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Vertebral Age Estimation: An Examination of the Seventh Cervical, Seventh Thoracic, and Fourth Lumbar Vertebrae

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VERTEBRAL AGE ESTIMATION: AN EXAMINATION OF THE SEVENTH CERVICAL, SEVENTH THORACIC, AND FOURTH LUMBAR VERTEBRAE

by

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VERTEBRAL AGE ESTIMATION: AN EXAMINATION OF THE SEVENTH CERVICAL, SEVENTH THORACIC, AND FOURTH LUMBAR VERTEBRAE

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This project examines the utility of vertebral osteophyte development to estimate age at death. Skeletal joint degeneration is a common method for estimating individuals' age at death, however studies regarding vertebral degeneration and age estimation are lacking. My study follows the work of Stewart (1958) in comparing stages of osteophytic lipping of vertebral bodies to age at death.

I examined the seventh cervical (C7), seventh thoracic (T7), and fourth lumbar (L4) vertebrae in 100 individuals of known ancestry, sex, and age at death from the Hamann-Todd skeletal collection. Degenerative stages and composite scores were analyzed through descriptive statistics and chi square analysis. Results of the study are similar to those of Stewart (1958). High degrees of lipping are typical of middle and older aged individuals, while lower stages of lipping are too widespread among age groups for accurate age assessment. In comparisons between males and females, and between Afro-Americans and Euro-Americans, there were no great differences between these groups. Overall, vertebral degenerative rates are not good indicators of age, although accuracy for estimating age is greater in individuals with the highest levels of osteophyte development.

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CHAPTER 1: INTRODUCTION

Assessment of age at death of a skeleton is an important element of human osteology and its sub-discipline forensic anthropology (Byers 2002; Meindl et al. 1985; Schmitt et al. 2002). Forensic anthropologists examine human skeletal remains for law enforcement agencies in order to gain information regarding age, sex, biological affinity, trauma, time since death, and manner of death (Byers 2002). For bioarchaeological studies, accurate age information is crucial for constructing prehistoric demographic profiles and life tables (Iscan and Loth 1989; Lovejoy et al. 1985a; Schmitt et al. 2002; Steele and Bramblett 1988).

In forensic and archaeological situations, skeletal remains are frequently incomplete and fragmentary due to taphonomic processes (Lovejoy et al. 1985a; Rogers et al. 1991). In contemporary and archaeological settings, taphonomic processes such as animal scavenging, geologic conditions, and weather may cause disarticulation and skeletal destruction of important primary skeletal indicators of age found in the pelvic and cranial regions (Haglund 1988, 1989). When the best skeletal indicators of age are missing, it is necessary to examine other skeletal regions. One potential skeletal region to examine is the vertebral column, as it can remain intact even when the skull and appendages become disarticulated (Haglund 1989). Thus, vertebrae may present an additional skeletal region providing age information.

The degree of degenerative change, such as osteophytic lipping, has been used in forensic and bioarchaeological situations to estimate adult age, but only one major study (Stewart 1958) attempts to correlate age and vertebral degeneration. Degenerative

changes are the only features researchers have discussed for aging adult vertebrae. Since these changes may vary between individuals and populations, age estimation from vertebrae has not been considered reliable. However, few studies have re-examined the use of vertebral aging methods (Snodgrass 2004). My study seeks to assess the utility of vertebral age estimation by comparatively examining three specific vertebrae of the cervical, thoracic, and lumbar regions.

CHAPTER 2: LITERATURE REVIEW

Methods for sub-adult skeletal age assessment

Standard methods for age estimation are based on bone and dental development (sub-adults) or on bone degeneration and remodeling (adults) (Byers 2002; Schmitt 2002; Ubelaker 1999). Assessment of the development and fusion of secondary centers of skeletal ossification (epiphyses) to primary centers of ossification is useful for distinguishing adults from sub-adults, and for estimating age of immature skeletons. In addition, dental eruption rates are useful, particularly for individuals aged 10 and younger (Ubelaker 1999). Epiphyseal closure for vertebrae has been effectively used for age estimation (Albert and Maples 1995; McKern 1970; McKern and Stewart 1957). Though sub-adult vertebral age estimation is important, my research project focuses on adult age assessment.

Methods for adult skeletal age assessment

Cranial methods

Adult aging methods of the skull utilize cranial suture closure and obliteration, and dental wear, loss, and subsequent alveolar resorption. Though many attempts have been made, studies generally fail to provide great accuracy for cranial suture closure as an age estimation technique (Brooks 1955; Galera et al. 1998; Key et al. 1994; Lovejoy et al. 1985a; McKern and Stewart 1957; Meindl and Lovejoy 1985; Todd and Lyon 1924, 1925). Problems with dental use include unusual wear patterns, and traumatic or pathological changes (Buikstra and Ubelaker 1994).

Post-cranial methods

Many osteologists rely predominantly on post-cranial methods for age estimation. Assessment of post-cranial joint surface degeneration is one standard technique for estimating adult age at death. Methods utilizing the os coxa provide the most reliable age estimates (Steele and Bramblett 1988). The primary os coxal regions, the auricular surface and pubic symphysis, have been extensively studied and represented in anthropological literature (Brooks 1955; Buckberry and Chamberlain 2002; Gilbert and McKern 1973; Hanihara and Suzuki 1978; Hoppa 2001; Hutchinson and Russell 2001; Jackes 1985; Katz and Suchey 1986; Lovejoy et al. 1985b; McKern and Stewart 1957; Suchey 1979; Suchey and Katz 1998; Todd 1920, 1921). The morphological changes seen in the pubic symphysis and auricular surface are associated with fibrocartilage degeneration, osteophytic reaction, and subchondral bone density (Lovejoy et al. 1985a). Though the pubic symphysis is considered the best indicator of adult age (Stewart 1957), it is frequently lost or damaged in archaeological specimen (Lovejoy et. al 1985a). Therefore, alternative aging methods would be useful.

The intervertebral joints are also composed of fibrocartilage, and may undergo similar age-related changes as those seen in the pubic symphysis and auricular surface (Jurmain 1999). This fibrocartilage degeneration suggests that age-related changes occurring in the intervertebral joints may provide an additional aging method.

Methods for vertebral age assessment

The most frequently studied vertebral degenerative features are osteophytes of the body and osteoarthritis of the zygapophyseal facets (Bridges 1994; Chapman 1972;

Derevenski 2000; Knusel et al. 1997; Jurmain 1977; Roche 1957; Snodgrass 2004; Stewart 1947, 1957, 1958; Waldron and Rogers 1991). Osteophytes are bony outgrowths that occur on the periphery of a joint surface and vary in size from barely discernable bony spicules to large projections (Larsen 1997; Roberts and Manchester 1997; Rogers and Waldron 1995). In vertebrae, osteophytosis is mainly seen as bony lipping around the margins of vertebral bodies, particularly along the antero-lateral margins of the intervertebral joints (Kerley 1970). When the intervertebral discs age, bony reactions to surrounding ligaments occur. Aging discs decrease in height, which causes increased, and oftentimes uneven, compressive stress to the joint surface (Kumaresan et al. 2001; Levangie and Norkin 2001, Pollintine et al. 2004). Sometimes fracturing of the anterior vertebral body occurs when it can not withstand this increased compressive stress (Pollintine 2004). Increased ligamentous slack can also create instability in the vertebral column (Levangie and Norkin 2001). Osteophytes are viewed as the vertebral column's method of re-enforcing joint stability in reaction to increased stress, as they are composed of stronger, more compact bone and they tend to develop where compressive stress is greatest (Kumaresan 2001; Nathan 1962). The shape of osteophytic development on vertebral bodies is even noted as resembling capitals and bases of pillars, an architectural technique of increasing resistance to compression (Nathan 1962). Osteophytes not only grow from the vertebral body, but can invade surrounding soft tissues such as ligaments to provide extra resistance to stress (Nathan 1962).

Lipping can also occur on the margins of zygapophyseal joints (Bourke 1967; Bridges 1994). The vertebral bodies and zygapophyseal facets are different joint types (cartilaginous and synovial, respectively) to handle different biomechanical forces, but

lipping of the zygapophyseal joint is also due to soft tissue degeneration (Jurmain 1999; Levangie and Norkin 2001). General indicators of osteoarthritis on any joint are osteophytic lipping and/or bone erosion on the joint surface (Bridges 1994; Derevenski 2000; Larsen 1997). In studies of vertebral degenerative changes, sometimes lipping is classified with osteoarthritis, and other times it is a separate category, particularly when examining both bodies and facets (Bridges 1994; Derevenski 2000; Steinbock 1976). Figures 2.1 and 2.2 show moderate and severe levels of osteophytic lipping of the vertebral bodies.

Figure 2.1

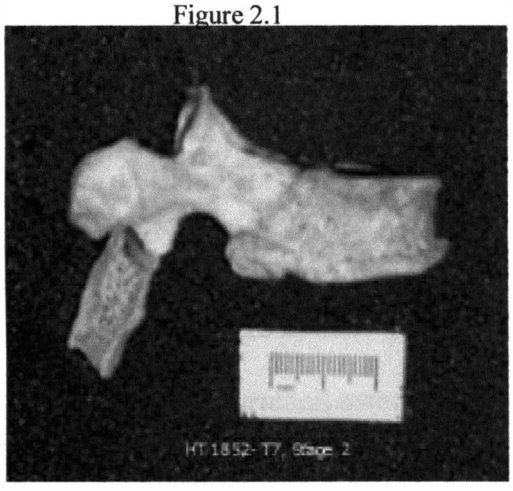
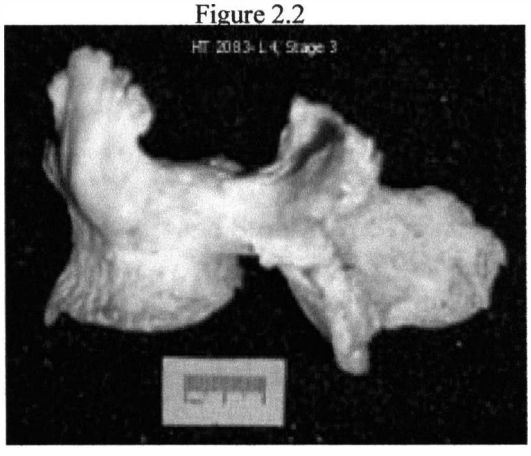


Figure 2.2



Osteophytic lipping that is moderately (Figure 2.1) and severely (Figure 2.2) developed.

Early studies of vertebral osteophytosis and its possible use for age estimation stem from work by T.D. Stewart (1947, 1957, 1958). Stewart (1958) found that in all regions of the vertebral column, marginal lipping develops slowly until the age of 30. After 30 years of age, marginal lipping increases and becomes pronounced after age 50. However, substantial variation in vertebral osteophyte development exists and Stewart

(1958) concludes that it does not allow for a close estimation of age. Evidence of marginal lipping in a general sense is said to be a useful tool in identifying older age groups, particularly those over age 40 (Rogers and Waldron 1995; Stewart 1958). In individuals under 30 years of age, vertebral osteophytes are likely to be associated with trauma (Stewart 1957).

When possible, vertebral aging techniques should be used in conjunction with other aging methods, as comprehensive approaches typically produce better results than individual ones (Baccino 1999; Bedford et al. 1993; Lovejoy et al. 1985a; Snodgrass 2004). However, my project will examine vertebral age estimation for instances when more reliable osteological features for aging cannot be assessed.

Stewart (1958) developed a five-stage classification system for assessing vertebral osteophyte development. Unlike other studies that include photographic examples of different stages (Chapman 1972; Derevenski 2000; McKern and Stewart 1957; Snodgrass 2004), Stewart's studies do not. Bridges (1994) and Chapman (1972) use five-stage systems for scoring vertebral osteophytic lipping of archaeological samples. Knusel (1997) and Waldron and Rogers (1991) use a three-phase system for scoring vertebral degenerative processes. Knusel's (1997) system applies to intervertebral and zygapophyseal joints of the vertebral column, while Waldron and Rogers (1991) classify osteoarthritis of lumbar facets. Derevenski (2000) uses a five-phase system for lipping of zygapophyseal facets, a four-stage system for remodeling of zygapophyseal facets, and a five-stage system for lipping of vertebral bodies. Descriptions of vertebral degenerative stages for Chapman (1972), Snodgrass (2004), and Stewart (1958) are listed in Table 2.1.

All studies discussed above except Stewart (1958) rank degenerative development by stages, but do not try to correlate them with age at death.

Table 2.1. Vertebral degenerative stage categories and descriptions from other researchers

Chapman (1972)

1. slight sharpness or lipping (discerned by tactile discrimination) at the superior and inferior margins of the vertebral bodies
2. a more pronounced lipping or exostosis, easily observable
3. extensive lipping, often resembling a mushroom-like eversion
4. bony spurs or bridges with an increase of outgrowth
5. actual body union or ankylosis of the joints between two or more vertebrae

Snodgrass (2004)

0. vertebral centra shows no (or virtually no) evidence of osteophytosis or formation of a vertebral rim
1. minor development of osteophytes; may be two small bony spurs or the beginning of formation of a vertebral rim
2. osteophytes more developed (larger or more than two small osteophytes) or extensive rim remodeling with pronounced lipping
3. enlarged osteophytes with severe modeling of the rim and/or formation of a large osteophyte or ostephytes that extend towards the center of the vertebral body (ie. Either superior or inferior) or projecting towards the adjacent vertebra (ie. Into the intervertebral space)
4. most extreme stage of osteophyte development, with extensive osteophyte development that, like stage 3, extends toward the intervertebral space or the center of the vertebral body, but is partially or completely (in contact with but not fused and in contact and fused, respectively) bridged to the adjacent vertebra.

Stewart (1958)

Stages 0 through ++++ represent no lipping through maximum lipping

Vertebral degenerative stages used by Chapman (1972), Snodgrass (2004), and Stewart (1958).

It is important to note that degenerative changes of the vertebral column can vary greatly between individuals and across different populations (Bridges 1994; Knusel 1997; Steele and Bramblett 1988; Ubelaker 1999). Everyday stresses, particularly from occupation-related activities, affect rates of joint degeneration (Iscan and Loth 1989; Kennedy 1989; Larsen 1997). Other potential influences on degeneration rates include

health of the individual (Kennedy 1989; Steele and Bramblett 1988), sex, hormones, heredity, trauma (Jurmain 1977), and structure and function of the vertebral column (Bridges 1994; Knusel et al.1997). In general, as one gets older there is an increased likelihood that degenerative changes will be defined as pathological (Chapman 1972; Jurmain 1977). Many times vertebral osteophytosis is examined for reconstructing past activities of an individual or population, but it is difficult to determine which particular activities left skeletal markers. Also, in middle aged and older individuals degenerative changes deemed activity-related may be due to the aging process rather than activities (Jurmain 1999).

In general, the lumbar vertebrae are most affected by degenerative changes due to their weight bearing function from bipedalism (Bridges 1994; Jurmain 1999; Larsen 1997; Steinbock 1976). The cervical vertebrae are the second-most affected area, followed by the thoracic vertebrae (Bridges 1994; Rogers and Waldron 1995). Bridges (1994) notes that population variations do occur (e.g. pre-historic California hunter-gatherers exhibit the most lipping on the thoracic region, and individuals in the Terry Collection show the greatest degenerative change in the cervical region). Most studies with "atypical" degenerative patterning show the cervical vertebrae as the most affected area, perhaps due to burden carrying on the head. In general, variation in patterning is likely due to activity-related stresses (Jurmain 1999). Derevenski (2000) and Snodgrass (2004) examined sex bias in osteophyte production for archaeological and museum collection samples respectively, but found rates were similar for males and females.

Some have doubts about the utility of lipping for age determination (McKern and Stewart 1957; Rogers and Waldron 1995). There is interobserver bias for scoring, plus

the observers' level of experience plays a role in scoring (Jurmain 1999; Waldron and Rogers 1991). There are borderline individuals whose degenerative changes cannot be neatly assigned into one stage or another (Stewart 1958). Currently, there is no technique for vertebral age estimation except for scoring an individual by vertebral degenerative stages, which Buikstra and Ubelaker (1994) recommend.

CHAPTER 3: MATERIALS AND METHODS

My project investigates the use of vertebrae for age estimation. The methods employed are based on the work of previous researchers (Bridges 1994; Chapman 1972; Derevenski 2000; Snodgrass 2004; Stewart 1958), but represent modifications I have developed. This chapter provides greater detail for the methodologies I have employed.

Materials

In order to assess the validity of techniques for adult age estimation based on the vertebral column, I sampled a skeletal collection of individuals with known sex, age at death, and ancestry. My sample is derived from the Hamann-Todd Collection, housed at the Cleveland Museum of Natural History, Cleveland, Ohio. The Hamann-Todd Collection contains over 3,100 human skeletons collected from the Cleveland area during the early 20th century, primarily from the morgues of Cuyahoga County and city hospitals. Documented information for each individual includes name, age, sex, ancestry, cause of death, weight, and over 70 standardized anthropometric measurements (Cleveland Museum of Natural History 2004; Quigley 2001).

The sample contains a near-equal number of individuals for each sex and biological affinity category. It includes 26 Euro-American males, 25 Euro-American females, 25 Afro-American males, and 24 Afro-American females (see Table 3.1). All vertebrae are free of pathological lesions not related to this study.

For this project on adult vertebral age estimation, three vertebrae (the seventh cervical (C7), seventh thoracic (T7) and fourth lumbar (L4)) were examined on 100 individuals. These vertebrae were selected for use in age assessment because they are located at anatomical sites of maximum spinal curvature, and these sites have the greatest potential for degenerative change (Bridges 1994). Individuals were assessed both visually and tactily for the degree of vertebral degeneration as evidenced by osteophytic development. Vertebrae were assigned to one of five stages of degenerative change detailed in Table 3.2.

