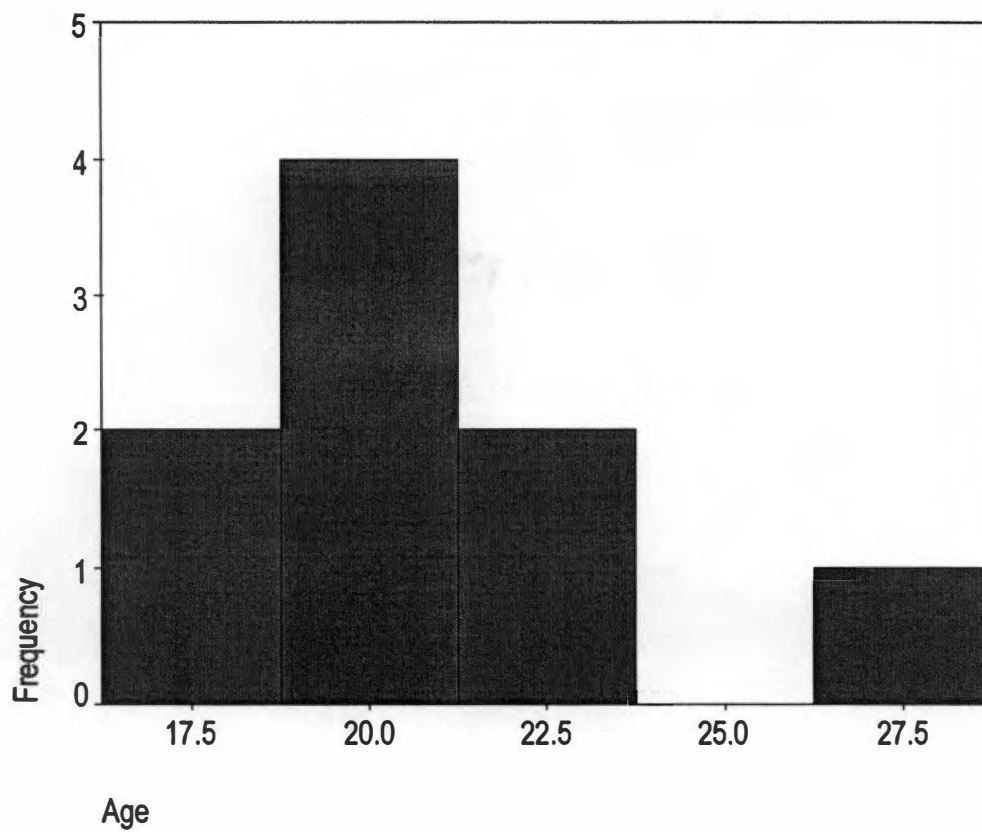


Figure A.13. Histogram of ages-at-death among Balkan females, Suchey-Brooks Pubic Symphyseal Phase 1.

