STANDARDS FOR EPIPHYSEAL UNION IN SOUTH AFRICAN CHILDREN BETWEEN THE AGES OF 6 TO 24 YEARS USING LOW DOSE X-RAY (LODOX)

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DECLARATION

I Kavita Novinchandra Lakha, hereby declare that the work on which this dissertation is based is my original work. Where the works of others have been used, they have been acknowledged using the Council of Biological Editors referencing style. Neither the whole work nor any part of it has been, is being, or is to be submitted for any other degree in this or any other university. I empower the university to reproduce for the purpose of research either the whole or any portion of the contents in any manner whatsoever.

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ABSTRACT OF THESIS

Standards for Epiphyseal Union in South African Children between the ages of 6 to 24 years using low dose x-ray (LODOX)

By

Kavita Lakha

Skeletal age is a measure of biological maturation and is based on the stages of formation of bones. As age increases, skeletal maturation progresses and the various hard tissue changes which take place are uniquely identifiable and defining to each stage of development. Age assessment using skeletal maturation is a diagnostic tool used clinically and in forensic investigations.

Radiographs of the hand and wrist are frequently used to estimate age (Greulich and Pyle, 1959); however studies conducted in South Africa have shown that these methods are not applicable to South Africans since the method over estimates age in the 17 - 22 year olds (Dembetembe and Morris, 2013) and both over and underestimates age in 0 - 13 year old individuals (Speed, 2012). There currently is a lack of comprehensive data and studies on the union of the major joints in South African children despite the need for population specific data in age estimations. The LODOX Statscan system, which emits low dose radiation and full body radiographs in thirteen seconds, was used to assess radiographs of 1891 individuals between the ages of 6 - 24 years. Union was classified in four stages ranging from one (non-union) to stage four (complete union). Radiographs were obtained from the Red Cross War Memorial hospital and Groote Schuur hospital in Cape Town and Tygerberg and Salt River mortuaries in Cape Town as well as the Chris Hani Baragwanath and Milpark hospitals in Johannesburg. The standards developed on radiographs were later used to conduct gross analysis of skeletal material obtained from the Raymond Dart Collection.

Complete union was classified as the age at which 95% of the both males and females showed stage 4 of union. Complete union of all joints in females occurs by age 21 years and 24 years in males with the iliac crest being the last epiphysis to fuse in both males and females. Ordinal logistic regression found significant differences between males and females in the stages of union and age ($p < 0.05$). There is however no significant differences in stage of union and age between different ethnic groups and individuals from various socio-economic status backgrounds ($p > 0.05$).

Data for union times in South African children show that maturity in females at the elbow, hip and ankle are achieved at approximately 15 years of age followed by the knee at 16 years, wrist at 18 years, and shoulder at 20 years. The radiographically visible epiphyses the iliac crest are the last epiphyses to complete union at 21 years. Males progress through union in the same sequence with the exception that there is a two year delay in age at maturity. The elbow in males completes union at approximately 17 years followed by the hip and ankle at 18 years, knee at 19 years, wrist at 20 years, and shoulder at 21 years and finally the iliac crest at 22 years.

The methodology derived on radiographs was successfully applied to gross observations of skeletal material. It therefore provides a useful diagnostic tool for use in skeletonised forensic cases in the absence of skeletal material from which to derive such standards. The current work provides an alternative to the Greulich and Pyle (1959) method and is specifically tailored toward South African Children.

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CHAPTER 1: INTRODUCTION

The formal identification of a deceased individual when only skeletal remains are present has great social and financial implications. In the absence of documents or identifiable features and soft tissue, forensic anthropologists are able to examine human skeletal remains from which a biological profile (ancestry, age, sex and stature) may be formulated. The finalisation of a biological profile is easier in adults than it is in juvenile remains. Features on bones such as the skull and pelvis, which are relied upon to determine genetic background and sex will only be of significance post puberty where altered levels of hormones facilitates alterations in the male and female skeletons which make them sexually dimorphic (Lewis and Rutty, 2003). Therefore, the estimation of age at death in juvenile human skeletal remains is of great importance as it is the only biological parameter which can be determined with any accuracy (Scheuer *et al*., 2000).

Growth which is positively correlated with age refers to the progressive increase in size and changes in physical morphology of an individual over time (Scheuer *et al*., 2000). A relatively reliable indicator of growth is skeletal maturity which refers to the termination of skeletal growth through a process of epiphyseal union. Growth can therefore be assessed through the study of various developmental milestones such as epiphyseal union (Schaefer and Black, 2005 and O‟Connor *et al*., 2008). Other examples of developmental milestones include events such as the appearance of ossification centres, the timing and sequence of dental eruption and stages of formation and calcification of teeth.

Skeletal maturity is attained through a process which begins with endochondral ossification and terminates at epiphyseal union which also marks the end of longitudinal growth. Long bones for example are formed on a cartilage template (referred to as endochondral ossification) in the region of the primary ossification centre. Secondary ossification centres appear after birth and form the epiphyses of long bones (Haines, 1967 and Scheuer *et al*., 2000). Throughout growth, regions of the primary and secondary centres are separated by an organised region of rapid growth (growth plate, epiphyseal plate or physis). When the rate of cartilage proliferation is exceeded by the rate of osseous deposition; the growth plate will narrow and eventually be replaced by bone so that epiphyseal fusion will occur.

Epiphyseal union is promoted by puberty, a biological phase in which the alterations of levels of sex steroids and growth hormones results in the pubertal growth spurt, attainment of secondary sex characteristics and physical maturation (Ellison and Reiches, 2012 and Hauspie and Roelants, 2012). The growth spurt in skeletal dimensions and weight due to the alteration of hormones during maturation in males and females is characteristic of growth taking place during adolescence. The timing, durations and magnitude of the spurt varies between populations and between individuals within a population (Swerdoff, 1978; Loesch *et al*., 1995; Hauspie and Roelants, 2012). This phase also leads to accelerated skeletal growth terminated by the fusion of the epiphyseal cartilages and attainment of adult height (Wheeler, 1991). Earlier skeletal maturation in females compared to males may be attributed to the onset of puberty approximately two years earlier in females (Swerdoff and Ontell, 1975; Wheeler, 1991 and Hauspie and Roelants, 2012). This earlier onset of puberty is associated with the earlier secretion of estrogen whose effects are mainly to increase bone maturation (Root, 1973; Swerdoff, 1978 and Loesch *et al*., 1995).

Estradiol in males and females is primarily responsible for the changes observed at puberty (Ellison and Reiches, 2012). Estradiol receptors are expressed both by active chondrocytes and by osteoblasts and osteoclasts in the growth plate of growing bone. Increased concentrations of estrogen stimulate mineralization by osteoblasts and oppose demineralization by osteoclasts causing the growth plate to close (Ellison and Reiches, 2012). Chondrocyte stimulation predominates at lower concentrations of estradiol and osteocyte stimulation predominates at higher estradiol concentrations (Ellison and Reiches, 2012). Union will be differently affected by factors such as nutrition, population affinity and socio-economic status.

Age at death estimation for juvenile skeletal remains are achieved by assessing the state of bone development, referred to as a skeletal age (SA) and correlating it to a standard reference population of children of known ages (chronological ages (CA)) (Ubelaker, 1987; Johnston and Zimmer, 1989; Introna and Campobasso, 2006; Coqueugniot and Weaver, 2007; Cardoso, 2008a and Cardoso, 2008b). Therefore, age at death estimation from skeletal remains is given as a skeletal age rather than a true chronological age.

1.1 Application of Age Estimation Studies

The use of age estimation for the purposes of forensic investigations has increased over the last decade due both to the increasing number of unidentified bodies (Ritz-Timme *et al.*, 2000) and to the influx of asylum seekers into countries of the European Union (Ritz-Timme *et al.,* 2000; Baccino and Schmitt, 2006 and Pruvost *et al.,* 2010). Age estimation in the case of individuals seeking asylum status is of special importance where the person in question is under the age of 18 years. According to the United Nations High Commission of Refugees (UNHCR), unaccompanied children who have been granted asylum status are entitled to special care and protection and may not be kept in detention; long-term placement in a community with full access to education must also be arranged (Pruvost *et al.,* 2010). Additionally, the judicial system requires the assigning of age in legal proceeding to determine whether the offender will be tried under juvenile delinquency law or general criminal law (Introna and Campobasso, 2006 and Pruvost *et al.,* 2010). Clinically, the assessment of skeletal maturity is of great significance in the management of children with various endocrine pathologies involving the thyroid, pituitary and gonads (Introna and Campobasso, 2006).

Forensic age estimation in criminal rape cases is becoming of increasing importance in India with the increase in the number of cases reported (Sahni and Jit, 1995). While the consensual age for sex is 16 years it has become necessary to determine whether a girl is below that age as the severity of the punishment of the perpetrator maybe influenced if the victim is underage (Sahni and Jit , 1995).

Age assessment is not limited to individuals seeking refuge or criminal cases involving rape, age estimation techniques are also being used in sports such as football in order to develop appropriate age category related tournaments (Dvorak *et al*., 2007). The use of these techniques to estimate age rose out of the need to investigate doubts raised that the biological ages of some sportsmen and women do not match their chronological ages (Dvorak *et al.,* 2007). The necessity for the development of age based categories in such tournaments is that sport specific skills such as dribbling, ball control with the body and shooting accuracy are attained by a combinations of age, stage of pubertal development, experience and body size (Dvorak *et al.,* 2007). These age related skills in older individuals are misinterpreted as "talent" which provides an unfair advantage over their younger peers (Dvorak *et al.,* 2007).

The above mentioned applications of age estimation techniques apply to living individuals, where radiographs of the long bones of the hand and wrist are used to determine age. Though the methods and standards derived by a study conducted by Greulich and Pyle (1959) are the most commonly used in estimating age from radiographs of the wrist, it has been used with some reservations on populations different from the one in which the standards were developed (Zhang *et al.,* 2009; Dembetembe and Morris, 2012 and Speed 2012).

Forensic age estimation techniques are also used in cases involving human skeletal remains. These may involve the studies of past populations or in contemporary cases in which the state of decomposition is so advanced that analysis and development of a biological profile is accomplished by the study of the remains in question. Age at death for these unidentified human remains can be estimated by comparing the state of maturation of the bone with a chronological age based reference sample (Coqueugniot and Weaver, 2007; Cardoso, 2008a and Cardoso, 2008b) .

While many of the defining studies are relevant for this decade (Tanner *et al*., 2001; Dembetembe and Morris, 2012 and Speed 2012) the contemporary research centres around validation studies of these influential studies with little effort at developing new simplistic methods which incorporate the use of multiple variables which reflect the growth and maturation parameters of the modern population (Baumann *et al.,* 2008 and Zhang *et al.,* 2009). The applications of age estimation standards in forensic, criminal and clinical cases have been mentioned above and highlight the fact that different circumstances will require the use of different methodologies. With regard to the use of radiographic material, there is a need to develop new standards as a review of available publications has revealed that there is a mismatch of the methods and a lack of uniformity in classifying the stages of union to determine states of bone development (Ubelaker, 1987; Saunders, 2007; Meijerman, *et al*., 2007 and O‟Connor *et al*., 2008). These act as limitations which impair subsequent research from comparing, reproducing and verifying the original outcomes. Even though the Greulich and Pyle (1959) method has become synonymous with age estimation, hand radiographs of the living are of little use in cases involving human skeletal remains. Therefore, new methodologies need to be developed to be able to incorporate both types of studies (i.e. dry bone and radiographic). It is the lack of a reliable database for age related changes in South African children which necessitates the development of new standards.

1.2 The Application of Greulich and Pyle (1959) Methods to South Africans

The Greulich and Pyle (GP) (1959) radiographic atlas is the most commonly used reference when estimating age by radiographic examination of the hand and wrist. This method provides an estimate of chronological age based on skeletal maturity. For an age assessment, a radiograph is compared to the atlas and a skeletal age is assigned to the radiograph. The Greulich and Pyle (1959) method has also been criticised since its application is limited to well off North-American children. Secondly the method has been proven to be poor at recognising racial differences (Zhang *et al.,* 2009; Dembetembe and Morris, 2012 and Speed, 2012) and is poor at defining the variation which may exist since radiographic atlas depict the normative illustration but not the variation.

The Greulich and Pyle (1959) method was studied extensively by Dembetembe and Morris (2012) and Speed (2012) and was found to be inaccurate in estimating age in South African children. The former study found that the method is not applicable to South African individuals of African descent since it underestimates skeletal age by approximately 1 year. These differences were most pronounced at age 16.5 years in males and 15.5 years in females and there were discrepancies in the age of growth termination (Dembetembe and Morris, 2012). In her sample of 0 - 13 year old individuals, Speed (2012) found that a high degree of variation existed which resulted in the over and underestimation of skeletal age across both sexes and all age groups (Speed 2012). Dembetembe and Morris (2012) attributed their observed differences to the differences of biological origin of the samples.

Neither study rules out the effects of socio-economic status as an environmental factors and their effects on union.

With this in mind, it is important to note that no accurate data for the rest of the epiphyses exist for South African children. Studies relating to epiphyseal union have been conducted on different joints of the body in many other world populations and studies dealing with union in all the major joints of the body were scarce. These studies are conducted on both skeletal collections as well as living individuals through the study of radiographic material. Even though the popularity of the GP (1959) method makes it the method of choice, the inclusion of multiple areas of assessment of skeletal maturity of an individual provides a broader basis for accurate assessment and thus should be utilised as such (McKern and Stewart, 1957). They (1957) showed that not all epiphyses are of equal value in estimating age and that the best indicators according to their study were the proximal humerus, medial epicondyle, distal radius, femoral head, distal femur, iliac crest, medial clavicle, third and fourth sacral joints and lateral sacral joints. Such studies have become rarer because of the recognition of the ethical issues around unnecessary exposure of children to radiation. The introduction of Statscan™ (LODOX) technology to health care provides revived opportunities for validation studies.

1.3 Research Aims and Objectives

The aim of this study is therefore to formulate standards of epiphyseal union in South African children through to early adulthood.

Objectives:

1. To gather data on chronological age for South African children from radiographic images;

2. To develop a standard of epiphyseal union that will enable accurate skeletal age estimation from radiographic and dry bone images;
3. To identify differences in developmental landmarks for South African males and females in relation to other world populations; and
4. To assess the role of population origin and socio-economic status as confounding agents in the timing of skeletal development in South African children.

CHAPTER 2: REVIEW OF CURRENT METHODS

2.1 Review of Current Age Estimation Methods

2.1.1 Studies Dealing with Radiographic Assessment: Tanner and Whitehouse (1975)

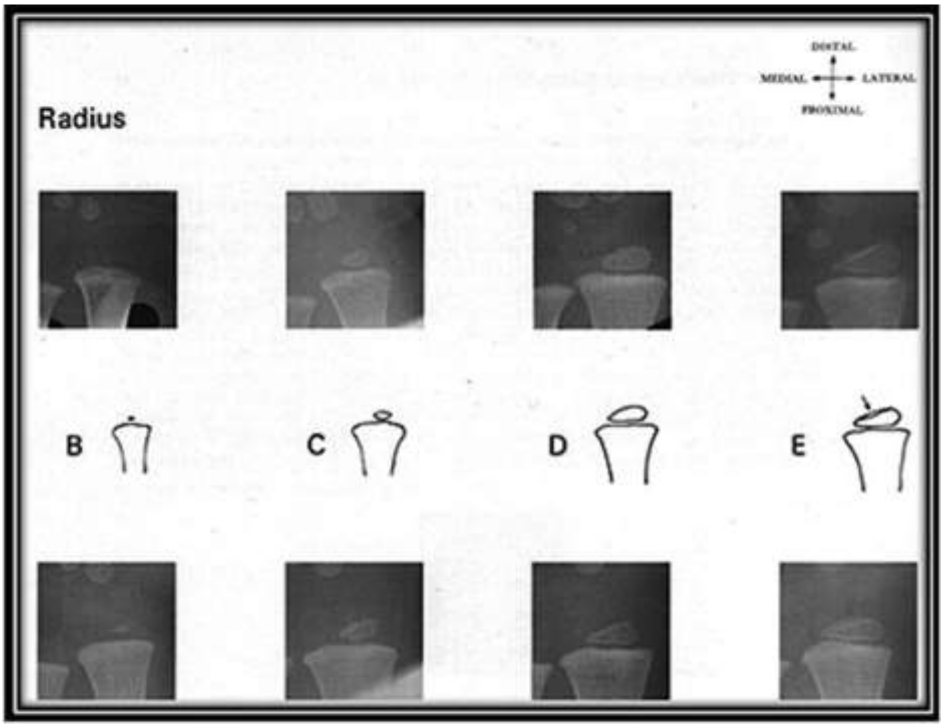
The earliest well-known studies to address skeletal maturity and epiphyseal union took place soon after the introduction of radiographs by Roentgen. The first practical guide was published in 1937 by T. Wingate Todd and followed by Greulich and Pyle in 1959. The Greulich and Pyle (1959) study were based on a longitudinal study of 1000 children carried out in 1931, of children of North European ancestry, of high socioeconomic status, who were born in the United States of America (Greulich and Pyle, 1959). To formulate a standard radiograph for a particular age, GP selected 100 radiographs of children matched for age and sex, and then designated the radiograph with the most commonly observed maturity indicators as the standard for that age group. The maturity indicators are represented as line drawings which are accompanied by a description of the characteristics which indicate the level of maturity (Greulich and Pyle, 1959). Thus a researcher would compare the wrist radiograph with the standard radiograph of individuals of the same sex and closest age (Greulich and Pyle, 1959).

Age estimation from the Greulich and Pyle atlas is obtained by comparing the patient radiograph to radiographs photographically reproduced in an atlas. The chronological age assigned to the standard which most closely approximates the radiograph is the bone age of the subject (Cameron, 2004). However, this method has been criticised because of the lack of relationship between chronological time and maturation time. One year of chronological time is not equal to one year of maturation time (Cameron, 2004).

Therefore, each individual passes through the same chronological time span, but having done so at very different rates of maturation.

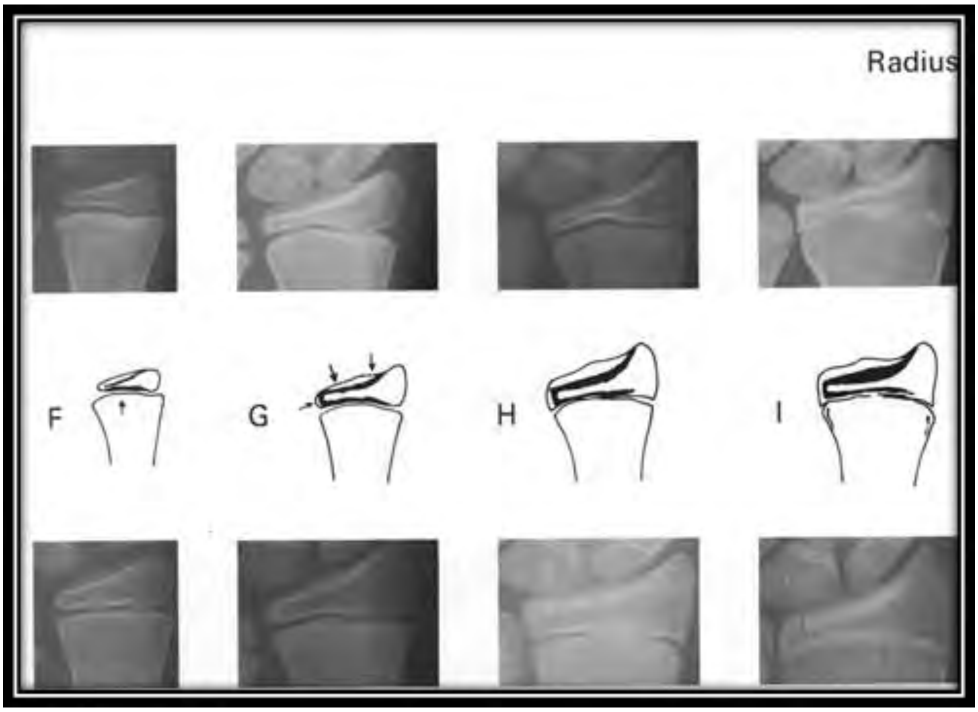
Unlike the direct comparison of radiographs to the GP (1959) atlas, the Tanner Whitehouse (1975) method involves allocating a score rather than an age to the appearance of maturity indicators (Cameron, 2004). Maturity indicators were defined as "*discrete recognisable events within the continuous stages of maturation* (Cameron 2004, Pg516)*.*" The TW2 method as it is known allows the researcher to differentiate between the uneven rates of maturity which may be observed within a single region such as the wrist (Cameron, 2004). Although it has yet to be proved, it has been suggested that the scores of the 13 bones which make up the radius, ulna and short bone (RUS) component of the TW2 method will differ from scores derived for the carpals (Tanner, *et al*., 1975). The method involves obtaining a maturity score from the assessment of 20 bones of the hand and wrist in three different categories. The bones which make up the first category are the radius, ulna and first, third and fifth metacarpals, the first, third and fifth proximal phalanges, the third and fifth middle phalanges and the first, third and fifth distal phalanges. These bones make up the group called the radius, ulna and short bones (RUS). The carpals are assessed separately in the following sequence: capitate, hamate, triquetral, lunate, scaphoid, trapezium and trapezoid. Finally, the 20 TW20 bones score is made up of the sum of the RUS and carpal scores. Therefore scores will be derived for the RUS, carpals and the sum of the RUS and carpals which is defined as the 20TW2.

The radius, metacarpals, phalanges, hamate and trapezium are classified into one of nine stages (*Figure 2.01 and 2.02*), whereas the ulna and the rest of the carpals are classified into one of eight stages. The stages describe the size, appearance and relative gap of the epiphyses and diaphysis. Depending on the observed criteria i.e. size, space and appearance; each maturity indicator is assessed on a level of one to eight or nine depending on the bones assessed. The sum of the 13 RUS bones as well as the 8 carpal bones derives a score which is then referenced against the centile tables. Additionally the sum of the RUS and carpal bones yields the 20 TW2 bone scores which themselves provide an age estimate using the centile tables. These tables in turn yield a bone age (*Table 2.01*). The lower the maturity score the lower the age, and the converse also holds true.