Table 3.1. Distribution of sample (n=100) classified by age and sub-group

Age in years	AA-M	AA-F	EA-M	EA-F	total
18-29	4	6	4	3	17
30-39	4	4	4	4	16
40-49	4	4	4	4	16
50-59	4	4	4	4	16
60-69	4	4	5	3	16
70+	5	2	5	7	19
total	25	24	26	25	100

Distribution of sample grouped according to age, sex and ancestry.
AA=Afro-American EA=Euro-American M=Male F=Female

Table 3.1 shows the distribution of individuals by age, sex, and ancestry. Age categories are broken down by decade of life, however the youngest age category also includes 18 and 19 year olds. The age groups are classified as young (18-29 and 30-39), middle (40-49 and 50-59), and old (60+) for simplification. A near equal number of individuals from each age group were sampled. Before the study began I determined how many individuals of each age and subgroup were needed for examination by creating

a table similar to Table 3.1. Individuals were selected at random from the collection for inclusion in the study.

Methods for age assessment

My research focuses on the relationship between age and degenerative changes of the vertebral column, specifically osteophytic lipping of the vertebral bodies. Following the work of Bridges (1994), Chapman (1972), Derevenski (2000), Snodgrass (2004), and Stewart (1958), I classified degenerative changes into five stages (see Table 3.2). These stages are estimated from composite descriptions and photos, the primary source being Snodgrass (2004). I have modified the methodology of previous researchers by adding the use of tactile of the degree of osteophytic development in early degenerative stages. (see Table 3.2 for descriptions of degenerative stages). Figures 3.1-3.5 illustrate these five stages of osteophytic development.

Table 3.2. Descriptions of the five stages of vertebral degenerative change

Stage 0- None: No noticeable osteophytic lipping. The rim will look slightly rounded, and will be smooth and rounded to the touch (see Figure 3.1).

Stage 1- Minor: Earliest stages of lipping. The previously rounded rim becomes more angular, and it will be sharp and pointed to the touch. The sharpness may not be visually distinct, but will be known with tactile examination. Osteophytic activity is small, and may only be noticeable on either the superior or inferior edge (see Figure 3.2).

Stage 2- Moderate: Osteophytes are larger and project further from the vertebral body. Lipping occurs on the superior and inferior surface, though osteophytic activity may not be uniform on the body Tactile examination is not necessary to assess the size of the osteophytes, but there is enough growth to pinch with the fingers (see Figure 3.3).

Stage 3- Severe: Osteophytic growths are similar to those in stage 2, though more severe. Large projections are present, sometimes seen as a few large osteophytes with stage 1 and 2 changes on the remainder of the body. Tactile examination is unnecessary as visual examination is adequate (see Figure 3.4).

Stage 4- Extreme: Osteophytic development is so great that two or more vertebrae fuse together. Tactile is examination unnecessary (see Figure 3.5).

Five stages of vertebral degenerative change modified from Bridges (1994), Chapman (1972), Derevenski (2000), Snodgrass (2004) and Stewart (1958).

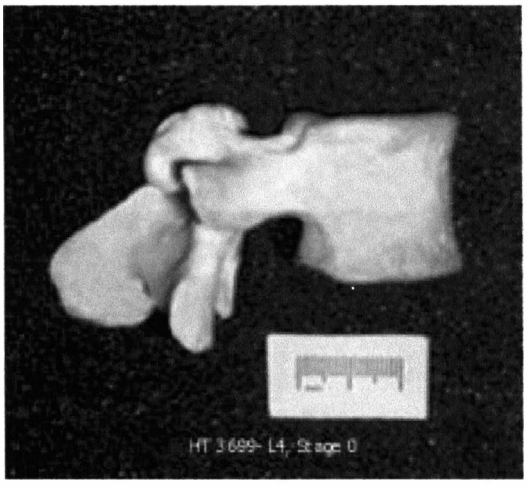


Figure 3.1. Stage 0: None.
Relatively smooth vertebral rim and
no osteophytic activity.

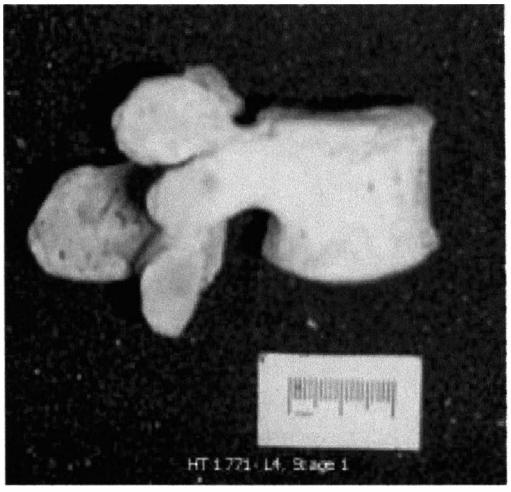


Figure 3.2. Stage 1: Minor.
Beginning stage of degenerative activity
marked by small osteophytes, giving the
rim a sharper look and feel.

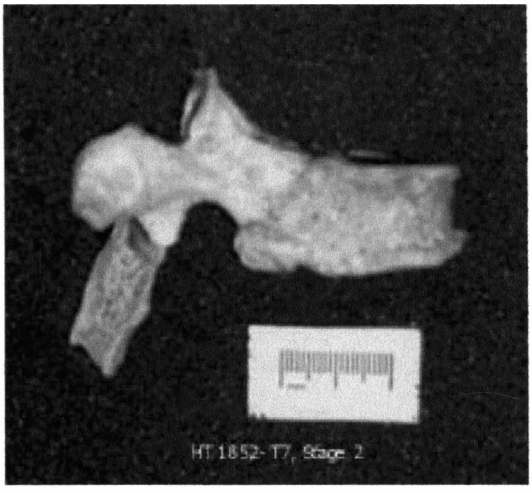


Figure 3.3. Stage 2: Moderate.
Lipping is now obvious, with projecting osteophytes
on both superior and inferior surfaces.

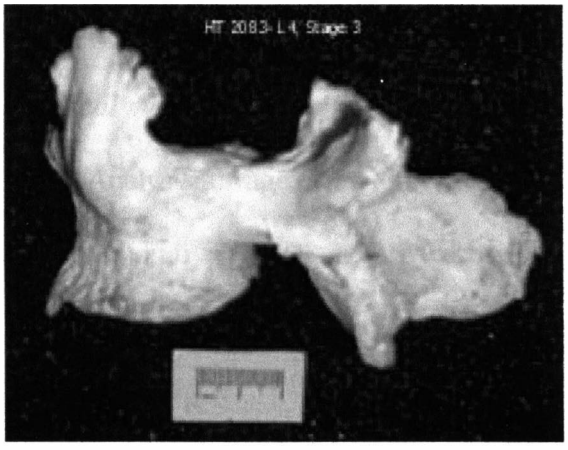


Figure 3.4. Stage 3: Severe.
Large osteophytes present. The superior and inferior margins may be affected differently, but advanced stages of degenerative change will be present throughout.

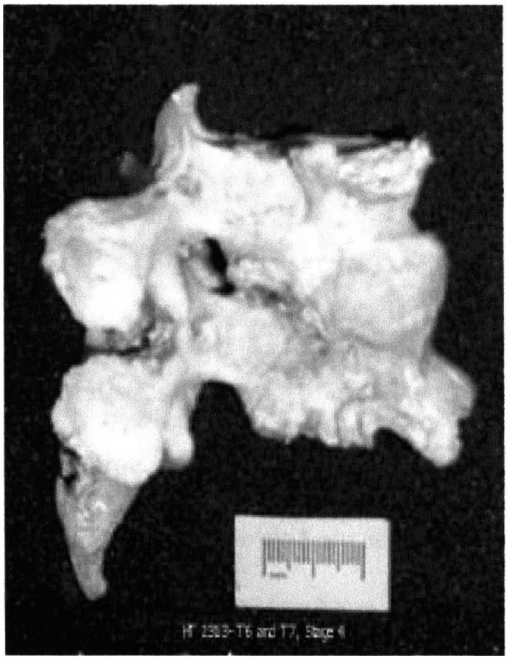


Figure 3.5. Stage 4: Extreme.
Fusion of two or more vertebrae occurs due to the extreme amount of osteophytic growth.

An individual's degenerative stages were scored by examining the C7, T7, and L4 respectively with scores ranging between 0 and 4. If a vertebra was borderline between two stages, both stages were recorded and the closest fitting stage was underlined to indicate its final classification.

Two types of composite scores were used for age analysis. The first type of composite score sums an individual's stage numbers for the C7, T7, and L4. Possible scores range from 0 to 12. Decades of life were collapsed into three age groups (young, middle, and old). Composite scores were grouped into four collapsed categories (0-2, 3-5, 6-8, and 9-12) for easier analysis and comprehension of the results. A second method utilizes only the C7 and L4 since lordosis in these regions is unique to hominins. The

range of scores for this composite system is 0-8. Initial age groups and composite scores were later collapsed into three age groups (young, middle, and old) and three score groups (0-2, 3-5, and 6-8).

Statistical methodology for age estimation

Analysis for age estimation utilizes descriptive statistics and chi-square tests to compare 1) individual degenerative scores for each vertebrae to age at death 2) total composite scores (C7, T7, and L4) to age at death, and 3) reduced composite scores (C7 and L4) to age at death. Data was also organized into frequency tables and bar graphs for each of the three methods, comparing degenerative stage or composite scores to age at death.

Hypotheses for age estimation

Two hypotheses were generated to test rates of vertebral degeneration. The first hypothesis tests whether or not there is an association between vertebral degeneration and age at death. This hypothesis is listed below and will be applied to these scoring methods: (1) degenerative stages of the C7, (2) degenerative stages of the T7, (3) degenerative stages of the L4, (4) total composite scores, and (5) reduced composite scores. Additionally these methods will not only be examined for the total sample, but for the sub-samples of males, females, Euro-Americans, and Afro-Americans. Thus 25 different combinations are present for analysis.

H0: The occurrence of vertebral degeneration is independent of age.

H2: The occurrence of vertebral degeneration is not independent of age.

Expected observation: Degree of degeneration should increase with age due to the aging process and the long-term physical effects of activity-related stresses on the vertebral column. Low scores for degenerative stages should be concentrated in the younger age groups, while middle and higher stages should be seen more in middle and old age groups. Most individuals should reflect an overall, typical patterning of increasing frequency and degree of degeneration with age.

The second hypothesis tests whether there are great differences between males and females, and between Afro-Americans and Euro-Americans. The null and alternative hypotheses, and expected observations are explained below.

H0: Rates of degenerative change between males and females will be similar.

H6: Rates of degenerative change between males and females will not be similar.

Expected observation: Preliminary expectations are that males, due to greater occupation related stresses, will demonstrate greater vertebral degeneration than females of similar ages. Two recent studies (Derevenski 2000; Snodgrass 2004) failed to show significant sex bias in vertebral osteophyte development in archaeological and modern samples. These studies suggest that I may not find great differences in vertebral degeneration between males and females in my study either, perhaps due to similar work-related influences on vertebral degeneration. Even if degeneration rates are comparable between male and female samples, I expect more individuals with the highest stages of degeneration to be male.

H0: Rates of degenerative change between Afro-Americans and Euro-Americans will be similar.

H7: Rates of degenerative change between Afro-Americans and Euro-Americans will be not similar.

Expected observation: Afro-Americans are usually of a lower socioeconomic class than Euro-Americans. Their "harsher" occupations and lifestyles might be reflected as greater vertebral degenerative change compared to Euro-Americans of the same age group. However, many individuals comprising the Hamann-Todd Collection were unclaimed bodies from morgues, which signals lower socioeconomic class. I expect Afro-Americans to display greater lipping than their Euro-Americans counterparts, though the gap between the two groups may be small due to both groups being of a similar class.

The materials and methods I have presented are utilized for comparisons of vertebral degeneration and age at death. Vertebral degeneration is classified into one of five stages of osteophyte development, and this degeneration is assessed for individuals' C7, T7, and L4 vertebrae. In addition to examination of each vertebral type, composite scores summing an individual's C7, T7, and L4 scores (total composite scores) or an individual's C7 and L4 scores (reduced composite scores) are also analyzed. My sample is divided into sub-groups based on sex and ancestry, which allows for comparisons between these groups.

CHAPTER 4: RESULTS

Degenerative stages and age at death

Figures 4.1-4.3 present a graphic display of the distribution of degenerative stages across the age groups for the C7, T7, and L4 vertebrae. For these samples, the relationship between degenerative stage and age group were examined through frequencies, percentages, and chi square tests. First, I examined the vertebral degeneration of the samples across seven initial age groupings (Figures 4.1-4.3 and Table 4.1). Later I collapsed these seven age categories into three broad adult age categories of young (18-29, 30-39), middle (40-49, 50-59) and old (60+). See Figures 4.4-4.6 and Table 4.2. Results of these analyses for the four sub-groups (Euro-American males, females, and Afro-American males, females) are found in Appendix D. Graphs displaying age ranges for individual degenerative stages for are located in Appendix A.

Initial age groups

From Figures 4.1- 4.3 general statements about age and degenerative stages can be made. Stage 0 is seen primarily in younger age groups and its frequency generally declines with age. However the presence of Stage 0 is found in a wide range of age categories. Stage 1 is prominently represented in every age group. Stage 2 has a multi-decade span like Stages 0 and 1, however individuals with Stage 2 degeneration are typically in older age categories. Still, there are exceptions as two individuals aged 30-39 have Stage 2 degeneration in their thoracic vertebrae. With Stages 3 and 4, there was a much smaller sample size with such levels of degenerative change. These individuals were no younger than 50 years old.

Table 4.1. Distribution of degenerative stages by initial age groups

	18-29 n=16*, 17		30-39 n=15*, 16		40-49 n=16		50-59 n=16		60-69 n=16		70-79 n=15		80-89 n=4		Total n=98*, 100	
C7	count	%	count	%	count	%	count	%	count	%	count	%	count	%	count	%
Stage 0	11	11.22	5	5.1	8	8.16	8	8.16	3	3.06	—	—	—	—	35	35.71
Stage 1	5	5.1	10	10.2	8	8.16	5	5.1	11	11.22	12	12.24	2	2.04	53	54.08
Stage 2	—	—	—	—	—	—	2	2.04	1	1.02	3	3.06	1	1.02	7	7.14
Stage 3	—	—	—	—	—	—	1	1.02	1	1.02	—	—	1	1.02	3	3.06
Stage 4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
T7																
Stage 0	5	5	3	3	2	2	2	2	1	1	—	—	—	—	13	13
Stage 1	12	12	11	11	10	10	11	11	12	12	7	7	2	2	65	65
Stage 2	—	—	2	2	4	4	3	3	2	2	6	6	—	—	17	17
Stage 3	—	—	—	—	—	—	—	—	—	—	—	—	2	2	2	2
Stage 4	—	—	—	—	—	—	—	—	1	1	2	2	—	—	3	3
L4																
Stage 0	14	14	7	7	3	3	1	1	—	—	—	—	—	—	25	25
Stage 1	3	3	9	9	12	12	14	14	10	10	7	7	1	1	56	56
Stage 2	—	—	—	1	1	1	—	—	4	4	5	5	1	1	11	11
Stage 3	—	—	—	—	—	—	1	1	2	2	3	3	2	2	8	8
Stage 4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Distribution of sample for each vertebral type comparing degenerative stage to age at death (decade of life)
*Sample size for C7 due to exclusion of two C7 vertebrae from the study.

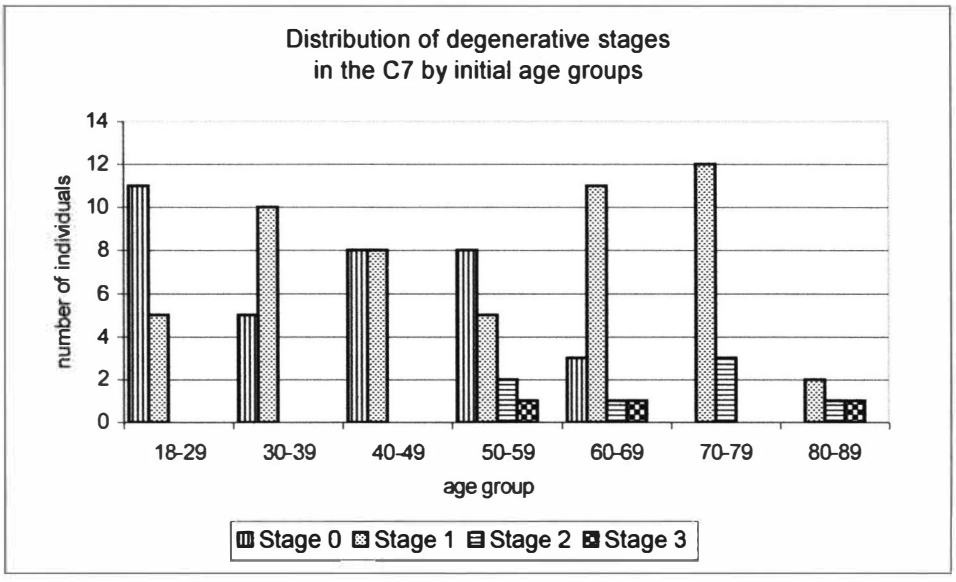


Figure 4.1. Distribution of degenerative stages in the C7 by initial age groups. Sample sizes per age group are: 18-29 (n=16), 30-39 (n=15), 40-49 (n=16), 50-59 (n=16), 60-69 (n=16), 70-79 (n=15), 80-89 (n=4).

