2007

Reevaluating age in subadult remains in response to secular changes in skeletal growth

Katherine Ann Blackwelder
Louisiana State University and Agricultural and Mechanical College

REEVALUATING AGE IN SUBADULT REMAINS IN
RESPONSE TO SECULAR CHANGES IN
SKELETAL GROWTH

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Arts
in
The Department of Geography and Anthropology

By

Katherine Ann Blackwelder
B.A. University of North Carolina at Charlotte

August 2007

ACKNOWLEDGEMENTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The goal of forensic anthropology is the analysis and identification of human skeletal remains in a medicolegal context (Byers 2005:1-2). A forensic anthropologist can determine the age of subadult remains by various means, including dentition, centers of ossification, cranial suture closure, and epiphyseal union. Epiphyseal union is when all bones have completed their growth and fused, which happens for all bones by early adulthood. In this way, a forensic anthropologist can analyze the extent of epiphyseal union to determine the age of a deceased individual. This is done by comparing the skeletal remains to age-specific x-ray images of bones featured in various atlases. The only such atlas for the hand and wrist is Greulich and Pyle's *Atlas of Skeletal Development of the Hand and Wrist* (1959). By using this atlas forensic anthropologists can estimate the age of the decedent at his or her death and thereby assign an age range to the remains that will help law enforcement authorities to make a positive identification. Greulich and Pyle's atlas is nearly 50 years old and some researchers suggest it has become less accurate in its representation of growth and development stages in the hand and wrist. The onset of puberty as measured by the age at menarche is now earlier than in the past, and puberty coincides with specific changes in bone growth (Eveleth and Tanner 1990:207).

To determine the extent of potential error in Greulich and Pyle's *Atlas of Skeletal Development of the Hand and Wrist,* I studied the current x-rays of the hand and wrist in subadults of known ages and sex. My study revealed that the epiphyseal union of the

hand and wrist of contemporary subadults is not significantly different than the data

represented in the *Atlas of Skeletal Development of the Hand and Wrist*. This suggests

that there has not been a substantial increase in the rate of development as a result of

secular change. As such, the standards created by Greulich and Pyle remain accurate

and should continue to be used for the identification of age in subadult remains.

C H A P T E R   1

INTRODUCTION

Forensic anthropologists often are called upon to create a biological profile for skeletonized remains in order to aid in positive identification of the individual. Characteristics of the biological profile include the age, sex, race/ancestry, height, any trauma suffered by the victim at or around the time of death, and any identifying markers, such as previously broken bones or evidence of surgery. The creation of this profile becomes much harder if the remains are those of a child or subadult. In these cases, definitively determining race/ancestry and sex is difficult at best. Many attempts at assessing sex and ancestry from subadult remains have been made, but none has been conclusive. Those techniques that have limited accuracy require a complete skeleton as well as complete dentition (Snow and Luke 1984:264). As a result, age at death is the best method for helping law enforcement with the identification of the victim.

Age in subadult remains can be determined in many ways, including dentition, centers of ossification, cranial suture closure, and epiphyseal union. One method should never be the determining factor, but decisions about age should be based on a combination of all available resources. The correct determination of age is vital to the identification process.

Because of changes in the timing of adolescence and earlier puberty, children may reach skeletal maturity sooner than their chronological age may reflect. In response

to this potential problem, the current study has been conducted using contemporary

subadult x-rays of known chronological age and sex. The results are compared with

standards outlined by Greulich and Pyle in their book, *Radiographic Atlas of Skeletal*

Development of the Hand and Wrist (1959).

C H A P T E R 2

LITERATURE REVIEW

The children included in *Radiographic Atlas of Skeletal Development of the Hand and Wrist* by Greulich and Pyle were also part of the Brush Foundation Longitudinal Study (Greulich and Pyle 1959:xii). The children were Caucasian and of Northern European descent. In addition, all were from an above average socioeconomic status and upon examination were found to be free of any "gross physical or mental defects" (Greulich and Pyle 1959:xii). Those included in the study were examined at three-month intervals during the first year of life, every six months from ages one to five, and every year after age five until the cessation of growth (Greulich and Pyle 1959:31). The book of standards follows this format with x-rays every three months for birth through the first year of life, every six months for ages one to five, and every year from five to eighteen in females and nineteen in males. At the time of puberty the standards occur at six-month intervals. Some of the standards do not follow the set three-to-twelve-month pattern because the authors either chose to use the same child for a series of standards despite the fact that the skeletal status of the individual did not match the mode of chronological ages, or because certain stages needed to be included and otherwise would not have been illustrated by the standards (Greulich and Pyle 1959:33). For example, included is an additional x-ray for a thirteen-and-a-half-year-old female standard and a fifteen-and-a-half-year-old-male standard to reflect the rapid rate that skeletal changes occur during puberty (Greulich and Pyle 1959:xiii). Those x-rays selected for the book of standards

were chosen out of 100 of the same age and sex. For each standard position, the possible x-rays were laid out in order of the least to most mature. The x-ray that was chosen was selected because it best represented the "central tendency, or anatomical mode of the particular array" (Greulich and Pyle 1959:32).

One of the most widely cited sources for information on skeletal growth is the United States Army Technical Report EP-45 by McKern and Stewart (1957), also known as *Skeletal Age Change in Young American Males*. This report's purpose was to document the different methods available to determine chronological age of skeletal remains in order to better identify the remains of American military personnel. McKern and Stewart analyzed the remains of 450 servicemen stationed in South Korea who were either killed in action (KIA) or died as prisoners of war (POW) during the Korean War (1950-1953) (McKern and Stewart 1957:iii). Some of the servicemen's remains had previously been identified and others had not, but the researchers performed their study without knowledge of the ages of any remains. After using various methods to estimate the age of the men, McKern and Stewart could determine which one proved to be the most accurate. One of the methods that they tested involved an examination of the epiphyses of the bones that fuse by subadulthood. The epiphyses that are the last to fuse, or exhibit "delayed union," were the most useful to use to assign an age to skeletal remains because they are most likely to be unfused in younger soldiers (McKern and Stewart 1957:41). Most remains in their study were from soldiers aged 18 to 20 (McKern and Stewart 1957:10).

To systematically determine age, McKern and Stewart assigned numbers to the stages of epiphyseal union for each bone. Those stages ranged from one to four, with one representing the beginning of fusion and four the completion (Figure 1) (McKern and Stewart 1957:5).
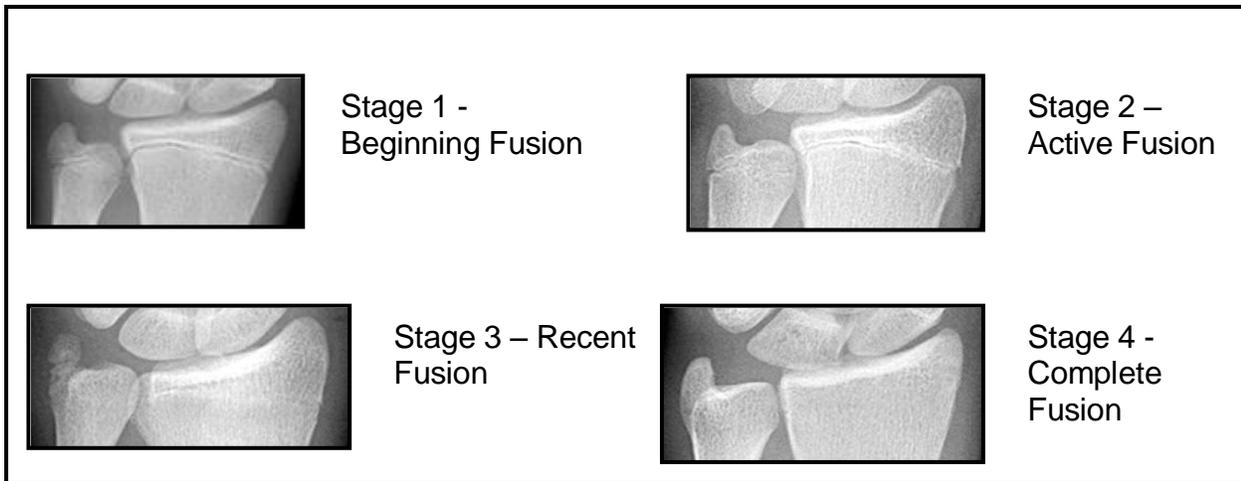
Figure 1 – Four stages of fusion according to McKern and Stewart (1957) and x-ray examples of each (Gilsanz and Ratib 2005) (With kind permission of Springer Science and Business Media).

According to McKern and Stewart, previous studies estimated the age of complete fusion for both the distal radius and ulna between the ages of 19 and 21. However, they found that the distal radius had completely fused in one soldier who was as young as 18, whereas it fused in others as old as 23. For complete fusion of the ulna, they found that it had occurred in some individuals by 17 years of age with everyone having it fused by 23 (McKern and Stewart 1957:43). The sample appears to adequately represent a random sample of males in the United States during the time of the Korean War. As such, McKern and Stewart's research serves as an appropriate comparative study to measure any

changes in the timing of epiphyseal union of the distal radius and ulna that have occurred since the early 1950s.