Boys Scores TW 2	Boys Scores RUS			Girls scores TW2	Girls scores RUS
15	16	(i)	**Stage B** The centre is just visible as a single deposit of calcium, or more rarely as multiple deposits. The border is frequently ill-defined	17	23
17	21	(i)	**Stage C** The centre is distinct in appearance and oval in shape with a smooth continuous border. (The maximum diameter is less than half the width of the metaphysis.	19	30
21	30	(i) (ii) (III)	**Stage D** The maximum diameter is half or more the width of the metaphysis The epiphysis has broadened chiefly at its lateral side, so that this portion in thicker and more rounded, the medial border more tapering The centre third of the proximal surface is flat and slightly thickened and the gap between it and the radial metaphysis is narrowed to about a millimetre	25	44
27	39	(i)	**Stage E** A thickened white line has appeared just inside the distal border of the epiphysis; this represents the edge of the palmar surface and the newly appeared bone distal to it is the edge of the dorsal surface.	33	56

Figure 2.01: *The eight stage scoring system according to Tanner and Whitehouse (1975) for the distal ulna in males and females.*



Boys Scores TW2	Boys Scores RUS			Girls scores TW2	Girls scores RUS
			Stage F		
48	59	(i) (ii)	The proximal border of the epiphysis is now differentiated in palmar and dorsal surfaces; the palmar surface is now visible as a broad irregularity thickened white line at the proximal edge of the epiphysis Both ends of the epiphysis, but particularly the medial one, have grown outwards and proximally since the last Stage so that the proximal border now conforms to the shape of the metaphysis along most of its extent	54	78
			Stage G		
77	87	(i) (ii)	The dorsal surface now has distinct lunate and scaphoid articular edges joined at a small hump. Lateral to the scaphoid surface the styloid process caries the border distally in a distinct convexity The medial border of the epiphysis has developed palmar and dorsal surfaces for articulation with the ulnar epiphysis; either palmar or dorsal surface may be the one which projects medially, depending on the position of the wrist. (iii) The proximal border of the epiphysis is now slightly concave	85	114
			Stage H		
96	138	(i)	The epiphysis now caps the metaphysis on one (usually the medial) or both sides. (the styloid process is much further developed than in the last Stage.	99	160
			Stage I		
106	213	(i)	Fusion of epiphysis and metaphysis has begun. A line may still be visible composed partly of black areas where the epiphyseal cartilage remains and partly of dense white areas where fusion is proceeding; or the line may have disappeared	106	218

Figure 2.02: *The eight stage scoring system according to Tanner and Whitehouse (1975) for the distal radius in males and females.*

Table 2.01: Example of a Centile Table created by Tanner and Whitehouse (1975) for the estimation of age based on the score.

Maturity score	Bone "age"	Maturity score	Bone "age"	Maturity score	Bone "age"	Maturity score	Bone "age"
-	1.1	189	6	330	11	744	16
-	0.1	192	6.1	334	11.1	762	16.1
-	0.2	194	6.2	337	11.2	780	16.2
-	0.3	197	6.3	340	11.3	798	16.3
-	0.4	199	6.4	342	11.4	816	16.4
-	0.5	202	6.5	346	11.5	833	16.5
26	0.6	204	6.6	349	11.6	850	16.6
32	0.7	207	6.7	352	11.7	867	16.7
38	0.8	209	6.8	354	11.8	883	16.8
43	0.9	212	6.9	358	11.9	899	16.9
49	2	215	7	361	12	915	17
55	2.1	218	7.1	365	12.1	928	17.1
61	2.2	222	7.2	369	12.2	940	17.2
65	2.3	224	7.3	373	12.3	951	17.3
70	2.4	227	7.4	378	12.4	962	17.4
75	2.5	230	7.5	382	12.5	971	17.5
80	2.6	233	7.6	386	12.6	980	17.6
84	2.7	235	7.7	391	12.7	986	17.7
89	2.8	238	7.8	395	12.8	992	17.8
93	2.9	240	7.9	400	12.9	995	17.9
98	3.0	243	8	405	13	997	18
101	3.1	245	8.1	410	13.1	999	18.1
105	3.2	248	8.2	416	13.2	1000	ADULT
108	3.3	251	8.3	422	13.3		
112	3.4	253	8.4	427	13.4		
115	3.5	257	8.5	434	13.5		
118	3.6	260	8.6	440	13.6		
122	3.7	263	8.7	447	13.7		
125	3.8	266	8.8	454	13.8		
128	3.9	269	8.9	463	13.9		
132	4	272	9	472	14		
135	4.1	275	9.1	481	14.1		
138	4.2	278	9.2	490	14.2		
141	4.3	281	9.3	501	14.3		
144	4.4	283	9.4	512	14.4		
147	4.5	286	9.5	524	14.5		
150	4.6	289	9.6	536	14.6		
153	4.7	292	9.7	548	14.7		
156	4.8	295	9.8	560	14.8		
159	4.9	297	9.9	574	14.9		
162	5	300	10	588	15		
165	5.1	303	10.1	602	15.1		
168	5.2	306	10.2	616	15.2		
171	5.3	309	10.3	630	15.3		
173	5.4	312	10.4	645	15.4		
177	5.5	316	10.5	660	15.5		
180	5.6	319	10.6	675	15.6		
182	5.7	321	10.7	692	15.7		
185	5.8	325	10.8	708	15.8		
187	5.9	328	10.9	726	15.9		

Unlike the GP (1959) study, the TW2 study incorporated in its sample approximately 3000 British individuals who came from middle and lower social classes. The difference in maturity between the more affluent GP (1959) and the TW2 method was a delay of 9 months for the British cohort. TW2 20 bone scores were revised and the new method was published as TW3 method in 2001 (Tanner *et al*., 2001). The system was revised to account for the effects of growth in overall size and maturity due to the effects of secular trends (Cameron, 2004), such that as the size gets larger, maturational events occur earlier. Therefore, the rates of skeletal maturation will also have advanced and the new system would be a reflection of the effects of secular growth. The new scores were derived from a sample of European and American subjects and have become known as the EA90 scores. The differences between results of TW2 and TW3 (EA90 scores) was a differences of 12 to 18 months, showing that secular trends had in fact influenced the rate of skeletal maturation (Cameron, 2004).

2.2 Studies Addressing Epiphyseal Union in Areas Apart from the Wrist

2.2.1 A Sequence of Epiphyseal Union

In 1957, McKern and Stewart studied the remains of Korean War dead and suggested that the epiphyses of the body unite in two groups namely the early uniting epiphyses and the late uniting epiphysis. The former group consists of the epiphyses of the elbow, hip and ankle while the latter consists of the knee, wrist and shoulder. The updated version of the sequence was later published by Scheuer *et al*., (2000) and Schaefer (2008). This is an accepted guideline. According to Scheuer *et al*., (2000), all long bones have two ends. One end of the long bone will contribute a greater percentage to the length of the bones and is called the growing end of the bone. Growth in height ceases when these epiphyses unite; therefore these ends remain unfused till the very end.

The growing end of the humerus is situated at the proximal end, that of the radius and ulna are situated at their distal ends. Similarly the growing end of the femur is located at the distal end and those of the tibia and fibula are situated at their proximal ends. The opposite ends of these long bones therefore form part of the early uniting epiphyses whereas those of the growing ends form part of the later uniting epiphyses. Through their extensive review of literature, Scheuer *et al*., (2000) state that the knee contributes 70% of the final length of the bones whereas the wrist contributes 75% while the proximal humerus contributes 80% of union. It is therefore suggested that the knee, wrist and shoulder complete union in the sequence of bones which contribute the least to the final length of the long bone. Therefore at the early uniting epiphyses, the bone contributes the least amount to the length of the long bone. However those which contribute more to the length of the bone need to stay open for longer.

2.2.2 Macroscopic Assessment of Epiphyseal Union

Reference sources for standards of epiphyseal union based on skeletal elements other than the wrist can be found in various textbooks (Krogman and Iscan, 1986; Buikstra and Ubelaker, 1994; White and Folkens, 2011 and Krogman *et al*., 2013). However, they are used less frequently than the age assessment references published by Greulich and Pyle (1959) and more recently Tanner and Whitehouse (2001). Reference standards for the assessment of union from other skeletal elements are derived using two methodologies. One is based on the macroscopic observation of dry bone and the second deals with radiographic observations of union.

Each of these methods is associated with its own advantages and disadvantages. While the preferred method of conducting such assessments is macroscopic analysis (Sorg *et al*., 1989; Coqueugniot and Weaver 2007 and Cardoso, 2008b), the major problem with deriving chronologies of human skeletal remains is that there are rarely large samples of documented skeletal remains available for examination (Johnston and Zimmer, 1989; Sorg *et al*., 1989; Lewis and Rutty, 2003; Saunders, 2007; Coqueugniot and Weaver 2007; Cardoso, 2008a and Cardoso, 2008b).

Secondly, major gaps exist in the documentation of epiphyseal union in the literature due to the lack of samples at various age ranges. The study by McKern and Stewart (1957) is one such example in which the entire window of fusion activity could not be documented because their samples lacked individuals younger than 17 years of age. Similarly, Schaefer and Black (2005) studied male individuals from the Bosnian conflict whose age ranges were between 14 and 30 years. Data for female individuals in both these studies are lacking.

Table 2.02 which follows was taken from White and colleagues (2011), list the various collections of human skeletal remains which are available for research worldwide.

The under-representation of females in collections is evident. It is also evident that some of the individuals who make up these collections are born in decades which are susceptible to secular trends in height, weight and maturity and should therefore be used with caution when evaluating age in contemporary samples (Schutte, 1980; Tobias, 1985; Chaning-Pearce and Solomon, 1986; Frietas *et al*., 2004; Cardoso, 2007; Hawley *et al*., 2009; Anholts *et al*., 2013 and Stull *et al*., 2014).

The effects of secular increases in growth manifest as increasing height, weight and accelerated maturation compared to the previous generations (Garn, 1987). This is due to major improvements in social and economic conditions as well as medical care and access to nutrition (Goduka, 1992; Jahari *et al*., 2000; Fleshman, 2000; Freitas *et al*., 2004; Garamendi *et al*., 2005; Schmeling *et al*., 2006; Cardoso 2007; Fotso, 2007; Meijerman, *et al*., 2007; Cardoso, 2008a and Hawley *et al*., 2009). The reverse also holds true: some populations have shown actual decreases rather than increases in secular trends attributed to economic disruptions and war time shortages. (Tobias, 1985 and Garn, 1987).

Evidence of increases in the rates of hand wrist maturation were observed in samples from South Africa (Hawley *et al*., 2009) and Portugal (Freitas, *et al*., 2004) suggesting that secular increase in maturation had taken place. Therefore, the choice of sample utilised to formulate reference standards for contemporary populations should be chosen with caution.

Table 2.02: List of Skeletal Collections Available Worldwide (White and Folkens, 2011)

Collection Location	Individuals	Dates of death	Sex bias?	Age bias?	Ancestry	Available for research?
Hamann- Todd Coll. Case Western Reserve Univ. Cleveland, Ohio	3713	1912-1918	80% male (2979♂, 700♀)	Most 20-80 Range 0-105	61% black, 38% white	Yes
Korean War dead, U.S. army Quartermaster Corps	450	1950- 1953	Primarily male	Most 17-25 Range 17-50	Primarily white	No Reburial (1956-1958)
Terry Collection, Washington, DC	1728	1920-1965	59% male	Most ≥45 Range 14-102	45% white	Yes
Huntington Collection, Washington, DC	4054	1892-1920	75% male		About 70% "White"	Yes
W. Montague Cobb Coll, Washington, DC	634	1932-1969	70% male (684♂, 287♀)	Most > 25 (only 13 ≤ 25)	84% black, 19% white	Yes
NMNH Fetal Collection, Washington, DC	320	1904-1917	54% male (152♂, 129♀)	Fetal-neonate only	43% white, 54% black	Yes
Maxwell collection, Albuquerque, NM	257 and growing	1975-present		Range: 0-80+		Yes
Univ. of Iowa/ Stanford Coll. Iowa City, IA	1100	1910"s to 1920"s				Yes
St. Thomas Cemetery. Ontario, Canada	579	1821-1874			European-Amer.	No: Reburied
J.C.B. Grant Collection, Toronto, Ontario, Canada	202	1928- early 50"s	87% male (176♂, 26♀)	73% over 40 years old	European-Amer.	Yes
Christ Church, Spitalfields, London, UK	968	1729-1859		81% adult (782/968)	European	Yes
St. Bride"s Church. London, UK	244	1761-1851		94% ≥18 (range: 0-91)	European	Yes
Universiteit Leiden, Netherlands					European	
Meseu Bocage Collection. Lisbon, Portugal	1692 and growing	1880 -1975	"sexes equally represented"	"adults and juveniles"	European	Yes
Coimbra cemetery Coll. Portugal	570	1904-1938	63% male (357♂, 213♀)		European	Yes
Dart Collection. Johannesburg, SA	2605	1920- present	71% male (1840♂, 756♀)	94% ≥ 20 (range: 1-100)	71% "SA African", 18% "white"	Yes
Cape Town Univ. South Africa	Ca. 200	1980-1999		Most ≥50	Coloured and white with some African	Yes
Pretoria Bone Collection. SA	290 Skeletons, 704 skulls and 54 postcrania	1943- present		Ranges 0- 100	African	Yes

Accompanying the scarcity in the representation of human remains in these collections is a larger problem with the under representation of infant and juvenile remains in collections (Johnston and Zimmer, 1989 and Saunders, 2007). In archaeological collections, preservation as well as poor recovery of remains hinders growth of skeletal collections (Johnston and Zimmer, 1989 and Saunders, 2007). The use of archaeological material is not recommended as they are not considered to be a representation of the normal healthy children but rather a population who lived but rather become part of a biased mortality sample (Johnston and Zimmerman, 1989).

Some of the most notable published studies dealing with macroscopic observations of epiphyseal union are represented in *Table 2.03* to *Table 2.06* below. These studies represent the union times for all the major joints of the body. The results of these publications are often difficult to compare due to the lack of uniformity in representing the data and union times therefore differ across studies (Saunders, 2007 and O‟Connor *et al*., 2008). These differences may be a consequence of population variability, secular changes or simply a lack of standardised methodology (O‟Connor *et al*., 2008).

While it is quite conservative to suggest that no union takes place between 7 and 20 years for the proximal epiphysis of the humerus (Coqueugniot and Weaver, 2007), these references do not provide qualitative information. These studies act as a guide on the ages of union of the various joints.

Table 2.03: Age of Union by Macroscopic Observation of Dry Bone in Males

Author	Bone	Epiphysis	Stage 1: No Union	Stage 2: Partial Union	Stage 3: Complete Union
Cardoso (2008 a)	**Humerus**	Proximal Epiphysis	≤ 18 years	16-21 years	≥ 17 years
	Humerus	Medial Epicondyle	≤ 16 years	16- 18 years	≥ 16 years
	Humerus	Distal Epiphysis	≤ 16 years	-	≥ 14 years
C&W(2007)*	**Humerus**	Proximal Epiphysis	7- 20 years	19-23 years	20- 29 years
	Humerus	Medial Epicondyle	7-19 years	16-20 years	16- 29 years
	Humerus	Distal Epiphysis	7-15 years	16 years	16- 29 years
Cardoso (2008 a)	**Ulna**	Distal Epiphysis	≤ 18 years	16- 20 years	≥ 17 years
C&W(2007)	**Ulna**	Distal Epiphysis	7 - 21 years	19- 21 years	20 - 29 years
Cardoso (2008b)	**Femur**	Proximal Epiphysis	≤ 16 years	15-18 years	≥ 16 years
	Femur	Distal Epiphysis	≤ 18 years	17 years	≥ 16 years
	Femur	Greater Trochanter	≤ 16 years	15-18 years	≥ 16 years
	Femur	Lesser Trochanter	≤ 16 years	15-18 years	≥ 16 years
C&W(2007)	**Femur**	Proximal Epiphysis	7- 20 years	16-24 years	19- 29 years
	Femur	Distal Epiphysis	7- 20 years	16-21 years	19- 29 years
	Femur	Greater Trochanter	7- 20 years	16- 20 years	16- 29 years
	Femur	Lesser Trochanter	7- 20 years	16-21 years	19- 29 years
Cardoso (2008b)	**Tibia**	Proximal Epiphysis	7- 20 years	16-21 years	19- 29 years
	Tibia	Distal Epiphysis	7- 19 years	16- 20 years	16- 29 years
C&W(2007)	**Tibia**	Proximal Epiphysis	7- 17 years	12-22 years	19-29 years
	Tibia	Distal Epiphysis	7- 17 years	14-19 years	17-29 years
Cardoso (2008b)	**Fibula**	Proximal Epiphysis	≤ 18 years	17 years	≥ 16 years
	Fibula	Distal Epiphysis	≤ 16 years	15-18 years	≥ 17 years
C&W(2007)	**Fibula**	Proximal Epiphysis	8- 20 years	16- 21years	19 - 29 years
	Fibula	Distal Epiphysis	7- 20 years	16- 21years	20 - 29 years
Cardoso (2008b)	**Innominate**	Iliac Crest	≤ 14 years	16-21 years	≥ 19 years
C&W(2007)	**Innominate**	Iliac Crest	7-20 years	16-24 years	20-29 years

* ***Coqueugniot and Weaver (2007)***

Table 2.04: Age of Union from Gross Observations of Skeletal Material

Author	Epiphysis	Age of latest union	Age of latest In-Complete union	Age range for partial union
McKern and Stewart (1957)	Proximal Humerus	20 years	17 years	?-23 years
Schaefer (2005)		20 years	18 years	?-21 years
McKern and Stewart (1957)	Distal Radius	20 years	17 years	?-22 years
Schaefer (2005)		18 years	17 years	?-20 years
McKern and Stewart (1957)	Distal Ulna	20 years	17 years	?-22 years
Schaefer (2005)		20 years	17 years	?-20 years
McKern and Stewart (1957)	Distal Femur	19 years	17 years	?-21 years
Schaefer (2005)		18 years	17 years	?-20 years
McKern and Stewart (1957)	Proximal Tibia	19 years	17 years	?-22 years
Schaefer (2005)		18 years	17 years	?-20 years
McKern and Stewart (1957)	Proximal Fibula	19 years	17 years	?-21 years
Schaefer (2005)		18 years	17 years	?-20 years
McKern and Stewart (1957)	Iliac Crest	20 years	17 years	?-22 years
Schaefer (2005)		18 years	18 years	?-21 years
McKern and Stewart (1957)	Acromion Process	22 years	17 years	?-22 years
Schaefer (2005)		19 years	17 years	?-19 years

Table 2.05: Age of Complete Union from Schaefer and Black (2009)

		Female			Males		
		Open	Partial	Complete	Open	Partial	Complete
Humerus	Proximal	≤ 17	14 - 19	≥ 18	≤ 20	16 - 21	≥ 18
	Medial	≤ 15	13 - 15	≥ 16	≤ 18	16 - 18	≥ 16
	Distal	≤ 15	11 - 15	≥ 15	≤ 15	14 - 18	≥ 15
Radius	Proximal	≤ 15	11 - 15	≥ 16	≤ 18	14 - 18	≥ 16
	Distal	≤ 18	14 - 19	≥ 17	≤ 19	16 - 20	≥ 17
Ulna	Proximal	≤ 15	11 - 15	≥ 15	≤ 16	14 - 18	≥ 15
	Distal	≤ 18	15 - 19	≥ 17	≤ 20	17 - 20	≥ 17
Femur	Head	≤ 15	14 - 17	≥ 16	≤ 18	16 - 19	≥ 16
	Greater Trochanter	≤ 15	14 - 17	≥ 16	≤ 18	16 - 19	≥ 16
	Lesser Trochanter	≤ 15	14 - 17	≥ 16	≤ 18	16 - 19	≥ 16
	Distal	≤ 16	14 - 19	≥ 17	≤ 19	16 - 19	≥ 17
Tibia	Proximal	≤ 17	14 - 18	≥ 17	≤ 18	16 - 20	≥ 17
	Distal	≤ 17	14 - 17	≥ 16	≤ 18	16 - 18	≥ 16
Fibula	Proximal	≤ 17	14 - 17	≥ 17	≤ 19	16 - 20	≥ 17
	Distal	≤ 17	14 - 17	≥ 17	≤ 18	15 - 20	≥ 17
Pelvis	Iliac Crest	≤ 16	14 - 21	≥ 18	≤ 20	17 - 22	≥ 18

Table 2.06: Comparative Studies of Macroscopic Assessment of Union in Females

Author	Bone	Epiphysis	Stage 1: No Union	Stage 2: Partial Union	Stage 3: Complete Union
Cardoso (2008 a)	**Humerus**	Medial Epicondyle	≤ 16 years	15 years	≥11 years
		Distal Epiphysis	≤ 14 years		≥11 years
C&W(2007)		Proximal Epiphysis	7- 19 years	17-23 years	20-29 years
		Medial Epicondyle	7- 12 years	14-29 years	14-29 years
		Distal Epiphysis	7- 12 years	12-29 years	12-29 years
Ubelaker 1994		Proximal Epiphysis	-	-	14-23 years
		Medial Epicondyle	-	-	11-16 years
		Distal Epiphysis	-	-	11-16 years
Cardoso (2008 a)	**Radius**	Proximal Epiphysis	≤ 14 years	13-16 years	≥11 years
		Distal Epiphysis	≤ 16 years	14- 19 years	≥17 years
C&W(2007)		Proximal Epiphysis	7- 12 years	12- 17 years	17-29 years
		Distal Epiphysis	7- 19 years	17-22 years	22-29 years
Ubelaker 1994		Proximal Epiphysis	-	-	14-18 years
		Distal Epiphysis	-	-	17-22 years
Cardoso (2008 a)	**Ulna**	Distal Epiphysis	≤ 16 years	14- 19 years	≥17 years
C&W(2007)		Distal Epiphysis	7- 19 years	17-21 years	20-29 years
Cardoso (2008b)	**Innominate**	Iliac Crest	≤ 16 years	15 - 21 years	≥18 years
C&W(2007)		Iliac Crest	7- 19 years	11-19 years	12-29 years
Ubelaker 1994		Iliac Crest	-	-	14-22 years
Cardoso (2008b)	**Femur**	Proximal Epiphysis	≤ 15 years	14-16years	≥15 years
		Distal Epiphysis	≤ 16 years	14-19years	≥17 years
		Greater Trochanter	≤ 15 years	13- 16 years	≥14 years
		Lesser Trochanter	≤ 15 years	13-16 years	≥14 years
C&W(2007)		Proximal Epiphysis	7- 17 years	12-22 years	17-29 years
		Distal Epiphysis	7- 19 years	17-19 years	17-29 years
		Greater Trochanter	7- 12 years	17-19 years	14-29 years
		Lesser Trochanter	7- 12 years	13-19 years	17-29 years
Ubelaker 1994		Proximal Epiphysis	-	-	16-20 years
		Distal Epiphysis	-	-	14-21 years
		Greater Trochanter	-	-	16-20 years
		Lesser Trochanter	-	-	16-20 years
Cardoso (2008b)	**Tibia**	Proximal Epiphysis	≤ 16 years	14-19 years	≥18 years
		Distal Epiphysis	≤ 16 years	14-16 years	≥15 years
C&W(2007)		Proximal Epiphysis	7- 17 years	12-22 years	19-29 years
		Distal Epiphysis	7- 17 years	14-19 years	17-29 years
Ubelaker 1994		Proximal Epiphysis	-	-	16-22 years
		Distal Epiphysis	-	-	14-20 years

Author	Bone	Epiphysis	Stage 1: No Union	Stage 2: Partial Union	Stage 3: Complete Union
Cardoso (2008b)	**Fibula**	Proximal Epiphysis	≤ 16 years	14-17 years	≥17 years
		Distal Epiphysis	≤ 16 years	14-16 years	≥15 years
C&W(2007)		Proximal Epiphysis	7- 19 years	17-19 years	20-29 years
		Distal Epiphysis	7- 17 years	17-21years	19-29 years
Ubelaker 1994		Proximal Epiphysis	-	-	14-21 years
		Distal Epiphysis	-	-	14-20 years

2.2.3 Radiographic Assessment of Epiphyseal Union

Studies based on radiographic assessment are becoming increasingly popular due to the accessibility of study material. Radiographic images also represent a contemporary sample of individuals and hence prove to be advantageous. However, there are ethical issues surrounding the unethical exposure of individuals to radiation and hence X-rays. More recent studies, as in the present study, utilise samples of individuals who attend medical institutions for medical treatment. The revolutionary equipment developed in South Africa is able to take full body radiographs of a patient in just 13 seconds. This technology allows the present research to focus on all the major joints of the body. Together with the development of new technology which emits negligible levels of radiation, the utilisation of radiographic material is becoming increasingly popular.