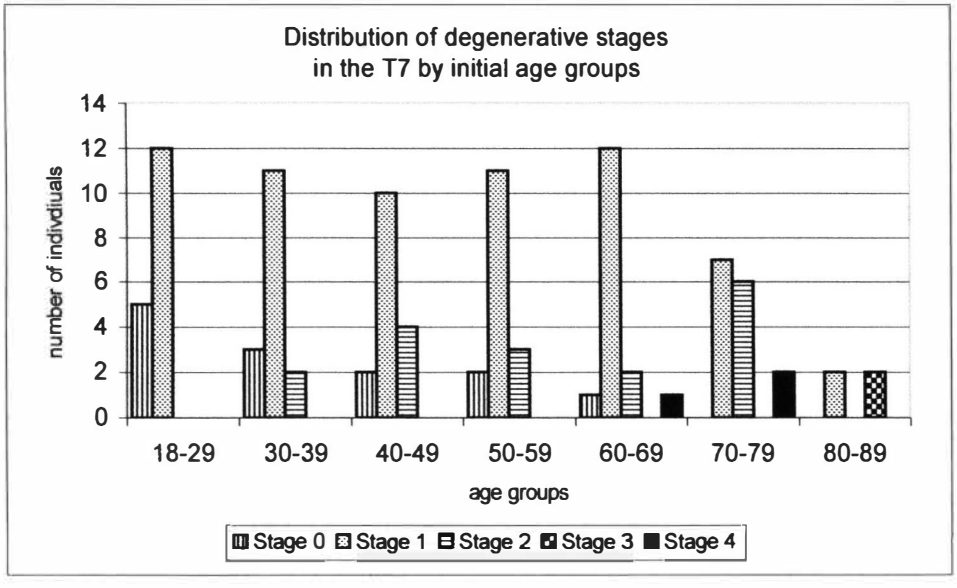


Figure 4.2. Distribution of degenerative stages in the T7 by initial age groups. Sample sizes per age group are: 18-29 (n=17), 30-39 (n=16), 40-49 (n=16), 50-59 (n=16), 60-69 (n=16), 70-79 (n=15), 80-89 (n=4).

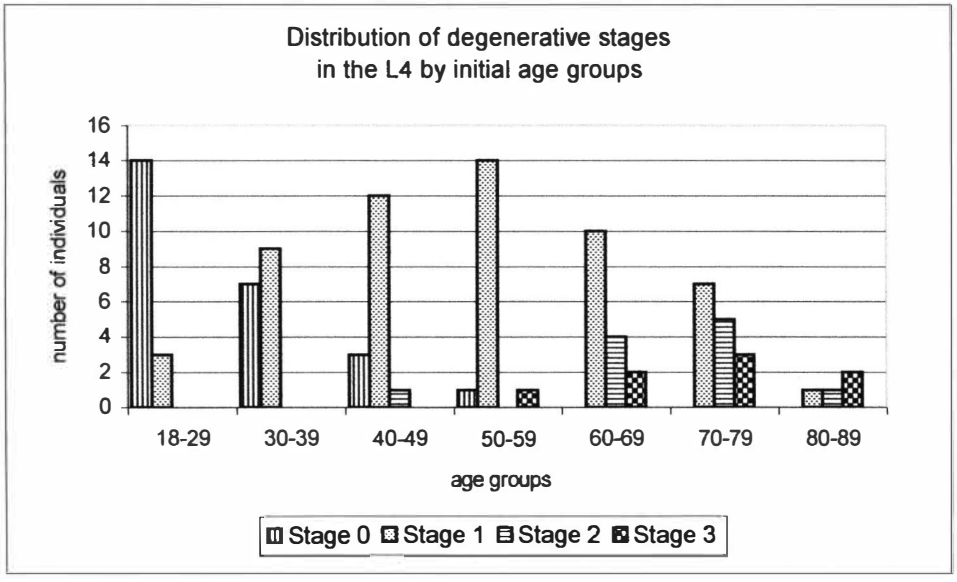


Figure 4.3. Distribution of degenerative stages in the L4 by initial age groups. Sample sizes per age group are: 18-29 (n=17), 30-39 (n=16), 40-49 (n=16), 50-59 (n=16), 60-69 (n=16), 70-79 (n=15), 80-89 (n=4).

Collapsed age groups

Collapsed age categories were then employed in the analysis to understand the relationship between broader age groups and vertebral degeneration. Figures 4.4-4.6 and Table 4.2 show the distribution (frequency and percentage) of stages when life decades are combined into the age categories of young (18-29 and 30-39), middle (40-49 and 50-59) and old (60+).

Stage 0 is present in all age groups for the C7 and T7, but is present in just the young and middle age groups in the L4. Stage 1 is consistently found in each age group, regardless of vertebral type. Stage 2 is primarily a characteristic of middle and old ages, though a couple exceptions are seen in the young age group. Stage 3 is predominantly seen in old age, with just two of 12 individuals in the middle age group. The few cases (3 in total) of Stage 4 are from old individuals.

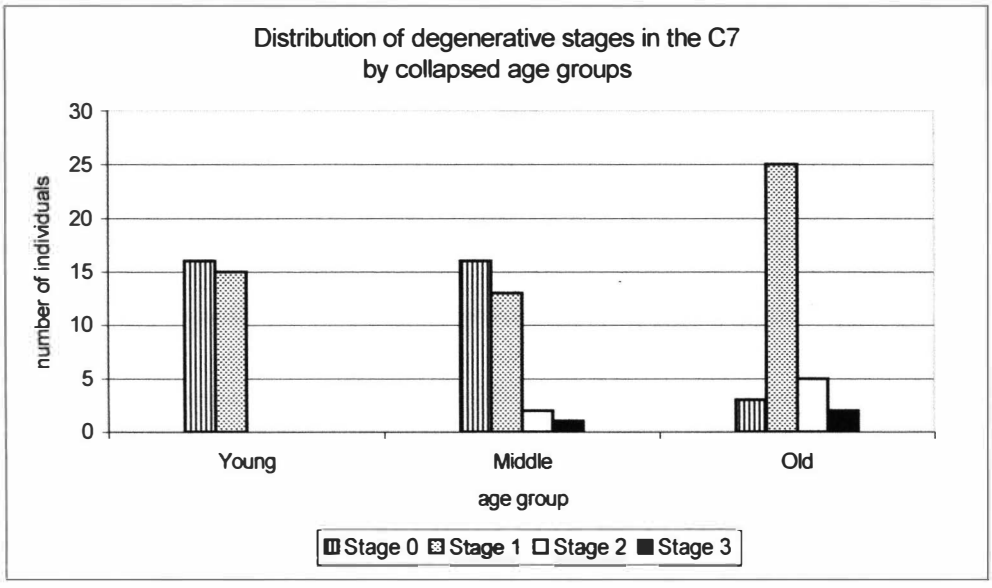


Figure 4.4. Distribution of degenerative stages in the C7 by collapsed age groups. Ages are classified as: young (18-29, 30-39), middle (40-49, 50-59) and old (60+). Sample sizes for age groups are: young (n=31), middle (n=32), old (n=35).

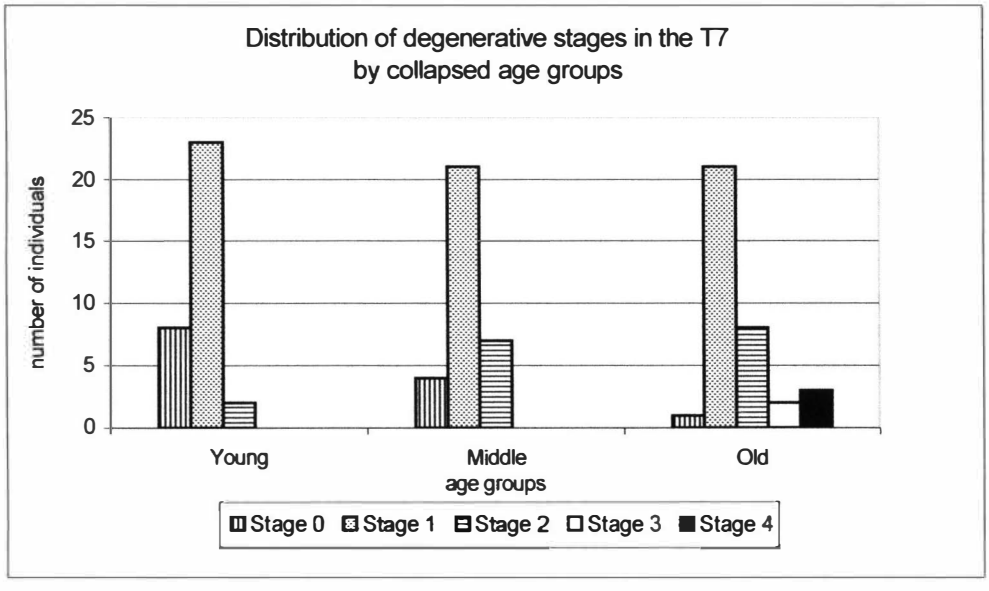


Figure 4. 5. Distribution of degenerative stages in the T7 by collapsed age groups. Ages are classified as young (18-29, 30-39), middle (40-49, 50-59) and old (60+). Sample sizes for age groups are: young (n=33), middle (n=32), old (n=35).

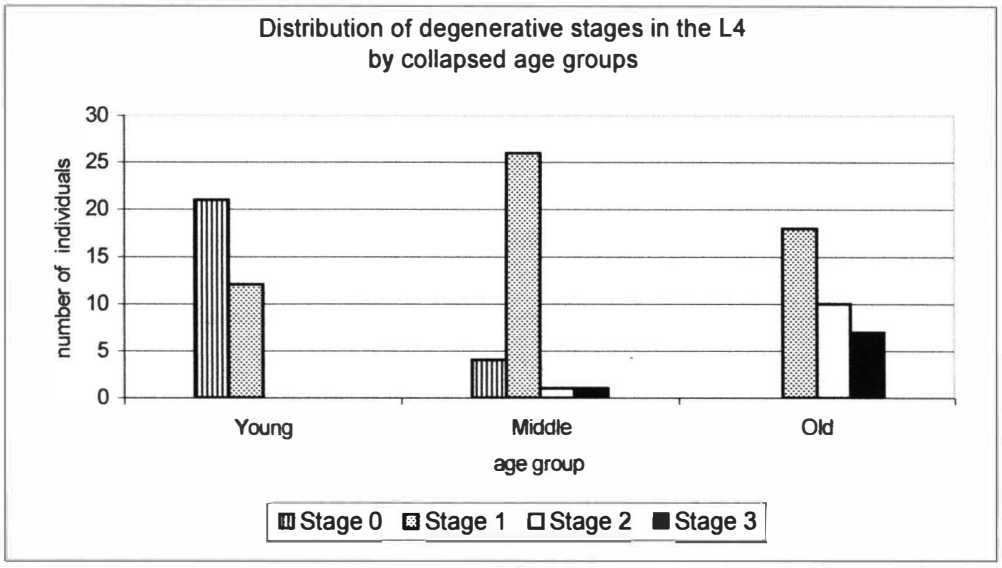


Figure 4.6. Distribution of degenerative stages in the L4 by collapsed age groups. Ages are classified as young (18-29, 30-39), middle (40-49, 50-59) and old (60+). Sample sizes for age groups are: young (n=33), middle (n=32), old (n=35).

Table 4.2. Distribution of degenerative stages and collapsed age groups

	Young		Middle		Old		Total	
	count	%	count	%	count	%	count	%
C7								
Stage 0	16	16.32	16	16.32	3	3.06	35	35.71
Stage 1	15	15.3	13	13.27	25	25.51	53	54.08
Stage 2	—	—	2	2.04	5	5.1	7	7.14
Stage 3	—	—	1	1.02	2	2.04	3	3.06
Stage 4	—	—	—	—	—	—	—	—
T7								
Stage 0	8	8	4	4	1	1	13	13
Stage 1	23	23	21	21	21	21	65	65
Stage 2	2	2	7	7	8	8	15	17
Stage 3	—	—	—	—	2	2	2	2
Stage 4	—	—	—	—	3	3	3	3
L4								
Stage 0	21	21	4	4	—	—	25	25
Stage 1	12	12	26	26	18	18	56	56
Stage 2	—	—	1	1	10	10	11	11
Stage 3	—	—	1	1	7	7	8	8
Stage 4	—	—	—	—	—	—	—	—

Distribution of the total sample by degenerative stage and collapsed age group.

Statistical analysis

Results of the chi square test (Table 4.3) show that the C7 and L4 are better indicators of the relationship between degenerative change and age at death. For the T7 sample, no association could be established between degeneration and age at death for all five test groups (male, female, Euro-American, Afro-American, and total samples). All L4 groups showed significant relationships ($p < .05$). Females, Euro-Americans, and total population samples for the C7 have significant associations. Post hoc tests tell us which tests group and degenerative stage combinations show the most differences between expected and observed frequencies. Typically 18-29 year-olds with Stage 0 lipping, and 60+ year-olds of all degenerative stages show the greatest dissimilarities between expected and observed frequencies. Expanded results for the analysis of the C7, T7, and L4 are located in Appendices E, F, and G.

Composite scoring

Total composite scores

My second aging technique based on vertebral degeneration uses composite scores of the cervical, thoracic, and lumbar vertebrae scores. Composite scores can range from 0-12. As before, the initial age decades were collapsed into three adult age categories (young, middle, and old) for comparative analysis.

Total composite score results are very similar to my analyses comparing degenerative stages to initial and collapsed age groups (see Figures 4.7-4.8 and Tables 4.4-4.5). The trends are the same for all studies: lower scores are widespread and higher scores are concentrated in older age. Though scores 0-2 are seen in all three collapsed age groups,

Table 4.3. Chi square results for degenerative stage and age at death

		Degrees of freedom	Chi square value	p-value
C7	Males	12	17.04	.1482
	Females	12	21.51	.0434*
	Afro-American	12	16.6	.1655
	Euro-American	12	26.11	.0104*
	Total	12	27.62	.0063*
T7	Males	16	13.22	.6563
	Females	12	13.56	.3295
	Afro-American	16	13.99	.5996
	Euro-American	12	11.2	.5121
	Total	16	20.71	.1899
L4	Males	12	37.91	.0002*
	Females	12	34.17	.0006*
	Afro-American	12	30.83	.0021*
	Euro-American	12	47.31	<.0001*
	Total	12	70.15	<.0001*

Chi square results for each vertebral type by sex, ancestry, and total sample.

Sample sizes for C7 are: males (n=51), females (n=48), Euro-American (n=50), Afro-American (n=49), total (n=99).

Sample sizes for T7 and L4: males (n=51), females (n=49), Euro-American (n=51), Afro-American (n=49), total (n=100).

* indicates p-values that are statistically significant

the frequency declines with age. Scores 3-5 are found in each age group with frequency increasing with age. Scores 6-8 and 9-12 are only seen in old age. In comparisons of degenerative stage and collapsed age groups the highest scores could also be found in middle age, though few in number. Some differences are present between groups of different ancestry and/or sex, but the differences do not significantly affect the results of the study. Composite score results for each subgroup are located in Appendix B.

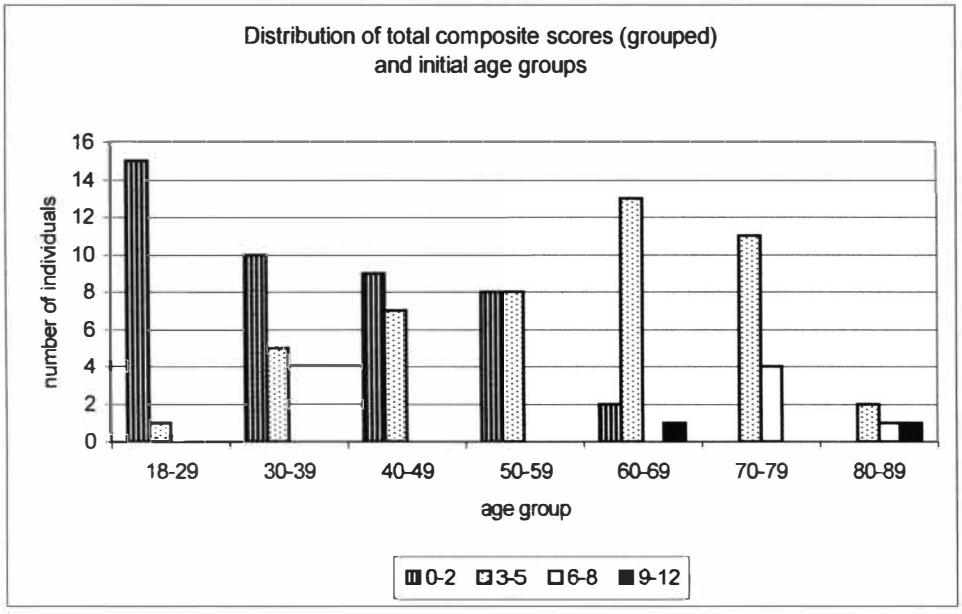


Figure 4.7. Distribution of total composite scores (grouped) and initial age groups. Sample sizes for age groups are: 18-29 (n=16), 30-39 (n=15), 40-49 (n=16), 50-59 (n=16), 60-69 (n=16), 70-79 (n=15), 80-89 (n=4).

Table 4.4. Composite score (C7, T7, L4) and initial age group distribution

Age group	Scores							
	0-2		3-5		6-8		9-12	
	count	%	count	%	count	%	count	%
18-29	15	15.31	1	1.02	—	—	—	—
30-39	10	10.2	5	5.1	—	—	—	—
40-49	9	9.18	7	7.14	—	—	—	—
50-59	8	8.16	8	8.16	—	—	—	—
60-69	2	2.04	13	13.27	—	—	1	1.02
70-79	—	—	11	11.22	4	4.08	—	—
80-89	—	—	2	2.04	1	1.02	1	1.02
Total	44	44.9	47	47.96	5	5.1	2	2.04

Distribution of total composite scores (grouped) and decade of life
Sample sizes for age groups are: 18-29 (n=16), 30-39 (n=15), 40-49 (n=16), 50-59 (n=16), 60-69 (n=16), 70-79 (n=15), 80-89 (n=4).