Schaefer and Black (2005) studied the differences in rates of epiphyseal union that exist between races and nationalities. This involved comparing the rates of union between McKern and Stewart's dataset for American males and their own dataset for Bosnian males of approximately the same ages (17-30) who perished in the "fall of Srebrenica" (Schaefer and Black 2005: 778). They found that while the American sample shows greater maturity, the "Bosnian maturity advances more quickly and in the end terminates earlier" (Schaefer and Black 2005:780). The researchers concluded that there are salient differences in the rates and ages of epiphyseal union between the two populations. This difference was recognizable despite the fact that both study groups were frequently malnourished – some of the American soldiers were POWs and the Bosnians had limited food supplies during the two-year siege. This suggests that population-specific standards are important to consider to obtain a positive identification (Schaefer and Black 2005:782-3).

In the past twenty years other researchers have also attempted to assess the rates of change in the age of epiphyseal union in relation to the standards developed by Greulich and Pyle. These researchers focus their analyses on the application of assigning a skeletal age in order to diagnose certain musculoskeletal and metabolic disorders (Loder et al. 1993:1329). Their results are useful to compare with the results of my own research.

Loder et al. (1993) compared the standards put forth by Greulich and Pyle (1959) to those in their sample of x-rays taken from 1986 through 1990 (sample size = 841: males n = 452, females n = 389). In addition to testing the reliability of Greulich and Pyle to contemporary white children, Loder et al. also compared their standards to black children. Of the 841 children in their sample, 461 were black and the remaining 380 were white. Loder et al. compared the skeletal and chronological ages of their subjects to the data contained in the atlas and this allowed them to gauge for which groups the 1959 atlas was most outdated. The study showed that there were significant differences between skeletal ages and chronological ages for both males and females. Of all the subgroups analyzed, only white females matched the standards established by Greulich and Pyle. The analysis of white males, black males, and black females resulted in both advanced and retarded skeletal/chronological age ratios when compared to Greulich and Pyle's atlas (Loder et al. 1993:1331). When broken down by sex, they found that females exhibited a skeletal age that was 0.31 years more advanced than their chronological age; males showed a particularly strong skeletal advancement of 0.45 years (Loder et al. 1993:1331). Loder et al.'s results cast doubt over the applicability of Greulich and Pyle (1959) for estimations of skeletal ages in contemporary populations (Table 1).

The previous studies demonstrate the need for aging techniques used in subadults to be of the highest accuracy. Knowledge of these studies is necessary for understanding the current study and the need to reevaluate Greulich and Pyle. In order to appreciate timing of epiphyseal union in the bones of children and young adults, a brief review of bone growth in subadults is needed

Table 1 – Differences between bone and chronological ages (Loder et al. 1993).

Sex Group	Age Group	N	Mean (±SD) Difference
Black Females	Early Childhood (Birth-3yrs - 10mos.)	60	.043±0.66
	Middle Childhood (3yrs.11mos - 8yrs.4mos.)	50	0.27±1.01
	Late Childhood (8yrs.5mos. - 13yrs.3mos.)	50	0.68±1.22
	Adolescence (13yrs.4mos. - 18yrs.6mos.)	52	0.68±0.85
Black Males	Early Childhood (Birth-3yrs - 9mos.)	60	0.13±0.73
	Middle Childhood (3yrs.10mos - 7yrs.6mos.)	50	-0.03±0.76
	Late Childhood (7yrs.7mos. - 13yrs.3mos.)	70	0.31±1.29
	Adolescence (13yrs.4mos. - 18yrs.6mos.)	69	0.38±1.24
White Females	Early Childhood (Birth-3yrs - 10mos.)	46	-0.09±0.63
	Middle Childhood (3yrs.11mos - 8yrs.4mos.)	29	-0.10±0.99
	Late Childhood (8yrs.5mos. - 13yrs.3mos.)	46	0.23±1.37
	Adolescence (13yrs.4mos. - 18yrs.6mos.)	56	0.16±1.18
White Males	Early Childhood (Birth-3yrs - 9mos.)	43	-0.11±0.56
	Middle Childhood (3yrs.10mos - 7yrs.6mos.)	20	-0.91±0.84
	Late Childhood (7yrs.7mos. - 13yrs.3mos.)	70	-0.39±1.12
	Adolescence (13yrs.4mos. - 18yrs.6mos.)	70	0.45±1.38

C H A P T E R   3

BONE GROWTH IN SUBADULTS

In adult bones, the organic portion comprises 24 percent of the dry weight of the bone and the inorganic portion 76 percent. In children's bones, the organic portion constitutes a higher percentage. As a result, the bones of children are more cartilaginous and have a higher level of plasticity than adults (Baker et al. 2005:5).

Human growth consists of two processes: an increase in overall size and the "attainment of consecutive levels of maturity" (Scheuer and Black 2000:11). This accounts for children who have the same chronological age but may have vastly different skeletal ages and be at different stages of sexual maturity (Scheuer and Black 2000:11). A common example of this is seen in children of the same age but who have remarkably different statures.

Two types of bone growth are important to determine age in subadult remains: intramembranous and endochondral ossification. Intramembranous ossification is important for bone growth at infant stages. Here, bone ossifies by apposition of bone on top of bone tissue. This method of growth is particularly evident in the fetal or infant cranial bones. Most of the bones in the human body grow through endochondral ossification. As the body grows, there is an increase in both the diameter and length of the bones. In endochondral ossification, the bone that is laid down replaces already existing cartilage. The cartilage that exists prior to ossification is a type of soft tissue

composed mostly of collagen (White 2000:28). Consequently, upon death, the cartilage does not survive the decomposition process to the same extent that the harder bones do. Growth of the long bones occurs when the osteoblasts below the perichondrium deposit bone on the outside of the cartilage shaft. This is called the periosteum. In turn, the periosteum deposits bone layer by layer and increases the bone size appositionally, or in diameter. At the same time the bones grow in length through the epiphyseal plate or growth plate. The growth plate is a layer of cartilage that separates the primary center of ossification or metaphysis of the bone from the secondary center or epiphysis. The epiphyseal plate grows away from the shaft center and is replaced by bone from the diaphyseal side of the plate. Growth ceases when the cells in the epiphyseal plate stop dividing and the epiphysis fuses with the metaphysis or shaft (White 2000:29).

Various terms can describe the different periods that punctuate the lifespan of an individual. These include "infant," "child," "adolescent," and "juvenile." The use of this terminology to describe different periods of development can vary by country and discipline. For example, the term "puberty" is often used as a term to describe the physiological changes associated with the development of secondary sexual characteristics. Also, the term "adolescence" is sometimes used interchangeably with puberty to refer solely to behavioral and psychological changes that accompany puberty (Scheuer and Black 2000:9). In general, the term "subadult" is used to refer to any stage of development along the path to adulthood (Scheuer and Black 2000:10).

Differential preservation of subadult skeletal remains continues to be an important issue in both archaeological excavations and forensic investigations. This differential

preservation occurs because the smaller bone size makes subadults particularly vulnerable to the effects of bioturbation and because the bones themselves are less mineralized than those of adults. This also makes subadult bones more susceptible to postmortem damage (Baker et al. 2005:11). In terms of excavations, the state of preservation is of utmost importance with regard to interpretation.

One of the most controversial issues involving the differential preservation of skeletal material is what Wood et al. refer to as "selective mortality" (1992:344). Selective mortality acknowledges that the extant skeletal remains represent individuals from a certain age cohort who did not survive to the next stage of life. As they state, "All samples of the dead are inherently unrepresentative of the original living population at risk of death" (Wood et al. 1992:344). Therefore, examination of deceased children may not provide an accurate representation of the average physical condition of the age cohort. As such, when comparing the growth of individuals from contemporary and historic populations, it is important to remember that historic remains might be those of children who were of below-average health, while contemporary children's remains are presumed to be more reflective of the average child's health (Wood et al. 1994:351).

CHAPTER 4

DETERMINING AGE FROM SUBADULT REMAINS

The most reliable method to determine skeletal age in subadults is to study dentition. While people lose teeth throughout their entire lifetimes (Nafte 2000:95), tooth growth and development occur during the neonate, infant, and juvenile age ranges (Scheuer and Black 2000:12). The stages of dental development follow a strict sequence, and dentition is less affected by the environment than bone. Teeth are not "subject to the process of remodeling during life" and are very durable, lasting long after bone has decomposed in the ground (Nafte 2000:95).

Despite many advantages of using dentition to identify remains, it is not always possible. Cases where using dentition is inappropriate include those where there are no available dentitions because of perimortem or postmortem damage or the dentition is missing from the skeletal material.

When dentition is not present, a highly reliable method to determine age in subadult remains is to use the length of the diaphyses, the shafts of the long bones. When using diaphyseal length as an estimate of skeletal age, researchers correlate the length of the shaft with a chronological age. This creates a growth curve, or skeletal growth profile, to show the progression of age for a population to complete epiphyseal fusion (Hoppa 1992:277). However, in order for these correlations to be representative of the population, there must be a comparative collection from an identical population of

known chronological age. This could be problematic in situations wherein the unidentified remains are from an unknown population, especially when techniques for determining the race of subadult remains are inconclusive. Moreover, child remains from archaeological sites are often few and insufficient in number to produce a reliable growth curve (Hoppa 1992:285).