The specific advantage of this system is that there is no lack of samples. The disadvantage however, is that previous studies do not include all the joints in their assessments but rather concentrate on specific areas of the body such as the knee (*Table 2.07 and 2.08*) (O‟ Connor *et al.*, 2008) or ankle and wrist (Banerjee and Agarwal, 1998). This is probably due to the diagnostic procedures available. In the past X-rays were only taken of the affected joint/bone. *Table 2.07* is a summary of the studies which deal with epiphyseal union at the wrist and ankle in populations from around the world. Once again the observed variation in the age ranges of complete union may be a consequence of population variability, secular changes or simply a lack of standardised methodology (O‟Connor *et al.*, 2008).

The nature of these studies is that they fail to report the full ranges of variation in union times of the epiphyses since they are cross-sectional in design (Saunders, 2007). The advantage of using digital images is that they can detect the stages of fusion which cannot be seen on dry bone. However, the disadvantage is having access to a larger sample of information for the formulation of standards which cannot be used on dry bone specimens.

Table 2.07: Radiographic Assessment of Union at the Knee (O'Connor *et al.*, 2008)

				Males (age in years)			**Females (age in years)**		
Author	**Year**	**Population**	**Stages**	**Femur**	**Tibia**	**Fibula**	**Femur**	**Tibia**	**Fibula**
	1924	US	4	19	19	19	19	19	19
Davies and Parsons	1927	UK	2	19	19-20	20-22	19	19-20	20-22
Hepworth	1929	Indian	2	16.5 -17.5	16.5-17.5	16.5-17.5	16.5-17.5	16.5-17.5	16.5-17.5
Paterson	1929	UK	2	18	18-19	18	16-17	16	16-17
Todd	1930	US	9	17.5-18.5	17.5-18.5	17.5-18.5	17.5-18.5	17.5-18.5	17.5-18.5
Flecker	1932	Australian	2	16-19	16-19	16-19	14-19	14-19	14-18
Pillai	1936	Indian	N/S	14-17	14-17	14-17	14-17	14-17	14-17
Gaulstaun (Bengali)	1937	Indian	2	less than 18	16-17	16	less than 17	14-15	16
Flecker	1942	Australian	2	16-19	16-19	16-19.66	14-19	14-19	14-18
Agarwal and Pathak	1957	Indian	N/S	-	-	-	14.5-16.5	14.5-16.5	15-16.5
McKern and Stewart **	1957	US	5	22	23	22	-	-	-
Narayan and Bajaj	1957	Indian	2	18-19	18-19	18-19	16	16	16
Johnston **	1961	American	3	18.5	18	18	17-18	16-18	16-19
Hansman	1962	US	2	14-19	14.5-19.5	15-20	17-18		
Saksena and Vyas	1969	Indian	2	18-19	18-19	18-19	16-17	16-17	16-17
Das Gupta *et al.*,	1974	Indian	2	18-19	18-19	20-21	17-18	17-18	20-21
Pfau and Sciulli	1994	US	3	-	-	-	-	-	-
Schaefer and Black **	2005	Bosnian	5	17-20	17-20	17-20	-	-	-
O' Connor (2008)	2008	Irish		19.0 +	17.5 +	16.5-18.5	16.5-18.0	16.5-18.5	16.5-18.5
Saeed (2008)				19	19	19	16	16	17

**** Studies conducted on dry bone**

Table 2.08: Comparison of Union Times for Ankle and Wrist (yrs.) (Banerjee and Agarwal, 1998)

				Radius		Ulna		Tibia		Fibula	
Author	**Year**	**Sample Origin**	**HDI**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
Gaulstaun (Bengali)	**1937**	West Bengali	0.492	18	16-17	18	16-17	14.4	14	14-16	13-15
Saksena and Vyas	**1969**	Madhyra Pradesh	0.375	19-20	17-18	19-20	17-18	-	-	-	-
Lall and Townseed	**1939**	Uttar Pradesh	0.38		19		19	-	-	-	-
Kothari	**1974**	Rajasthan	0.434	18-19	17-18	18-19	17-18	-	-	-	-
Dalal	**1981**	Haryana	0.552	18-19	17-18	18-19	17-18	-	-	-	-
Basu and Basu	**1938**	Bengal		-	16-17	-	16-17	-	14-15	-	15
Agarwal and Pathak	**1957**	Punjab	0.605	-	-	-	-	13.75-15	13.75-15	13.75-15	13.75-15
Hepworth	**1929**	Indian		-	-	-	-	16.5-17.5	16.5-17.5	17-18	17-18
Pillai	**1936**	South India		-	-	-	-	14	14	17	17
Bajaj *et al*	**1967**	Delhi	0.75	17.6	16.4	17.6	15.8	-	-	-	-
Pryor	**1929**	America	0.944	20	19	19	16	-	-	-	-
Paterson	**1929**	England		21	20	21	20	18-19	16-17		
Flecker	**1932**	Australia		19	18	19	17	17	14	17	14
Banerjee and Agarwal	**1998**	Delhi	0.75	19-20	18-19	19-20	18-19	17-18	16-17	17-18	16-17
Baumann (2009)	**2009**			22.0 ± 4.1	$20.4\ 0 \pm 4.3$	17.0 ± 2.3	16.80 ± 3.5	-	-	-	-
Sahni (1995)	**1995**				< 19						

2.2.4 Interplay between Radiographic and Macroscopic Observations

Macroscopic (conducted as assessment on dry bone) and radiographic assessment (assessed on radiographs of usually the living) of union has been shown to produce varying results. Thus their timings cannot be used interchangeably (Drennan and Keen, 1953; Krogman and Iscan, 1986; Ubelaker, 1987; Sorg *et al*., 1989; Coqueugniot and Weaver, 2007; Cardoso, 2008a and Schaefer, 2008). Disagreements in observational variation in macroscopic and radiographic examinations are based on a number of factors. According to Krogman and Iscan (1986), the process of union begins centrally and progresses quite far before the external epiphyseal margin is fused. In this case x-rays would indicate a more advanced state of union than would the naked eye. Meijerman and colleagues (2007) found fusion can be detected earlier in X-rays compared to dry bone due to changes which occur in the cartilaginous end plates in adjacent bones, which are not present at death (dry bone).

The second factor is the appearance of a radio-dense line which can be interpreted as recent fusion thereby suggesting that it is a stage of less advanced union compared to the naked eye and may show a three year delay in the timing of complete fusion (Cardoso, 2007). Epiphyseal fusion studied on a sample derived from the 1950‟s showed that fusion observed on dry bone was one to four years delayed compared to that observed on digital images (Cardoso, 2007). Similarly, a study conducted on the innominate and lower limb (dry bone) showed a delay of one to four years in union compared to the same locations assessed on X-Ray (Crowder and Austin, 2005).

Comparisons between the Irish population (O‟Connor *et al*., 2008) and that of the Bosnians (Schaefer and Black, 2005) found that the epiphysis of the knee in the Irish sample commenced union approximately two years earlier (16 years) than the latter sample which commenced union around 18 years of age (Schaefer and Black 2005). The difference however lies in the fact that radiographs were assessed by O‟Connor and colleagues (2008) while Schaefer & Black (2005) assessed union on human skeletal remains. This was the first radiographic study to explore differences in ages of complete union in the knee with those of macroscopic observations of bones (O‟Connor *et al*., 2008) (*Table 2.07*). Macroscopic assessments have been included in *Table 2.07* and written in red. The most significant difference is observed in the results reported by McKern and Stewart (1957) who report the latest union for epiphyses (both macroscopically and radiographically). The study also compared their results to other radiographic studies assessing union at the knee (*Table 2.07*).

It is therefore suggested that reference standards developed on macroscopic observations of osseous material should only be used on a sample of such and vice versa (Cardoso, 2007) until such time that results from X-Ray can be successfully applied to dry bone (Sorg *et al*., 1989). Thus far however, there has been no systematic assessment on the comparability of results from these two techniques (Sorg *et al*., 1989).

2.3 Age Estimation based on South African Individuals

2.3.1 Birth to 20: A South African Longitudinal Study Assessing Skeletal Maturity

The Birth to 20 (BT 20) study commenced in 1994 in post-apartheid South Africa to track the growth and wellbeing of previously disadvantaged Black individuals residing in Soweto, Johannesburg. The sample consists of Black South African children affectionately called "Mandela"s children" as their inception into this study took place seven weeks following the release of Nelson Mandela from prison in 1990 (Richter *et al*., 2007). The aim of the study was to determine whether post-apartheid South Africa provided an adequate environment for development of these so called "Born Frees". The adequacy of the developmental environment was assessed by determining whether skeletal age was either in advance of or delayed compared to chronological age. The measure for this difference was called the relative skeletal maturity (RSM). According to Hawley and colleagues (2012), advanced skeletal maturation is a reflection of adequate conditions for optimal development whereas delayed maturation suggests inadequate conditions for optimal development.

RSM was assessed on a sample of 131 individuals from the BT20 study (Hawley *et al.,* 2012) using the Tanner and Whitehouse RUS (TW3) method (2001). The results found that males showed a 0.66 year delay in skeletal maturity whereas females showed a delay of approximately one year relative their chronological ages. These results should be interpreted with caution as the RSM was assessed using reference standards formulated on a non-South African sample. The results suggest that the skeletal maturity of the sample is delayed when compared to international references; suggesting that the developmental environment of the BT 20 sample is inadequate (Hawley *et al.,* 2012).

However, in 2009 Hawley and colleagues conducted a study to assess skeletal maturity of South African Whites and Blacks by comparing the results of the 1962 Pretoria National

Nutrition survey to their 2001 sample of BT 20 subjects. Results showed that skeletal maturity in White males and females in 2001 was in advance of the 1962 Pretoria cohort by an average of 3.4 months and 2.0 months respectively (Hawley *et al*., 2009). Black males and females from the BT 20 cohort were significantly in advance of the Pretoria cohort by an average of 9.7 months and 15.8 months respectively, showing a larger increase in skeletal maturity for the Black South Africans compared to their White counterparts.

This suggests that while South African children may be delayed in the skeletal maturity compared to international standards, there has been an observed secular increase in maturity among Black and White South Africans since 1962. The secular trends observed are thought to be in harmony with the secular changes in stature and growth occurring in the South African population (Hennenberg and van der Berg 1990 and Jones *et al*., 2009). Factors associated with increased stature and tempo of growth are improved nutrition, healthcare, social environment as well as migration both geographical and from low to high socio-economic status and living conditions (Root, 1973). Whereas delayed skeletal maturity has been associated with social deprivation and poor economic circumstances (Bogin, 1983).

Between 1960 and 1990, when the children of BT20 were born, there were significant changes in the environment for South Africans. Life expectancy rose from 50.0 years in 1960 to 61.9 years in 1990 (United Nations, 2009) and the under five-mortality rate fell from 115.20 to 63.60 per 1000 births over the same period (Unicef, 2009) indicating improvements in healthcare. Both Black and White children exhibited positive secular trends in skeletal maturity, which may be explained by the changing environment. Because the magnitude of the increase in skeletal maturity is larger in the Black population, it has been suggested that this reflects greater transition (healthcare, socio-economic and improved nutrition) in this population compared to the relatively stable White population. The effects of socio-economic conditions and their effect on growth rates could not be determined since the sample represented a homogenous group of individuals who all grew up in the same environment and were exposed to similar constraints (Hawley *et al*., 2012). The effect would be easier to study on individuals from the more affluent northern suburbs that were less affected by the negative aspects of apartheid (Hawley *et al*., 2012).

2.3.2 Age Estimation Based on the Lengths of Diaphyses and Breadth of Epiphyses

Until recently age estimation was primarily carried using standards derived for epiphyseal maturation. Stull and colleagues (2014) derived univariate and multivariate equations with prediction intervals (is an estimate of an interval in which future observations will fall, with a certain probability) to estimate age of South African children between birth and 12 years. This is the first such study to develop a multivariate approach for diaphyseal dimensions on contemporary South African sample representative of the current South African demographic.

The study found that the predictions of these multivariate equations were limited to use in individuals 12 years and younger as the multivariate models had lower prediction intervals for older children (Stull *et al*., 2014). The study found that there was larger variation in diaphyseal length in older children and less variation in the younger children. The size of the prediction interval was seen to increase with age especially during adolescence (Stull *et al*., 2014). This has been attributed to the variation which exists in the initiation of the growth spurt in males and females. The study failed to find significant differences in males and females which should be expected especially since females enter the growth spurt earlier than males. This study does not differentiate between the different ethnic groups but expects that the prediction intervals would be improved if this was done.

It has been suggested by the authors that for prediction intervals greater than 12.99 years should be augmented by epiphyseal union data. This method (Stull *et al*., 2014) provides an alternative to the Greulich and Pyle (1959) method which has been shown to be inappropriate in application to South Africans. It may also be utilised on forensic cases involving human skeletal analyses since Stull and colleagues (2013) demonstrated that there is low distortion and a 97% agreement in measurements of the skeletal material and measurements of the radiographs of the skeletal material. The measurements of diaphyseal breadths in the absence of the epiphyses make it a recommended method for 0 - 12 years old South Africans.

2.4 Factors which Influence Union

The review of literature associated to skeletal maturation studies suggests that socio-economic variables are often implicated as a factor which significantly influences the rate of union (Schutte, 1980; Tobias, 1985; Chaning-Pearce and Solomon, 1986; Frietas *et al*., 2004; Schmeling *et al*., 2006; Cardoso, 2007; Hawley *et al*., 2009; Anholts *et al*., 2013 and Stull *et al*., 2014). This direct association suggests that the extremely poor who will also have access to less food of lower quality and nutritional value will be malnourished (Frisancho, *et al*., 1970; Johnston and Zimmer, 1989; Flores - Mir *et al*., 2005; Schmeling *et al*., 2006; Nannan *et al*., 2009; Sheppard *et al.,* 2009 and Willey *et al*., 2009). Chronic malnutrition results in stunting of children and delayed maturation (McKern and Stewart, 1957; Fleshman, 2000; BÜken *et al*., 2007; Monteiro *et al*., 2009 and Hawley *et al*., 2012). The delayed onset of menarche due to malnutrition in females was also noted by Schaefer and Black (2005). Changes in stature and age at menarche are key indicators of maturational tempo (Bogin, 1983).

The effects of chronic malnutrition in South American children showed a 30% delay in skeletal maturation (Frisancho, *et al*., 1970). The effects of delayed maturation are less severe at the adolescent phase during which an apparent relative improvement in skeletal maturation with a resultant stunting of growth occurs (Frisancho *et al*., 1970). There is a theory that suggests that during adolescence, there is a potential for a growth catch up to occur thus reducing the maturity deficit and the prolonged growth period which follows compensates for earlier growth deficit (Frisancho *et al*., 1970; Flores - Mir *et al*., 2005 and Willey *et al*., 2009). A South African study also found that the effect of poor nutrition during the first 3 years of life has negative effects of attainment of maximum adult height and delayed skeletal maturity (Willey *et al*., 2009).

However, the converse also holds true. Improved access to nutrition, healthcare and social benefits results in positive secular trends which result in transformations in body size, body proportions, growth rates, height and maturational timing (Freitas *et al*., 2004; Schmeling *et al*., 2006; Cardoso, 2007; O‟Connor *et al*., 2008; Demerath *et al*., 2009; Monteiro *et al*., 2009 and Hawley *et al*., 2012). Improved health care is reflected in statistics reported for infant mortality rates, under five mortality rates and life expectancy.

In a recent publication Willey and colleagues (2009) published information relating to the stunting of growth and the influence of socio economic variables on child growth. Variables such as employment status, access to household water, sanitation and electricity, type of cooking fuel used as well as the ability to afford life insurance and the services of a domestic worker implied some information about the socio-economic situation of families. This study found that the higher the frequency of items possessed, the less the likelihood was for stunting. This effect is further amplified by access to social support in the form of a live-in partner or spouse. Maternal education also contributed to a decreased likelihood of stunting of growth (Willey *et al*., 2009). Similar observations were confirmed in the Brazilian population (Monteiro *et al*., 2009).

In 1931, Todd established that there were no differences in skeletal maturation related to genetic background and stated that "*the observed variability in the pattern and rate of ossification results mostly from ill-health, poor nutrition or unhygienic conditions"* (Todd 1931 in Cardoso, 2008). In 2007 Meijerman and colleagues (2007) found that race did not influence the rate of union. However, on the contrary Zang and colleagues (2009) came to the conclusion that the GP (1959) atlas was not applicable to Hispanic and Asian individuals as GP is inaccurate at estimating age in individuals of mixed ancestry. While locally, Dembetembe and Morris (2012) found that GP (1959) underestimates age in children of African descent, while Speed (2012) found a variation in results.

CHAPTER 3: MATERIALS AND METHODS

3.1. MATERIALS

This study is of a cross sectional nature. Opposed to longitudinal studies cross sectional studies are thought to capture much more of the variation as it avoids repeated measurements and assumes independent error (Stull *et al*., 2014). According to Stull and colleagues (2014) cross sectional studies are better suited to estimating age whereas longitudinal studies are better suited at evaluating growth (Evelenth and Tanner, 1990 and Ousley *et al*., 2013).

In this retrospective study, pre-existing full body radiographic material in the form of LODOX images were collected from the Red Cross War Memorial Children"s Hospital (hereafter referred to as Red Cross), Groote Schuur Hospital, Salt River and Tygerberg Mortuaries in Cape Town. Archived radiographs were also collected from the Charlotte Maxeke (Formerly Johannesburg General Hospital), Chris Hani Baragwanath and Milpark hospitals in Johannesburg. Ethical approval was granted for the current research from the Health Sciences Faculty at the University of Cape Town (REC REF: 274/2009) and Human Research Ethics Committee R14/49 WITS: M10456 for samples from Charlotte Maxeke hospital. Written permission for the use of the images was granted by the Heads of Paediatric Radiology at Red Cross and the Head of Forensic Medicine at the University of Cape Town as well as Chris Hani Baragwanath and Milpark hospitals (*Appendix 1*).

The radiographs for this study were taken using a Statscan^{TM} system (LODOX ^{TM} Systems, (Pty) Ltd., Sandton, South Africa). The precursor to this system was previously used in diamond mines to detect theft of diamonds by mine workers. The slit scanning technology is primarily responsible for the delivery of lower doses of radiation as well as image quality comparable to conventional radiography. The result is that it is able to produce full-body radiographs in just 13 seconds, and is even faster in children (Douglas *et al*., 2010). The

Statscan^{TM} has been shown to deliver lower doses of minimum and maximum radiation such that the total dose from 10 full body scans does not exceed the limit of 1 mSv (where Sv = Sievert unit of radiation) (Maree *et al*., 2007).

Radiographs obtained from the hospitals around Cape Town and Johannesburg represent a sample of living individuals who were admitted to the hospital due to circumstances of trauma. The extent or causes of their injuries were ascertained after radiographs by attending medical practitioner. The samples obtained from the mortuary represent deceased individuals where it is standard practice to perform radiographic imaging of deceased individuals who pass through the mortuary, however; it is not common among all mortuaries.

The radiographic images generated by the Statscan^{TM} system were collected from the LODOX ^{TM} technicians in Johannesburg and Cape Town depending on their schedule for the service and backup of data. The researcher approached the technician bi-annually to deliver an external storage device upon which the data could be saved for the purposes of this research.

All the hospitals besides Milpark hospital can be considered to be public hospitals and can presumably act as a representation of the general population in the area. It can therefore be presumed that while the public hospitals cater for lower socio-economic backgrounds, those who attend private hospitals are likely to come from higher socio-economic backgrounds. However, this was not the case. Milpark is the first Private hospital in South Africa to receive Level one Trauma accreditation and provides treatment to individuals from various socio-economic backgrounds.

3.1.2 Distribution of Hospital and Mortuary Patients

The general sample is representative of the population of South Africa. The data from the most recent census estimated that the population of South Africa is 51.8 million and is broken down into the following proportions: black individuals making up 79.2% of the population; Coloured 8.9%, Indian 2.5% and Whites 8.9% (Statistics South Africa, 2013). The largest proportion of the sample originated from the mortuaries and hospitals from the Western Cape (92.5%) a smaller sample of individuals are derived from Johannesburg (7.5%).