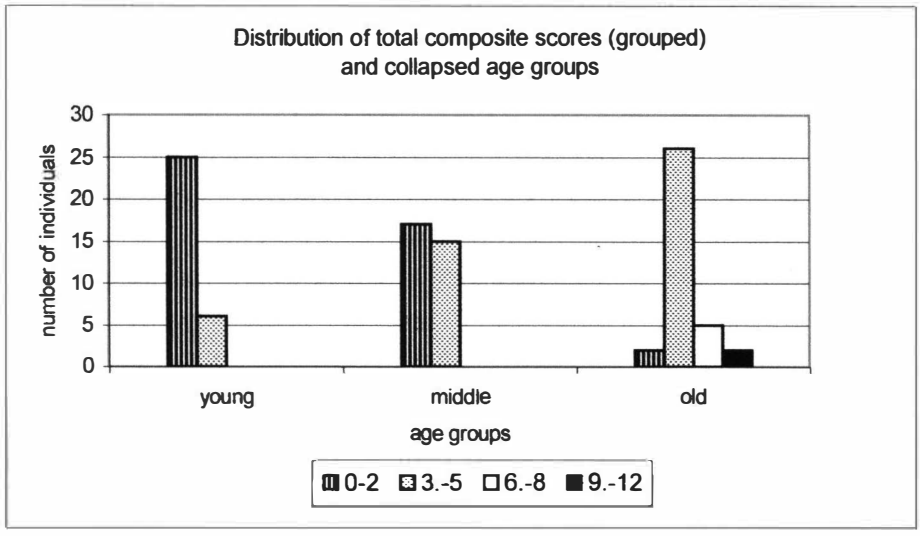


Figure 4.8. Distribution of total composite scores (grouped) and collapsed age groups. Sample sizes for age groups are: young (n=31), middle (n=32), and old (n=35).

Table 4.5. Distribution of grouped composite scores (C7, T7, L4) and collapsed age groups

Age group	Scores			
	0-2	3-5	6-8	9-12
Young	25	6	—	—
Middle	17	15	—	—
Old	2	26	5	2
Total	44	47	5	2

Distribution of total composite scores (grouped) and collapsed age groups. Sample sizes for age groups are: young (n=31), middle (n=32), and old (n=35).

Reduced composite scores

The second type of composite scoring system excludes the T7 as part of the score, so the range of scores is 0-8. The results of this study are very similar to those of total composite scores (see Figures 4.9-4.10 and Tables 4.6-4.7). The lowest score group (0-2) is present in all three collapsed age groups with frequency decreasing as age increases. The middle score range (3-5) increases in frequency with increasing age, and can be found in middle and old ages. One individual scored in the highest possible range (6-8) for this study, and is classified into the oldest initial age group (80-89 years). Reduced composite score results for subgroups can be found in Appendix C.

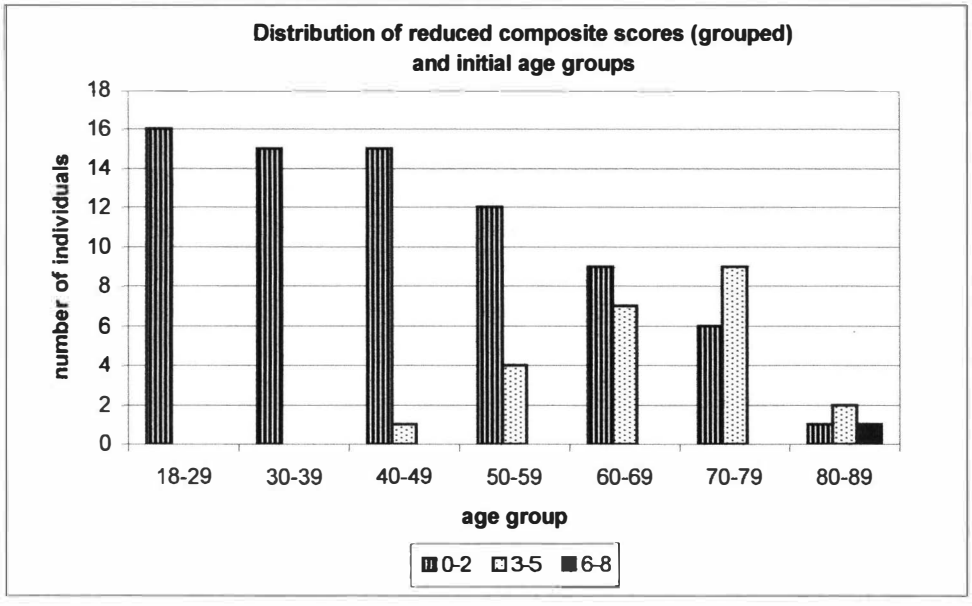


Figure 4.9. Distribution of reduced composite scores (grouped) and initial age groups. Sample sizes for age groups are: 18-29 (n=16), 30-39 (n=15), 40-49 (n=16), 50-59 (n=16), 60-69 (n=16), 70-79 (n=15), and 80-89 (n=4).

Table 4.6. Distribution of composite scores (C7, L4) and initial age groups

Age groups	Scores		
	0-2	3-5	6-8
18-29	16	—	—
30-39	15	—	—
40-49	15	1	—
50-59	12	4	—
60-69	9	7	—
70-79	6	9	—
80-89	1	2	1
Total	74	23	1

Reduced composite scores (grouped) and decade of life.
Sample sizes for age groups are: 18-29 (n=16), 30-39 (n=15), 40-49 (n=16), 50-59 n=(16), 60-69 (n=16), 70-79 (n=15), and 80-89 (n=4).

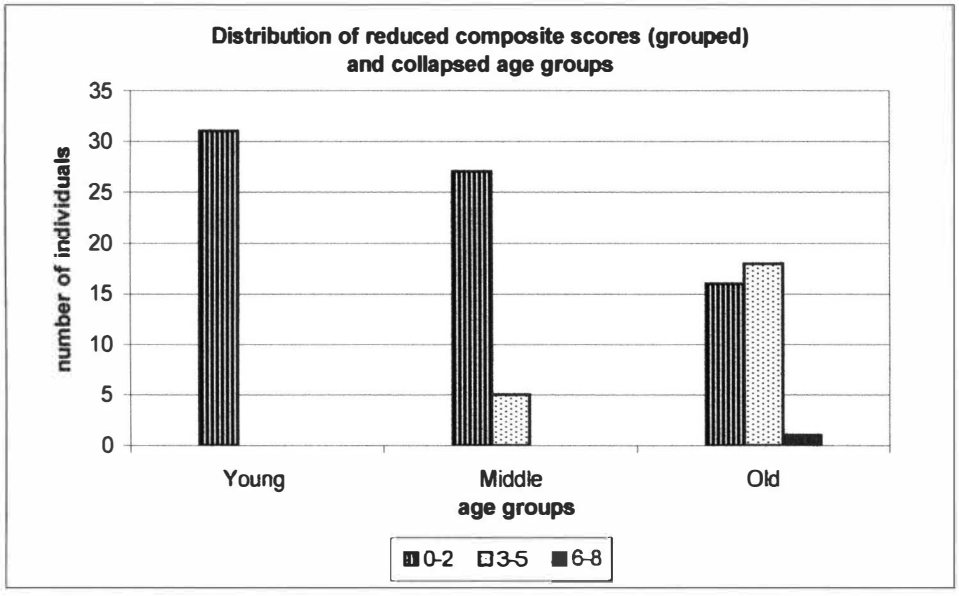


Figure 4.10. Distribution of reduced composite scores (grouped) and collapsed age groups.
Sample size for age groups are: young (n=31), middle (n=32), and old (n=35).

Table 4.7. Distribution of grouped composite scores (C7, L4) and collapsed age groups

Age group	Scores		
	0-2	3-5	6-8
Young	31	—	—
Middle	27	5	—
Old	16	18	1
Total	74	23	1

Distribution of reduced composite scores (grouped) and collapsed age groups. Sample sizes for age groups are: young (n=31), middle (n=32), and old (n=35).

Statistical analysis for total and reduced composite scores

Chi square analysis for composite scores (see Table 4.8) show that a significant relationship between age and vertebral degeneration could not be found for Afro-Americans using either total or reduced composite scoring methods. This is the only group for either type of composite scoring system that does not show an association between vertebral degeneration and age at death. Post hoc tests for total and reduced composite scores show a similar pattern as those for degenerative stages. Most differences between observed and expected frequencies occur in young individuals with low composite scores, and in old individuals regardless of degree of vertebral degeneration. It is important to note that while chi square tests indicate whether an association exists between vertebral degeneration, they do not tell us the predictive value of vertebral lipping for age assessment. Expanded chi square results for total and reduced composite scores are located in Appendices H and I.

Table 4.8. Chi square results for total and reduced composite scores

		Degrees of freedom	Chi square value	p-value
Total composite (C7, T7, L4)	Males	12	23.58	.025*
	Females	8	22.96	.0035*
	Euro-Americans	12	29.85	.005*
	Afro-Americans	12	18.86	.10
	Total	12	46.8	<.001*
Reduced composite (C7, L4)	Males	8	21.14	.01*
	Females	8	15.99	.04*
	Euro-Americans	4	15.83	.003*
	Afro-Americans	8	14.16	.075
	Total	8	30.05	<.001*

Chi square results for each vertebral type by sex, ancestry, and total sample.

Sample sizes for total composite scores are: males (n=51), females (n=47), Euro-Americans (n=50), Afro-Americans (n=48), total (n=98)

Sample sizes for reduced composite scores are: males (n=51), females (n=47), Euro-Americans (n=50), Afro-Americans (n=48), total (n=98)

* indicates p-values that are statistically significant

Comparisons between males and females, and Afro-Americans and Euro-Americans

A final examination of the relationship between vertebral degeneration and age compares males against females, and Afro-Americans against Euro-Americans. Though these comparisons are further divided into the four subgroups (Afro-American males, Afro-American females, Euro-American males, and Euro-American females) in the appendices, the total samples are utilized here for comparison. Using total composite

scores, graphs were created to compare the groups. The patterning in vertebral degeneration distribution between females and males (Figures 4.11, 4.12) is very similar throughout the age groups. Only in older age is there a noticeable change in patterning, with a few males showing greater levels of degeneration than females. Differences between Afro-Americans and Euro-Americans (Figures 4.13, 4.14) were also negligible. Rates of degenerative change were similar in younger and middle aged individuals, though more variation occurs in ages 60+. However, this variation is small considering only a few cases differ between the groups.

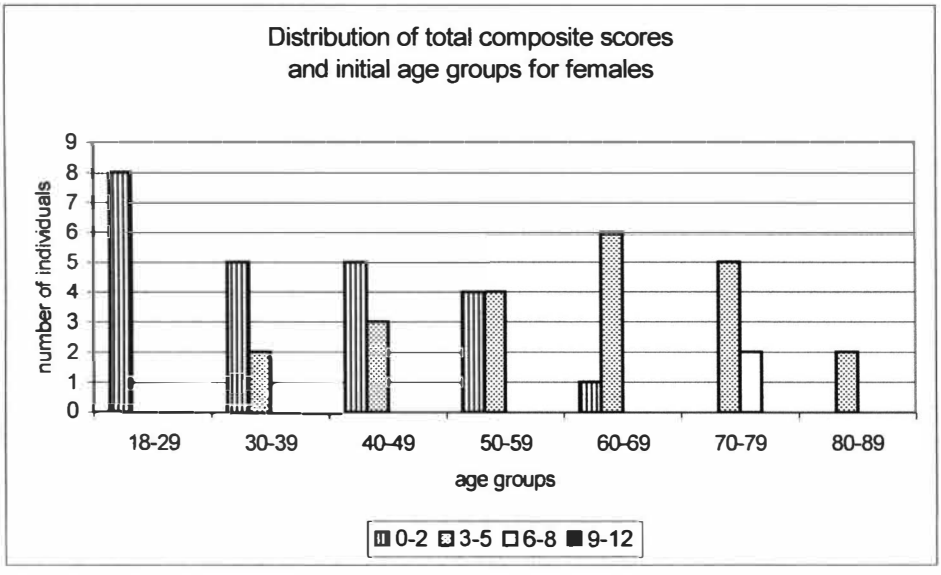


Figure 4.11. Distribution of total composite scores and initial age groups for females. Sample sizes for age groups are: 18-29 (n=8), 30-39 (n=7), 40-49 (n=8), 50-59 (n=8), 60-69 (n=7), 70-79 (n=7), 80-89 (n=2).

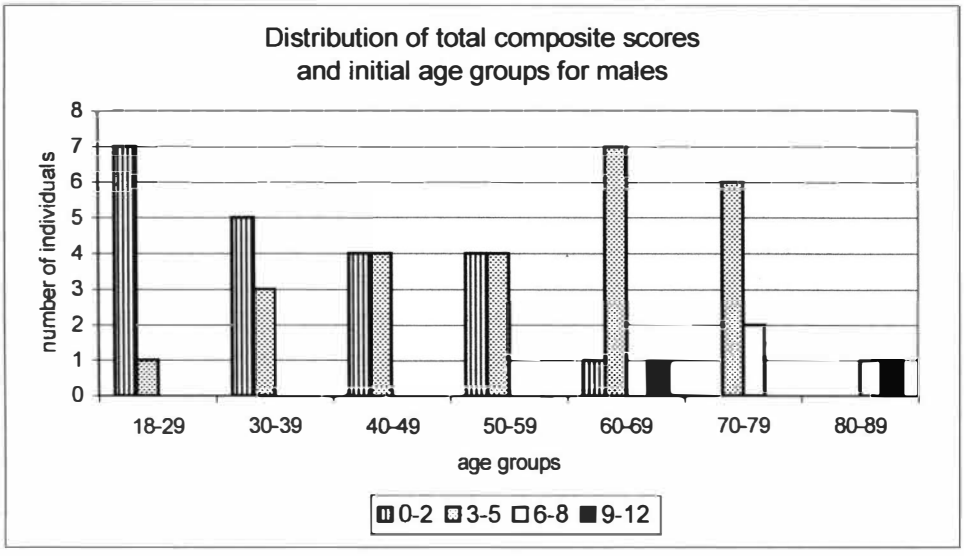


Figure 4.12. Distribution of total composite scores and initial age groups for males. Sample sizes for age groups are: 18-29 (n=8), 30-39 (n=8), 40-49 (n=8), 50-59 (n=8), 60-69 (n=9), 70-79 (n=8), 80-89 (n=2).

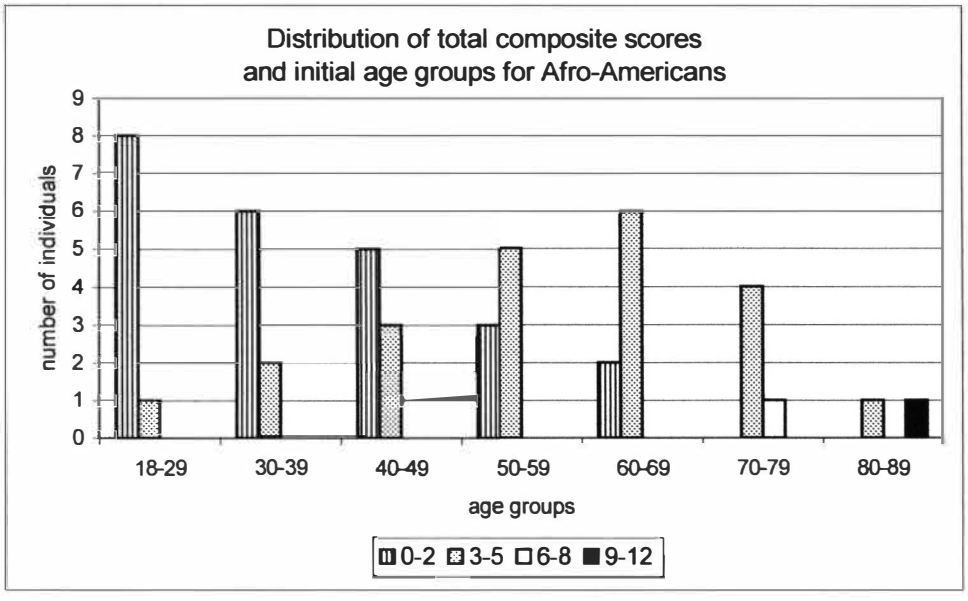


Figure 4.13. Distribution of total composite scores and initial age groups for Afro-Americans. Sample sizes for age groups are: 18-29 (n=9), 30-39 (n=8), 40-49 (n=8), 50-59 (n=8), 60-69 (n=8), 70-79 (n=5), 80-89 (n=2).

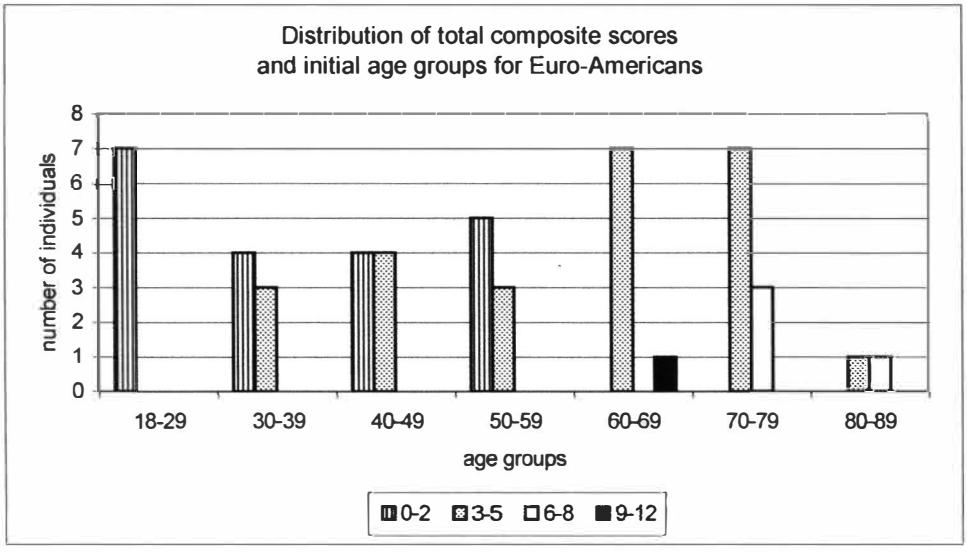


Figure 4.14. Distribution of total composite scores and initial age groups for Euro-Americans. Sample sizes for age groups are: 18-29 (n=7), 30-39 (n=7), 40-49 (n=8), 50-59 (n=8), 60-69 (n=8), 70-79 (n=10), 80-89 (n=2).