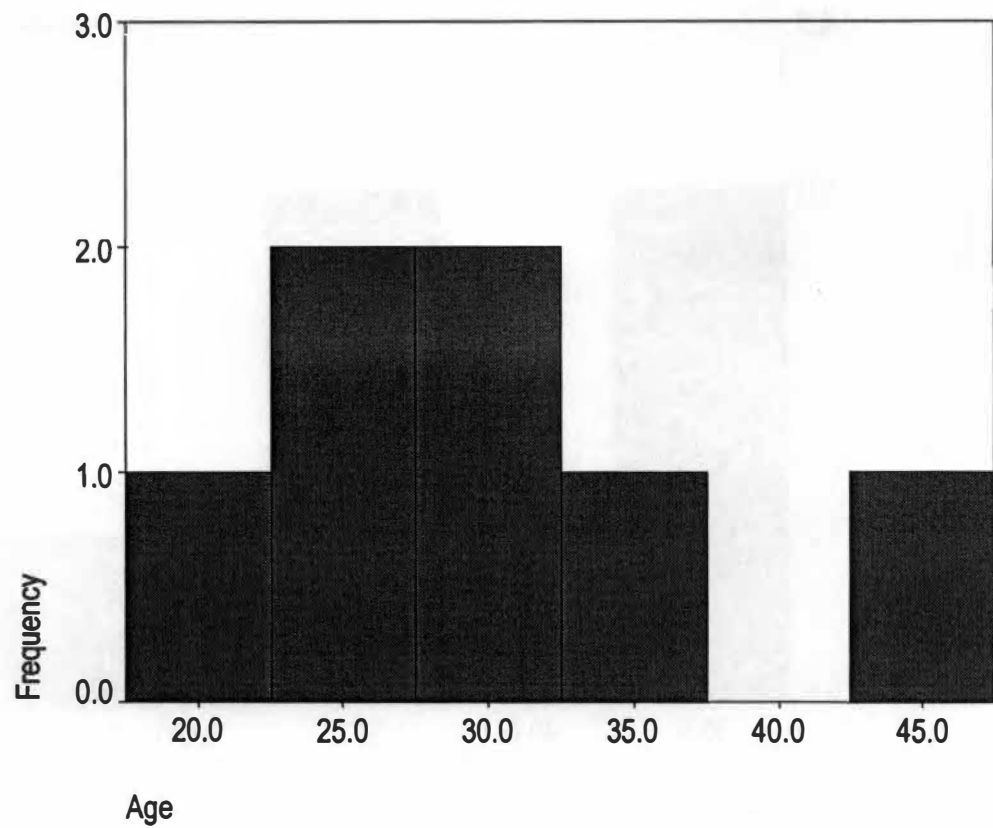


Figure A.14. Histogram of ages-at-death among Balkan females, Suchey-Brooks Pubic Symphyseal Phase 3.