Fortunately, there are established x-ray standards for the singular purpose of correlating chronological and skeletal ages. However, a problem with these standards is that they are outdated. As already mentioned, one of the most popularly used books of x-ray standards is Greulich and Pyle's *Radiographic Atlas of Skeletal Development of the Hand and Wrist,* which was written in 1959. Their results demonstrate the differences between chronological and skeletal age of a subadult population from over 50 years ago. I will argue that children's skeletons are changing as a result of lifestyle and nutritional changes in recent decades. These secular changes could result in a discrepancy between Greulich and Pyle's (1959) standards as applied to juvenile skeletal remains of the twenty-first century.

CHAPTER 5

CHANGING RATES OF MATURATION

Evidence suggests that in the last 150 years, there is an "increase in height and weight of adults and a decrease in age at which adult size is achieved" (Scheuer and Black 2000:5). This stems from changing social environments and lifestyle choices, not necessarily genetic factors. There is a marked trend toward a younger age at puberty and the adolescent growth spurt. The adolescent growth spurt can be defined as "an increase in growth velocity… which eventually reaches a maximum during the spurt and then gradually declines" (Malina et al. 1988:188).

Earlier maturation is evident in the soft tissue physiology. However, it remains to be determined whether an earlier age of puberty also affects the hard tissue and results in skeletal ages for contemporary individuals that are vastly different from their chronological age according to standards established decades ago. Puberty is exhibited by the secondary sexual traits of breast and pubic hair development, menarche in females, and genital growth in males. The early onset of puberty results in a younger age when adult height is reached.

The development of breasts in females and pubic hair in both sexes represents secondary sexual characteristics, meaning that these two have nothing to do with the actual act of sexual reproduction. In a clinical setting, secondary sexual characteristics are recorded with Tanner stages, which serve to document the level of pubertal

development in children and adolescents. The Tanner stages use five levels of development for the breasts, genitalia, and pubic hair (Eveleth and Tanner 1990:173). The problem with using these stages is that they rely on soft tissues to determine the level of maturation. These stages can be documented and compared to previous longitudinal studies to determine any changes that may have occurred in rates of maturation across time. Unfortunately, they cannot be used to determine rates of growth for past populations or in the forensic context with skeletal remains. In addition, the Tanner stages are subject to discrepancies because of the arbitrary nature of individual and independent observation.

Contemporary children are much heavier than their historic counterparts were. Today's children consume more and exercise less than any previous generation. Herman-Giddens (2006) draws the comparison that adolescents today have the same high protein, high calorie diet combined with restricted movement as commercial livestock. These animals are bred and raised to be larger at ever-earlier ages and thereby increase profit margins. Like livestock, sedentary children with high-calorie diets are entering earlier maturation.

Obesity is a prime cause of early maturation (Adair and Gordon-Larsen 2001:642). Some researchers suggest that predisposition to obesity is the single factor in a person's genetic makeup that leads to earlier puberty. The truth is that "the genetic composition of the population does not change rapidly. Therefore, the large increase in . . . [obesity] must reflect major changes in non-genetic factors" (Hill and Trowbridge 1998:3). The medical definition of obesity is a body mass index of >30 percent in adults. For children and

teenagers, obesity is determined based on percentiles for height and weight. Children and teenagers classified as obese are in the 95th percentile or higher, which means that they weigh more than 95 percent of other children and adolescents at the same age and height (www.cdc.org).

Previous studies have determined that early maturers tend to weigh more than their peers. In addition, those who are categorized as late maturers take longer to reach menarche after the initiation of the adolescent growth spurt (Frisch and Revelle 1970:397). The cessation of growth is the complete fusion of most of the skeletal epiphyses, which occurs prior to menarche in females. In fact, Greulich and Pyle report in their study, "Menarche occurred between the beginning and the completion of the epiphyseal fusion in the phalanges – usually soon after the fusion of the epiphyses of the distal phalanges with their shafts" (1959:11). According to Adair and Gordon-Larsen, "Early maturing girls are twice as likely as average maturing girls to be overweight" (2001:643).

The "critical fat" hypothesis is one of the most common explanations for the role of obesity in earlier maturation and attainment of menarche. This theory notes that in both late and early maturing females, the mean weight for the start of the adolescent growth spurt, the maximum rate of growth, and menarche are the same for each type of girl. In other words, although these events may take place at different times in the growth cycle, they take place at or around the same weight. Proponents of the critical weight theory propose that weight is indeed a determining factor in growth and pubertal development. As such, the increasing number of children who are overweight or obese could contribute

to the increase in rates of early maturation. Frisch and Revelle state that weight and the

initiation of the growth spurt could be related because the "attainment of a body weight in

the critical range causes a change in metabolic rate, which in turn, reduces the sensitivity

of the hypothalamus to estrogen, thus altering the ovarian-hypothalamus feedback"

(1970:398). The feedback response is a result of the weight increase to a critical range

that could trigger the release of growth hormones and cause the initiation of the growth

spurt (Frisch and Revelle 1970:398).

In Adair and Gordon-Larsen's study comparing weight and maturation rates, they

found that "early maturing girls were nearly twice as likely as average maturing girls to be

overweight" (2001:643). Adair and Gordon-Larsen define overweight as a Body Mass

Index (BMI) greater than the 85th percentile (2001:643). In the study, 57.5% of early

maturing African American females exceeded the 85th percentile for BMI. By comparison,

in the 1960s, only 12.1% of African American females were considered overweight; by

the mid 1990s, this percentage had increased to 30.7% (Adair and Gordon-Larsen

2001:642).

Other theories of earlier maturation include everything from the altitude of specific

geographic locations and low birth weight to the absence of a father figure in a young

girl's life and soy-based infant formula (Setchell et al. 1998). Scientists hypothesize that

low birth weight has an effect on age at puberty and menarche because menarche is tied

to the growth and development of the skeletal anatomy. According to Ibanz et al., girls

born at a low birth weight have menarche 1.6 years later than those of normal birth

weight, as well having their heights reduced by > 5 cm (2000:72). Normally, young girls

who are predisposed to early puberty progress through it slowly, and this extends the duration of the adolescent growth spurt. As a result, they experience menarche at or around the same time as average girls. Girls who are both predisposed to early pubertal development and have a low birth weight do not advance slowly through puberty but instead have menarche earlier as well as a reduced adult stature. This demonstrates a control mechanism that compensates individuals with early puberty by slowing its progression. This mechanism does not appear to be present in girls born at low birth weights (Ibanez et al. 2000:73).

In addition to other secular changes, the onset of earlier puberty has been attributed to parental instability. The stresses involved in living in parentally unstable situations seem to affect the rate of maturation for contemporary populations. A self-report study by Bogaert linked the presence or absence of a biological father in the lives of both adolescent males and females to the likelihood of experiencing early puberty. In the study, individuals were asked to recall both the age that puberty (as determined by menarche in females and change in voice or pubic hair in males) was reached and with whom they were living at age 14 (Bogaert 2005:542). The choices ranged from living with both parents, to just the mother, just the father, mother and step-father, and other male or female family member. The study determined that only the presence or absence of the biological father had any effect on pubertal timing; the presence or absence of a biological mother did not have an effect on the timing of puberty. In addition, the effect was present in both males and females (Bogaert 2005:544). This suggests that the same mechanisms affecting the changes in growth and adolescence in young females are also affecting

young males. In addition, the study demonstrates the effect that stress can have on the timing of pubertal events (Bogaert 2005:541).

Experts have noted an increase in the growth rates of children throughout the industrialized nations of the Western world. The lifestyle effects of industrialization not only increase height and weight but also result in earlier maturation or puberty. This is regarded as a secular trend and is viewed as the result of such environmental factors as "improved nutrition, control of infectious disease through immunizations and sanitation, reduced family size, more widespread health and medical care, and population mobility" (Eveleth and Tanner 1990: 205). These secular changes imply that it might not be entirely appropriate to use non-contemporaneous data for the determination of age based on skeletal material for recently deceased individuals. This is not to say that there is no individual variation within a population, but that a portion of this variation is not genetic (Eveleth and Tanner 1990:1).

These secular changes in physiology do not stem from industrialization alone but are also attributable to such factors as warfare, economic uncertainty, and even stress (Graber et al. 1995:355). Recently, Tahirovic studied young Bosnian girls to document the effect these stresses have on maturation. The age range for the study was between eight and seventeen years. These adolescent females were residents of Srebrenica from the end of 1992 to mid-1995 and were witnesses to acts of shelling, bombings, and attacks on family members. Adding to the stressful situation in Srebrenica were the deaths of more than 1,000 children that resulted from starvation and disease. Tahirovic examined the age at menarche for these females and compared them to a control group of girls who

were also Bosnian, but from an area that was peaceful and unoccupied at the time (1998:978). The results of the study showed that the mean age of menarche for the Srebrenica sample was 10.75 years, compared with the control group mean of 9.75 years. The author also determined that the percentage of the control sample of females who reached menarche was 57.6 percent as compared to the Srebrenica sample that was only 34.3 percent (Tahirovic 1998:979). Based on these results, the author concluded that "Psychological trauma, physical injury, and low socioeconomic status provoked by the events of war, delay menarchal age" (Tahirovic 1998:980).

One of the best determinants in females for the onset of puberty is menarche. Menarche is not subject to individual discrepancies that the Tanner stages are. The Tanner stages are subject to the arbitrary nature of individual and independent observation. The onset of menses is "more reliable than those which require assessment of physical characteristics" (Herman-Giddens et al. 1997:509).