This difference is due largely to the fact that the LODOX systems were established earlier in the Western Cape where the data collection for the present research was undertaken. Not only were the images of better quality, the records kept at these institutions were readily accessible and contained sufficient information relating to age, date of birth, image date, language spoken, reasons for hospitalisation, home address and method of payment. The aim of collecting data from two regions in South Africa was to determine if within population difference existed in the sample. However; the samples generated from Johannesburg were not large enough to undertake such comparisons.

Factors such as religion, language and region and were used to determine ancestry since research has shown that South African self-identify with these (Stull *et al.*, 2014). Information about the ancestry of the individuals in the hospital samples was provided on the patient register by assessment of language spoken. This information was absent for some individuals and was left as such. Of the individuals with known biological background from the Western Cape 52.5% of the sample were Black; 36% Coloured; 1% Indian and 2 % European White.

3.1.3 Research Sample

A total of 28 294 images were collected and these consisted of images of only heads, or were duplicated. Therefore it is estimated that that approximately 10 000 images were assed to obtain a final sample of 2151 individuals (*Table 3.01*). A further 69 radiographs of the skeletonised individuals were collected from the Raymond Dart Collection. The sum total of the sample is therefore 2220 individuals. The first radiograph collected from the LODOX system was dated to January 2000 while the last one which forms part of the current sample was taken in June 2012. These were derived from two hospitals in Cape Town and three in Johannesburg as well as two government mortuaries from Cape Town.

Table 3.01: Breakdown of Sample of Whole Body Scan by Institution

Institution	Males	Females	Total
Red Cross	531	326	857
Groote Schuur	813	141	954
Tygerberg Mortuary	56	4	60
Salt River Mortuary	82	18	100
Chris Hani Baragwanth	107	0	107
Milpark	72	1	73
Dart Collection	45	24	69
Total	**1290**	**445**	**2220**

3.1.4 Selection Criteria for Images:

(a) ***Age***: Individuals between ages of 6 - 24 years were selected. Individuals older than 24 years were not included. This age range was chosen to reflect the extent of morphological variation prior to union. There are a smaller number of individuals in this age range because there were no significant changes in the appearance of the joints once compete union had been reached. The age intervals are based on the chronological age of individuals and were calculated from date of birth and scan date or date of death. Individuals between 6 – 6.99 years formed the 6 year olds; those between 7 – 7.99 years formed the 7 year olds and so on.

(b) ***Sex***: The sample for the current study consists of both males and females. This information is supplied on the radiographic images; however, in some cases the sex of the individual was not stated. In these cases the researcher could determine sex by studying the soft tissue in the region of the genitalia. This was easier to carry out in the older individuals compared to the younger ones. In cases where this was not conclusive the researcher had to consult the patient"s medical records situated at the hospitals/mortuaries.

(c) ***Image quality***: Radiographs were omitted if the visual assessment of the joint in question was impaired either due to axial rotation, distortion of the images due to movement or over loading of the visual content. The images generated by the Red Cross hospital as well as those from Groote Schuur in Cape Town were of great quality with correct anatomical orientation of the limbs and less hindrances to the observations. The image quality from Johannesburg was less easy to work with. This may be attributed to the technicians experience with the machines. While those in Cape Town had been operation for at least five years prior, Johannesburg was fairly recently exposed to this new machinery.

(d) ***Side chosen for observation***: Standard protocol dictates that the left side be studied, however in cases in which this was not possible the joints of the right side of the body were studied. Generally there were no observed differences between the two sides. If differences were observed, the images were discarded.

(e) ***Joint observation***: The images were taken in the anterior-posterior (AP) plane which pose as a limitation as union may only be assessed anteriorly. The epiphyses of the joints displayed in *Figure 3.01a and b* were assessed for stages of union. Certain joints were not in this plane due to axial rotation. In such cases the same joint on the opposite side was studied. Mortuary samples proved to be a greater challenge to work due to the influence of rigor mortis. In cases where no observations could be made it was noted as such and abbreviated as N/O.

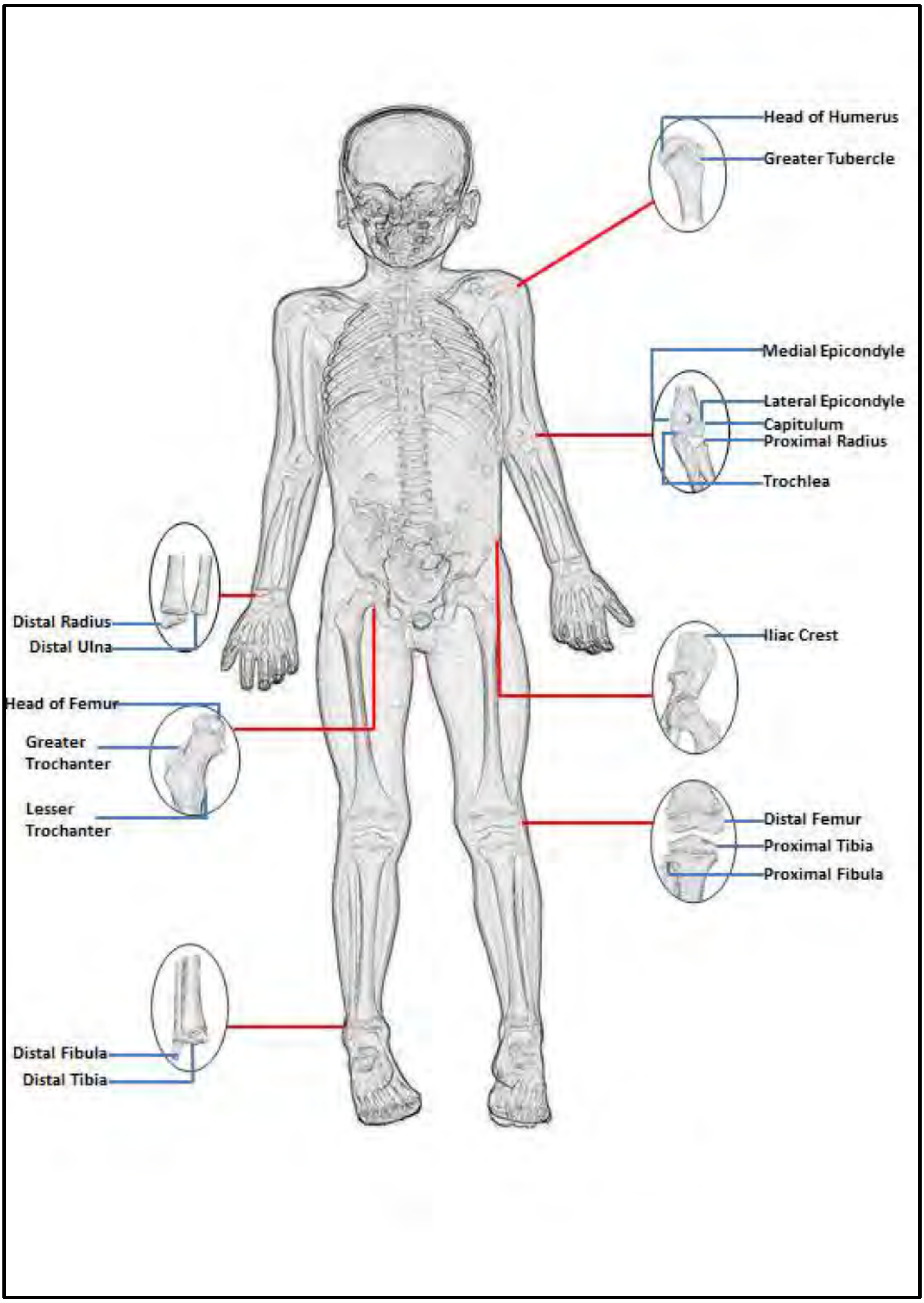


Figure 3.01 (a): Sketch of the epiphyses assessed in the present study. *The joints represented are shoulder, elbow,wrist, hip, knee, ankle and iliac crest*

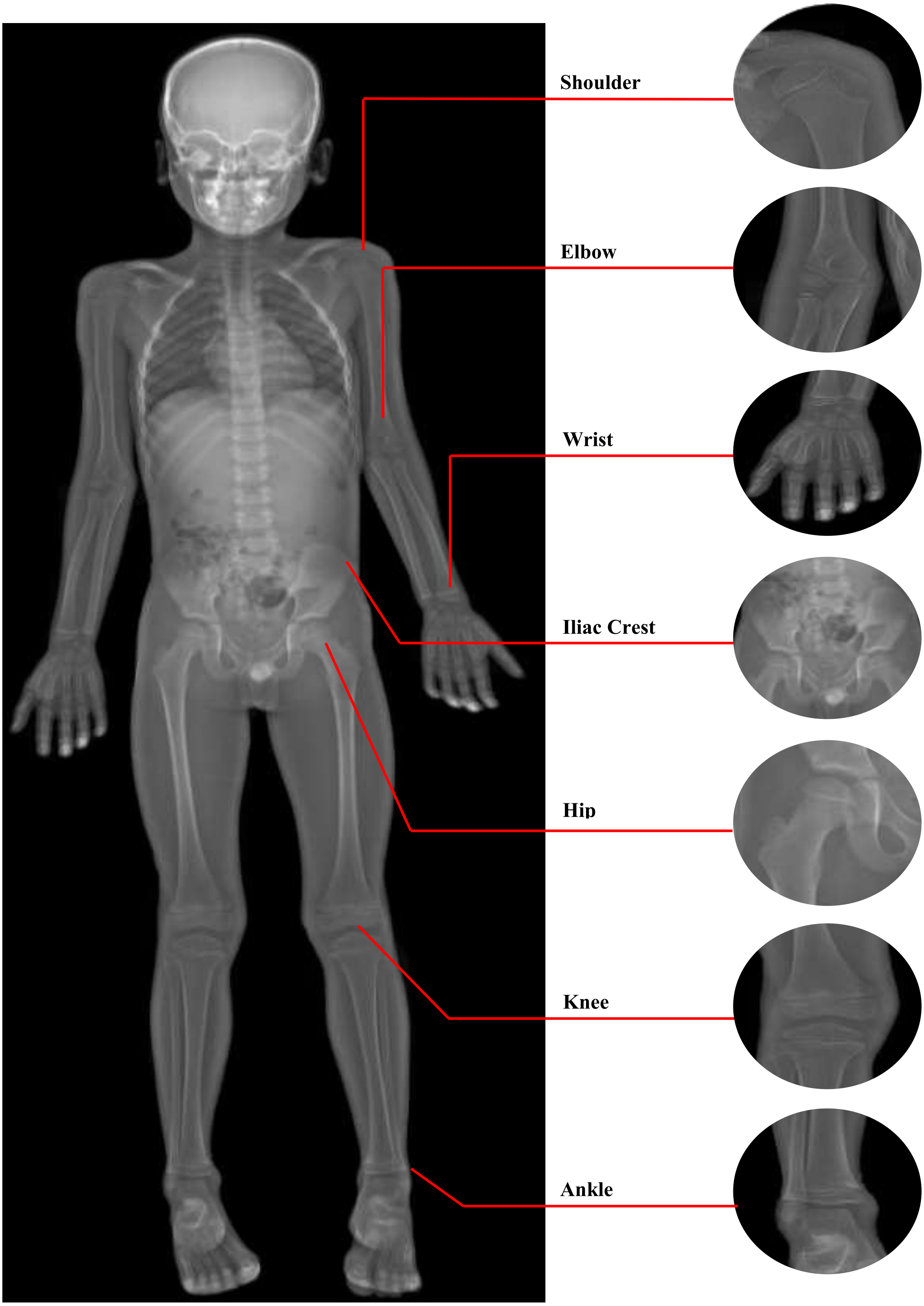


Figure 3.01 (b): *Radiograph showing the epiphyses assessed in the present study. The joints represented are shoulder, elbow, wrist, hip, knee, ankle and iliac crest*

3.1.5 About the Sample: Age and Sex Distribution as well as Biological Origin

The sample consists of males and females between the ages of 6 - 24 years. Male subjects make up the majority of the sample (75%) whereas females consists of only (25%) of the sample. These age ranges were chosen to track the developmental changes in epiphyseal union taking place during maturity. The initial age range set for this study had a lower age limit of 13 years; however; after conducting some preliminary analyses not many changes in development milestones were noted. Therefore, the lower age range was reduced to six years of age.

The data were primarily collected from the Western Cape namely the Red Cross Children"s Hospital, Groote Schuur Hospital, Tygerberg and Salt River mortuaries. Additional information in the form of reasons for admission into hospitals and mortuaries were collected from the patient files. These data reveal that the most prevalent cause for admission include road accidents (Motor Vehicle Accident (MVA)) followed by gunshot injury (GSW- Gun Shot Wound) and pedestrian vehicle accidents (PVA). These variables along with those listed in *Figure 3.02* below account for the observed distribution of the current sample.

Children between the ages of 6 - 14 years of age make up 52% of the sample. The remainder of the 48% is made up individuals between the ages of 15 - 24 years. The age categories that record the highest number of individuals are those between 7 - 14 years and 17 - 24 years respectively. Children between the ages of 7 - 14 years are predominantly admitted to hospital due to reasons associated with MVAs and PVAs. Previous studies have found that found that among children between the ages of 1 - 14 years MVAs and PVAs were the largest single cause of injury-related death (System N.I.M.S, 2002; Bradshaw *et al*., 2003 and Matzopoulos *et al*., 2008). In the 17 - 24 year category the major reason of concern is the prevalence of gunshot injuries followed by PVAs. Males were at more risk than females across all groups (*Figure 3.02*).

These results were also observed by the National Injury Mortality Surveillance System (NIMMS) (System N.I.M.S). Similarly, Bradshaw and colleagues (2003) found that among children between the ages of 1 - 14 years MVAs and PVAs were the largest single cause of injury-related death (System N.I.M.S, 2002 and Matzopoulos *et al*., 2008). They also found that the peak in road traffic incidence correlated with the times at which children were travelling to and especially from school. The second largest group in which high numbers of individuals were recorded was those between the ages of 17 to 24 years. The principal reasons for admissions to hospitals or mortuaries in these individuals are due to circumstances of violence (GSW) followed by MVAs and assault. These results were also highlighted Donson (2009) who studied the causes of fatal injuries in South Africa and concluded that the major causes were related to circumstances of violence as well as transport incidents.

His study also found that the majority of injury and death occurred among African and Coloured males in the economically active age range of 15 to 44 years (Donson, 2009). While the leading manner of non-natural deaths in the former for males was sharp-object related violence, the current study finds that gunshot trauma was the leading cause of injury and or death in African and Coloured males (249 and 111 respectively).

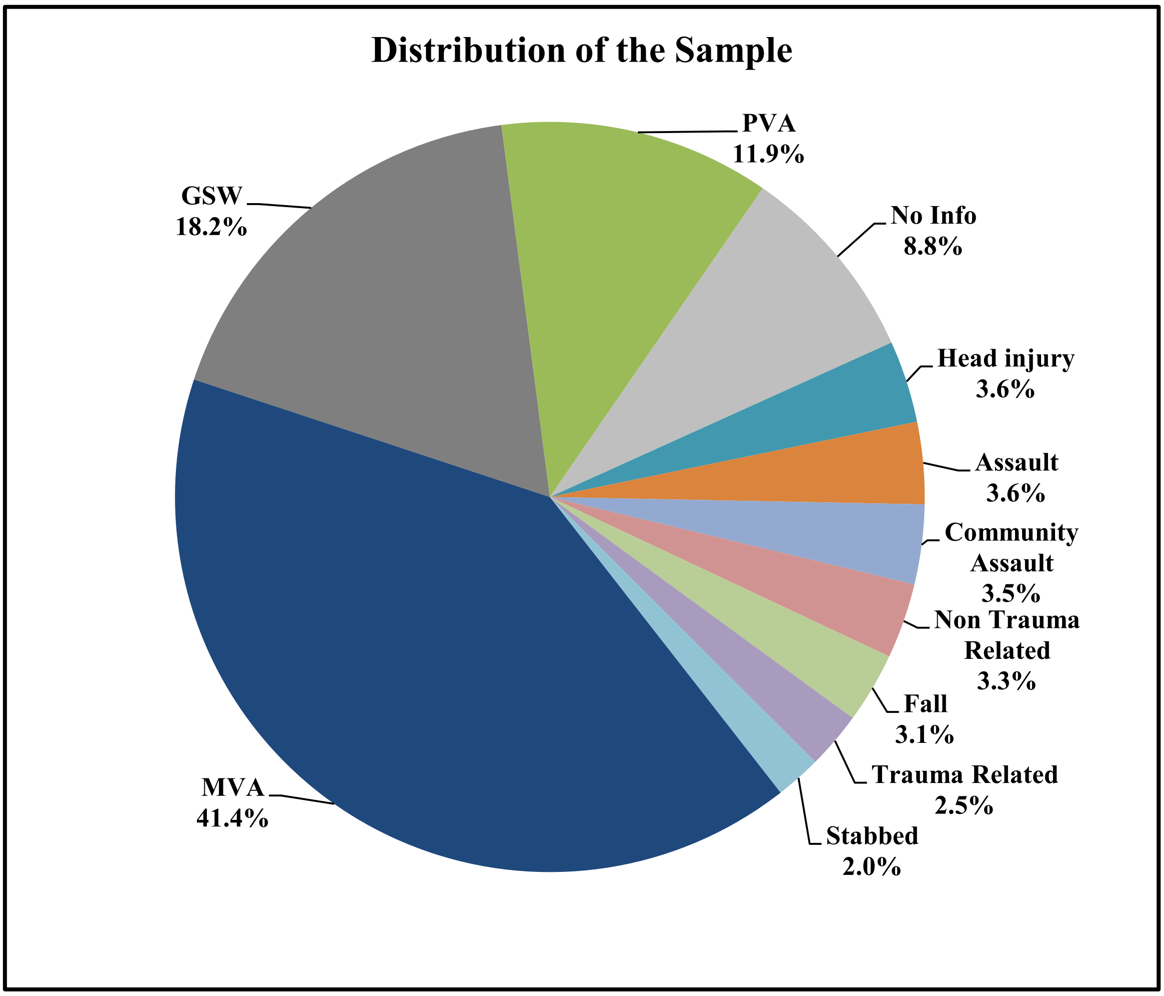


Figure 3.02: *Distribution of injuries in the current sample.*

3.1.6 Skeletal Sample:

In order to compare the observations of radiographs of the living children against those of the skeletal sample, it was necessary to take radiographic images of human skeletal remains. Similar to previous studies, the representation and use of juvenile human skeletal remains is limited to its representation in skeletal teaching collections. Two criteria had to be satisfied before the sample could be chosen. Firstly, the collection should be easily accessible and close to a LODOX Statscan system and second of all, it should have a large enough number of individuals of interest. A review of the available collections around Johannesburg showed that of all the collections, the Raymond Dart Collection of Human Skeletons (hereafter referred to as the Dart Collection) at the University of the Witwatersrand Medical School *(Table 3.02)* had 44 male and 25 females between the ages of 10 - 19 years compared to the four male and one female between 10 - 19 years from the University of Pretoria (L'abbe *et al*., 2005) *(Table 3.03)*.

69 skeletonised individuals were selected from the Dart collection (*Table 3.04*) which is considered to be one of the largest documented cadaver-derived human skeletal assemblages in the world (Dayal *et al*., 2009). The collection consists of skeletons of indigenous and immigrant populations from Southern Africa, Europe and Asia whose acquisition is a mix between unclaimed and bequeathed (Dayal *et al*., 2009). The Dart collection is considered to be an ideal skeletal reference collection since it satisfies the three characteristics which are:

i. Known age-at-death for skeletons
ii. Adequate representation of the living population from which skeletons derived with respect to variation in socio economic status, genetic background and health.
iii. Representation of all ages both males and female.

Table 3.02: Age at Death Categories for Skeletal Material from the Dart Collection

		Age Ranges (10 years)				
	Population Group	**0 - 10**	**10 - 19**	**20 - 29**	**30 - 39**	**40 - 49**
Males	SA African	21	38	135	242	311
	SA Whites	2	1	1	6	26
	SA Coloured	1	1	6	9	15
	SA Indians		0	0	0	1
	Other SA			3	3	6
	Other African		4	16	19	12
	Unknown			1		
	Total	**24**	**44**	**162**	**279**	**371**
Females	SA African	15	22	80	105	88
	SA Whites	1	1	3	1	9
	SA Coloured	1	1	7	10	7
	SA Indians	0	0	0	0	0
	Other SA				1	3
	Other African	1	1	4	1	2
	Total	**18**	**25**	**94**	**118**	**109**

Table 3.03: Breakdown of the Pretoria Skeletal Sample by Age

		Age ranges (years)				
	Population Group	**0 - 9**	**10 - 19**	**20 - 29**	**30 - 39**	**40 - 49**
Male	White	2	0	0	1	2
	Black	12	3	16	32	64
	Other	0	1	1	1	2
	Total	**14**	**4**	**17**	**34**	**68**
Female	White	3	0	0	0	3
	Black	1	1	4	15	17
	Other	0	0	1	1	1
	Total	**4**	**1**	**5**	**16**	**21**

3.1.7 Selection Criteria for Skeletal Sample:

A total of 69 individuals were selected for this aspect of the study. Their breakdown is shown in *Table 3.04.*

a) ***Age***: Individuals between the ages of 13 - 23 years were chosen. The ages at death were recorded at the time of autopsy whose accuracy is harder to confirm.

b) ***Sex:*** Obtained from the records within the collection which were originally obtained from medical records and/or soft tissue inspections which were recorded at the time of death and more reliable than the age estimates.

c) ***Population affinity*:** Since the radiographic data collected from hospitals and mortuaries represented primarily individuals from an African background, the sample of skeletal material also represented individuals from an African origin. The collection has a larger number of South African African specimens which were chosen for the current research. According to the records, many individuals represented by the skeletons in the collection were migrant workers whose origins were either unknown or not accurately recorded on their death certificates. In some cases it is reported that the „tribe" name was determined from an individual"s surname.

d) ***Choice of source of skeletal sample:*** The Dart collection was chosen because it had a larger number of skeletal individuals which were of interest to this study and it was situated close to Statscan facility.