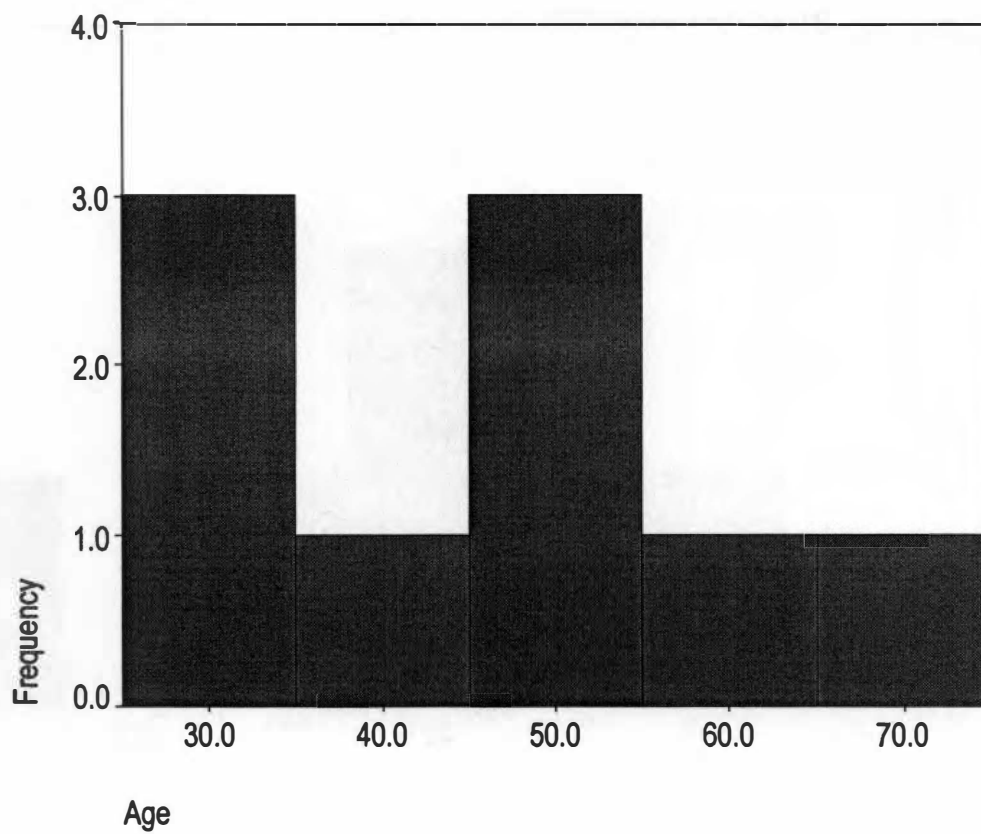


Figure A.15. Histogram of ages-at-death among Balkan females, Suchey-Brooks Pubic Symphyseal Phase 4.

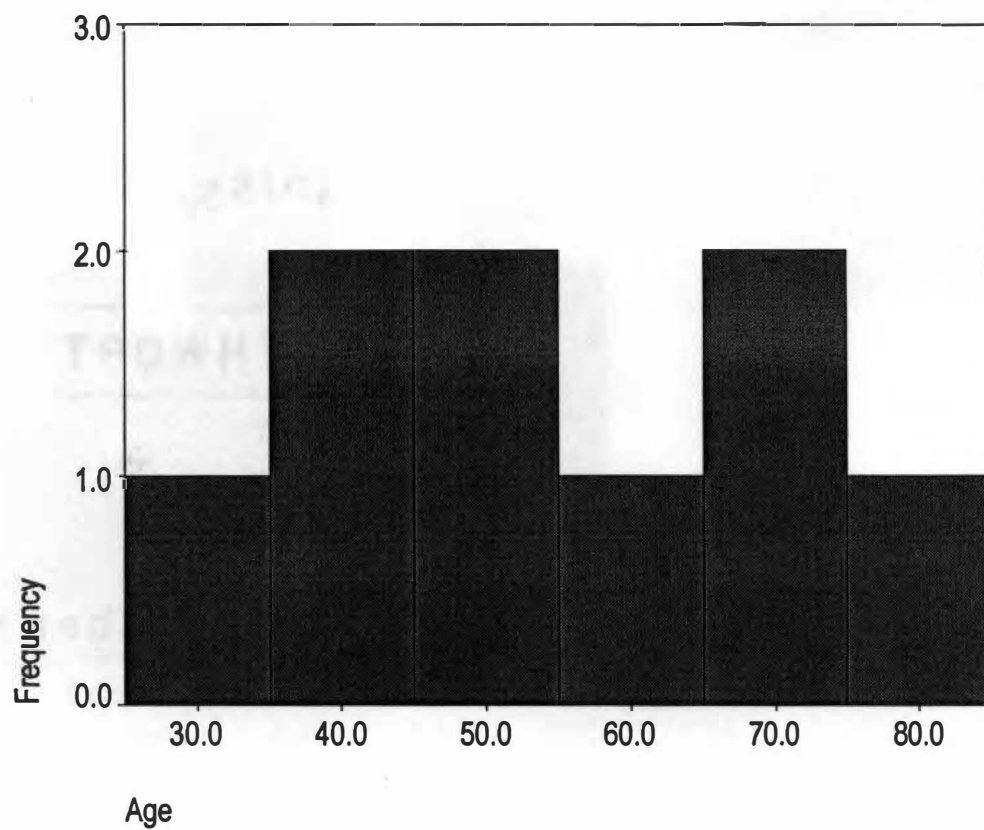


Figure A.16. Histogram of ages-at-death among Balkan females, Suchey-Brooks Pubic Symphyseal Phase 5.