Results of hypotheses testing

The first five hypotheses utilize results from the previously reported chi square tests. These hypotheses test whether or not an association exists between age at death and vertebral degeneration for (1) total sample, (2) males, (3) females, (4) Afro-Americans, and (5) Euro-Americans. For each sampled group, results are reported for (a) degenerative stages of the C7, (b) degenerative stages of the T7, (c) degenerative stages of the L4, (d) reduced composite scores (C7 and L4), and (e) total composite scores (C7, T7, and L4). For testing of males against females, and Afro-Americans against Euro-Americans, the information reported in Figures 4.11-4.14 was used for comparison purposes. Hypothesis test results are presented below and in Table 4.9.

H0: The occurrence of vertebral degeneration is independent of age (total sample).

H1: The occurrence of vertebral degeneration is not independent of age (total sample).

Results: The alternative hypothesis (H1) is accepted for comparisons of the C7, L4, reduced composite scores, and total composite scores. The null hypothesis (H0) is only accepted in the case of the T7 total sample. Thus, for all but one group, an association between vertebral degeneration and age exists.

H0: The occurrence of vertebral degeneration is independent of age (males).

H2: The occurrence of vertebral degeneration is not independent of age (males).

Results: The alternative hypothesis (H2) is accepted for the L4, reduced composite scores, and total composite scores. The null hypothesis (H0) is accepted for the C7 and T7 male samples. Therefore, three of five scoring methods show an association between vertebral degeneration and age.

H0: The occurrence of vertebral degeneration is independent of age (females).

H3: The occurrence of vertebral degeneration is not independent of age (females)

Results: The alternative hypothesis (H3) is accepted for the C7, L4, total composite scores, and reduced composite scores. The null hypothesis is accepted for the T7. Only the T7 sample does not show a relationship between vertebral degeneration and age.

H0: The occurrence of vertebral degeneration is independent of age (Euro-Americans).

H4: The occurrence of vertebral degeneration is not independent of age (Euro-Americans).

Results: The alternative hypothesis (H4) is accepted for the L4, total composite scores, and reduced composite scores. The null hypothesis (H0) is accepted for the C7 and T7 samples. Thus, three of five methods result in an association between vertebral degeneration and age.

H0: The occurrence of vertebral degeneration is independent of age (Afro-Americans).

H5: The occurrence of vertebral degeneration is not independent of age (Afro-Americans).

Result: The alternative hypothesis (H5) is accepted only for the L4. The null hypothesis (H0) is accepted for the C7, T7, total composite scores, and reduced composite scores. Afro-Americans are the only group where the null hypothesis is accepted more times than the alternative hypothesis.

H0: Rates of degenerative change between males and females will be similar.

H7: Rates of degenerative change between males and females will not be similar.

Results: Based on Figures 4.11 and 4.12, the differences in the distribution of total composite scores between males and females are slight. The only notable difference is the presence of scores 9-12 in the male sample (2 cases), and the absence of those

scores in females. Overall, there is weak evidence to suggest significant sex bias in the rate of vertebral degeneration. The null hypothesis (H0) is therefore accepted.

H0: Rates of degenerative change between Afro-Americans and Euro-Americans will be similar.

H7: Rates of degenerative change between Afro-Americans and Euro-Americans will not be similar.

Results: Based on Figures 4.13 and 4.14, the patterning of osteophytic development is too similar between the groups to indicate great differences between rates of vertebral degeneration. The null hypothesis (H0) is accepted.

Table 4.9. Hypothesis test results

	Accept H0 (no association)	Accept Ha (association)
Total	T7	C7, L4, total, reduced
Males	C7, T7	L4, total, reduced
Females	T7	C7, L4, total, reduced
Afro-Americans	C7, T7, total, reduced	L4
Euro-American	C7, T7	L4, total, reduced
Males vs. females	accept	
Euro vs. Afro-Americans	accept	

Results of hypothesis testing using chi square tests for the samples: total, males, females, Afro-American, and Euro-American. Graphs (Figures 4.11-4.14) were used to compare males vs. females, and Euro-Americans vs. Afro-Americans.

CHAPTER 5: DISCUSSION AND CONCLUSIONS

In terms of accuracy of age estimation from degenerative stages, the lowest stages have too wide an age range to be very useful, though higher stages have a narrower range. Because the presence of Stage 0 is strongest in the young and middle age categories, individuals of unknown age exhibiting this stage will likely be young or middle aged. Stage 1 is the most prominent stage in the sample and its relatively equal presence in all three collapsed age groups means it is of little value in vertebral age estimation. Most individuals exhibiting Stage 2 changes are middle and old aged, so an individual of unknown age will most likely belong to these age groups. For Stages 3 and 4, the majority of cases are classified into the old age category, so this is the best fitting age group for individuals with these levels of vertebral degeneration. Still, these age ranges are too broad even in the highest stages to be a good estimator of age. In addition, the sample size for Stages 3 and 4 are fairly small, so results for these stages are not as reliable as those for groups with larger sample sizes. My findings are similar to those of Stewart (1958) who concluded osteophyte growth alone cannot produce a close age estimation, but extensive lipping is characteristic of an individual over 40 years of age. Therefore, in both my study and in Stewart's study a closer relationship between degenerative stage and age exists in higher stages, though the relationship is still fairly broad.

Composite score results demonstrate the same trends as studies between degenerative stage and age groups. Though low scores (0-2) are seen in all three collapsed age groups, the declining frequency with age signals a correlation between

vertebral degeneration and age. For classification purposes, the scores are still too widespread for a close estimation of age. Therefore its utility in age assessment is lacking. The same can be said for scores 3-5 in that a trend of increasing frequency with age implies a relationship between degenerative change and age. Again, the distribution of scores is too widespread among the three age groups to allow for close age estimation. Because the highest scores (6-8 and 9-12) are only seen in old age, these stages give a closer estimation of age at death. However, there is a multi-decade span in the old age group, so estimation is still not precise enough to be of great utility.

It is important to note that while the closest age estimations may only be possible in the most severe cases of osteophyte development, trends regarding age and degenerative change can still be helpful. In general, the frequency of low degenerative stages decreases with age while the frequency of mid-high stages increases with age. Chi square tests show that an association between stages of lipping and age exists for most individuals, except for the T7 samples, which show no such association.

The variability in the condition of the vertebrae in my sample is likely from the role lifestyle played. It is well known that occupational stresses are a major cause of joint degeneration (Jurmain 1999), and this may be the cause of differences in degenerative change between individuals of similar ages. For example, all five degenerative stages are present in old age for T7, so age cannot be the only influence in the degree of osteophytic development. Factors besides age and physical stress, including health, heredity, and structure of the vertebral column, could be additional causes of variability in rates of vertebral degeneration (Bridges 1994; Jurmain 1977; Kennedy 1989; Knusel et al.1996; Steele and Bramblett 1988).

An additional step I took in the study of vertebral age assessment was dividing the research sample into four sub-groups based on both ancestry and sex (Euro-American males, Euro-American females, Afro-American males, Afro-American females), in case these factors influence the results (see Appendices B, C, and D). There are some differences between the sub-groups, but there is not enough variability to change the overall results. Perhaps with an average sub-group sample size of 25, the samples were too small for great variability between the sub-groups to be expressed. When the sample is categorized only by sex or ancestry (ie. males, females, Euro-Americans, Afro-Americans) statistical testing shows that the association between vertebral degeneration and age of Afro-Americans is more frequently a non-significant association. Other groups show a mostly significant relationship utilizing the degenerative stages and composites scores, but Afro-Americans are the exception. Upon review of Afro-American chi square results (Appendices E-I) the non-significant result is due to the patterns of the age groups matching too closely. For example, using the T7 sample (see Appendix F) we can see that in each age group the number of observed cases begins low in Stage 0, then increases in Stage 1, and then decreases in stages 2-4. Because this uniform trend is found through the age groups, the chi square test determines that degenerative stages and age are independent of one another.

The individuals in this study were acquired during the early 20th century for the Hamann-Todd Collection. As previously stated, lifestyle plays a role in vertebral degenerative change, but how would lifestyle affect a current-day population sample? Most of the individuals in my study were born in the 19th century when life was much different than today. A potential problem with age estimation is whether the techniques

and resulting data from a collection such as the Hamann-Todd Collection can be useful for population groups of a different space or time. Although I based my stages of vertebral degeneration on the stages previous researchers utilized, only Stewart (1958) attempts to correlate osteophyte development with age at death. Thus, this is currently the only study to compare my results against. Snodgrass (2004) examined sex differences in osteophyte production in thoracic and lumbar vertebrae of individuals from the Terry Collection, but no information is given regarding relationships between specific degenerative stages and age groups. Bridges (1994), Derevenski (2000), and Chapman (1972) examine archaeological specimen for vertebral degeneration. However, these studies discuss osteophyte patterning and distribution of their samples, and also compare them to culturally and historically similar samples from other archaeological sites. Therefore, assessing the presence and severity of vertebral degeneration rather than comparing degeneration with age is the goal for these studies.

In closing, from the results of my study we find that although vertebrae show age-related differences, it is problematic to solely use vertebrae for age estimation. Only the most advanced stages of vertebral degeneration can be useful in age assessment, but the age ranges for these stages are still too broad for a close estimation of age.

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Appendices

A: Age ranges for each degenerative stage for the C7, T7, and L4

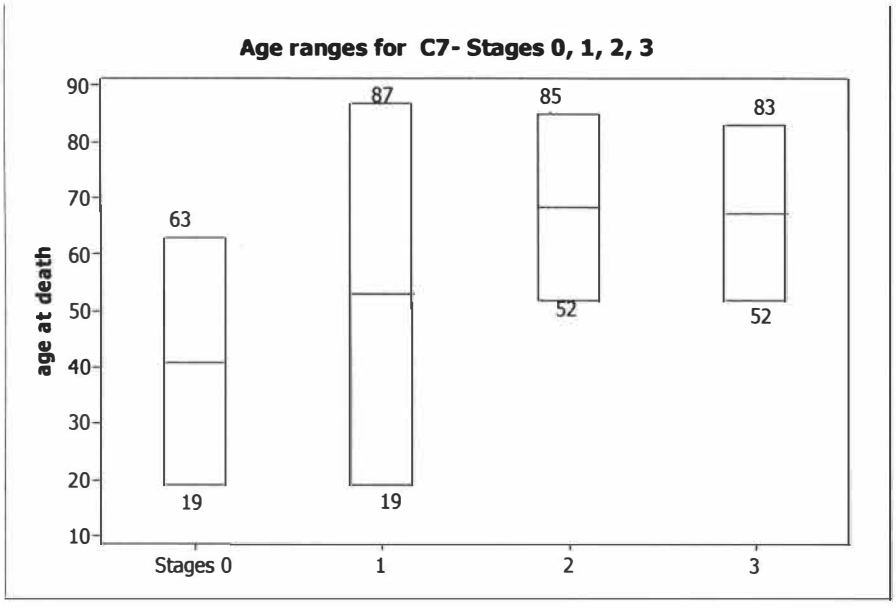

Figure 1. Minimum and maximum ages in each degenerative stage in the C7. Sample sizes are: stage 0 (n=35), stage 1 (n=53), stage 2 (n=7), stage 3 (n=3).

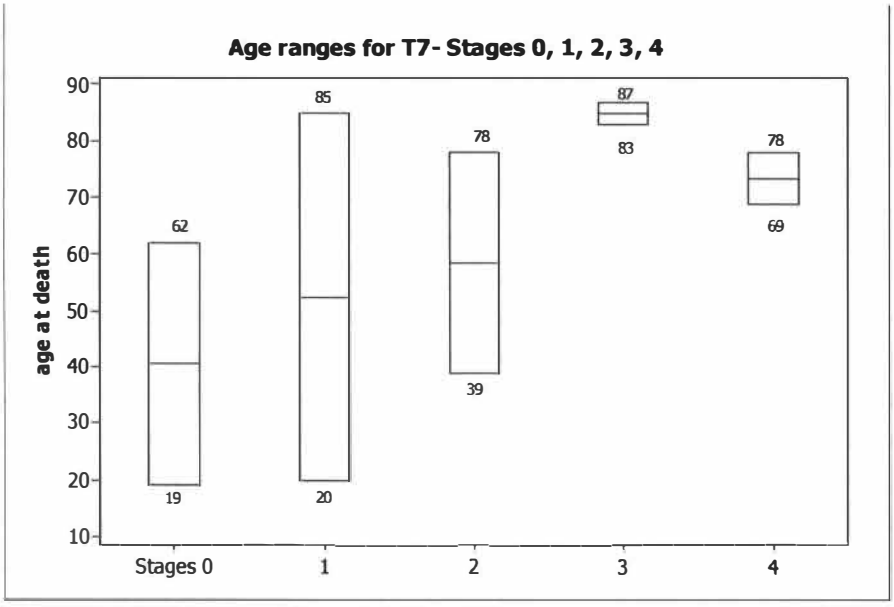

Figure 2. Minimum and maximum ages in each degenerative stage in the T7. sample sizes are: stage 0 (n=13), stage 1 (n=65), stage 2 (n=17), stage 3 (n=2), stage 4 (n=3).

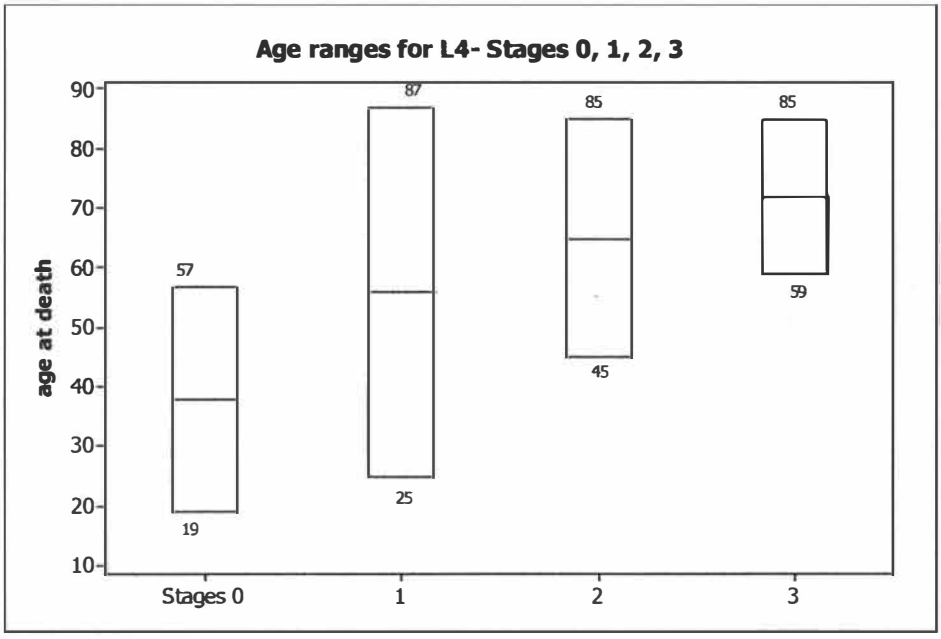

Figure 3. Minimum and maximum ages in each degenerative stage in the L4. Sample sizes are: stage 0 (n=25), stage 1 (n=56), stage 2 (n=11), stage 3 (n=8).

B: Total composite score results

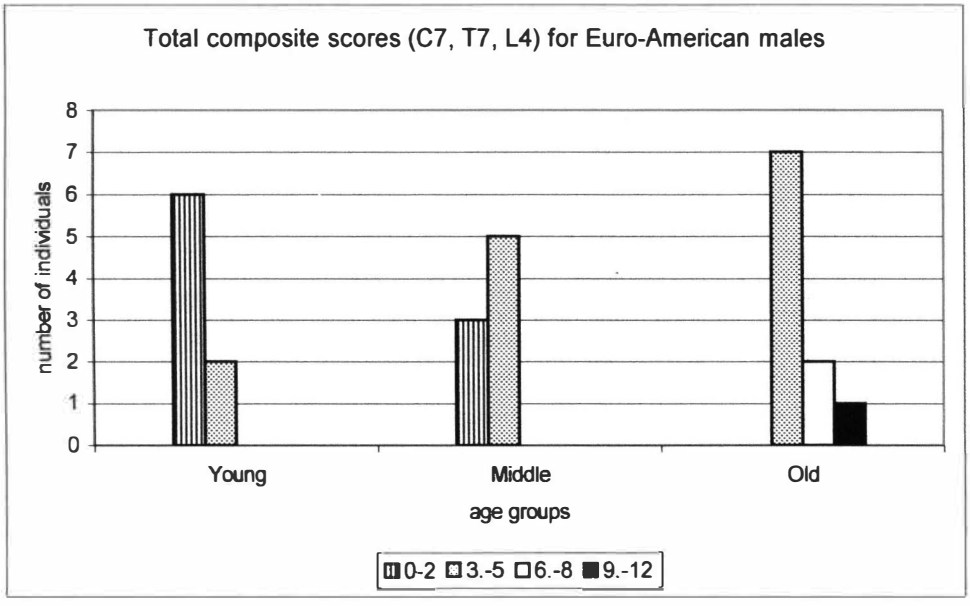

Figure 4. Grouped composite scores (C7, T7 and L4) and collapsed age groups for Euro-American males.