As stated earlier, secular changes can result in certain populations "getting larger and growing to maturity more rapidly" (Eveleth and Tanner 1990:205), but not all of these changes are regarded as "good" or advantageous. Many of these advancements are advantageous, such as improved nutrition and healthcare. However, some, such as increased obesity and stress, have resulted in negative effects in the development of adolescents. Obesity, while causing such health risks as type-2 diabetes (Adair and Gordon-Larson 2001:644), is also one of the determining factors in the occurrence of early maturation (Adair and Gordon-Larsen 2001:642). According to a study by Adair and Gordon-Larsen, "early maturing girls are twice as likely as average maturing girls to be

overweight" (2001:643). If this is the case, then juvenile obesity is in effect a causal factor in the steadily increasing numbers of adolescents with precocious puberty. A study by Herman-Giddens et al. found that in an analysis of 17,077 girls in the United States, the mean age for the onset of breast development was 8.87 years for African-Americans and 9.96 years for Caucasians. Public hair development was calculated at a mean age of 8.78 years and 10.51 years, respectively (Herman-Giddens et al. 1997:508). If these current mean ages for secondary sexual characteristics are accurate, then what is seen as the norm today was a few generations ago regarded as precocious puberty. Medical terminology and research have not been able to keep up with these trends, and, as a result, some young children with mature bodies are not being accurately classified. "Earlier puberty is a real phenomenon and this has important clinical, educational, and social implications" (Herman-Giddens 1997:505). During the past 100 years, the average age at menarche has been three to four months earlier per decade in Europe and the United States (Eveleth and Tanner 1990:207). Figure 2 illustrates the younger age at menarche for the years 1932 through 1994.

In order to evaluate whether or not documented secular change in the timing of puberty for some populations has also impacted skeletal growth and maturation, the current research examines x-rays of the distal radius and ulna for a random sample of subadults. These can then be compared to previous research on growth in subadults to determine whether or not secular changes have caused significant differences in the ratio of skeletal age to chronological age.

Change in Age at Menarche
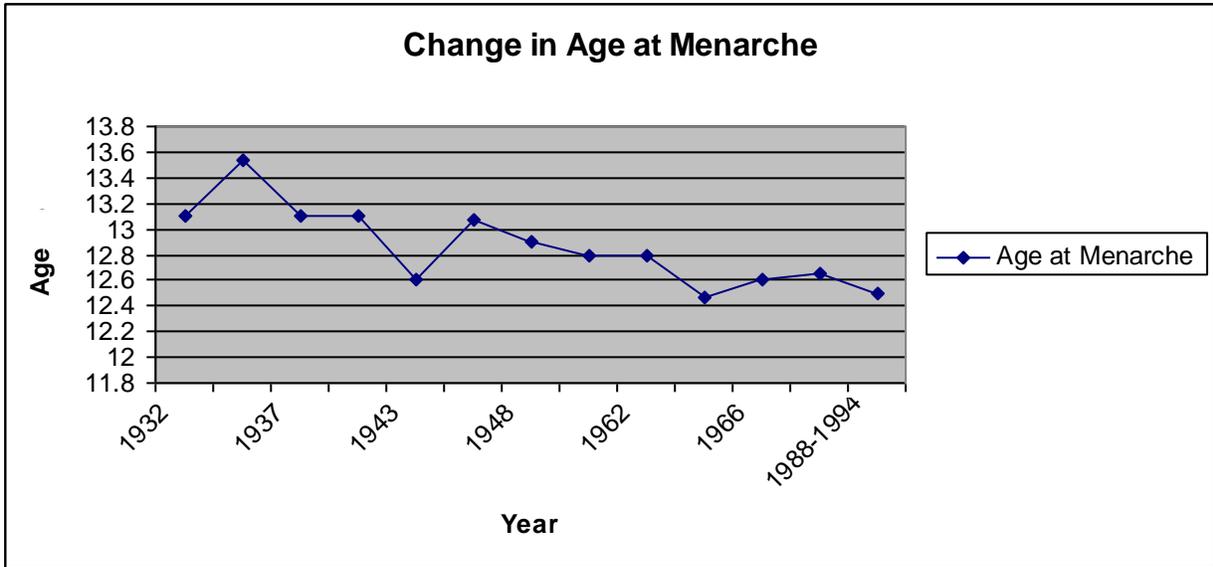
Figure 2 – Changes in the age at menarche (Chart derived from data presented in Herman-Giddens 2006)

CHAPTER 6

METHODOLOGY

The method that forensic anthropologists most commonly use to determine

skeletal age in subadult remains is based upon the epiphyseal union of the long bones.

Schaefer and Black note that epiphyseal union is ". . .a reliable indicator of age at death in

young adults and of greatest discriminatory value" (2005:777). To determine the stage of

epiphyseal union, researchers use an atlas of standards to compare the remains in

question to the x-rays of a population of subadults of known chronological age (White and

Folkens 2005:363). Originally, these standards, such as the one created by Greulich and

Pyle (1959), were developed using longitudinal studies conducted between 1930 and

1960 (Scheuer and Black 2000:8). These studies were performed by taking x-rays of

children three times in the first year of life and every six months thereafter until fully grown

(Sheuer and Black 2000:8). By comparing these x-rays to the remains in question, a

forensic anthropologist can determine the skeletal age. Unfortunately, these standards

cannot be duplicated using modern populations because the amount of x-ray exposure

that is needed for a longitudinal study is dangerous to the subject. This risk was not

understood or was underestimated in the mid-twentieth century (Scheuer and Black

2000:8).

In the *Radiographic Atlas of Skeletal Development of the Hand and Wrist,* Gruelich

and Pyle (1959) assessed the stages of epiphyseal union to determine a skeletal age

based upon the individual's stage of union of the bones of the hand and wrist. The radius is a good development marker because it is one of the most frequently fractured bones in children (Scheuer and Black 2000:293). As a result, there are numerous x-rays taken of the hand and wrist. Additionally, the radius is one of the last bones to completely fuse (Scheuer and Black 2000:293). It does not matter which hand is used in an x-ray for it to be used in analysis; however, most standards are taken using the left hand because most people are right handed, and, therefore, the left is the less likely to be injured. Because I use previously viewed x-rays that were taken for other purposes, I cannot guarantee that they will be from the left side, but there should be no difference between sides.

In 1931, The Brush Foundation began its study of longitudinal growth in children under the leadership of T. Wingate Todd that lasted until mid-1942. In 1937, Todd published the *Atlas of Skeletal Maturation.* Todd's atlas is the basis for the standards developed by Greulich and Pyle (Greulich and Pyle 1959:xii).

To evaluate the work of Greulich and Pyle, I studied a contemporary population using x-rays taken between 2005 and 2006. The individuals in the study were born between 1986-2000 and were between the ages of three and 21 at the time the x-ray was taken. At age 21, all individuals should exhibit complete fusion of all bones of the hand and wrist. These x-rays are from the orthopedic group OrthoCarolina in Charlotte, North Carolina, as part of their Research Institute. The OrthoCarolina Research Institute is "an independent, autonomous, not-for-profit research organization, the mission of which is to promote and support scientific research and education as it relates to orthopedic care" (www.orthocarolina.com). I chose to work with the OrthoCarolina Research Institute both

because of the availability of x-rays and the willingness of their research institute to aid in my data collection.

All of the x-rays were observed and the data were collected following recommendations found in *Radiographic Atlas of Skeletal Development of the Hand and Wrist*. The book of standards chronicles the growth and development, including epiphyseal union, of the distal radius and ulna, carpal bones, and metacarpals. According to Greulich and Pyle, "A satisfactory assessment of the hand-films of most normal children can be made by comparing them carefully with the standards illustrated" (1959:35). As recommended by Greulich and Pyle, each x-ray was assessed by first using the appropriate set of standards depending on the sex of the individual.

In addition to sex, other data on the subjects that I collected included their chart number, date of birth, and the date that the x-ray was taken. If any of this information was missing, the entire chart was excluded from analysis. In accordance with approval by the Louisiana State University Institutional Review Board (IRB), no personal information or identifying markers were collected, including the name of the individual. The total sample size was 132 individuals. Out of these, 123 were usable; the remaining nine were excluded for various reasons.

I examined the standard that was closest to that of the chronological age for the individual as well as the next oldest and youngest standard for the sex. I chose the standard that appears "superficially" to be the closest match to conduct a more detailed comparison (Greulich and Pyle 1959:35). Important features for comparison included the presence or absence of epiphyseal ossification centers and the degree of fusion of the

epiphyses with their shafts or diaphyses. After I chose the standard for comparison, I

made a more in-depth comparison of the individual bones. In accordance with the

recommendations made by Greulich and Pyle, I observed the bones in the following

order: distal radius and ulna, carpals, metacarpals, and phalanges (1959:35).

Unfortunately, because of time constraints stemming from the fact that each carpal

needed to be observed independently of the others, I performed no analysis of the

carpals. The same holds true for the analysis of the phalanges. Following the analysis of

each bone, I assigned a skeletal age. If I found no match from the standards for the

bones in question, I assigned a skeletal age based upon "those it most closely

resembles" (Greulich and Pyle 1959:36).

      I was also not able to obtain race or ethnicity for any of the individuals included in

the study as the information was on the patient's medical file and not on the x-ray itself.