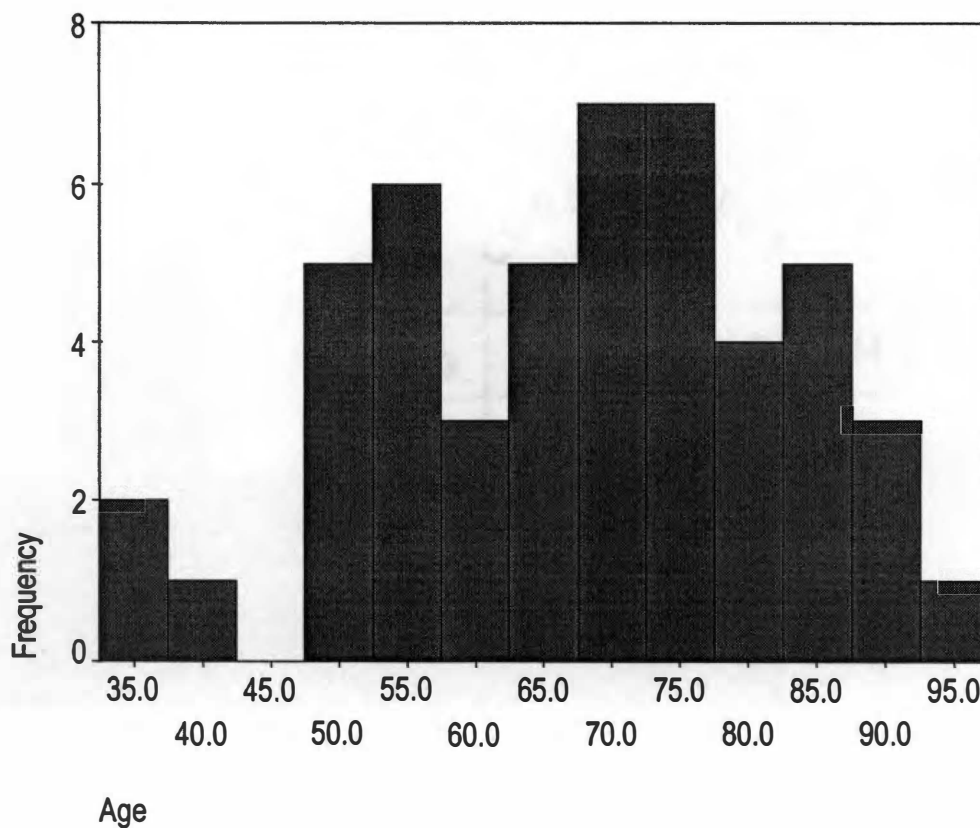


Figure A.17. Histogram of ages-at-death among Balkan females, Suchey-Brooks Pubic Symphyseal Phase 6.