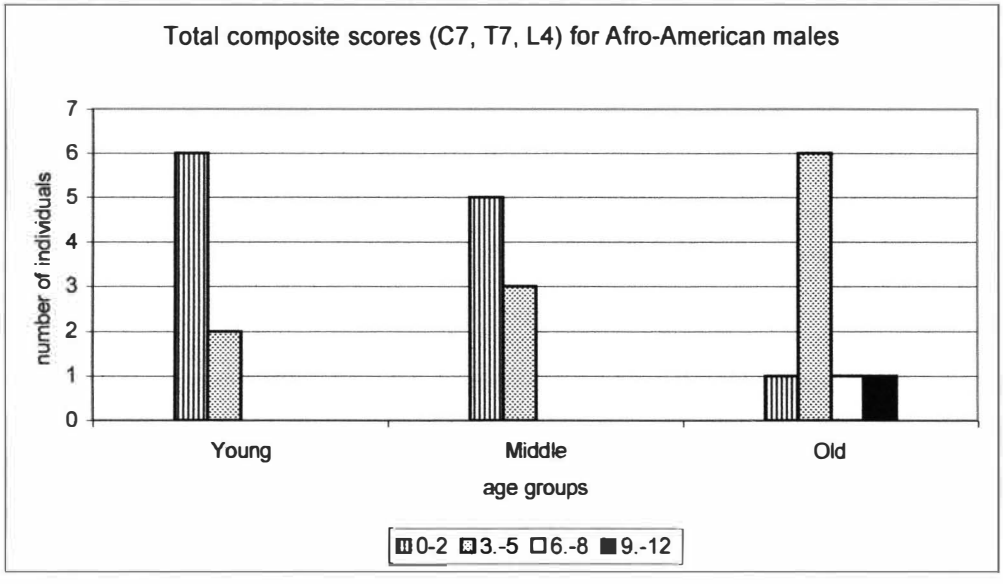

Figure 5. Grouped composite scores (C7, T7 and L4) and collapsed age groups for Afro-American males.

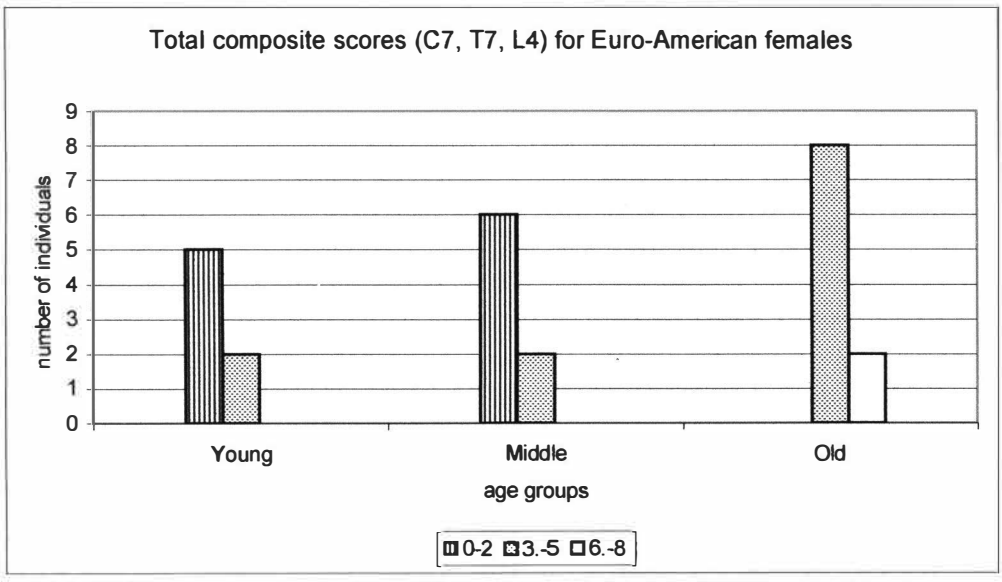

Figure 6. Grouped composite scores (C7, T7 and L4) and collapsed age groups for Euro-American females.

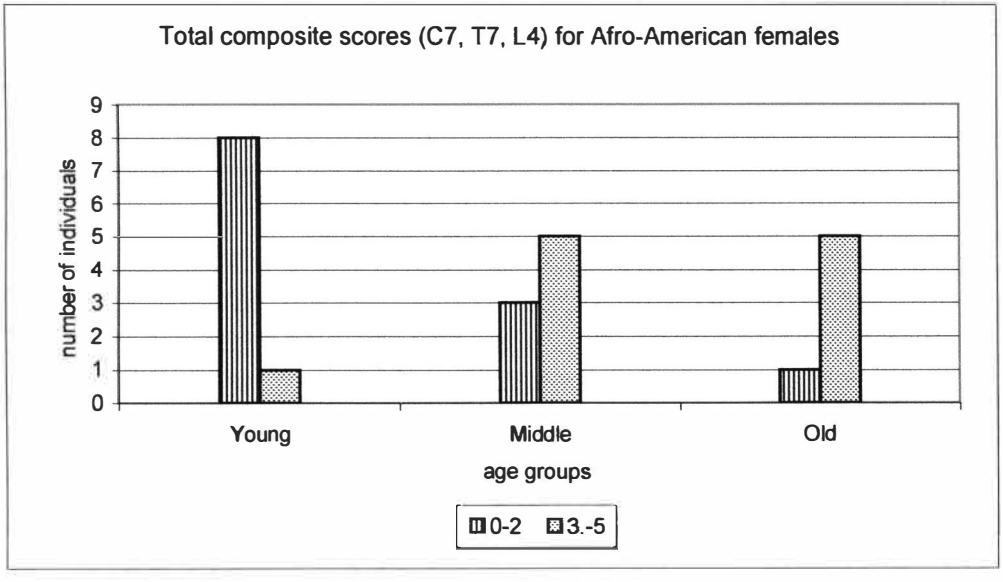

Figure 7. Grouped composite scores (C7, T7 and L4) and collapsed age groups for Afro-American females.

C: Reduced composite score results

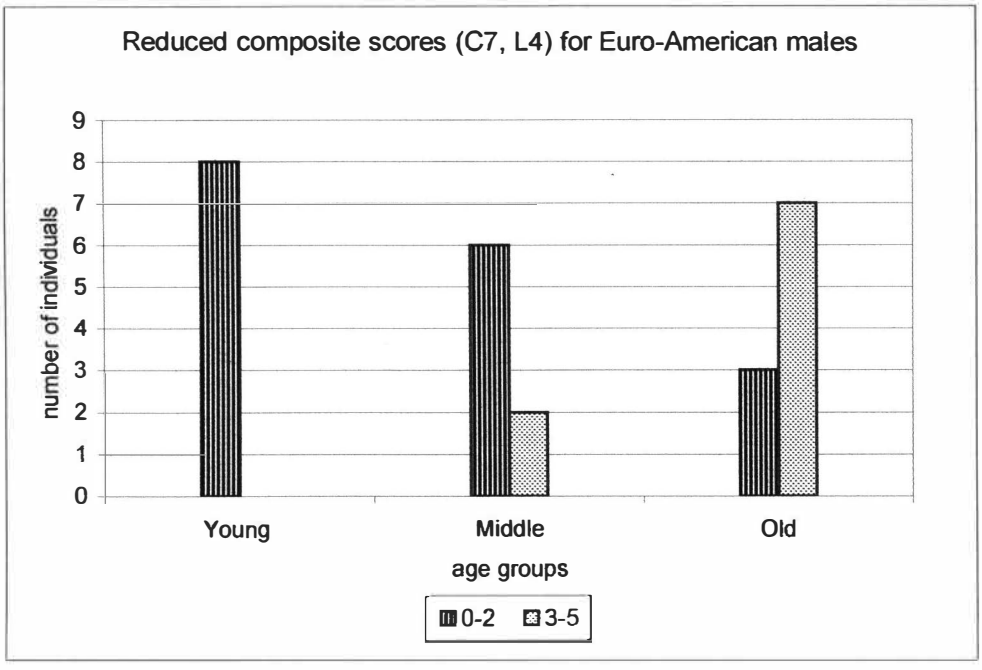

Figure 8. Grouped composite scores (C7, L4) and collapsed age groups for Euro-American males.

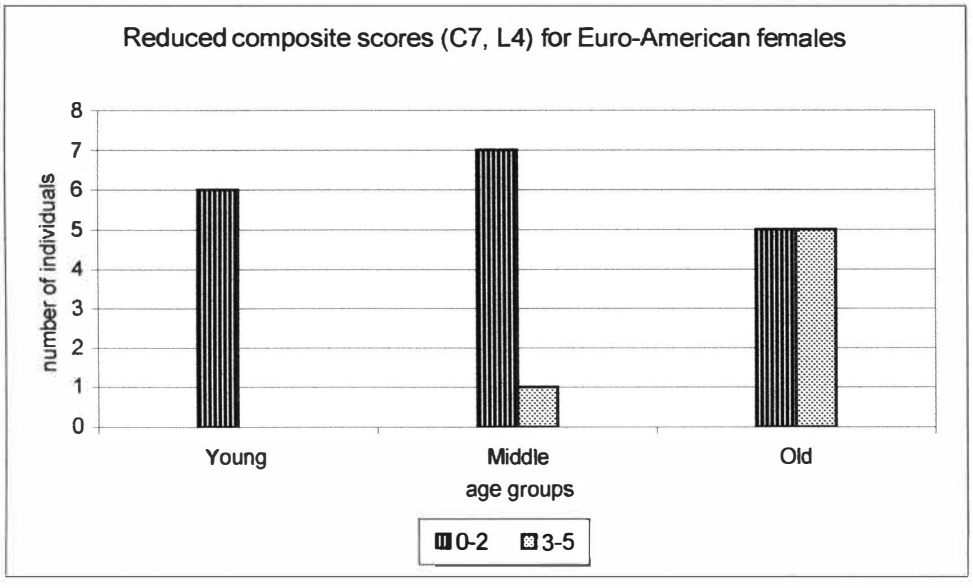

Figure 9. Grouped composite scores (C7, L4) and collapsed age groups for Euro-American females.

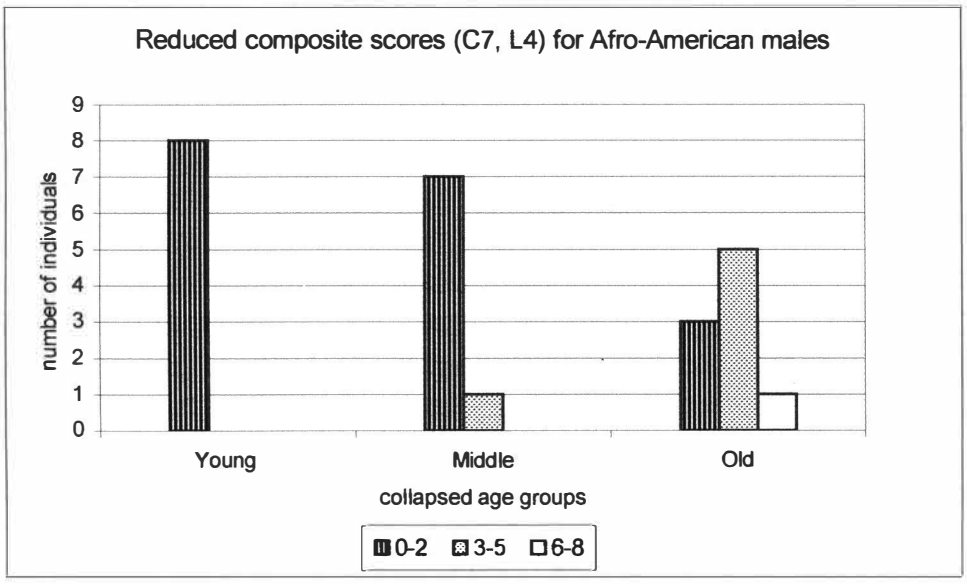

Figure 10. Grouped composite scores (C7, L4) and collapsed age groups for Afro-American males.

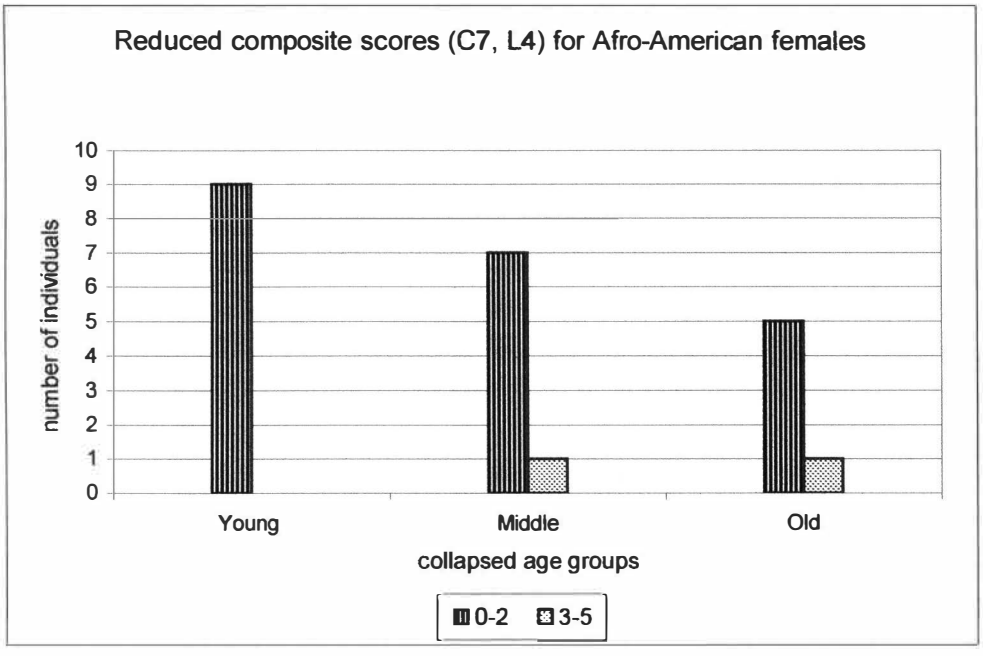

Figure 11. Grouped composite scores (C7, L4) and collapsed age groups for Afro-American females.

D: Distribution of degenerative stages in the C7, T7, and L4

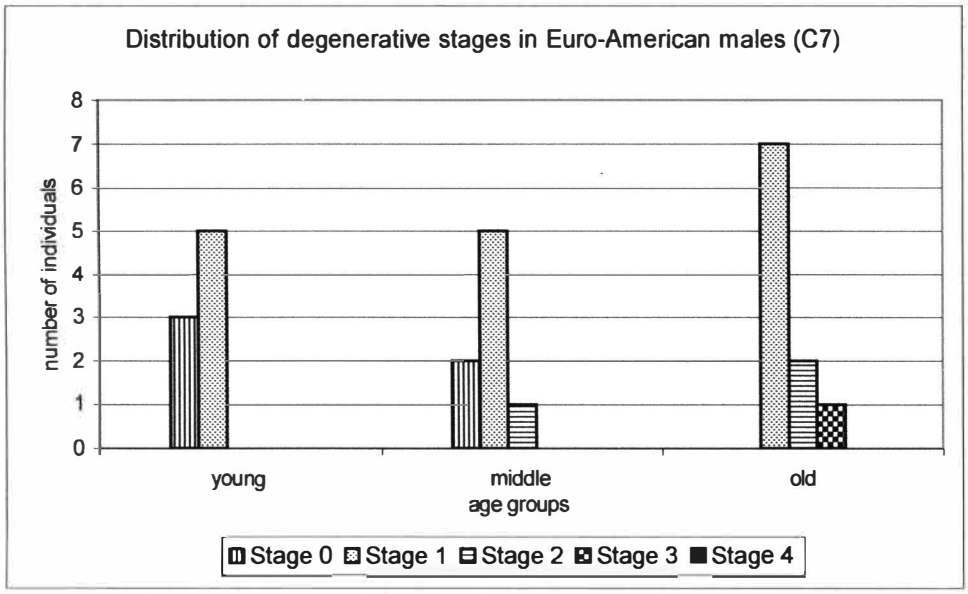

Figure 12. Cervical 7 degenerative stages and collapsed age groups for Euro-American males

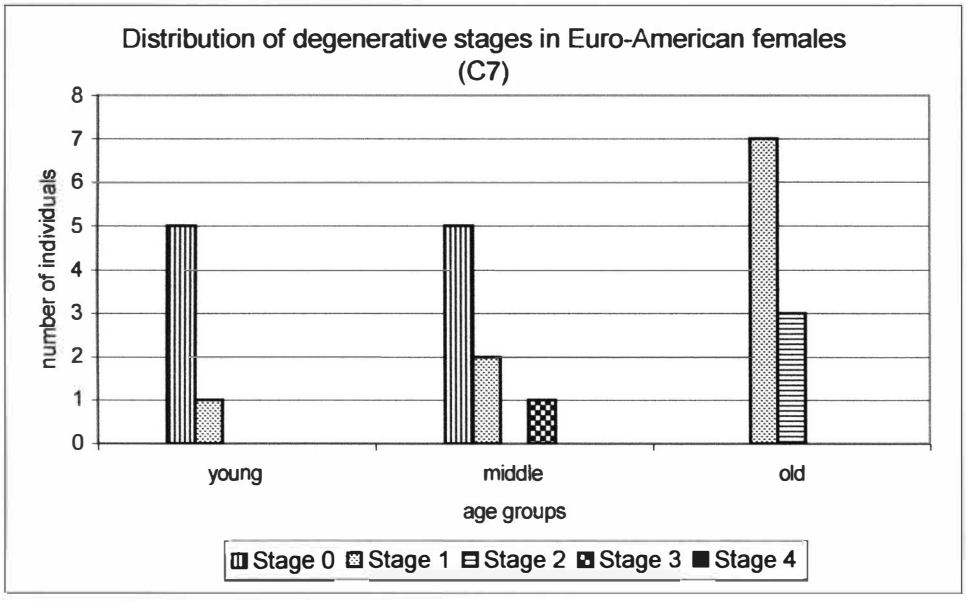

Figure 13. Cervical 7 degenerative stages and collapsed age groups for Euro-American females