Table 3.04: Breakdown of Raymond Dart Collection by Sex

Age	Male	Female	Total
13 years	1	1	2
14 years	1		1
15 years	2	1	3
16 years	4	2	6
17 years	5	1	6
18 years	7	2	9
19 years	2	4	6
20 years	5	2	7
21 years	6	3	9
22 years	8	3	11
23 years	4	5	9
Total	**45**	**24**	**69**

3.2 METHODS

Images generated by the Statscan ™ contain on them a number for reference to a particular patient. This number is generated by the computer and was used by the researcher during the initial stages of data collection which were to identify a viable sample. This information was later used to extract additional patient demographic information from patient files. Once the sample had been finalised a unique code was assigned to the individual incorporated into this study. The code was designed to include the institution and number (position) of the individual in the sample. For example, the first patient from Red Cross to be included in this sample would be allocated a code of RXH001; the second would be RXH002 and so on.

3.2.1 (a) Information Collected from the Radiographic Images:

The medical record number, scan number, surname, first name, sex, date of birth and scan date were collected from each image. The radiographs obtained from Milpark hospital were incomplete with regard to information. They did not contain on them the date of birth of patients and were much harder to assess as a sample. Patient records were first assessed, thereafter radiographs were chosen if the patient fell into the age range selected for the present study. For additional information regarding genetic background and residential address and reason for hospitalisation, the researcher approached each institution, to gain access to patient files where the information could be extracted.

3.2.1 (b) Information Collected from Mortuary data: Data for the Tygerberg mortuary was obtained after the researcher perused the radiographs. A list of individuals of possible interest was sent to the mortuary administrator. Since information on genetic background and cause of death was not included by the administrator, the researcher requested post mortem files of the deceased. By viewing photographs of the deceased an assessment was made on genetic background. Salt River mortuary on the other hand provided the breakdown of their mortuary data and this was used to extract a sample of interest to this study.

3.2.2 Assessment of Socio Economic Status (SES): Classification of the SES for the current sample was based on the residential address/ suburb as determined from patient records as suggested by Christopher (2002). The average incomes of the respective suburbs were determined from Suburb Reports of the Western Cape (http://www.capetown.gov.za/en/stats/Pages/2011-Census-Suburb-Profiles-land.aspx). These classifications are based on variables such as the type of dwelling (formal/ informal), use of electricity for cooking, access to piped water on the property, access to refuse removal, level of education and average monthly income. The names for the status classification of the groups were conducted based on the definitions by Seekings (2003), who suggested that social classes can be constructed based on the occupation of the individual. Seekings (2003) also utilised average monthly income in the classification. The differentiation into the upper, intermediate and marginal working classes for the South African sample was based on the average income per suburb of Western Cape.

The three social classes categorised for the purpose of this study comprise of the Marginal working class (MC) who earn less than R3,200 per month (considered to be minimum wage), the Intermediate working class (IWC) consists of between 22 - 60% individuals who earn less than minimum wage but have higher percentages of formal dwelling, are more educated and increased employment rate. Finally the Upper Class (UC) consists of the greatest percentage of educated individuals, who are predominantly employed and have the least amount of individuals who earn less than minimum wage. This system is similar to the one proposed by Tobias (1985), however the classification of non-industrialised and pastoral communities would not suffice in modern populations. The classification of suburbs of origin for individuals from the current study can be found in *Appendix 2*. Data for the classifications were obtained through communication with staff at Statistics South Africa (2014).

3.2.3 Assessment of Genetic Background: Was obtained either directly from patient records or as in the case of Groote Schuur Hospital from a numeric score allocated to a patient. This numeric score which represented the population affinity or genetic background and its interpretation was obtained from the database managers at the hospital through personal communication. English 1 (English first language) patients were classified as White; Coloureds as a 2; Indian or Asian as 3 and finally Black individuals were classified as a 4. If the numeric score was not provided, genetic background was classified as Coloured, White, Black or Indian. In the absence of such information, the genetic background classification was left blank.

3.2.4 Exclusion Criteria: Initially data was collected by selecting relevant images from the information provided on the radiographs. These were selected by assessing the year of birth. However, in many of the cases while going through patient records at the hospitals it was noted that the recorded date of births were incorrect. Where necessary they were corrected, however if the correction of the dates of birth increased the ages of the individual above 30 years or below eight years, the image was removed from the sample. Although the database from the Charlotte Maxeke hospital was assessed for viable images, the scans were not supported by additional patient data which were pivotal to this research such as age (date of scan and date of birth). Therefore all samples from this location were removed from the study. Some cases from the Western Cape represented individuals who were not born in South Africa. These were removed. Finally, radiographs were excluded if the assessment of the left and right side yielded differing scores.

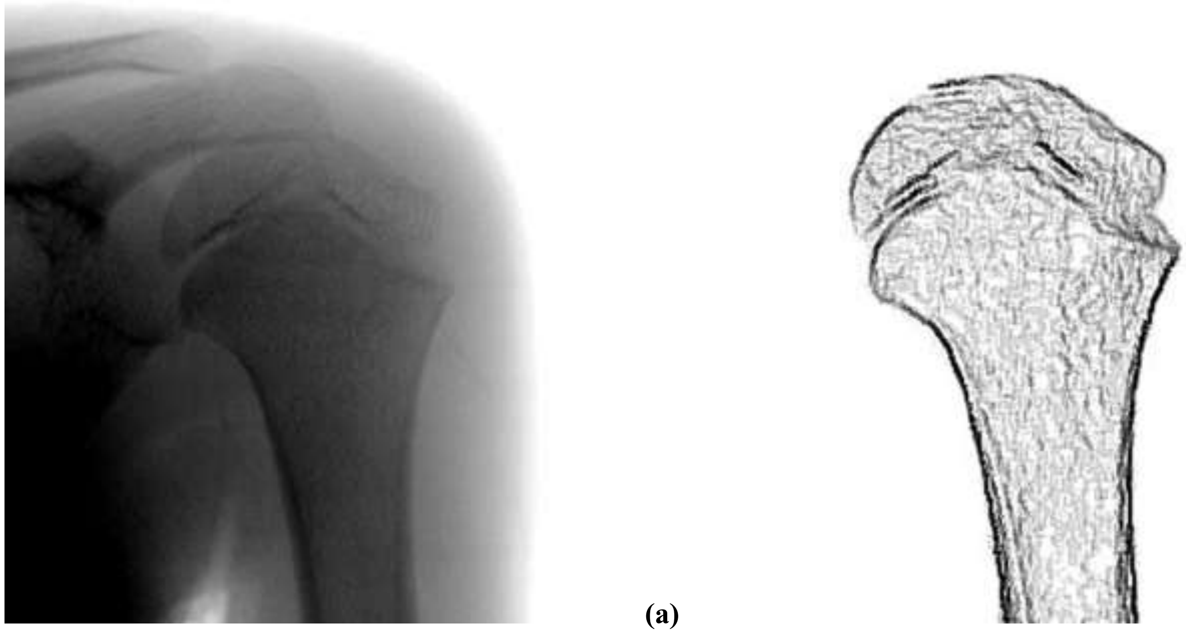
3.3 Assessment of Union

3.3.1 Assessment of Radiographs of Contemporary Sample

The stages used during the classification of state of union were derived by Ousley and colleagues (2013) were obtained through personal communication with Kyra Stull who collected radiographic images in the United States of America. Theirs is one of the few contemporary studies based on radiographs of the major joints of the body and not just the wrist. These descriptions were originally modified by the researcher from Schmeling *et al*., (2004). This current study uses the four stages described in *Table 3.05* by Ousley and colleagues (2013).

Table 3.05: Classification of Stages of Union (Ousley *et al*., 2013)

<u>Stage 1- Non Fusion</u>: Epiphyses range in size from absent to smaller than the metaphysis. Should epiphysis be present they are usually smaller in size than the metaphysis and may exhibit differences in shape. This stage is also characterised by the visible gap between the adjacent surfaces *(Figure 3.03a)*	 3.03 (a)
<u>Stage 2- Partial fusion of less than 50%:</u> Diameters of the metaphysis and diaphysis are similar in size and shape. 0 to 50% union may be observed. Less than 50% of the adjacent ends are touching *(Figure 3.03 b)*	 3.03 (b)
<u>Stage 3- Greater than 50% fusion:</u> Over 50% of the adjacent surfaces are in contact. Visible islands of cartilaginous ossification, however, there is increased continuity of shape between adjacent structures *(Figure 3.03c)*	 3.03 (c)
<u>Stage 4: Complete Fusion:</u> Complete articulation of epiphysis and diaphysis to form a single structure *(Figure 3.03d)*	 3.03 (d)



(a) (b)

Figure 3.04: *Stage 1 of the shoulder joint in a 6.5 year old female. The head is scored as a 1 since the epiphysis is smaller in size compared to the adjacent diaphysis and no union is taking place. The greater tubercle is also scored a 1 due to the difference in size between the epiphysis and adjacent diaphysis.*

** Figure (a) depicts the radiograph of the individual while (b) represents the sketch of the radio to enhance the observations*

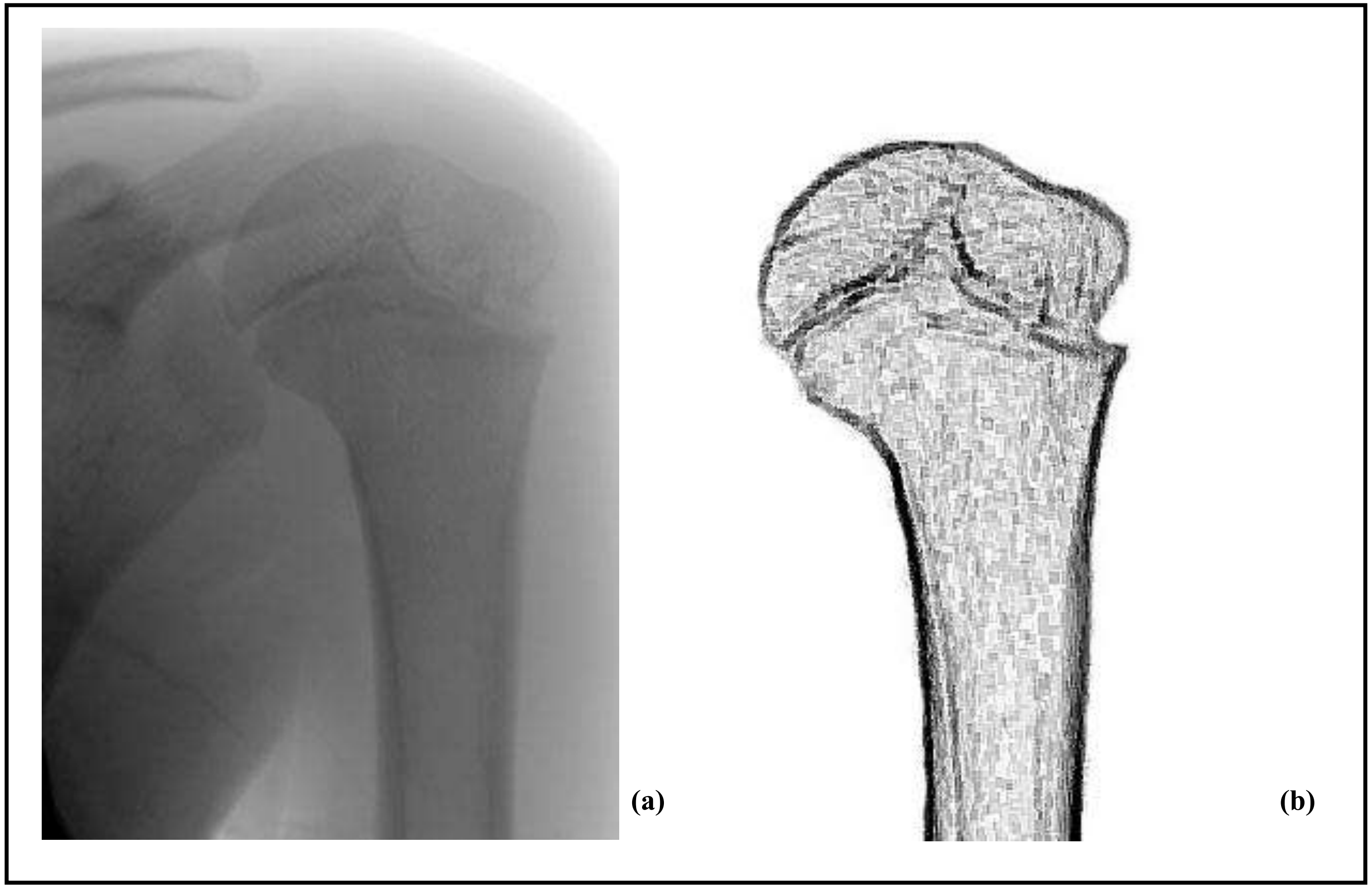


Figure 3.05: *Stage 2 of the shoulder (head of humerus and greater tubercle) in an 11 year old male.* *The head of the humerus is scored as a stage 2 as it is approximately the same size as the adjacent diaphysis but less than 50% union is occurring. The greater tubercle scored as 1 because it has still not reached complete size and less than 50% union is taking place.*

** Figure (a) depicts the radiograph of the individual while (b) represents the sketch of the radio to enhance the observations*

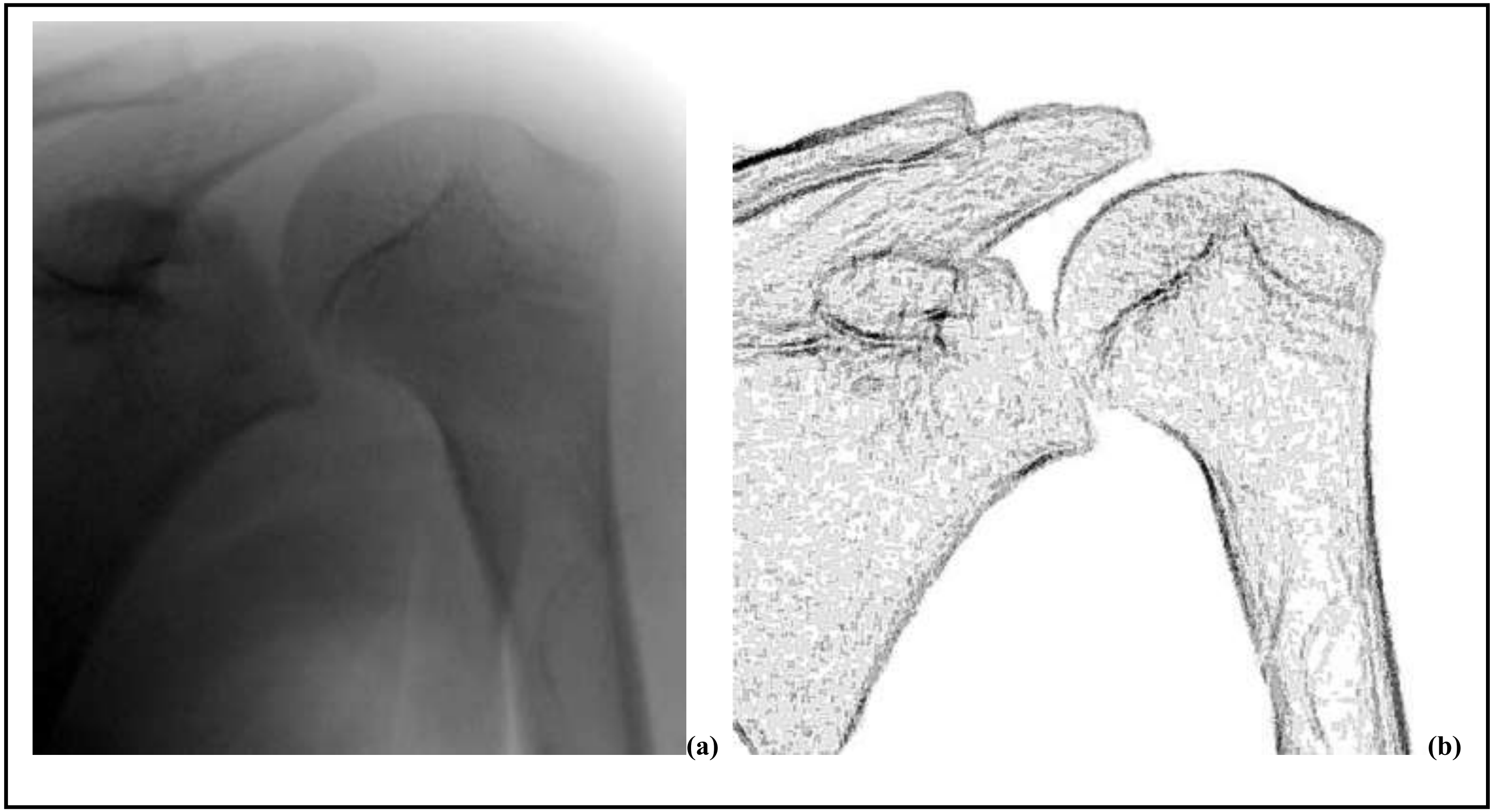


Figure 3.06: *Stage 3 at the shoulder in a 20.8 years old male.* *The shoulder (head of humerus and greater tubercle) is scored as 3 both epiphyses are of the same size and show greater than 50% union with the adjacent shaft.*

** Figure (a) depicts the radiograph of the individual while (b) represents the sketch of the radio to enhance the observations*

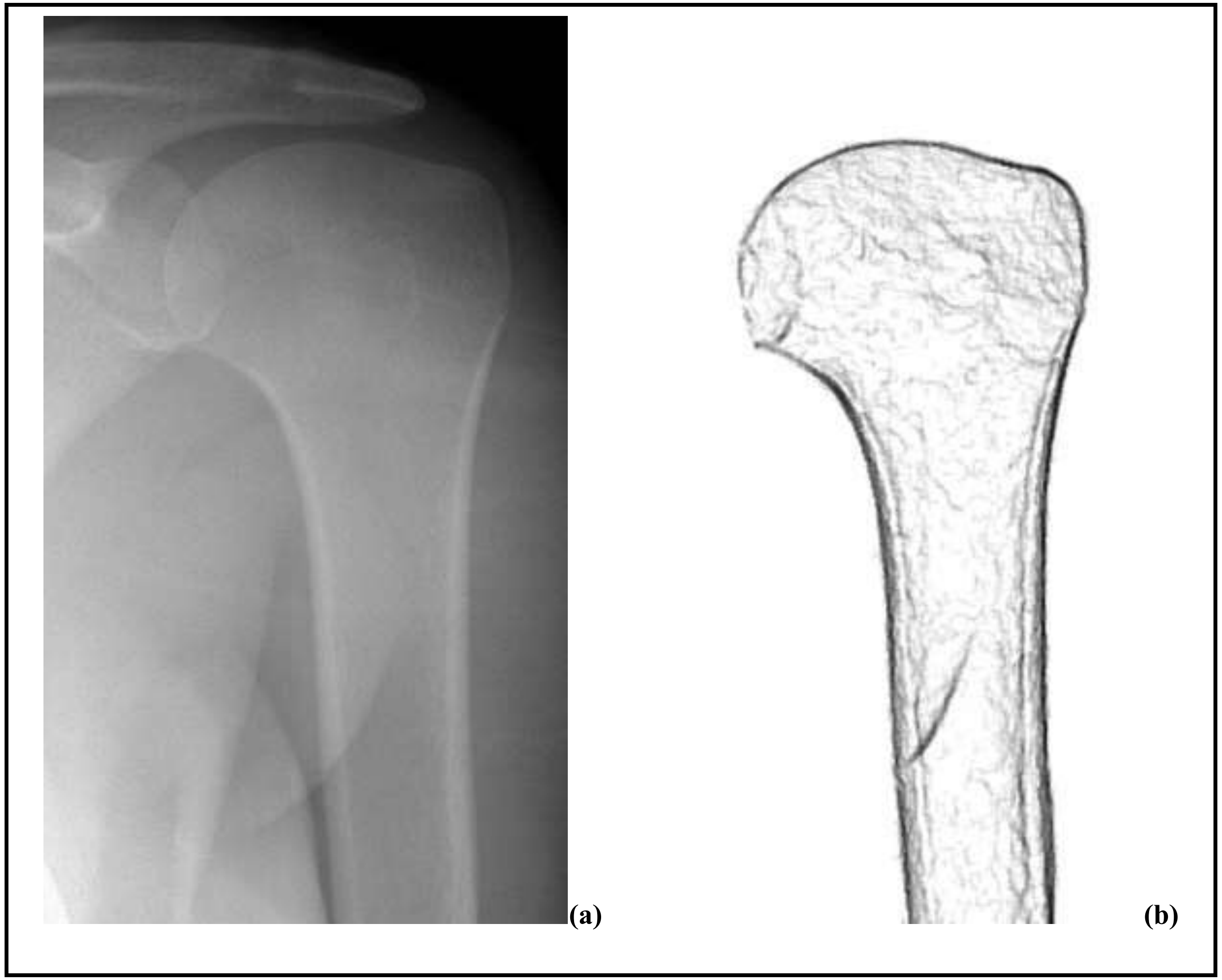


Figure 3.07: *Stage 4 (complete union) of the shoulder in a 17.5 years old female.*

** Figure (a) depicts the radiograph of the individual while (b) represents the sketch of the radio to enhance the observations*