As such, it is difficult to make assumptions regarding growth using Greulich and Pyle

simply because those data were based solely on Caucasian children. Despite this, the

information is useful in a forensic context because of the inability to determine race or

ethnicity in subadult remains. Therefore, data which combine all possible races or

ethnicities would be more beneficial than those which separate the data by race or

ethnicity.

      After reviewing each of the x-rays from a random selection of individuals who were

patients at OrthoCarolina, I assigned a skeletal age to the individual distal radius, ulna,

and metacarpals. the data were selected using a random sample of x-rays selected by

the computer. The only two established criteria were the individual's age and the location

of the x-ray. I then correlated the assigned skeletal ages to the known chronological age of each individual. From this, I was able to compare the chronological and skeletal ages of the subjects. I used the SPSS statistics computer program as well as Microsoft Excel to analyze the results.

CHAPTER 7

RESULTS

Overall, a positive correlation existed between the chronological ages and the

assessed skeletal ages. An average skeletal age is the result of an average of the

assessed ages for the radius, ulna, and metacarpals. Using a paired samples correlation

to test the relationship between the chronological ages and the average skeletal ages, the

correlation was 0.947. Because it was determined that the chronological and average

skeletal ages have a positive relationship, there is a basis for all other analyses. The

correlation between these two ages is positive, showing that the assessed skeletal ages

were in fact good indicators of the chronological age (Table 2).

Table 2 - Paired sample correlation of chronological and average skeletal age.

		N	Correlation	Sig.
Pair 1	Chronological age and average skeletal age	129	.947	< .001

In addition to the positive correlation between the chronological age and average

skeletal ages, a test of paired correlations shows that there is also a positive relationship

between the chronological ages and the assessed skeletal ages for the distal radius, ulna,

and metacarpals. The correlations between the chronological ages and the distal radius,

ulna, and metacarpals are 0.923, 0.891, and 0.935, respectively (Table 3). Among the

correlations, the strongest is between the chronological age and the metacarpal skeletal

age. The weakest correlation, although still strong, is between the chronological age and

the assessed skeletal age for the ulna.

Table 3 - Paired correlation – Chronological age and radius, ulna, and metacarpals

		N	Correlation	Sig.
Pair 1	Chronological Age & Radius Skeletal Age	132	.923	< .001
Pair 2	Chronological Age & Ulna Skeletal Age	132	.891	< .001
Pair 3	Chronological Age & Metacarpal Skeletal Age	132	.935	< .001

I used a paired samples t-test to determine if the means of different assessments

differ significantly from one another when both experience the variables of interest. A

paired samples t-test using the variables chronological age and average skeletal age

resulted in a t-value of 0.072 and 2-tailed significance of 0.943. The significance level was

>0.05. Therefore, there is not a significant difference between the chronological ages and

the average skeletal ages (Table 4).

I also ran a paired samples t-test for each of the three bones used in the

assessments, with chronological age as the second variable. This resulted in 2-tailed

significance for one of three assessments. The one assessment that did exhibit

significance was a test comparing the chronological age and the assessed skeletal age

for the radius (Table 5).

Table 4 - Paired samples t-test for chronological age and skeletal age

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Chronological age - Average age	.00682	1.07420	.09458	-.18032	.19396	.072	128	.943

Out of the total usable sample size of 123, 102 were male and 21 were female.

After the sexes were separated, I performed a paired correlation for each sex. This not

only compared the correlation between the chronological ages and the average skeletal

age, but also of the chronological ages and the assessed skeletal ages for each bone that

was assessed (Tables 6 and 7).

Table 5 - Paired samples t-test for chronological age and radius, ulna, and metacarpals

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Chronological Age - Radius Skeletal Age	-.31788	1.28277	.11165	-.53875	-.09701	-2.847	131	.005
Chronological Age - Ulna Skeletal Age	.11598	1.50498	.13099	-.14315	.37512	.885	131	.378
Chronological Age - Metacarpal Skeletal Age	.11598	1.16880	.10173	-.08526	.31723	1.140	131	.256

Table 6 - Paired correlation - Chronological age and skeletal age for males

		N	Correlation	Sig.
Pair 1	Chronological & Average	102	.929	< .001
Pair 2	Chronological & Radius	102	.940	< .001
Pair 3	Chronological & Ulna	101	.934	< .001
Pair 4	Chronological & Metacarpals	99	.933	< .001

Table 7 - Paired correlation - Chronological age and skeletal age for females

		N	Correlation	Sig.
Pair 1	Chronological & Average	21	.969	< .001
Pair 2	Chronological & Radius	20	.967	< .001
Pair 3	Chronological & Ulna	21	.938	< .001
Pair 4	Chronological & Metacarpals	19	.975	< .001

There is a positive correlation for all assessments when the sample is separated by sex. The correlation between the chronological ages and the average skeletal age for males is 0.929 and for females 0.969. As with the other data, there is a strong correlation between the chronological ages and both the average and assessed skeletal ages. For males, the three bone assessments yield correlations with the chronological ages of 0.940, 0.934, and 0.933 for the distal radius, ulna, and metacarpals, respectively (Table 6). In the female sample, the correlations for the distal radius, ulna, and metacarpals are 0.967, 0.938, and 0.975, respectively (Table 7). There is a higher correlation between the females for all assessments than those which are seen in the male sample.

As in the previous analyses, I employed a paired sample t-test to measure the significance between the means of the chronological ages for the sample and the assessed skeletal ages. In males (Table 8), there is not a significant difference between the means of the chronological ages and the average skeletal ages. There is also not a significant difference between the chronological ages and the assessed skeletal ages for

the metacarpals. The significance value is 0.957 for the chronological ages and the

average skeletal age. The value is 0.200 for the chronological ages and the assessed

skeletal ages for the metacarpals. There is a significant difference between the

chronological ages and the assessed skeletal ages for the radius and ulna.

Table 8 - Paired sample t-test for chronological age and skeletal age – males

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Chronological-Average	-.00647	1.19825	.11864	-.24183	.22889	-.055	101	.957
Pair 2	Chronological-Radius	-.26824	1.13497	.11238	-.49116	-.04531	-2.387	101	.019
Pair 3	Chronological – Ulna	.31218	1.22407	.12180	.07053	.55382	2.563	100	.012
Pair 4	Chronological–Metacarpals	.15263	1.17769	.11836	-.08226	.38751	1.289	98	.200

When the significance of the t-test with the female sample is observed (Table 9),

there is no significance between the chronological ages and the average skeletal age as

well as with all three bone assessments. The level of significance between the

chronological ages and the average skeletal age is 0.352. When I compared the

chronological ages and the three assessed skeletal ages, the level of significance was

0.239, 0.803, and 0.383.

Table 9 - Paired sample t-test for chronological age and skeletal age – females

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Chronological - Average	-.22762	1.09392	.23871	-.72557	.27033	-.954	20	.352
Pair 2	Chronological - radius	-.28550	1.04997	.23478	-.77690	.20590	-1.216	19	.239
Pair 3	Chronological - ulna	-.07762	1.40481	.30655	-.71708	.56184	-.253	20	.803
Pair 4	Chronological - metacarpals	-.22053	1.07480	.24658	-.73856	.29751	-.894	18	.383

I also divided the sample into three different age groups. Like Loder et al. (1993), my divisions were based upon the stages of maturation. This is to assess the differences between the chronological ages and the assessed skeletal ages at different stages of development. Group one consists of those individuals in early to mid childhood, or ages three to 10.5. Group two represents early adolescence, or ages 10.6 through 15.5. Lastly, group three contains those individuals in late adolescence and early adulthood, or ages 15.6 to 20.5.

There was a positive correlation between the chronological age and average skeletal age in all three age groups, although the correlation for those in late adolescence and early adulthood was considerably lower than the other two groups (Tables 10-12).

Table 10 - Paired correlation - early/mid childhood

		N	Correlation	Sig.
Pair 1	Chronological Age & Average Skeletal Age	20	.899	< .001

Table 11 - Paired correlation - early adolescence

		N	Correlation	Sig.
Pair 1	Chronological Age & Average Skeletal Age	68	.800	< .001

Table 12 - Paired correlation - late adolescence/early adulthood

		N	Correlation	Sig.
Pair 1	Chronological Age & Average Skeletal Age	43	.560	< .001

As with the test of correlation, a paired sample t-test demonstrates that all three age groups do not show significance between the chronological age and the average skeletal age (Tables 13-15). The group that was close to a .05 significance level was that of early/mid childhood, at 0.061. Unlike the paired correlation, those in late adolescence and early adulthood are not significant.