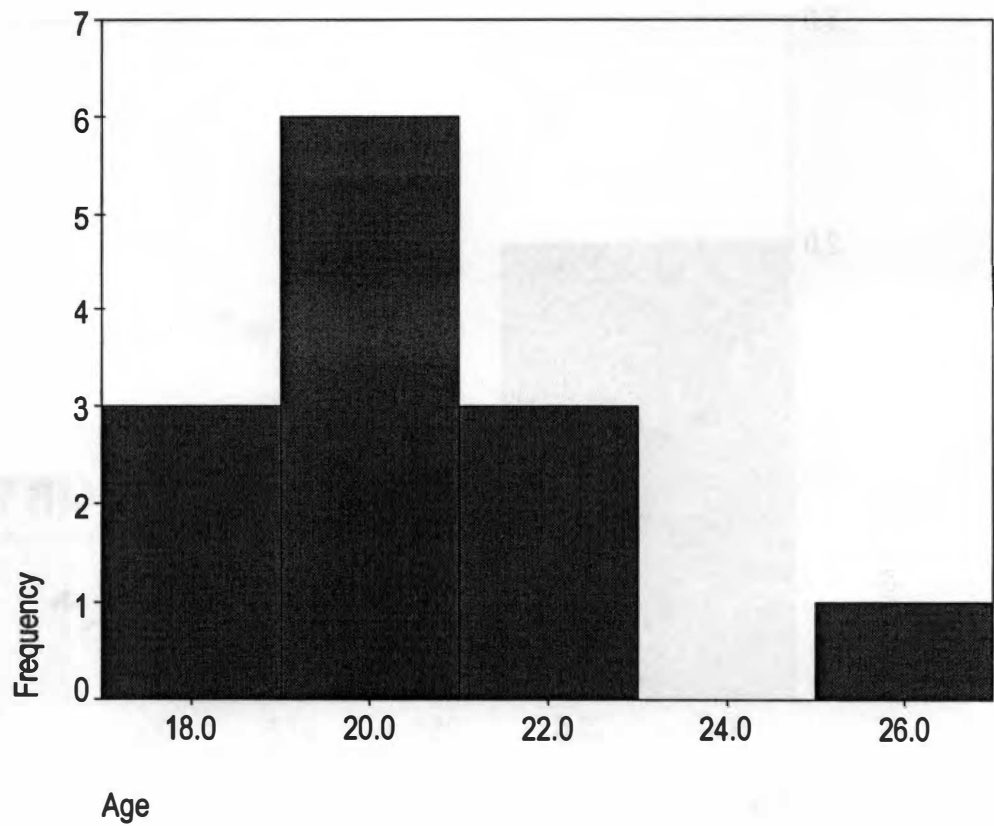


Figure A.18. Histogram of ages-at-death among Balkan males, Suchey-Brooks Pubic Symphyseal Phase 1.

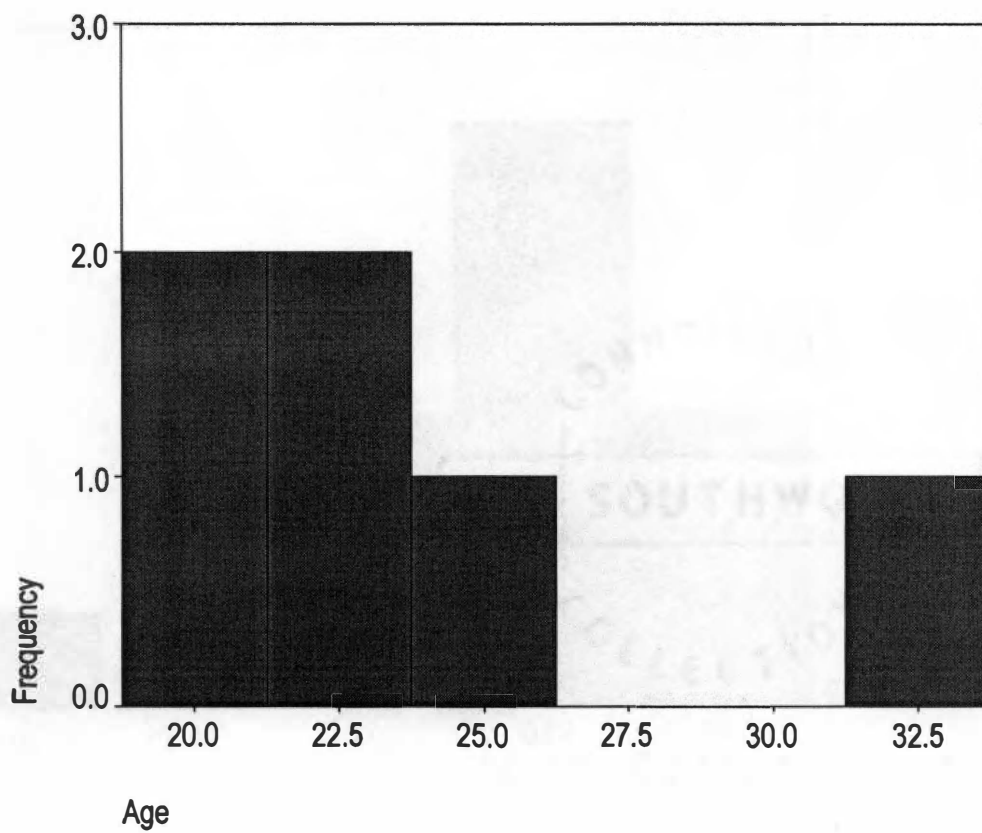


Figure A.19. Histogram of ages-at-death among Balkan males, Suhey-Brooks Pubic Symphyseal Phase 2.