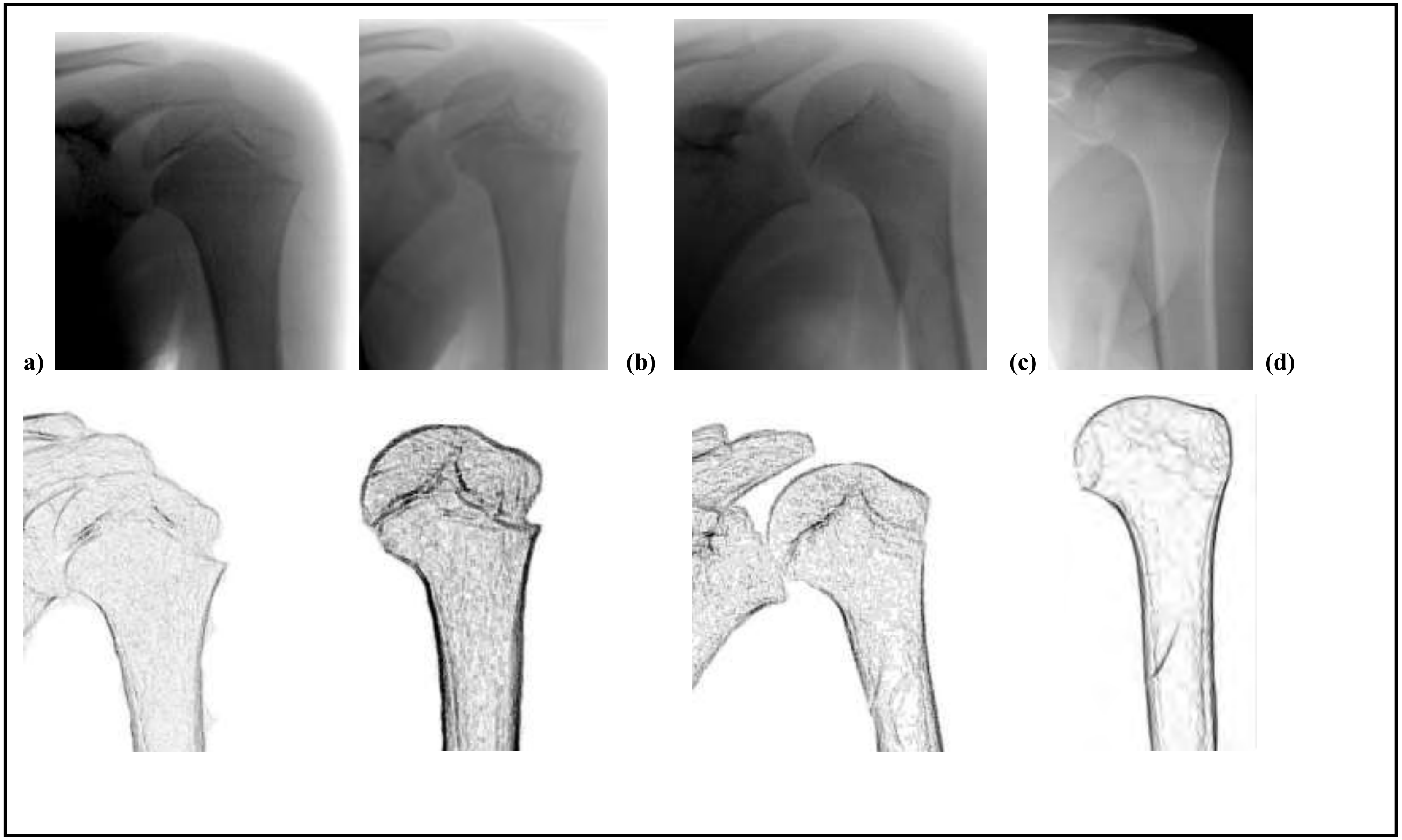


Figure 3.08: *Summary of union from stage 1 to stage 4 of union at the shoulder joint. Stage 1 is characterised by the absence of epiphyses and may include the formation of the epiphysis but they are usually smaller in size compared to the adjacent diaphysis. As union progresses, the epiphyses grow in size, the gap between the epiphyses and diaphyses narrows until complete union takes place (d).*

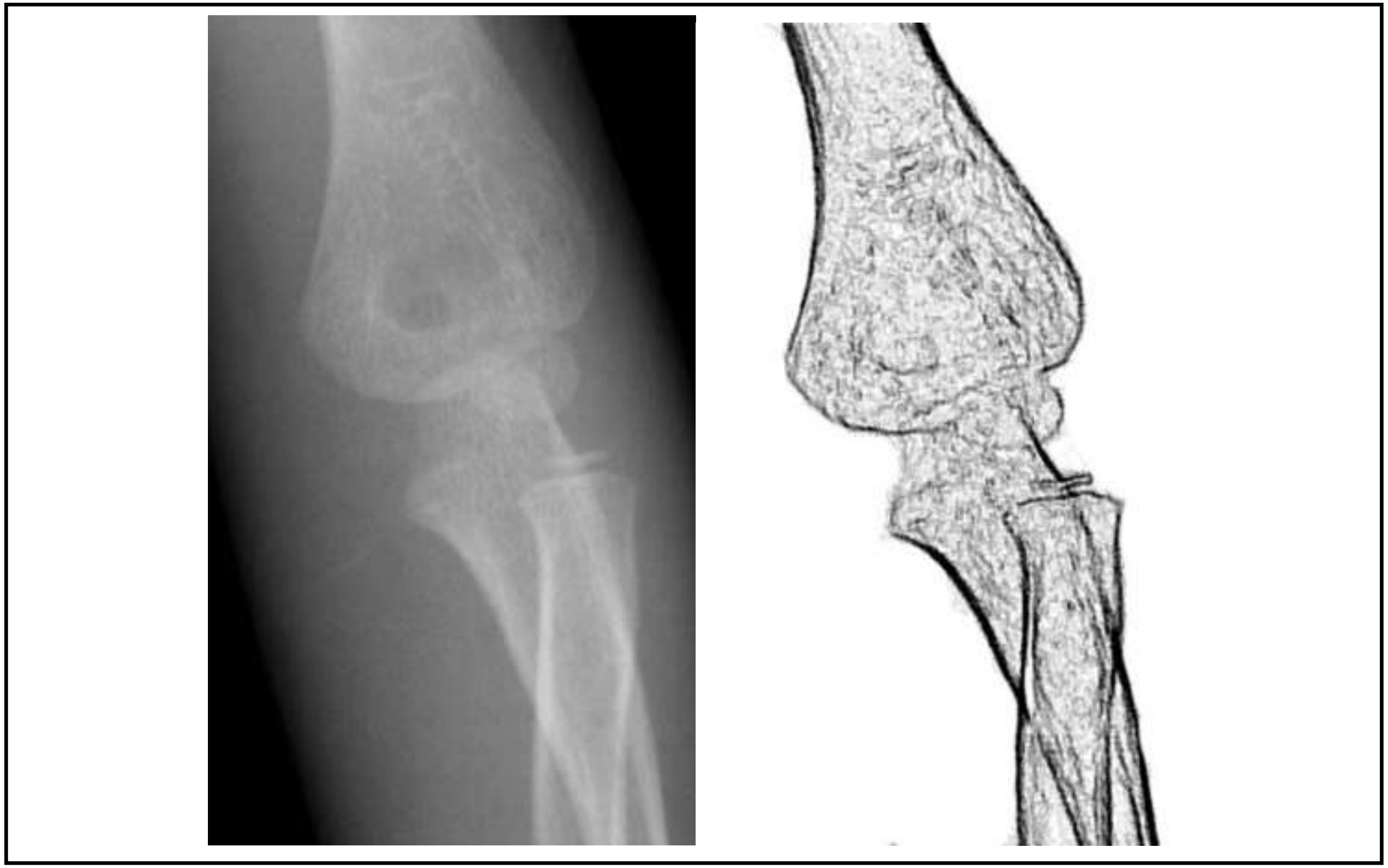
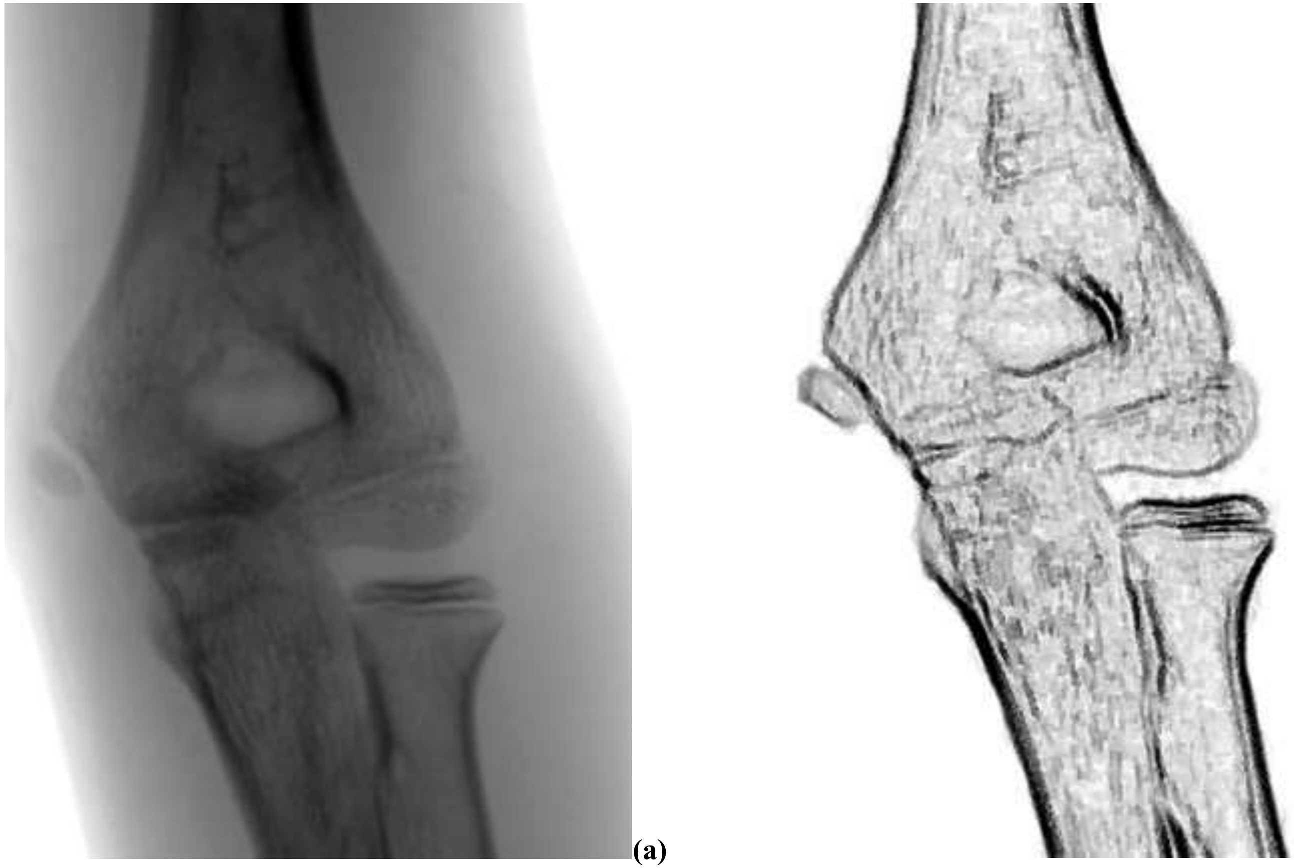


Figure 3.09: *Stage 1 of the elbow in a 7.3 years old male***,** *the medial epicondyle and trochlea are absent hence scored as 1. The capitulum is present but appears to be smaller in size compared to the adjacent epiphysis hence scored as 1. The absence of the lateral epicondyle is therefore also scored as 1. The epiphysis of the proximal radius is also scored as a 1 due to the difference in size of the epiphysis as well as the observed gap between the epiphysis and diaphysis.*



(a) **(b)**

Figure 3.10: *Stage 2 at the elbow in an 11.9 year old male showing stage 1 for the medial epicondyle (size of the epiphysis is smaller than diaphysis, stage 2 for the trochlea (similar in size but less than 50% union), stage 2 (similar in size but less than 50% union) for the capitulum and stage 1 for the lateral epicondyle as the epiphysis is not present yet.*

** Figure (a) depicts the radiograph of the individual while (b) represents the sketch of the radio to enhance the observations*

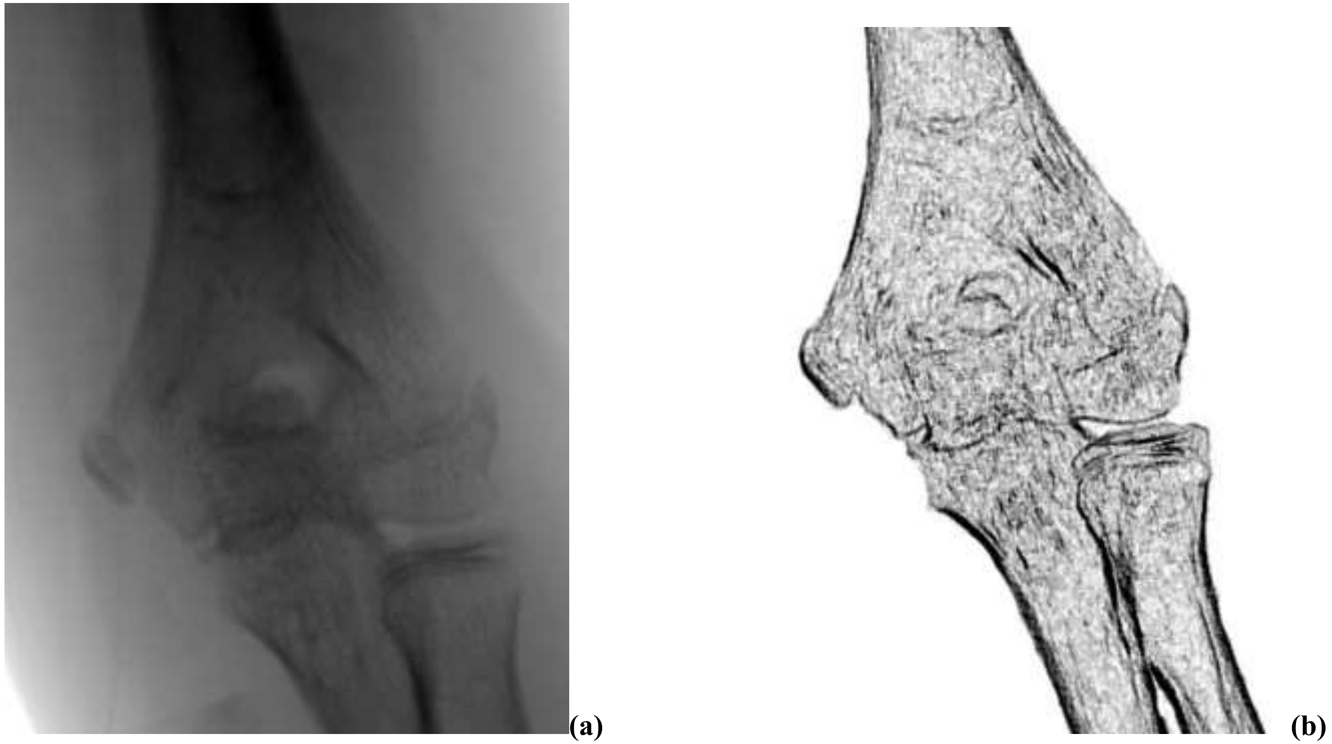
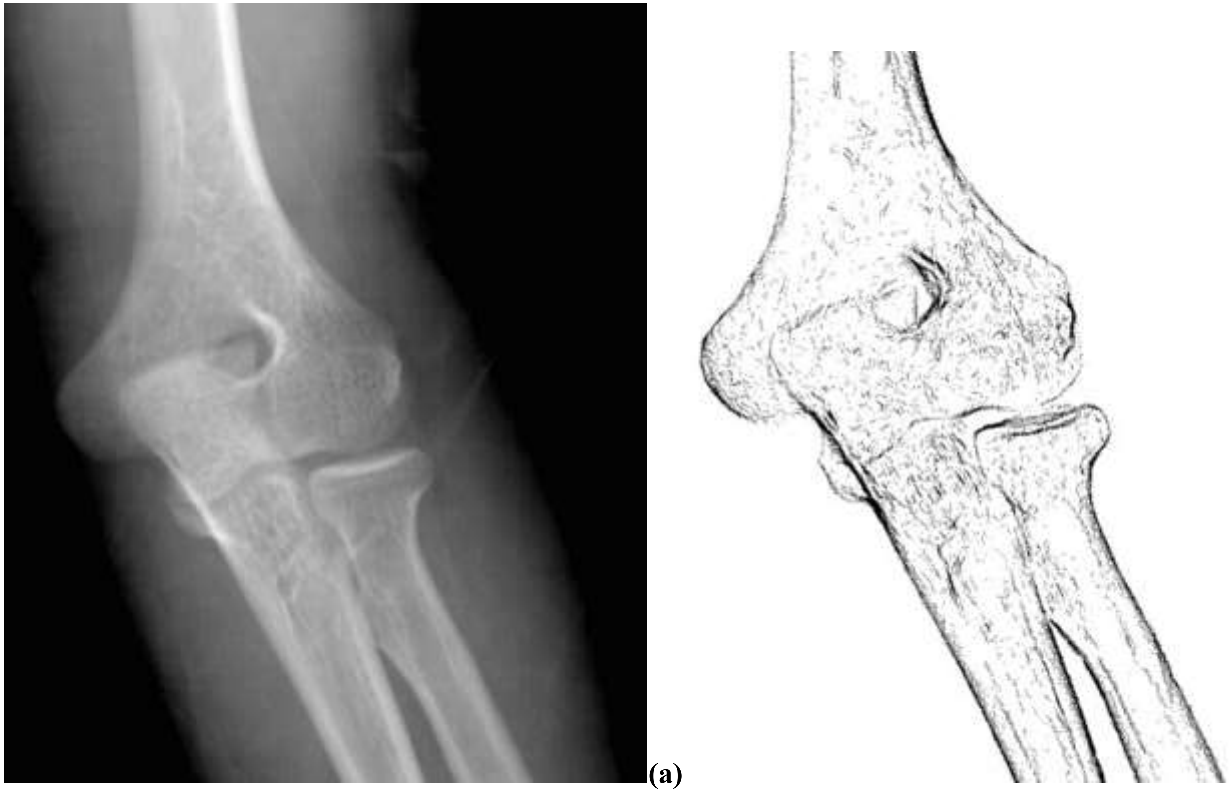


Figure 3.11: *Stage 3 of the elbow joint in a 20.8 year male the epiphyses which include the medial epicondyle, trochlea, capitulum, lateral and proximal radius are scored as three as they show (greater than 50% union with their adjacent shafts.*



(a) (b)

Figure 3.12: *Complete union of the elbow in a 14.1 year old female.*

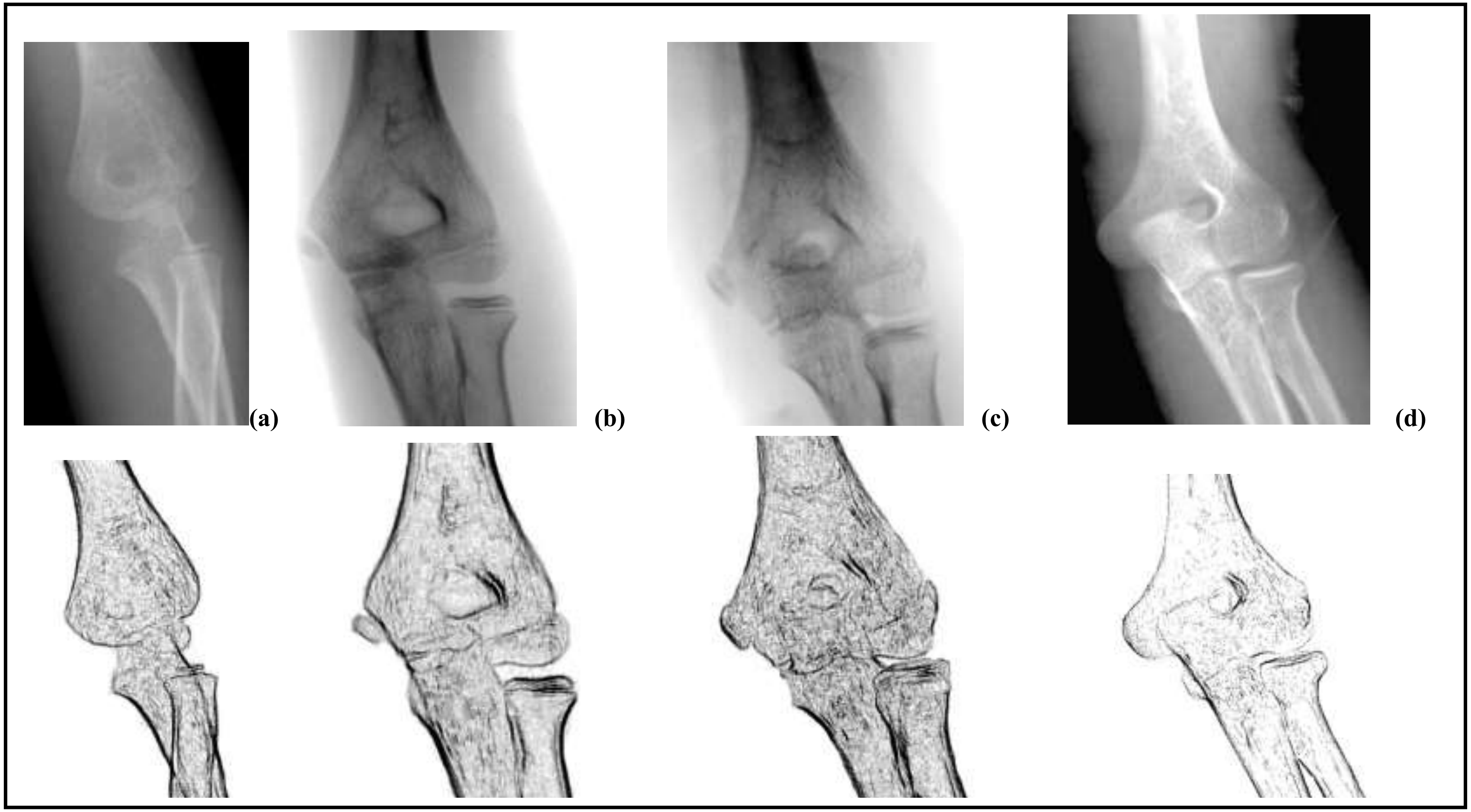


Figure 3.13: *Summary of the progression of union from stage 1 to stage 4 of union at the elbow joint. Stage 1(a) is characterised by the absence of epiphyses and may include the formation of the epiphysis but they are usually smaller in size compared to the adjacent diaphysis. As union progresses, the epiphyses grow in size, the gap between the epiphyses and diaphyses narrows until complete union takes place (d).*