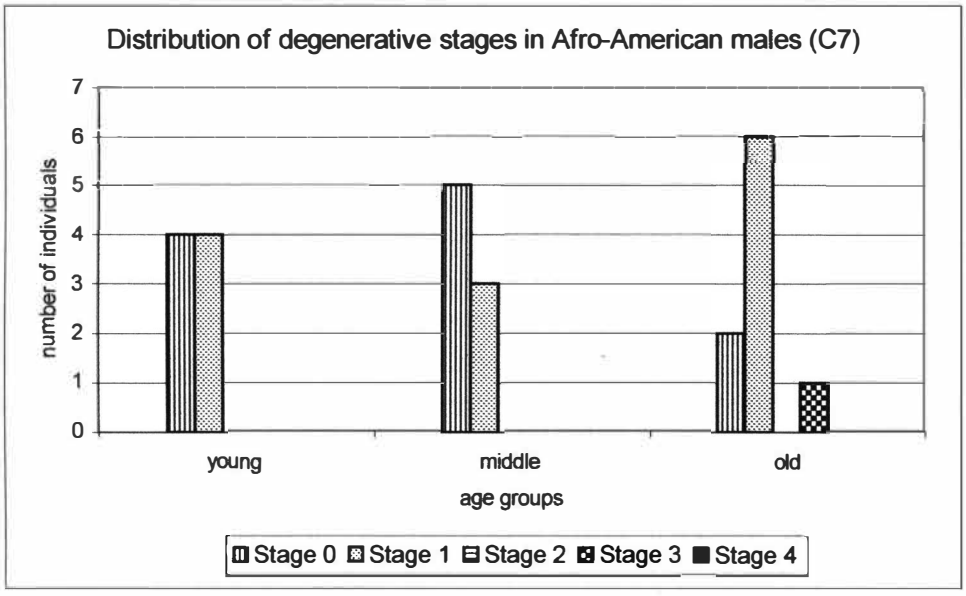

Figure 14. Cervical 7 degenerative stages and collapsed age groups for Afro-American males

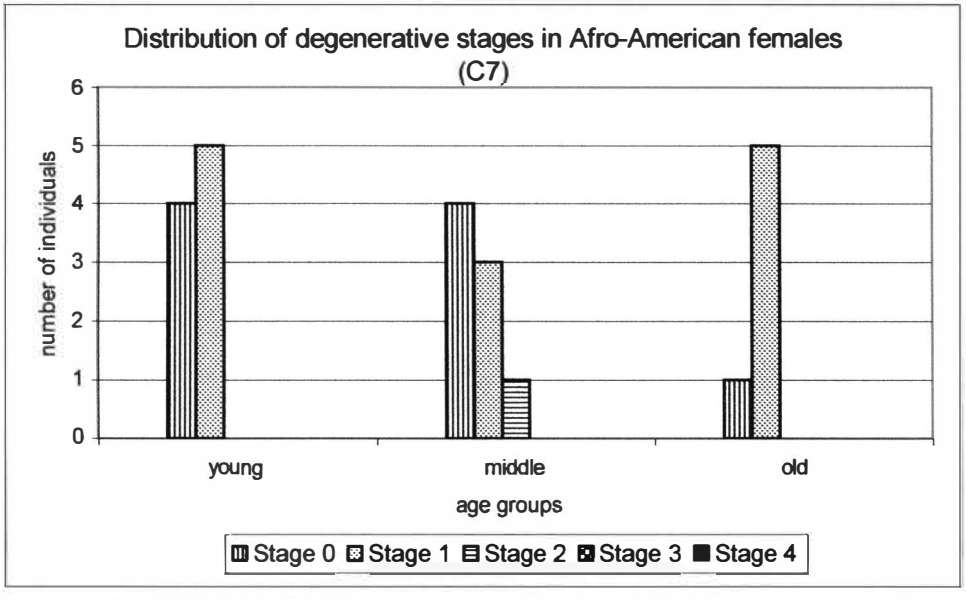

Figure 15. Cervical 7 degenerative stages and collapsed age groups for Afro-American females

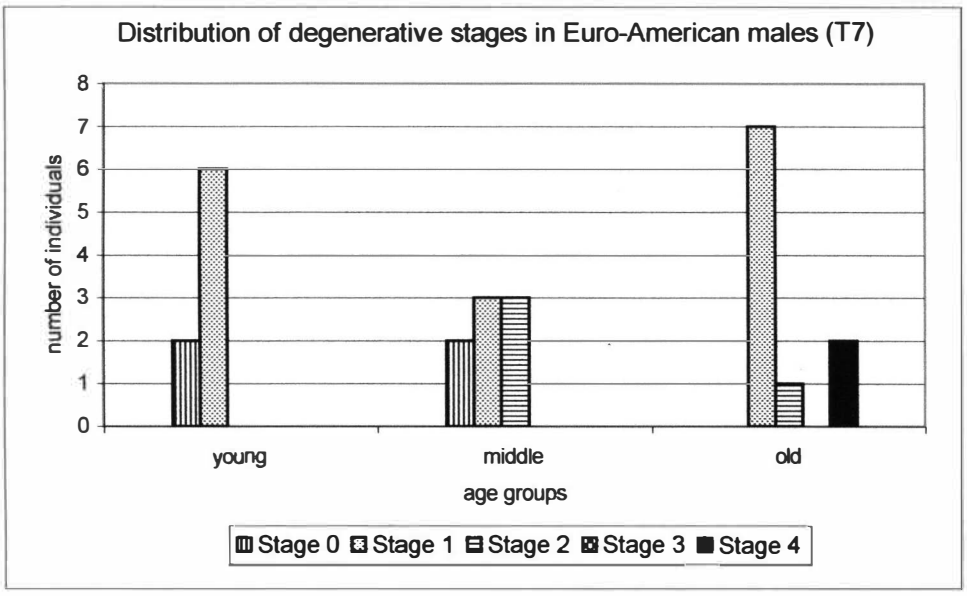

Figure 16. Thoracic 7 degenerative stages and collapsed age groups for Euro-American males

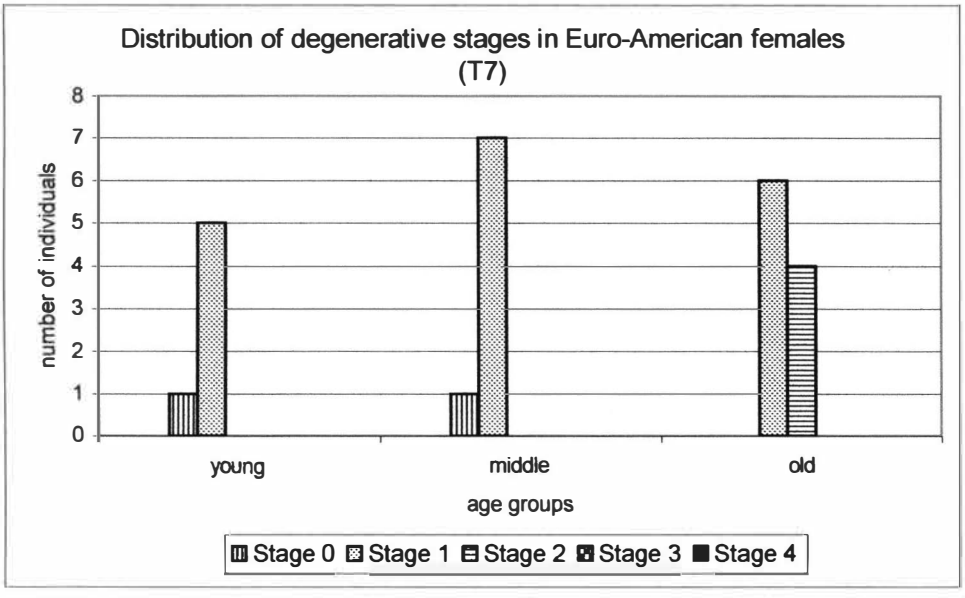

Figure 17. Thoracic 7 degenerative stages and collapsed age groups for Euro-American females

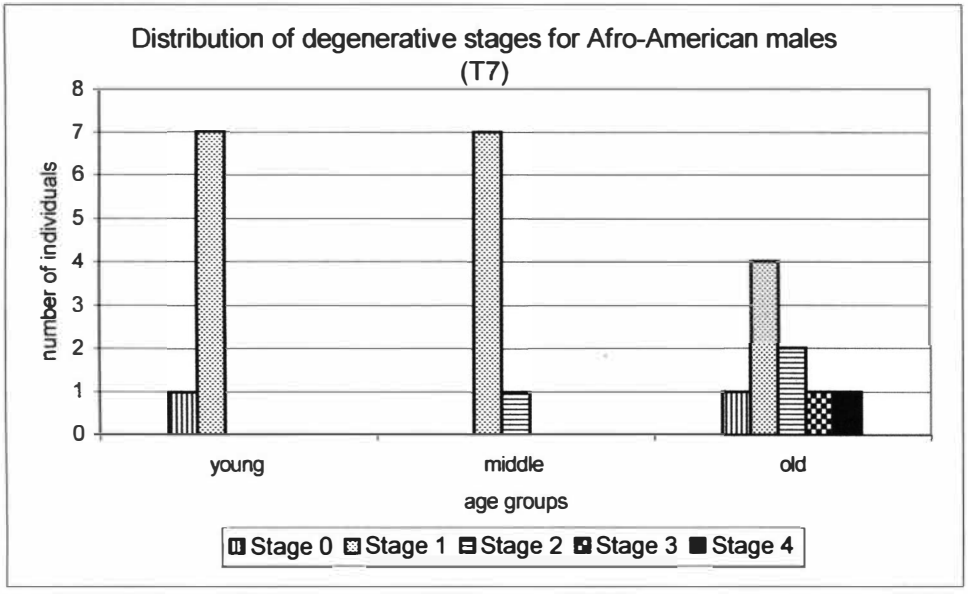

Figure 18. Thoracic 7 degenerative stages and collapsed age groups for Afro-American males

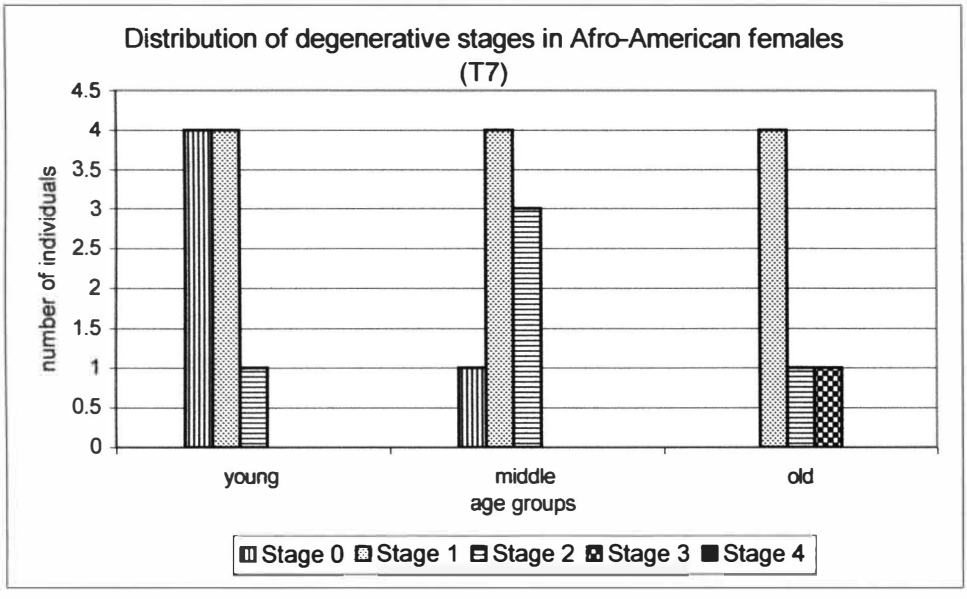

Figure 19. Thoracic 7 degenerative stages and collapsed age groups for Afro-American females

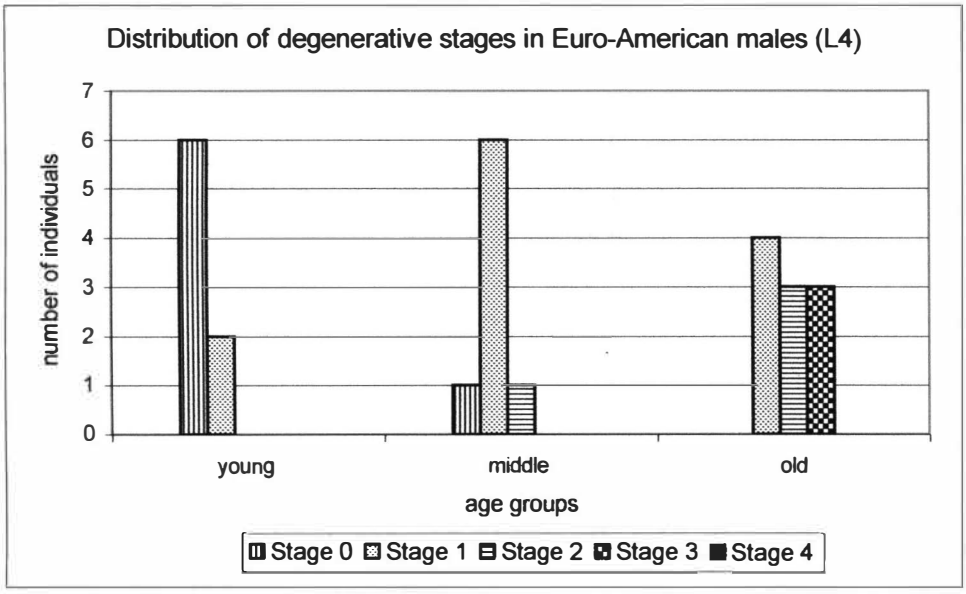

Figure 20. Lumbar 4 degenerative stages and collapsed age groups for Euro-American males

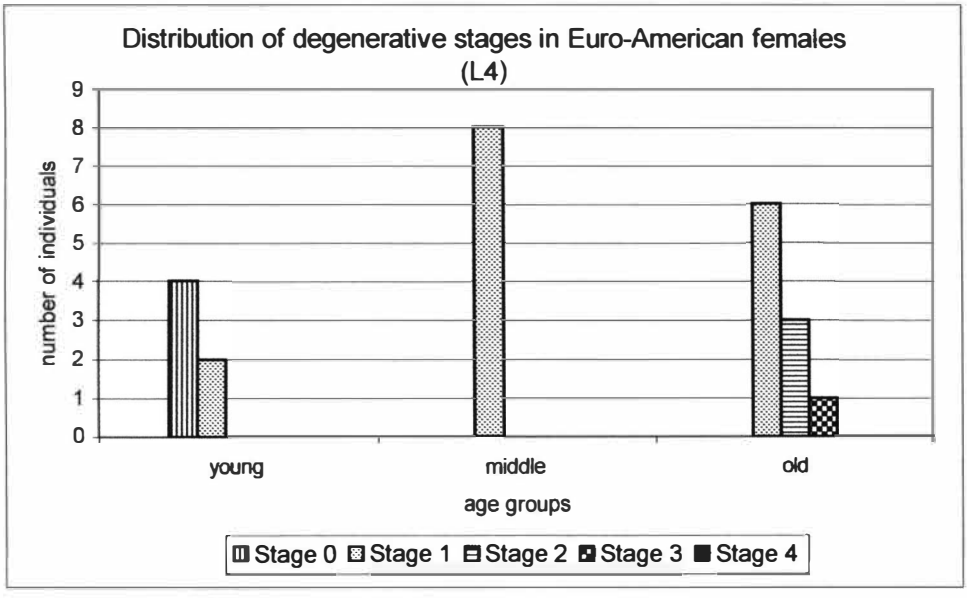

Figure 21. Lumbar 4 degenerative stages and collapsed age groups for Euro-American females

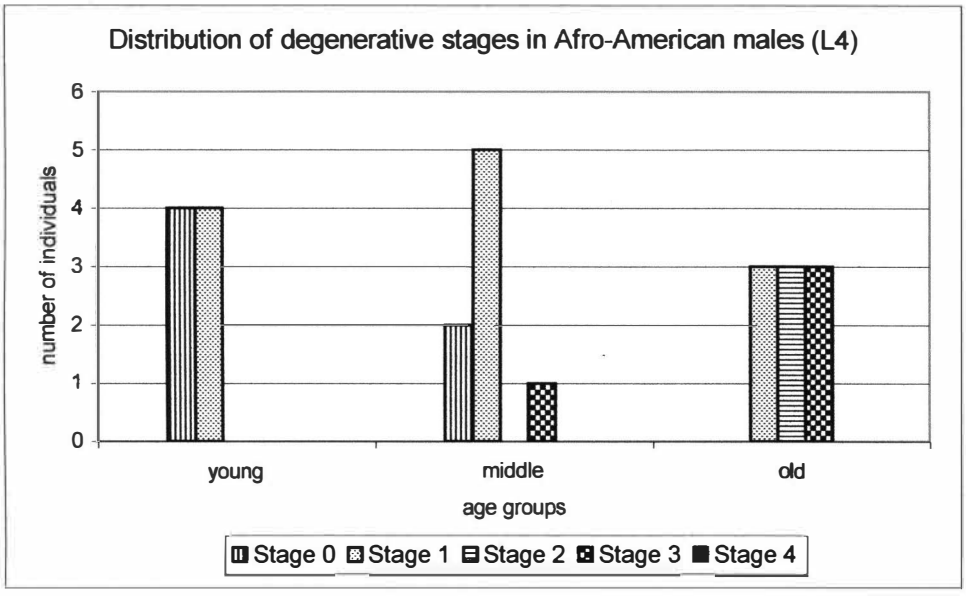

Figure 22. Lumbar 4 degenerative stages and collapsed age groups for Afro-American males

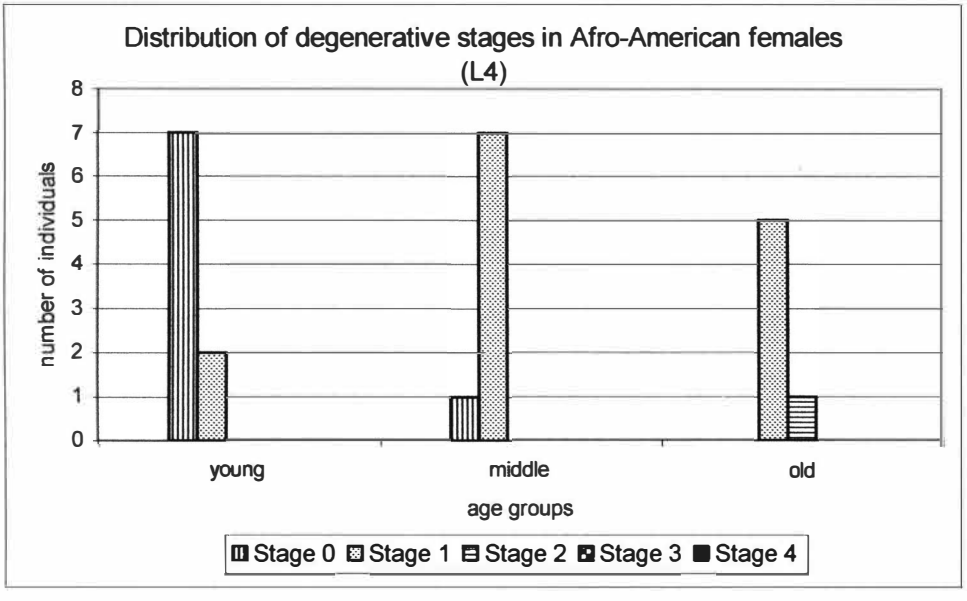

Figure 23. Lumbar 4 degenerative stages and collapsed age groups for Afro-American females