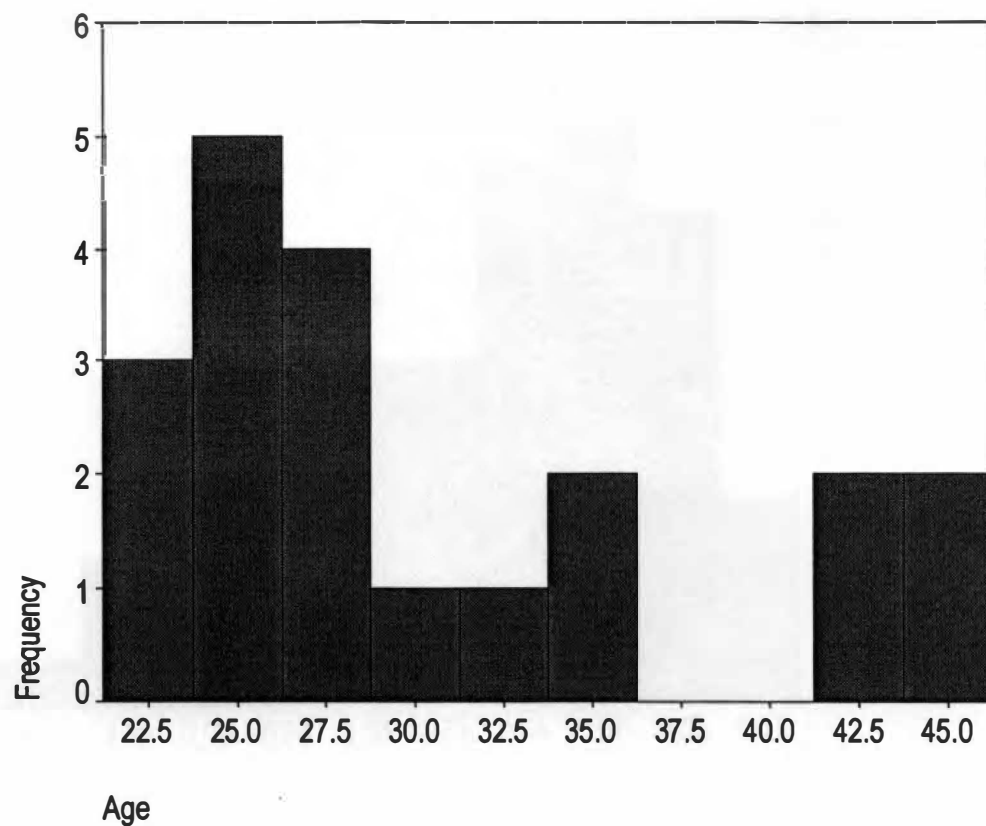


Figure A.20. Histogram of ages-at-death among Balkan males, Suchey-Brooks Pubic Symphyseal Phase 3.