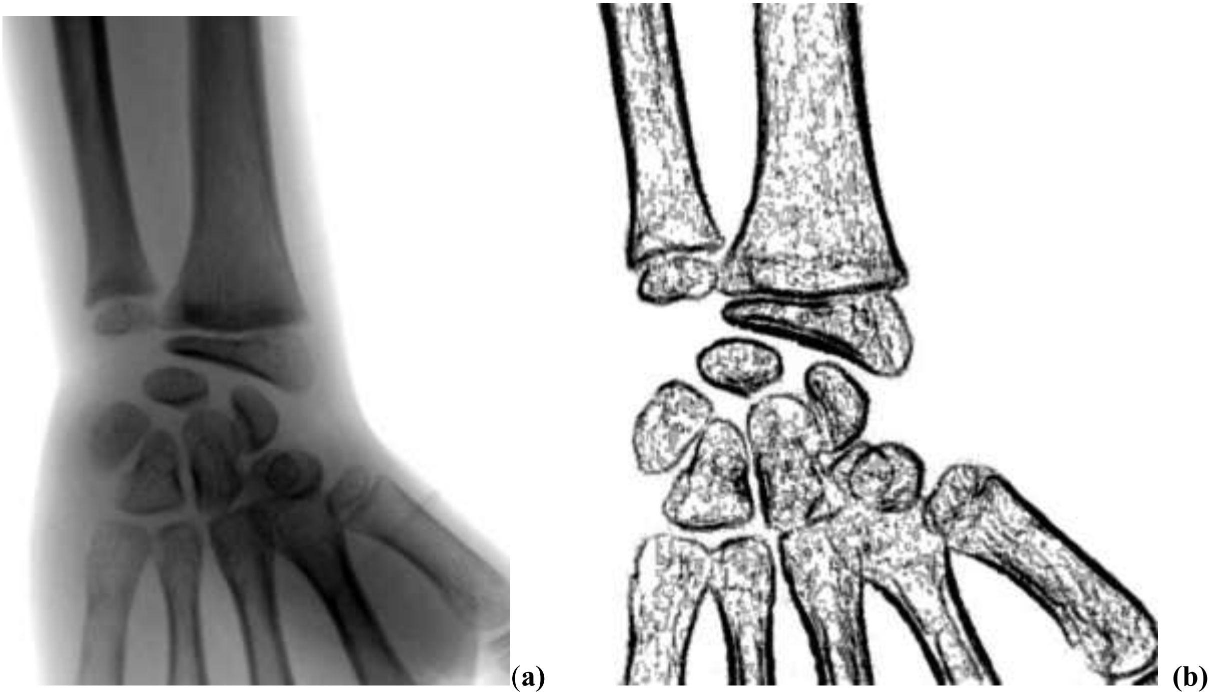


Figure 3.14 (a): *Stage 1 of the wrist in male aged 15 years. The epiphysis of both the distal radius as well as the ulna appears smaller in size compared to the diaphysis and the characteristic gap of stage 1 can be observed.*

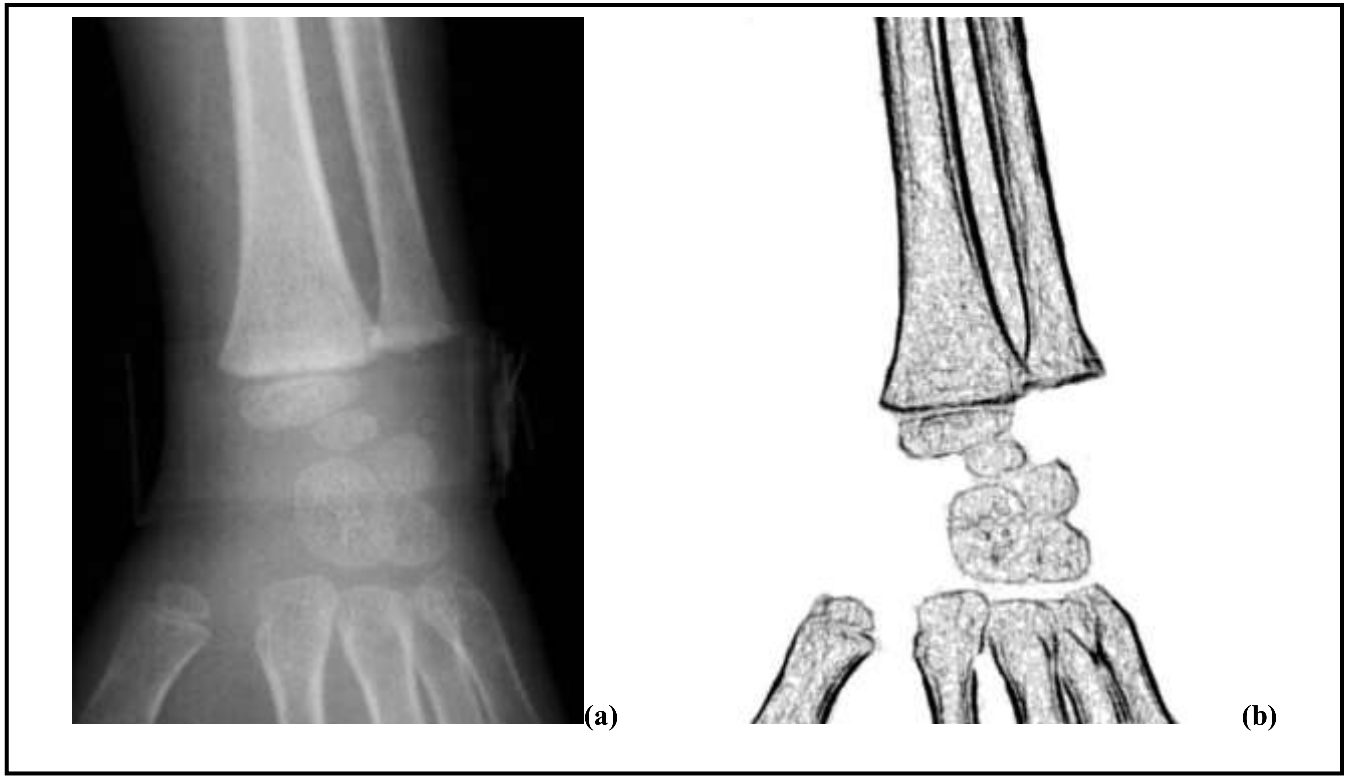
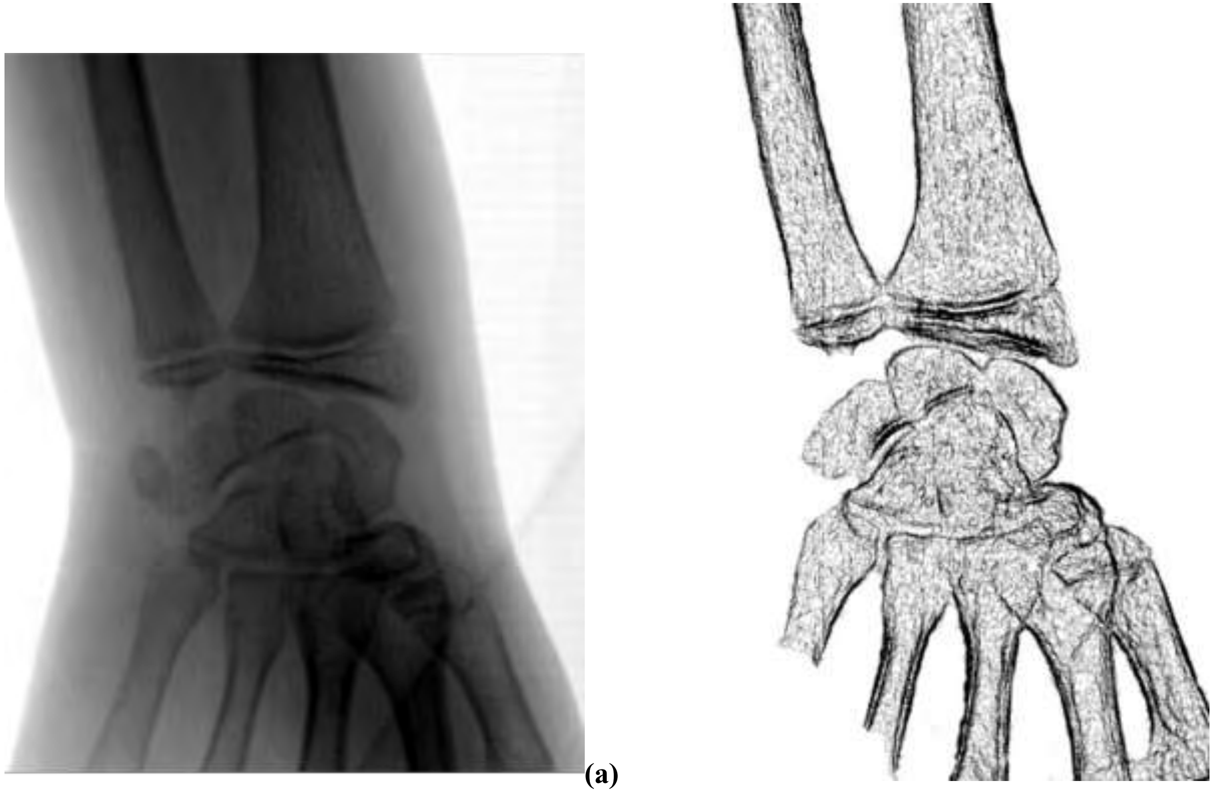


Figure 3.15: *Variation in stage 1 at the wrist in an 11 year old male. The distal epiphysis of the ulna is absent while the epiphysis of the distal radius appears smaller than the adjacent shaft and does not appear to be in full form. It is therefore scored as stage 1.*



(a) (b)

Figure 3.16: *Stage 2 of the wrist in a 10 year old female. Both the distal ulna and radius are of similar size to the diaphysis but show less than 50% union.*

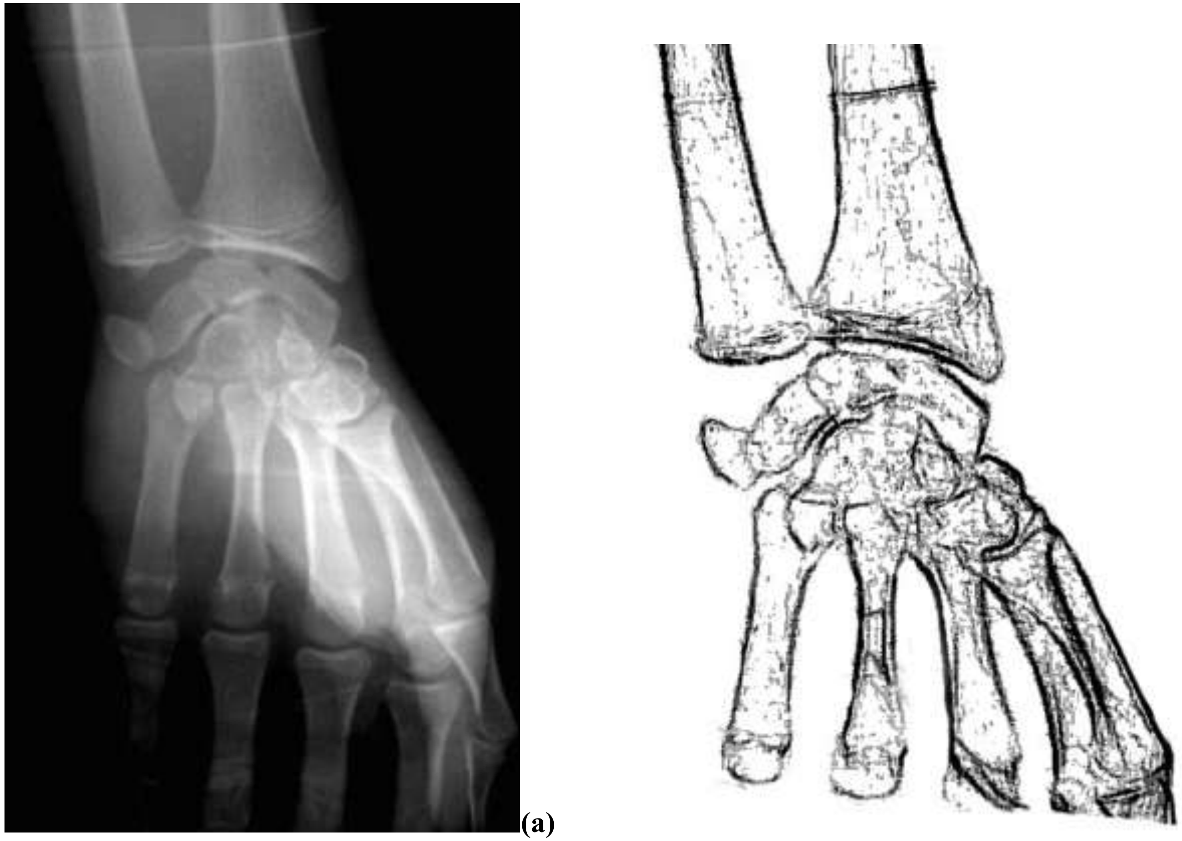


Figure 3.17: *Stage 3 of the wrist in an 11.9 year old female showing greater than 50% union in both distal ulna and radius.*

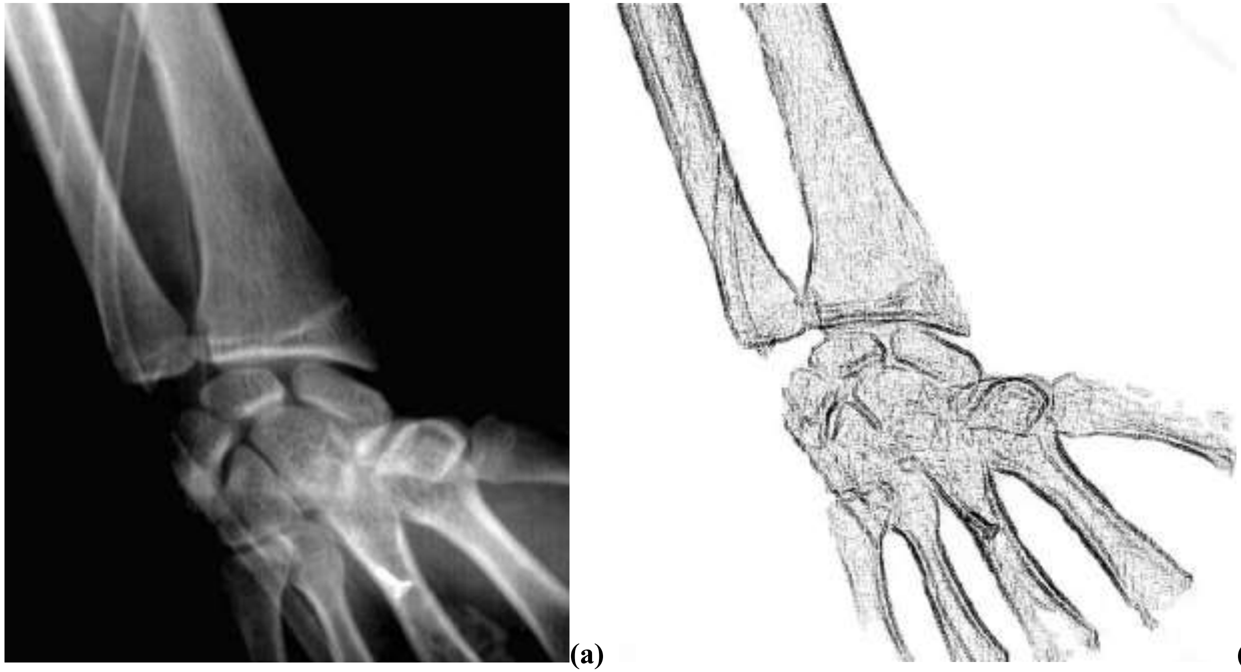


Figure 3.18: *Stage 4 (complete union) of the wrist in a 14.1 year old female. The lines of recent union can still be observed on the distal radius.*

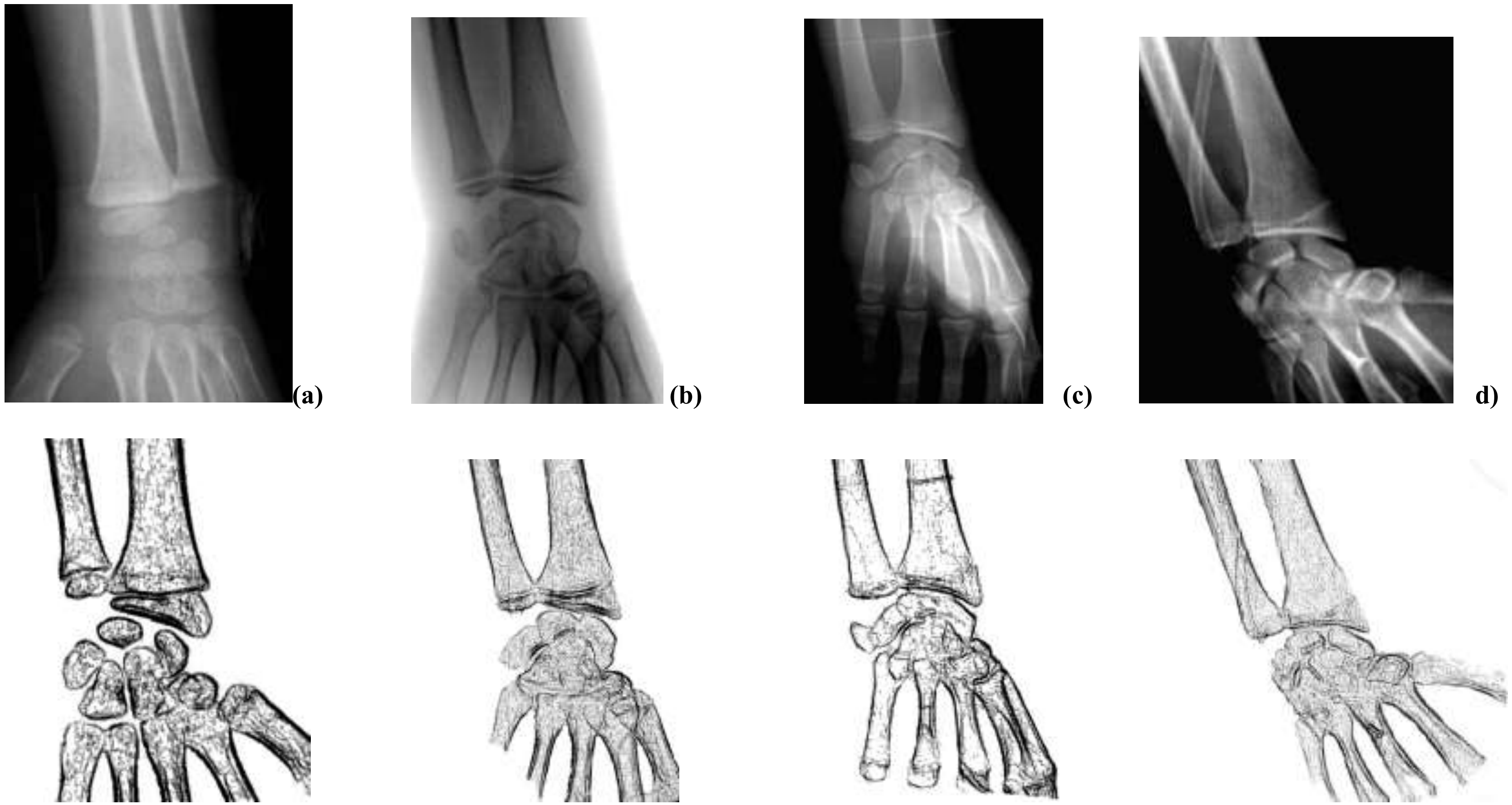
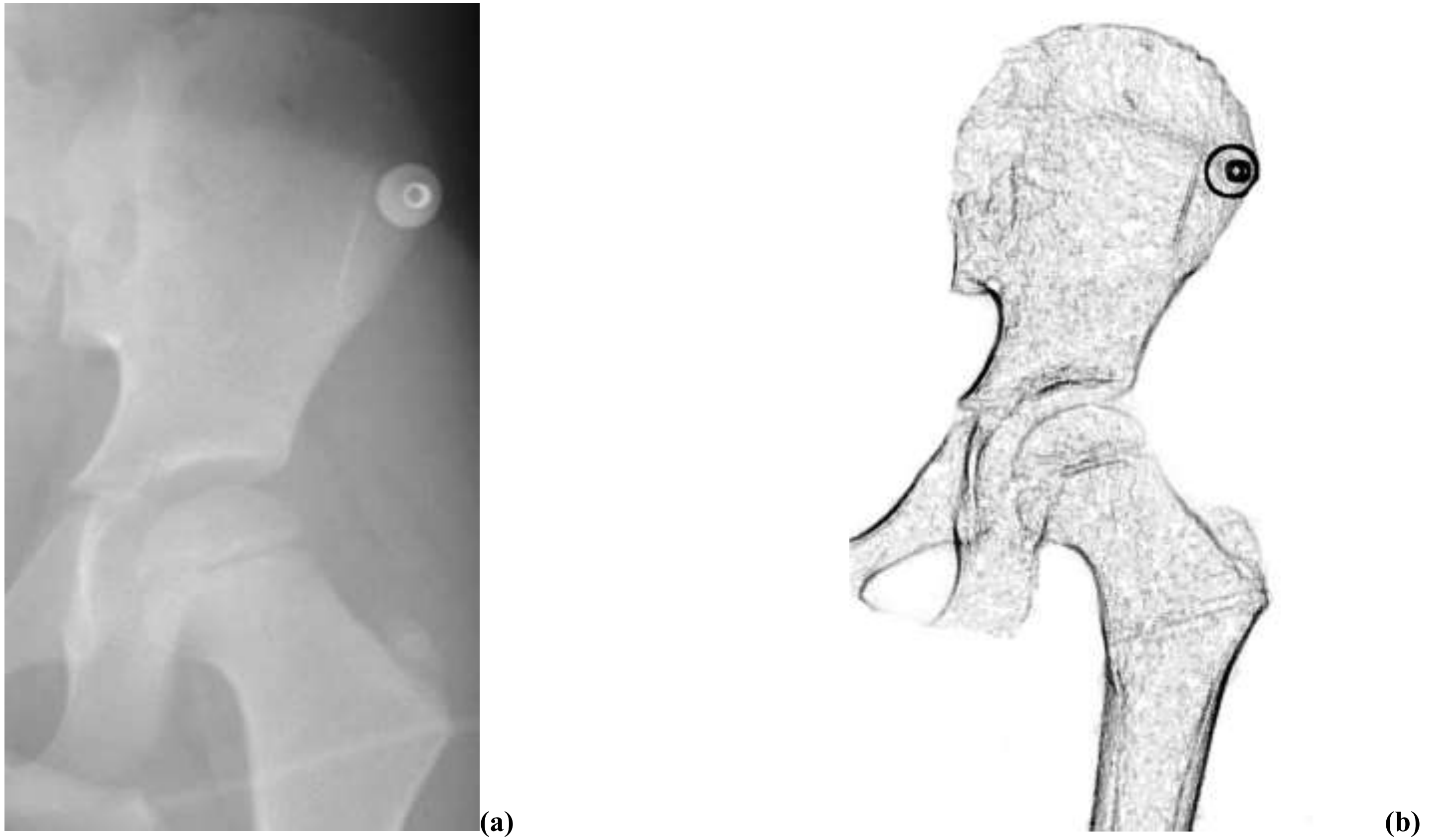