Table 13 - Paired Sample t-test for Early/Mid Childhood

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Chronological Age - Average Skeletal Age	-.39650	.89068	.19916	-.81335	.02035	-1.991	19	.061

Table 14 - Paired Sample t-test for Early Adolescence

		Paired Differences							Sig. (2-tailed)
				Std. Error Mean	95% Confidence Interval of the Difference				
		Mean	Std. Deviation		Lower	Upper	t	df	
Pair 1	chronlogical - average	.02015	1.03031	.12494	-.22924	.26954	.161	67	.872

Table 15 - Paired Sample t-test for Late Adolescence/Early Adulthood

		Paired Differences							Sig. (2-tailed)
				Std. Error Mean	95% Confidence Interval of the Difference				
		Mean	Std. Deviation		Lower	Upper	t	df	
Pair 1	Chronological - Average	.15605	1.17806	.17965	-.20651	.51860	.869	42	.390

Beyond the group statistics, nine individuals in the total sample exhibited a difference between the chronological age and the skeletal age of at least 1.75 years. All of the cases have been reexamined for error in assessing the x-ray and assigning the skeletal age and have been found to be accurate assessments. The individual with the largest advancement of the average skeletal age in comparison to the chronological age was that of chart number 550560. This individual was in the late adolescence/early adulthood age group. As a whole, the bones of the hand and wrist for chart number 550560 exhibit a skeletal age that is over two years older than the individual's chronological age. The development of the bones in this individual is much higher than that predicted by Greulich and Pyle in 1959.

In addition to some of the individuals showing accelerated growth, a few also displayed a delay in their skeletal growth when compared to that of their chronological age. Interestingly, only males showed an extreme delay in the skeletal age. Chart number 269546 is a male who shows delayed growth. The chronological age for this individual is 16.12 years, while his skeletal age is only 13.17 years, displaying almost a three year difference between the two. Figure 3 shows the x-rays of a sixteen year-old male and a thirteen year-old male. This is a representation of the skeletal differences seen at both ages.
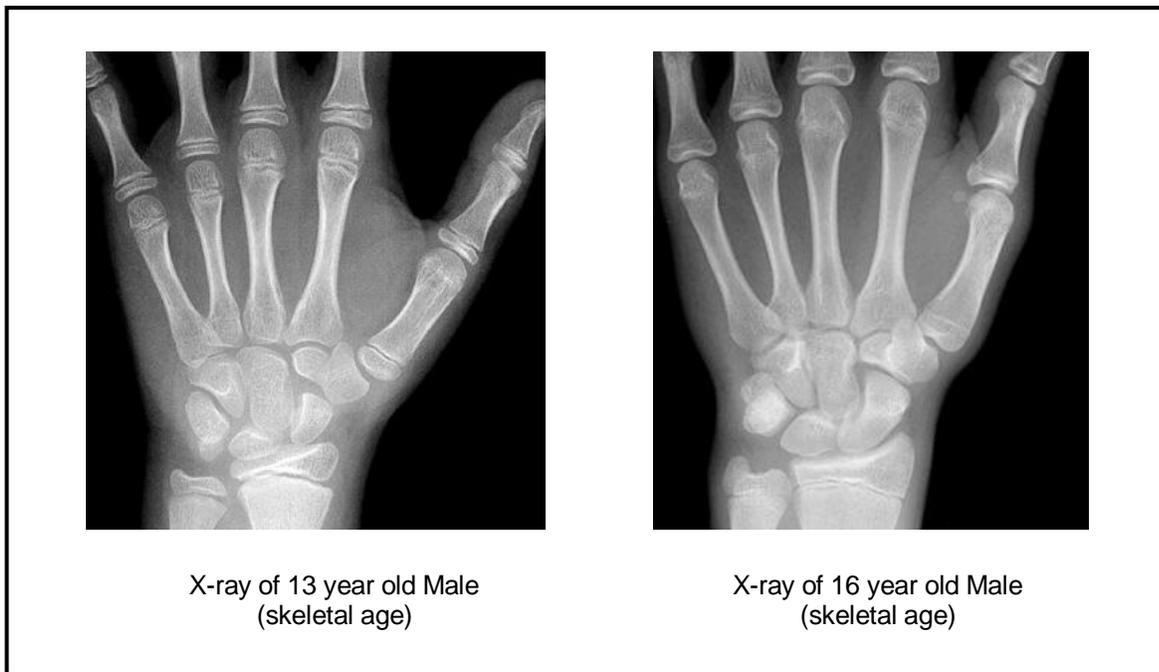
Figure 3 - Comparison between x-ray of chronological age (13 years) and skeletal age (16 years) (Gilsanz and Ratib 2005)(With kind permission of Springer Science and Business Media).

Chart number 550560 had a chronological age of 16.07 while his average skeletal age was 18.33 years. According to Greulich and Pyle, at sixteen years skeletal age the epiphyses of the second, third, fourth, and fifth metacarpals have begun to fuse with their shafts (1959:114). In addition, the epiphyses of the radius and ulna are as wide as the shaft and the ulna has actually begun to fuse with the shaft. Instead of this display, chart number 550560 exhibits a much older skeletal age of 18 years, in which all of the epiphyses have fused with their shafts except for that of the radius. Figure 4 represents the x-rays of both a sixteen year-old male and an eighteen year-old male and the skeletal differences between the two.
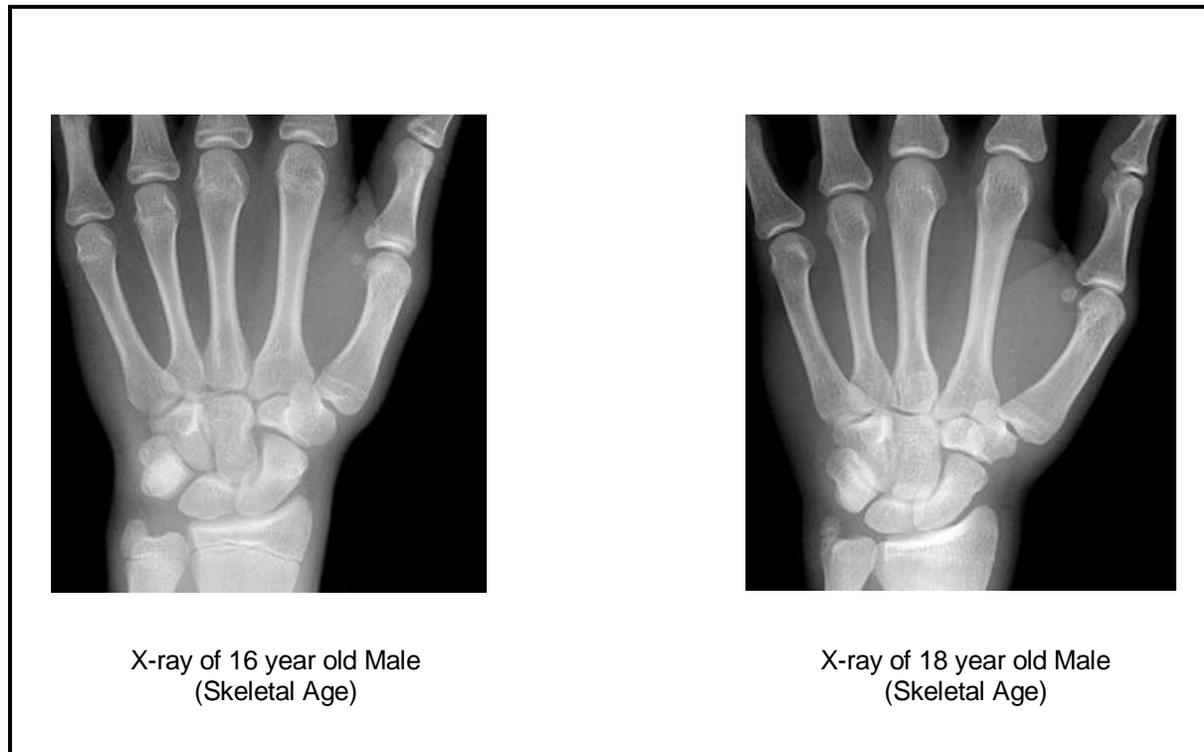
Figure 4 - Comparison between x-ray of chronological age (16 years) and skeletal age (18 years) (Gilsanz and Ratib 2005)(With kind permission of Springer Science and Business Media).

The bone assessments for the ulna are significant when a paired sample t-test is performed utilizing only the males in the sample. Looking back through the original data and notes, it appears that this may be because of the analysis of one particular individual, chart number 269611. This individual had a chronological age of 3.16 years. In contrast, his skeletal age is only 2.9 years. The assessments of the radius and the metacarpals are

close to the chronological age, being 3 years and 2 years 8 months, respectively.

Unfortunately, the skeletal age assessment for the ulna is 0 (Figure 5).
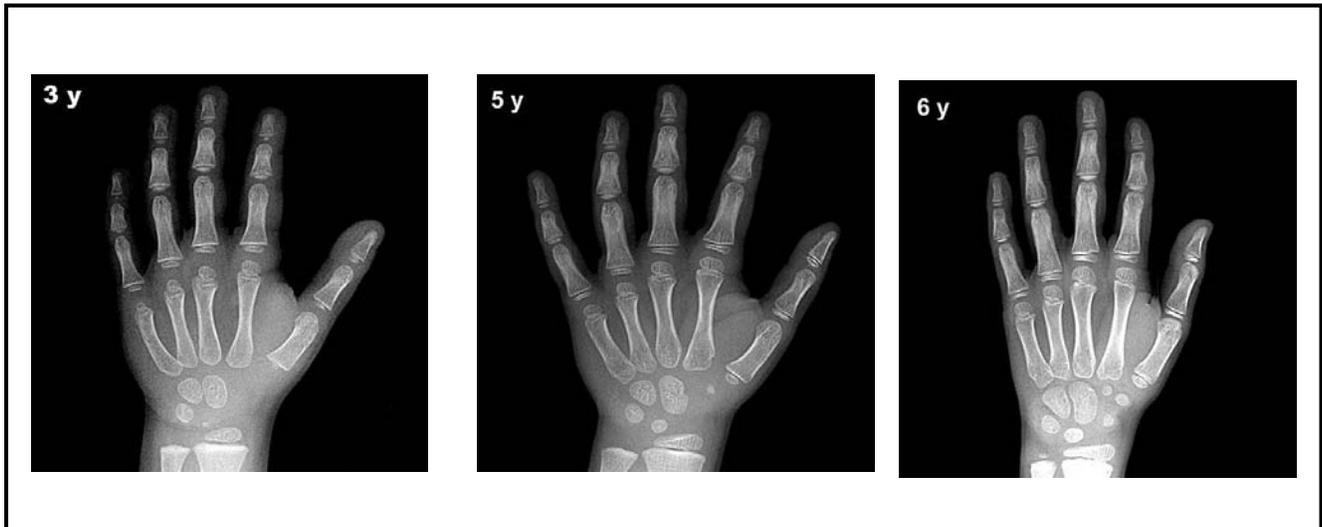
Figure 5 – No ulna epiphysis present until at least 6 years (Gilsanz and Ratib 2005) (With kind permission of Springer Science and Business Media).