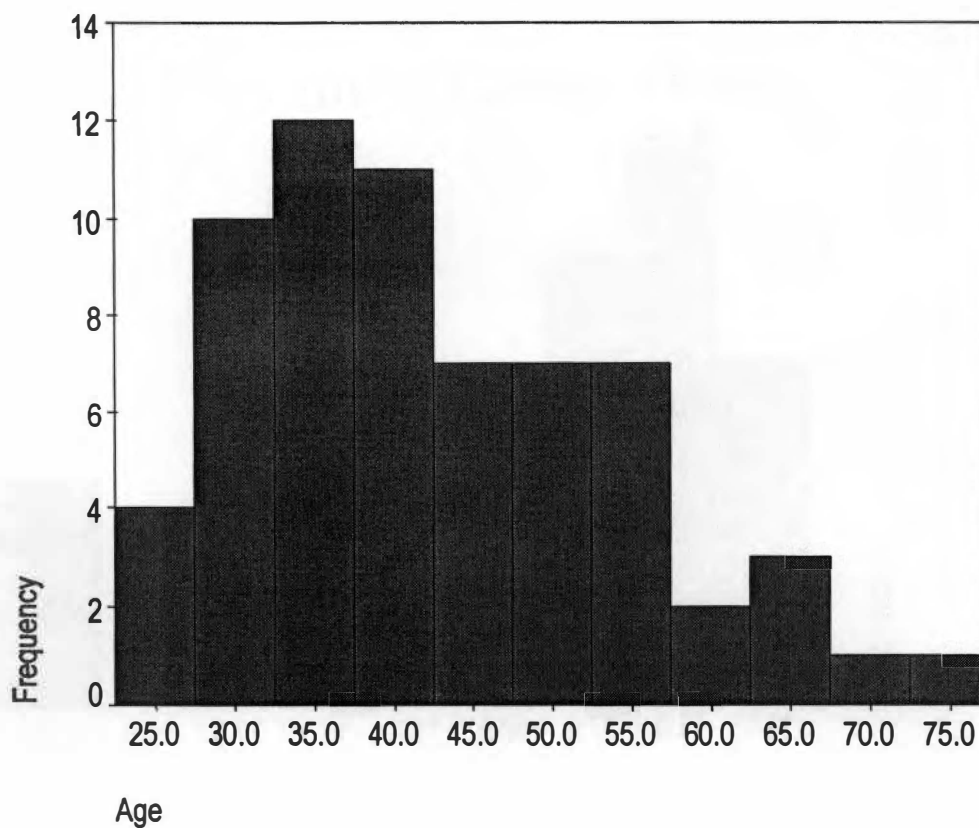


Figure A.21. Histogram of ages-at-death among Balkan males, Suchey-Brooks Pubic Symphyseal Phase 4.

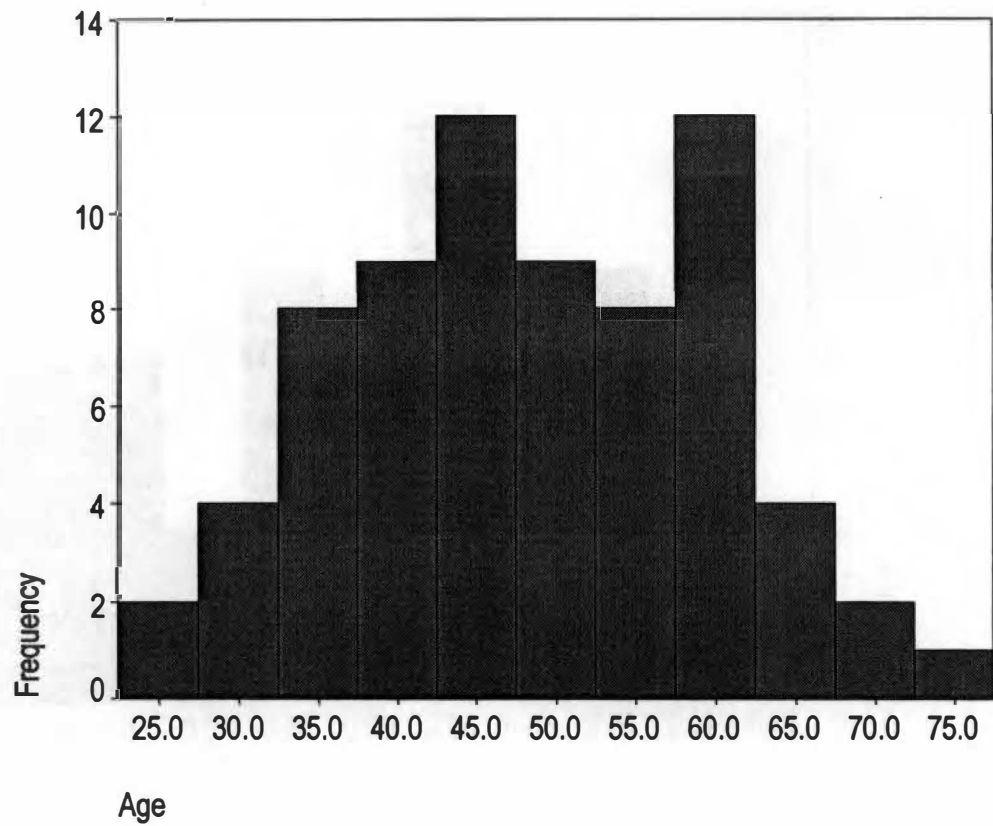


Figure A.22. Histogram of ages-at-death among Balkan males, Suchey-Brooks Pubic Symphyseal Phase 5.