E: Chi square results for degenerative stages of the C7

Table 1. Chi square results for C7- total sample

	0	1	2	3	Totals
18-29	11 (6.01)	5 (9.1)	0 (1.2)	1 (.69)	17
30-39	5 (5.3)	10 (8.03)	0 (1.06)	0 (.61)	15
40-49	8 (5.66)	8 (8.57	0 (1.13)	0 (.65)	16
50-59	8 (5.67)	5 (8.57)	2 (1.13)	1 (.65)	16
60+	3 (12.37)	25 (18.74)	5 (2.48)	2 (1.14)	35
Total	35	53	7	4	99

Number of observed frequencies are listed above number of expected frequencies (values in parentheses). $X^{2=}$ 27.62, df= 12, p=.0063

Table 2- Chi square results for C7- males

	0	1	2	3	Totals
18-29	5 (2.51)	3 (4.71)	0 (.47)	0 (.31)	8
30-39	2 (2.51)	6 (4.71)	0 (.47)	0 (.31)	8
40-49	2 (2.51)	6 (4.71)	0 (.47)	0 (.31)	8
50-59	5 (2.51)	2 (4.71)	1 (.47)	0 (.31)	8
60+	2 (5.96)	13 (11.18)	2 (1.12)	2 (.75)	19
Total	16	30	3	2	51

Number of observed frequencies are listed above number of expected frequencies (values in parentheses). $X^{2=}$ 17.04, df= 12, p=.1482

Table 3- Chi square results for C7- females

	0	1	2	3	Totals
18-29	6 (3.56)	2 (4.31)	0 (.75)	1 (.38)	9
30-39	3 (2.77)	4 (3.35)	0 (.58)	0 (.29)	7
40-49	6 (3.17)	2 (3.83)	0 (.67)	0 (.33)	8
50-59	3 (3.17)	3 (3.83)	1 (.67)	1 (.33)	8
60+	1 (6.33)	12 (7.67)	3 (1.33)	0 (.67)	16
Total	19	23	4	2	48

Number of observed frequencies are listed above number of expected frequencies (values in parentheses). $X^{2=}$ 21.51, df= 12, p=.0434

Table 4- Chi square results for C7- Afro-Americans

	0	1	2	3	Totals
18-29	6 (4.08)	3 (5.31)	0 (.20)	1 (.41)	10
30-39	2 (3.27)	6 (4.25)	0 (.16)	0 (.33)	8
40-49	6 (3.27)	2 (4.25)	0 (.16)	0 (.33)	8
50-59	3 (3.27)	4 (4.25)	1 (.16)	0 (.33)	8
60+	3 (6.12)	11 (8.0)	0 (.31)	1 (.61)	15
Total	20	26	1	2	49

Number of observed frequencies are listed above number of expected frequencies (values in parentheses). $X^{2=}$ 16.60, df= 12, p=.1655

Table 5- Chi square results for C7- Euro-Americans

	0	1	2	3	Totals
18-29	5 (2.1)	2 (3.78)	0 (.84)	0 (.28)	7
30-39	3 (2.1)	4 (3.78)	0 (.84)	0 (.28)	7
40-49	2 (2.4)	6 (4.32)	0 (.96)	0 (.32)	8
50-59	5 (2.4)	1 (4.32)	1 (.96)	1 (.32)	8
60+	0 (6)	14 (10.8)	5 (2.4)	1 (.8)	20
Total	15	27	6	2	50

Number of observed frequencies are listed above number of expected frequencies (values in parentheses). $X^{2=}$ 26.11, df= 12, p=.0104

F: Chi square results for degenerative stages of the T7

Table 6- Chi square results for T7- total

	0	1	2	3	4	Totals
18-29	5 (2.21)	12 (11.05)	0 (2.89)	0 (.34)	0 (.51)	17
30-39	3 (2.08)	11 (10.4)	2 (2.72)	0 (.32)	0 (.48)	16
40-49	2 (2.08)	10 (10.4)	4 (2.72)	0 (.32)	0 (.48)	16
50-59	2 (2.08)	11 (10.4)	3 (2.72)	0 (.32)	0 (.48)	16
60+	1 (4.55)	21 (22.75)	8 (5.95)	2 (.70)	3 (1.05)	35
Total	13	65	17	2	3	100

Number of observed frequencies are listed above number of expected frequencies (values in parentheses). $X^{2=}$ 20.71, df= 16, p=.1899

Table 7- Chi square results for T7- males

	0	1	2	3	4	Totals
18-29	1 (.94)	7 (5.33)	0 (1.1)	0 (.16)	0 (.47)	8
30-39	2 (.94)	6 (5.33)	0 (1.1)	0 (.16)	0 (.47)	8
40-49	1 (.94)	5 (5.33)	2 (1.1)	0 (.16)	0 (.47)	8
50-59	1 (.94)	5 (5.33)	2 (1.1)	0 (.16)	0 (.47)	8
60+	1 (2.24)	11 (12.67)	3 (2.61)	1 (.37)	3 (1.12)	19
Total	6	34	7	1	3	51

Number of observed frequencies are listed above number of expected frequencies (values in parentheses). $X^{2=}$ 13.22, df= 16, p=.6563

Table 8- Chi square results for T7- females

	0	1	2	3	Totals
18-29	4 (1.29)	5 (5.7)	0 (1.84)	0 (.18)	9
30-39	1 (1.14)	5 (5.06)	2 (1.63)	0 (.16)	8
40-49	1 (1.14)	5 (5.06)	2 (1.63)	0 (.16)	8
50-59	1 (1.14)	6 (5.06)	1 (1.63)	0 (.16)	8
60+	0 (2.29)	10 (10.12)	5 (3.27)	1 (.33)	16
Total	7	31	10	1	49

Number of observed frequencies are listed above number of expected frequencies (values in parentheses). $X^{2=}$ 13.56, df= 12, p=.3295

Table 9- Chi square results for T7- Afro-Americans

	0	1	2	3	4	Totals
18-29	3 (1.43)	7 (6.33)	0 (1.63)	0 (.41)	0 (.20)	10
30-39	2 (1.14)	5 (5.1)	1 (1.31)	0 (.33)	0 (.16)	8
40-49	0 (1.14)	6 (5.1)	2 (1.31)	0 (.33)	0 (.16)	8
50-59	1 (1.14)	5 (5.1)	2 (1.31)	0 (.33)	0 (.16)	8
60+	1 (2.14)	8 (9.49)	3 (2.45)	2 (.61)	1 (.31)	15
Total	7	31	8	2	1	49

Number of observed frequencies are listed above number of expected frequencies (values in parentheses). $X^{2=}$ 13.99, df= 16, p=.5996

Table 10- Chi square results for T7- Euro-Americans

	0	1	2	3	Totals
18-29	2 (.82)	5 (4.67)	0 (1.24)	0 (.28)	7
30-39	1 (.94)	6 (5.33)	1 (1.41)	0 (.31)	8
40-49	2 (.94)	4 (5.33)	2 (1.41)	0 (.31)	8
50-59	1 (.94)	6 (5.33)	1 (1.41)	0 (.31)	8
60+	0 (2.36)	13 (13.33)	5 (3.53)	2 (.78)	20
Total	6	34	9	2	51

Number of observed frequencies are listed above number of expected frequencies (values in parentheses). $X^{2=}$ 11.2, df= 12, p=.5121

G: Chi square results for degenerative stages of the L4

Table 11- Chi square results for L4- total

	0	1	2	3	Totals
18-29	14 (4.25)	3 (9.52)	0 (1.87)	0 (1.36)	17
30-39	7 (4.0)	9 (8.96)	0 (1.76)	0 (1.28)	16
40-49	3 (4.0)	12 (8.96)	1 (1.76)	0 (1.28)	16
50-59	1 (4.0)	14 (8.96)	0 (1.76)	1 (1.28)	16
60+	0 (8.75)	18 (19.6)	10 (3.85)	7 (2.8)	35
Total	25	56	11	8	100

Number of observed frequencies are listed above number of expected frequencies (values in parentheses). $X^{2=}$ 70.15, df= 12, p<.0001

Table 12- Chi square results for L4- males

	0	1	2	3	Totals
18-29	7 (2.04)	1 (3.77)	0 (1.1)	0 (1.1)	8
30-39	3 (2.04)	5 (3.77)	0 (1.1)	0 (1.1)	8
40-49	2 (2.04)	5 (3.77)	1 (1.1)	0 (1.1)	8
50-59	1 (2.04)	6 (3.77)	0 (1.1)	1 (1.1)	8
60+	0 (4.84)	7 (3.77)	6 (2.61)	6 (2.61)	19
Total	13	24	7	7	51

Number of observed frequencies are listed above number of expected frequencies (values in parentheses). $X^{2=}$ 37.91, df= 12, p=.0002

Table 13- Chi square results for L4- females

	0	1	2	3	Totals
18-29	7 (2.2)	2 (5.88)	0 (.74)	0 (.184)	9
30-39	4 (2.0)	4 (5.22)	0 (.65)	0 (.16)	8
40-49	1 (2.0)	7 (5.22)	0 (.65)	0 (.16)	8
50-59	0 (2.0)	8 (5.22)	0 (.65)	0 (.16)	8
60+	0 (3.92)	11 (10.45)	4 (1.31)	1 (.33)	16
Total	12	32	4	1	49

Number of observed frequencies are listed above number of expected frequencies (values in parentheses). $X^{2=}$ 34.17, df= 12, p=.0006

Table 14- Chi square results for L4- Afro-Americans

	0	1	2	3	Totals
18-29	7 (2.86)	3 (5.51)	0 (.82)	0 (.82)	10
30-39	4 (2.29)	4 (4.41)	0 (.65)	0 (.65)	8
40-49	3 (2.29)	5 (4.41)	0 (.65)	0 (.65)	8
50-59	0 (2.29)	7 (4.41)	0 (.65)	1 (.65)	8
60+	0 (4.29)	8 (8.27)	4 (1.22)	3 (1.22)	15
Total	14	27	4	4	49

Number of observed frequencies are listed above number of expected frequencies (values in parentheses). $X^{2=}$ 30.83, df= 12, p=.0021

Table 15- Chi square results for L4- Euro-Americans

	0	1	2	3	Totals
18-29	7 (1.51)	0 (3.98)	0 (.96)	0 (.55)	7
30-39	3 (1.73)	5 (4.55)	0 (1.1)	0 (.63)	8
40-49	0 (1.73)	7 (4.55)	1 (1.1)	0 (.63)	8
50-59	1 (1.73)	7 (4.55)	0 (1.1)	0 (.63)	8
60+	0 (4.31)	10 (11.37)	6 (2.75)	4 (1.57)	20
Total	11	29	7	4	51

Number of observed frequencies are listed above number of expected frequencies (values in parentheses). $X^{2=}$ 47.31, df= 12, p<.0001

H: Chi square results for total composite scores

Table 16- Chi square results for total composite- total

	0-2	3-5	6-8	9-12	Totals
18-29	15 (7.18)	1 (7.67)	0 (.82)	0 (.33)	16
30-39	10 (6.73)	5 (7.19)	0 (.77)	0 (.31)	15
40-49	9 (7.18)	7 (7.67)	0 (.82)	0 (.33)	16
50-59	8 (7.18)	8 (7.67)	0 (.82)	0 (.33)	16
60+	2 (15.71)	26 (16.79)	5 (1.79)	2 (.71)	35
Total	44	47	5	2	98

Number of observed frequencies are listed above number of expected frequencies (values in parentheses). $X^{2=}$ 46.8, df= 12, p<.001

Table 17- Chi square results for total composite- males

	0-2	3-5	6-8	9-12	Totals
18-29	7 (3.29)	1 (3.92)	0 (.47)	0 (.31)	8
30-39	5 (3.29)	3 (3.92)	0 (.47)	0 (.31)	8
40-49	4 (3.29)	4 (3.92)	0 (.47)	0 (.31)	8
50-59	4 (3.29)	4 (3.92)	0 (.47)	0 (.31)	8
60+	1 (7.82)	13 (9.31)	3 (1.12)	2 (.75)	19
Total	21	25	3	2	51

Number of observed frequencies are listed above number of expected frequencies (values in parentheses). $X^{2=}$ 23.58, df= 12, p=.025

Table 18- Chi square results for total composite- females

	0-2	3-5	6-8	Totals
18-29	8 (3.83)	0 (3.83)	0 (.33)	8
30-39	5 (3.83)	3 (3.83)	0 (.33)	8
40-49	5 (3.83)	3 (3.83)	0 (.33)	8
50-59	4 (3.83)	4 (3.83)	0 (.33)	8
60+	1 (7.67)	13 (7.67)	2 (.67)	16
Total	23	23	2	48

Number of observed frequencies are listed above number of expected frequencies (values in parentheses). $X^{2=}$ 22.96, df= 8, p=.0035

Table 19- Chi square results for total composite- Afro-Americans

	0-2	3-5	6-8	9-12	Totals
18-29	8 (4.5)	1 (4.13)	0 (.19)	0 (.19)	9
30-39	6 (4)	2 (3.67)	0 (.17)	0 (.17)	8
40-49	5 (4)	3 (3.67)	0 (.17)	0 (.17)	8
50-59	3 (4)	5 (3.67)	0 (.17)	0 (.17)	8
60+	2 (7.5)	11 (6.88)	1 (.31)	1 (.31)	15
Total	24	22	1	1	48

Number of observed frequencies are listed above number of expected frequencies (values in parentheses). $X^{2=}$ 18.86, df= 12, p<.001

Table 20- Chi square results for total composite- Euro-Americans

	0-2	3-5	6-8	9-12	Totals
18-29	7 (2.8)	0 (3.5)	0 (.56)	0 (.14)	7
30-39	4 (2.8)	0 (3.5)	0 (.56)	0 (.14)	7
40-49	4 (3.2)	4 (4)	0 (.64)	0 (.16)	8
50-59	5 (3.2)	3 (4)	0 (.64)	0 (.16)	8
60+	0 (8)	15 (10)	4 (1.6)	2 (.40)	20
Total	20	25	4	1	50

Number of observed frequencies are listed above number of expected frequencies (values in parentheses). $X^{2=}$ 29.85, df= 12, p=.005

I: Chi square results for reduced composite scores

Table 21- Chi square results for reduced composite- total

	0-2	3-5	6-8	Totals
18-29	16 (12.08)	0 (3.76)	0 (.16)	16
30-39	15 (11.33)	0 (3.52)	0 (.15)	15
40-49	15 (12.08)	1 (3.76)	0 (.16)	16
50-59	12 (12.08)	4 (3.76)	0 (.16)	16
60+	16 (26.43)	18 (8.21)	1 (.36)	35
Total	74	23	1	98

Number of observed frequencies are listed above number of expected frequencies (values in parentheses). $X^{2=}$ 30.05, df= 8, p<.001

Table 22- Chi square results for reduced composite- males

	0-2	3-5	6-8	Totals
18-29	8 (5.49)	0 (2.35)	0 (.16)	8
30-39	8 (5.49)	0 (2.35)	0 (.16)	8
40-49	7 (5.49)	1 (2.35)	0 (.16)	8
50-59	6 (5.49)	2 (2.35)	0 (.16)	8
60+	6 (13.04)	12 (5.59)	1 (.37)	19
Total	35	15	1	51

Number of observed frequencies are listed above number of expected frequencies (values in parentheses). $X^{2=}$ 21.14, df= 8, p=.01

Table 23- Chi square results for reduced composite- females

	0-2	3-5	6-8	Totals
18-29	8 (6.67)	0 (1.17)	0 (.17)	8
30-39	8 (6.67)	0 (1.17)	0 (.17)	8
40-49	8 (6.67)	0 (1.17)	0 (.17)	8
50-59	6 (6.67)	1 (1.17)	1 (.17)	8
60+	10 (13.33)	6 (2.33)	0 (.33)	16
Total	40	7	1	48

Number of observed frequencies are listed above number of expected frequencies (values in parentheses). $X^{2=}$ 15.99, df= 8, p=.04

Table 24- Chi square results for reduced composite- Afro-Americans

	0-2	3-5	6-8	Totals
18-29	9 (7.31)	0 (1.5)	0 (.19)	9
30-39	8 (6.5)	0 (1.33)	0 (.17)	8
40-49	8 (6.5)	0 (1.33)	0 (.17)	8
50-59	6 (6.5)	2 (1.33)	0 (.17)	8
60+	8 (12.19)	6 (2.5)	1 (.31)	15
Total	39	8	1	48

Number of observed frequencies are listed above number of expected frequencies (values in parentheses). $X^{2=}$ 14.16, df= 8, p=.075

Table 25- Chi square results for reduced composite- Euro-Americans

	0-2	3-5	Totals
18-29	7 (4.9)	0 (2.1)	7
30-39	7 (4.9)	0 (2.1)	7
40-49	7 (5.6)	1 (2.4)	8
50-59	6 (5.6)	2 (2.4)	8
60+	8 (14)	12 (6)	20
Total	35	15	50

Number of observed frequencies are listed above number of expected frequencies (values in parentheses). $X^{2=}$ 15.83, df= 4, p=.003