Along with comparisons with the study by Loder et al. (1993), comparisons must also be made with the study by McKern and Stewart (1956) from the Korean War. Because different techniques were used to analyze the sample, comparisons with raw data are impossible. However, it is possible to examine the chronological ages at epiphyseal union for the distal radius and ulna. In the study by McKern and Stewart (1956), the minimum age at fusion for the radius was 18 years and 17 years for the ulna. One hundred percent of the sample did not show complete fusion until 23 years. In the sample from OrthoCarolina, the minimum age for complete fusion in males was 16.07 for

both the radius and ulna. The entire sample shows complete fusion by 20.66 years.

Compared with those of McKern and Stewart (1956), these data reflect considerable

difference in the ages at complete fusion for males during the 1950s as compared to

those in contemporary populations.

C H A P T E R   8

Discussion

Since its publication, *The Radiographic Atlas of Skeletal Development of the Hand and Wrist* by Greulich and Pyle (1959) has been the sole reference for the skeletal development for the hand and wrist. To this day, it remains an important reference to help identify and diagnose issues in subadult growth and development. In addition, Greulich and Pyle also have important implications in forensic anthropology with regard to assigning age in subadult remains with the goal of identification. Comparisons of the present study with others who have also referenced Greulich and Pyle for their control group is also important. As such, a history of past studies serves to demonstrate that unlike my results, other studies have demonstrated that the difference between skeletal and chronological ages has continued to increase since Greulich and Pyle.

There was a positive correlation between the various assessed skeletal ages and the chronological ages. In other words, the skeletal age assessed for the x-rays was an accurate reflection of the chronological age. The paired sample t-test for the entire sample size showed that there is no significant difference between the chronological and skeletal ages. This does not support the hypothesis that there is a changing rate of maturation that is reflected in the skeleton. In addition, it does not support the hypothesis that there is a need for those standards used to determine age in subadults to be reassessed for their accuracy and applicability to contemporary populations.

The sample size was then broken down by sex, with the expectation that females would exhibit a higher level of significance than the males with regard to the chronological ages in a paired samples t-test. When the chronological ages and the average skeletal age were computed, the result was a non-significant difference for both sexes. Surprisingly, this did not hold true when the three bones were assessed separately and compared individually with the chronological ages. When this was done and the results were computed using a paired sample t-test, for females, there was no significance for any bones. Males showed a significant difference for the radius and ulna. Because the females did not exhibit a greater degree of significance, this does not support the hypothesis that females are reaching menarche earlier than they have in the past. As a result, there is no evidence using the age of fusion of the epiphyses to support that females are reaching puberty and achieving their maximum growth earlier than they ever have before.

To further test the hypothesis that those individuals who are experiencing puberty and their growth spurt earlier than in the past, the sample was broken down into age groups. The groups were divided based on the stages of maturation and the distribution of the sample size. The established groups are as follows: early/mid childhood, early adolescence, and late adolescence/early adulthood. Comparisons between the groups using a paired sample t-test show that contrary to what was predicted, none of the groups showed significance. The group consisting of early/mid childhood showed a level of significance at 0.06, which closely approaches significance.

43

In the study by Loder et al. (1993) that compared the applicability of Greulich and Pyle to children born in the 1980s, the only group studied wherein the standards created by Greulich and Pyle was still applicable was that of white females. When the mean differences between the chronological and skeletal ages of the sample from OrthoCarolina are examined, there are significant differences in females as a group, and in the early/mid childhood and early adolescence. Once again, there is no significance in the oldest group because the skeletal age can not be any older than 18 or 19 and the chronological age is older still. As such, the data are skewed so that the mean difference appears to be lower, meaning that the skeletal age is significantly younger than the chronological age. The data do not show very similar results with the sample from Loder et al. (1993). The reason for this is unclear, but it may be a reflection of the racial makeup of the sample and the fact that no race information was available for my sample. What is clear, is that my results do not show a significant difference to those presented by Greulich and Pyle in 1959, which is in direct contrast to conclusions by Loder et al.

Regarding group statistics, nine individuals displayed an interesting difference between chronological and skeletal ages. As a whole, the bones of the hand and wrist for chart number 550560 exhibit a skeletal age that is over two years older than the individual's chronological age. The development of the bones in this individual is much more advanced than that predicted by Greulich and Pyle in 1959.

In addition to some of the individuals showing accelerated growth, a few also displayed a delay in their skeletal growth when compared to that of their chronological age. Interestingly, only males showed an extreme delay in the skeletal age. It has been

44

suggested that while obesity has resulted in an advancements of the skeletal age in comparison to the chronological age in females, it has in fact caused a delay in males. It has been proposed that obesity which results in malnutrition is causing a delay in puberty and as a consequence a delay in skeletal growth in comparison to the chronological age. In accordance with various rules set forth by the Health Insurance Portability and Accountability Act (HIPPA) under the United States Department of Health and Human Services, I obtained no information regarding the health or any vital statistics of any individuals. As such, it is impossible to make assumptions about the rate of skeletal growth based on their weight or body mass index.

Nonetheless, there is ample evidence to support the theory that an increase in BMI in adolescence can have negative effects on the growing body, many of which are not completely understood. One of these consequences is advancement in skeletal development for both males and females. According to a study using a group of obese Italian children, female children at all ages that are obese are advanced by 0.75 year in skeletal age when compared to their normal counterparts. In addition, for male children, there is an advancement of 0.75 to one year in obese males with respect to those of a normal weight, although only until around age 11 (Parizkova and Hills:2000:89).

The main issue I encountered with respect to the data analysis was that some of the individuals were over 17 or 18 in chronological age, but this was not reflected in the calculations of their skeletal age. In other words, the skeletal age for each individual could not be older than the complete fusion of all epiphyses. Greulich and Pyle maintain that the fusion of all epiphyses in females occurs by 17 years and by 19 years old in males

45

(1959:122 and 176). Resultantly, their chronological ages are always higher than their skeletal ages. For example, chart number 724283 is a male with a chronological age of 20.66 years. All of his epiphyses are fused and there are no epiphyseal lines present. According to Greulich and Pyle, this occurs at 19 years in the radius and 18 in the ulna and metacarpals. Because of this, the skeletal age cannot be over 18.33 (the mean age for all three bone assessments), meaning that the difference between the average skeletal age and the chronological age is 2.33 years. This appears in the data as a delay in maturation because the bone age does not accurately reflect the skeletal age and can never reflect the appropriate age for this individual or any individual over the maximum age for epiphyseal union in all of the bones of the hand and wrist.

This is a particular problem with the assessment of the radius and comparing the difference of the means between the mean skeletal age of the radius and the mean chronological age. As illustrated above, a paired sample t-test of only the male individuals shows that there is significance (0.019) associated with comparisons between the radius and chronological ages. In a paired sample t-test involving just the females of the sample, the results were not significant (0.239).

When I examined the x-ray for chart number 269611 there was absolutely no presence or sign of the epiphysis of the ulna. This is not unusual for the skeletal age, after all, the epiphysis for the ulna does not form until six years (Greulich and Pyle 1959:90-91). Even so, because each component received its own skeletal age assessment there was no choice but to assess the age based on the absence of the ulna. There was no epiphysis, hence the age is zero. Alternatively, the

ulna could have been based on the fact that the last age that there is no epiphysis according to Greulich and Pyle (1959). In this case the skeletal age would be assessed at 5 years and the result would still be an average skeletal age that is not a very accurate estimation of the chronological age. This in turn shows the importance of using all of the bones available for an accurate assessment and not relying on the epiphyses of the larger radius and ulna to make an assertion to aid in the identification of the individual.

When only the radius and the ulna are available for study an accurate assessment of skeletal age can still be made, as in chart number 270548. In this case, the chronological age is 14.34 years, whereas the assessed skeletal age using only the radius and ulna is 14.5 years. Others that were missing aspects of the assessments did not lend themselves to such accurate results. Chart number 932419 had a chronological age of 15.27 years. The assessed average skeletal age was only 14 years because the ulna stage was young (13 years) and because no assessment for the metacarpals was made (which might have countered the effect of the low age for the ulna).