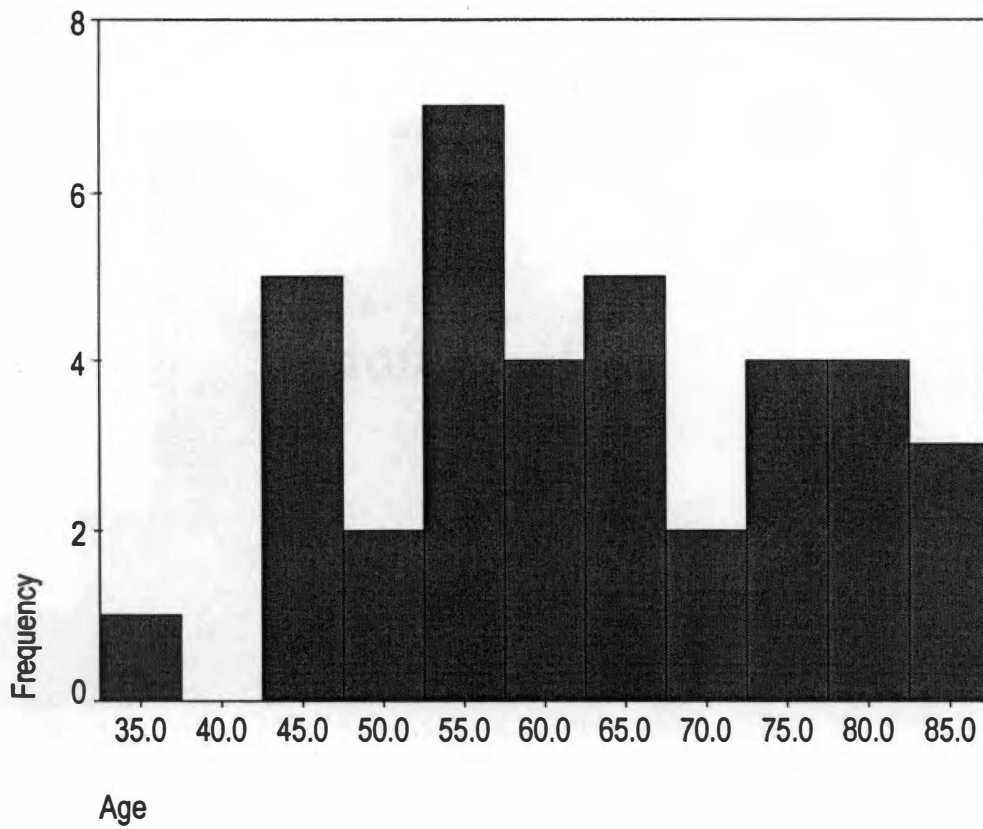


Figure A.23. Histogram of ages-at-death among Balkan males, Suchey-Brooks Pubic Symphyseal Phase 6.

## VITA

Erin H. Kimmerle received her B.A. in Anthropology from Hamline University and her M.A. in Physical Anthropology from the University of Nebraska. Following graduation from Hamline University, Erin worked as an osteologist for the National Museum of Natural History, Smithsonian Institution, in Washington, D.C. During her tenure at The University of Tennessee, she also worked as a Forensic Anthropologist for the United Nations on missions in Kosova, Croatia, and Bosnia-Herzegovina for the United Nations, International Criminal Tribunal for the Former Yugoslavia.

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