Another issue that could not be avoided and may have some unforeseen effect on the analysis is the ratio of male to females in the sample. The data were collected using a random sample. Consequently, the ratio of males to females could not be avoided without affecting the randomness of the sample. In addition, young males are more likely than females to break bones because of their rougher play activities. Consequently, more males x-rays were catalogued and the computer was more likely to select male individuals for analysis. Finally, over four times as many males as females were part of the study. The same issue and explanation applies to the age distribution for the sample,

47

with there being more individuals in the early adolescence and late adolescence/early

adulthood categories than in the early/mid childhood.

C H A P T E R 9

Conclusion

Contrary to my hypothesis, my results clearly indicate that the data collected by Greulich and Pyle over 50 years ago remains applicable to the children of today. Although my results are from a mixed race sample, the results show that for an individual of unknown race or ethnicity, the standards created by Greulich and Pyle, although only reflecting one racial group, are still applicable. Determining sex and race in subadult remains is improbable. Therefore, standards which combine race but allow for separation of sex can assist with the analysis when the sex and race are unknown. Through providing a greater range of variation such standards can assist law enforcement in their search for identification of the individual. Finally, the data have shown that the standards created by Greulich and Pyle using children of Northern European descent are still applicable when used to determine the skeletal age of children in the 21st century. As such, the standards should remain a vital resource for forensic anthropologist when determining the age of subadult remains.

REFERENCES CITED

Adair, L. S. and P. Gordon-Larsen
    2001 Maturational Timing and Overweight Prevalence in US Adolescent Girls.
        In American Journal of Public Health 91:4 Pp. 642-644.

Armelagos, George J.
    2002 Bioarchaeology as Anthropology. In Archaeological Papers of the
        American Anthropological Association 13:1 Pp. 27-40.

Baker, B., T.L. Dupras, M.W. Tocheri, and S.M. Wheeler
    2005 The Osteology of Infants and Children. College Station: Texas A and
        M University Press.

Bogaert, A.
    2005 Age at Puberty and Father Absence in a National Probability Sample.
        In Journal of Adolescence. 28:4 Pp. 541-546.

Byers, S.
    2005 Introduction to Forensic Anthropology: An Introduction. Boston: Pearson
        Education Inc.

Center for Disease Control
    2007 www.cdc.org. Obesity and Body Mass Index.

Eveleth, P. and J.Tanner
    1990 Worldwide Variation in Human Growth. Cambridge: Cambridge
        University Press.

Frisch, R. and R. Revelle
    1970 Height and Weight at Menarche and a Hypothesis of Critical Body
        Weights and Adolescent Events. *In* Science 169:3943 Pp. 397-399.

Gilsanz, V. and O. Ratib
    2005 Hand and Bone Age: A Digital Atlas of Skeletal Maturity.
        New York: Springer.

Graber, J., J. Brooks-Gunn and M.P. Warren
    1995 The Antecedents of Menarchal Age: Heredity, Family Environment,
        and Stressful Life Events. *In* Child Development. 66:3 Pp. 346-359.

Greulich, W. and S. Pyle

1959 The Radiographic Atlas of Skeletal Development if the Hand and
        Wrist. Stanford: Stanford University Press.

Health Insurance Portability and Accountability Act (HIPAA)
    2007 www.hhs.gov. HIPPA Final Enforcement.

Herman-Giddens
    2006   Recent Data on Pubertal Milestones in United States Children: the
            secular trend toward earlier development. *In* International Journal
            of Andrology. Vol.29 Pp. 241-246.

Herman-Giddens, M., E. Slora, R. Wasserman, C. Bourdony, M. Bhapkar, G. Koch, and
C. Hasemeier
    1997 Secondary Sexual Characteristics and Menses in Young Girls Seen in
            Office Practice: A Study from the Pediatric Research in Office Settings
            Network. *In* Pediatrics 99:4 Pp. 505-512.

Hill, J. and F. Trowbridge
    1998 Childhood Obesity: Future Directions and Research Priorities. *In*
            Pediatrics 101:3 Pp. 570-574.

Hoppa, R. and C. FitzGerald, eds.
    1999 Human Growth in the Past: Studies from Bones and Teeth. Cambridge:
        Cambridge University Press.

Ibanez, L., A. Ferrer, M. Marcos, F. Hierro, and F. de Zegher
    1999 Early Puberty: Rapid Progression and Reduced Final Height in Girls
            With Low Birth Weight. *In* Pediatrics 106:5 Pp. e72.

Loder, R., D.T. Estle, K. Morrison, D. Eggleston, D.N. Fish, M.L. Greenfield, and
K.E. Guire
    1993 Applicability of the Greulich and Pyle Skeletal Age Standards to Black and
            White Children of Today. *In* American Journal of Disease in Children. 147:Pp.
            1329-1328.

McKern, T. and T. Stewart
    1956 Skeletal Changes in Young American Males. Environment
            Protection Research Division Technical Report EP-45. Natick:
            Headquarters Quartermaster Research and Development Command.

Malina, R., C. Bouchard, and G. Beunen
    1988 Human Growth: Selected Aspects of Current Research on

Well-Nourished Children. *In* Annual Review of Anthropology 17 Pp. 187-219).

Nafte, M.
   2000 Flesh and Bone: An Introduction to Forensic Anthropology. Durham: Carolina Academic Press.

OrthoCarolina
   2007 www.orthocarolina.com. Research Institute Mission Statement.

Parizkova, J. and A. Hills
   2000 Childhood Obesity: Prevention and Treatment. Boca Raton: CRC Press.

Scheuer, L. and S. Black
   2000 Developmental Juvenile Osteology. San Diego: Academic Press.

Schaefer, M. and S. Black
   2005 Comparison of Ages of Epiphyseal Union in North American and Bosnian Skeletal Material. In Journal of Forensic Sciences 50:4 Pp. 777-784.

Setchell, K., L. Zimmer-Nechemias, J. Cali, and J.E. Heubi
   1998 Isofavone Content of Infant Formulas and the Metabolic Fate of these Phytoestrogens in Early Life. *In* American Journal of Clinical Nutrition. Vol. 68 Pp. 1453s-1461s.

Snow, C. and J. Luke
   1984 Oklahoma City Child Disappearances of 1967. *In* Human Identification: Case Studies in Forensic Anthropology. Ted A. Rathbun and Jane E. Buikstra, eds. Springfield: Charles C. Thomas Publisher.

Tahirovic, H.F.
   1998 Menarchal Age and the Stress of War: An Example from Bosnia. *In* European Journal of Pediatrics 157 Pp 978-980.

Todd, T.
   1937 Atlas of Skeletal Maturation. St. Louis: C V Mosby Company.

White, T.
   2000 Human Osteology. 2nd Ed. San Diego: Academic Press.

Wood, J., G.R. Milner, H.C. Harpending, and K.M. Weiss
   1992 The Osteological Paradox: Problems Inferring Prehistoric Health from Skeletal Samples. *In* Current Anthropology. 33:4 Pp. 343-370

APPENDIX

PERMISSION FROM SPINGER PUBLISHING COMPANY TO REPRODUCE IMAGES
FROM HAND AND BONE AGE: A DIGITAL ATLAS OF SKELETAL MATURITY BY
GILSANZ AND RATIB

Dear Ms. Blackwelder,

With reference to your request (copy herewith) to re-use material on
which Springer controls the copyright, our permission is granted free
of charge, on the following conditions:

*   it concerns original material which does not carry references to
other sources,
*   if material in question appears with credit to another source,
authorization from and reference to that source is required as well,
and permission is also obtained   from the author (address is given on
the imprint page or with the article);
*   allows you non-exclusive reproduction rights throughout the world,
*   permission includes use in an electronic form, on the condition
that content is
        - password protected,
        - at Intranet or
        - in CD-ROM/E-book;
*   full credit (book/journal title, volume, year of publication, page,
chapter/article title, name(s) of author(s), figure number(s),
original copyright notice) is given to the   publication in which the
material was originally published by adding: With kind permission of
Springer Science and Business Media.

Permission free of charge does not prejudice any rights we might have
to charge for reproduction of our copyrighted material in the future.

With best regards,

_

Alice Essenpreis
Springer
Rights and Permissions

_

Tiergartenstrasse 17 | 69121 Heidelberg GERMANY
FAX: +49 6221 487 8223
permissions.Heidelberg@springer.com
www.springer.com/rights

_

VITA

There is not a time in Katherine's life when she can remember being interested in anything but in anthropology. From elementary school, where she learned to spell archaeologist, to the present, her interests have never strayed. At the University of North Carolina at Charlotte, Katherine studied anthropology and criminal justice and received Bachelor of Arts degrees in anthropology and criminal justice in spring 2005. Following graduation, Katherine made her way to Baton Rouge and Louisiana State University to attend graduate school in anthropology.

While attending LSU, Katherine received a Robert C. West and R.J. Russell Field Research Award which enabled her to collected her thesis data in the summer of 2006. In addition to working on her thesis, Katherine was also a graduate assistant in the FACES lab and volunteered in the lab, under the direction of Ms. Mary Manhein. In the FACES lab Katherine gained experience working on forensic cases and was an active participant in the lab's community outreach program which teaches forensic anthropology to various groups in and around Baton Rouge, Louisiana.

Following graduation, Katherine plans to pursue a career integrating the fields of anthropology and law enforcement.