Figure 3.19: *Summary of the progression of union from stage 1 to stage 4 of union at the wrist joint. Stage 1(a) is characterised by the absence of epiphyses (distal ulna) and may include the formation of the epiphysis (b) but they are usually smaller in size compared to the adjacent diaphysis. As union progresses, the epiphyses grow in size; the gap between the epiphyses and diaphyses narrows until complete union takes place(d).*



(a) (b)

Figure 3.20: *Stage 1 of the hip in a male aged 7.3 years. The head of the femur, greater and lesser trochanters are all scored a 1. The head of the femur shows non-union and is smaller in size than the adjacent diaphysis. The greater trochanter has not reached adult shape and the epiphysis of the lesser trochanter has not appeared yet and hence scored as 1. The epiphysis of the iliac crest has not appeared and is also scored as stage 1.*

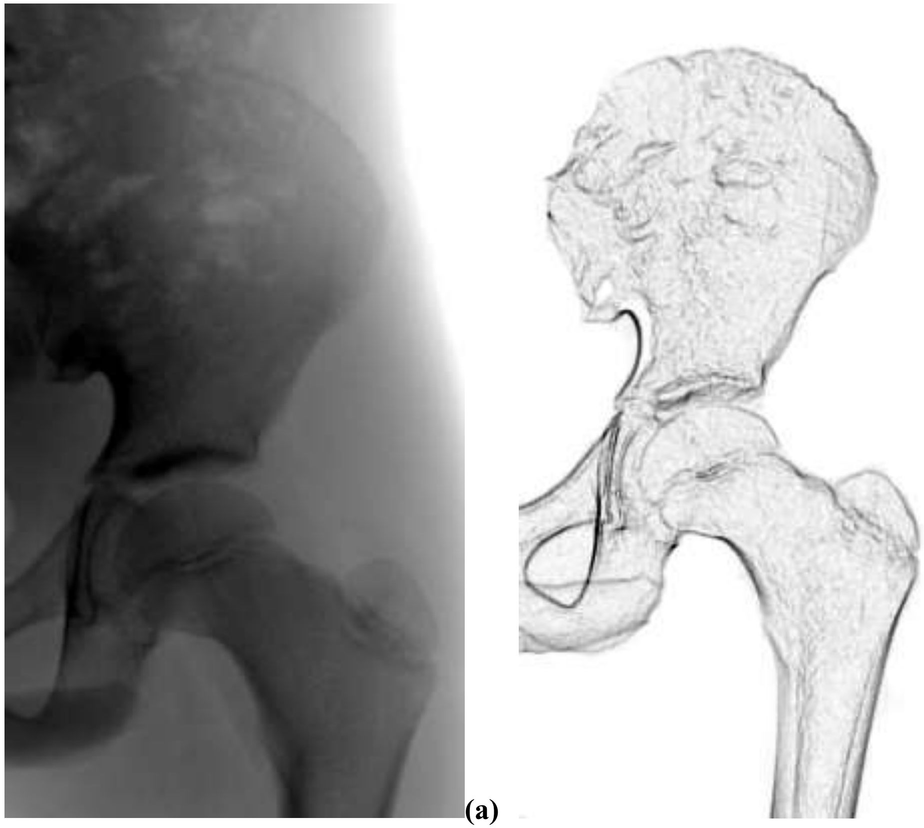


Figure 3.21: *A combination of stages 1 and 2 at the hip in an 11 year old male. The head of the femur and greater trochanter show less than 50% union, both epiphyses appear larger in size than stage 1 and show less than 50% union. The iliac crest and lesser trochanter are scored as a 1 due to the prominent absence of the epiphyses.*

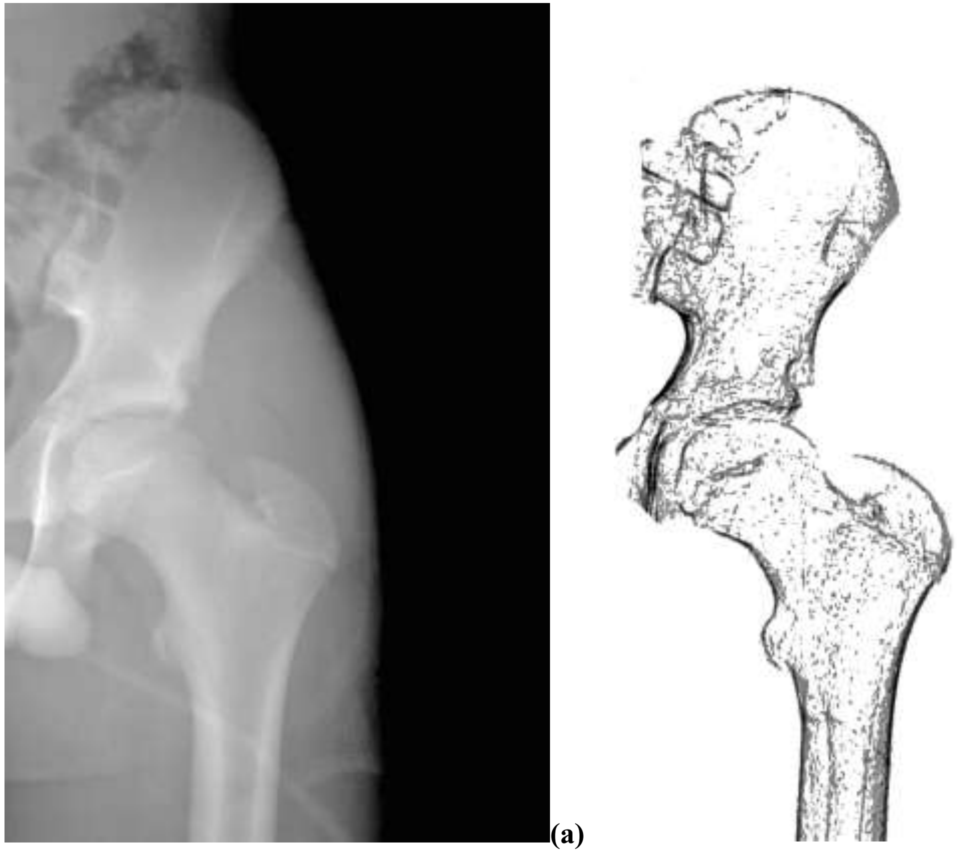
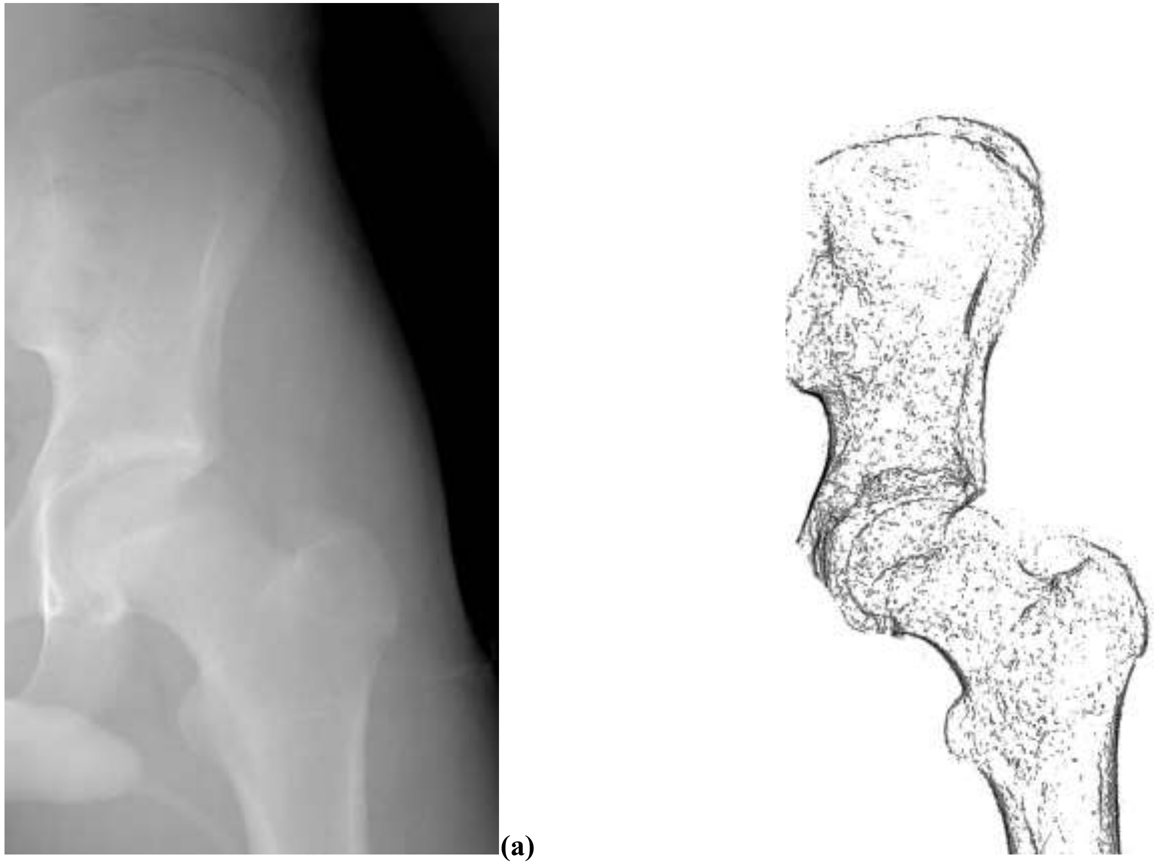

(a) (b)

Figure 3.22: *Stage 3 at the hip and stage 1 of the iliac crest in a 15 year old male***.** *The head, greater trochanter and lesser trochanter are scored as a 3 since they show greater than 50% union. The epiphysis of the anterior iliac crest on the other hand is still absent and hence scored as a stage 1.*



(a) **(b)**

Figure 3.23: *Stage 4 (complete union) at the hip in a 15 year old male. While the head of the femur as well as the greater and lesser trochanters are scored as completely united (4). The anterior view of the hip shows a small portion of epiphysis of the anterior superior iliac spine. The spine is scored as a 2 since the development of epiphysis of the iliac crest is unique.*

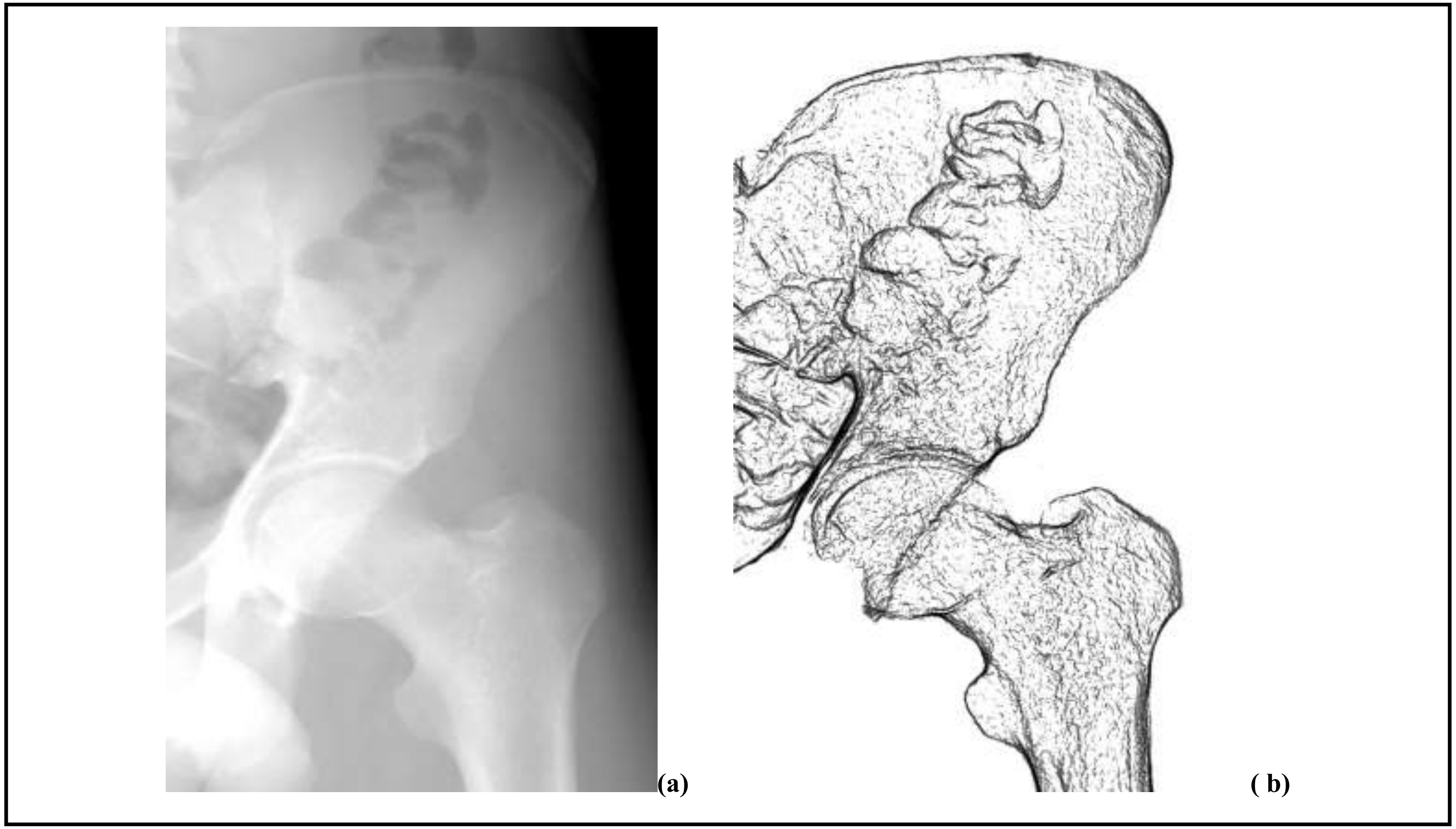


Figure 3.24: *Stage 3 of the iliac crest in a 19.5 year old male. The formation of the epiphysis is complete; although it appears complete it shows greater than 50% union. The head of the femur, greater and lesser trochanters are scored as 4 (complete union).*

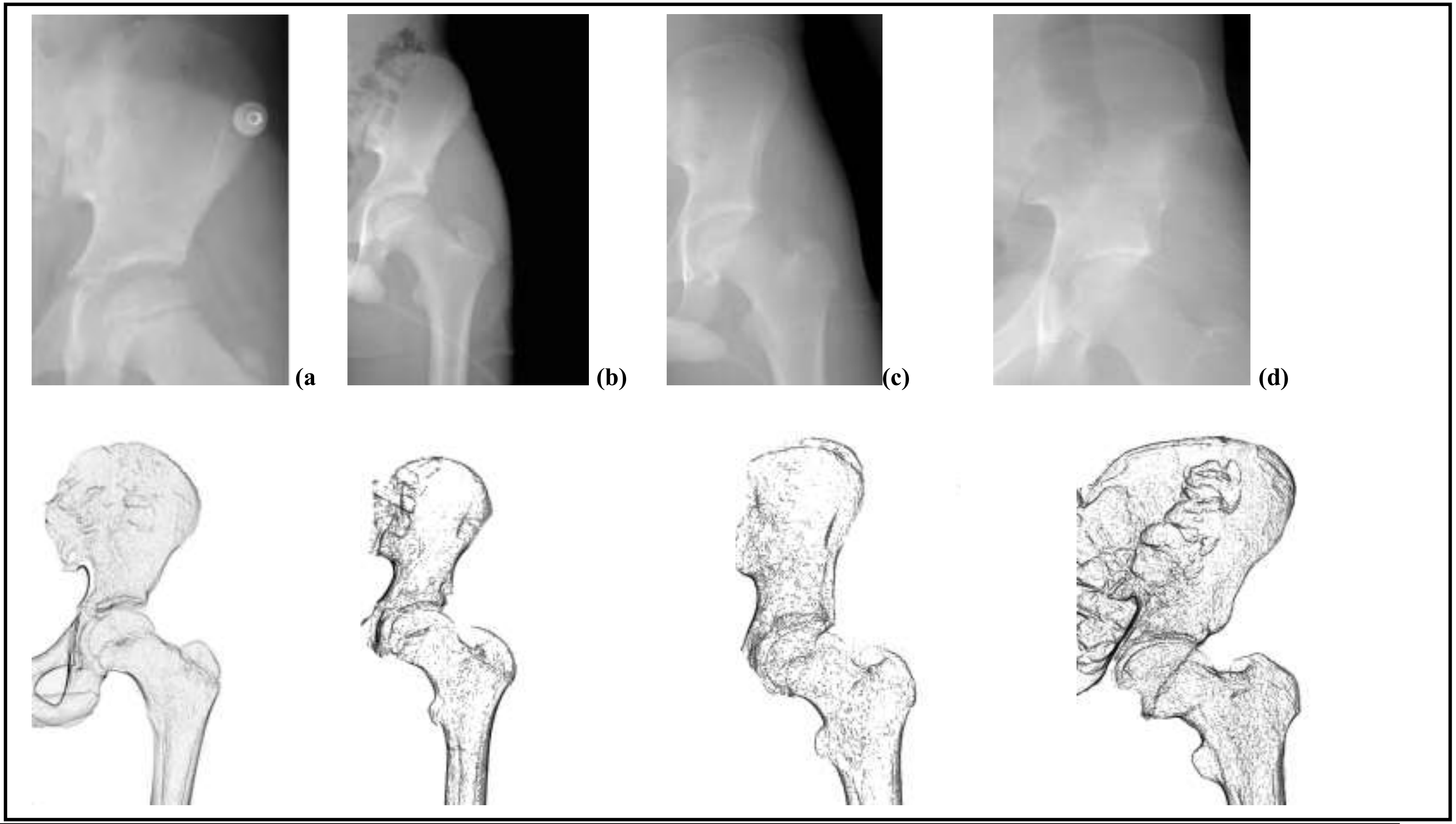


Figure 3.34: *Summary of the progression of union from stage 1 to stage 4 of union at the elbow joint. Stage 1 is characterised by the absence of epiphyses and may include the formation of the epiphysis, if present it is usually smaller in size compared to the adjacent diaphyses. As union progresses, the epiphyses grow in size and the gap between the epiphyses and diaphyses narrows until complete union takes place stage 4 (d).*

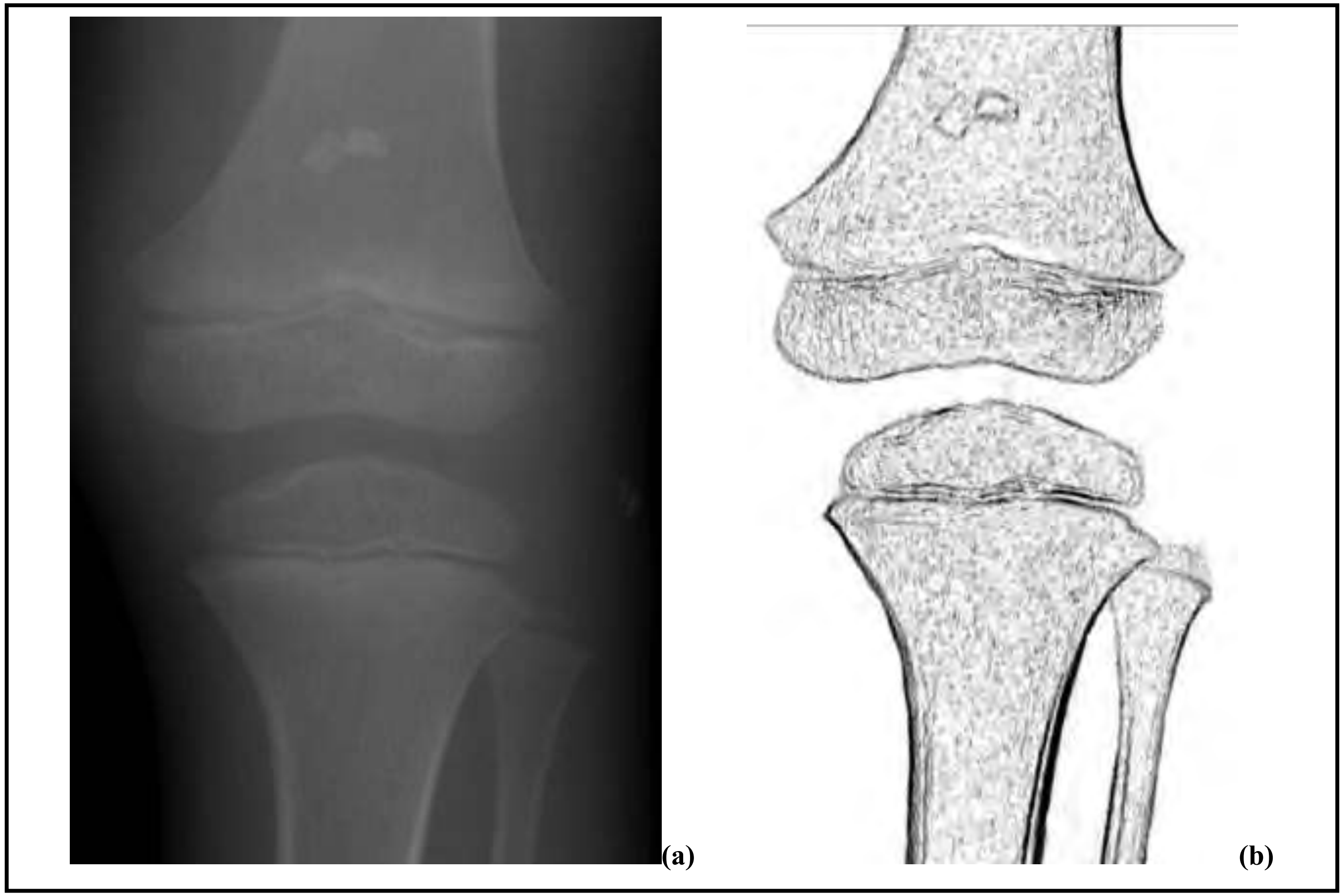


Figure 3.25: *Stage 1 of the knee in a 7.3 year old male. The epiphyses of the distal femur, proximal tibia and proximal fibula can all be scored as 1 as the epiphyses are smaller in size compared to the adjacent diaphysis. The gap although small; shows no union between the adjacent surfaces.*

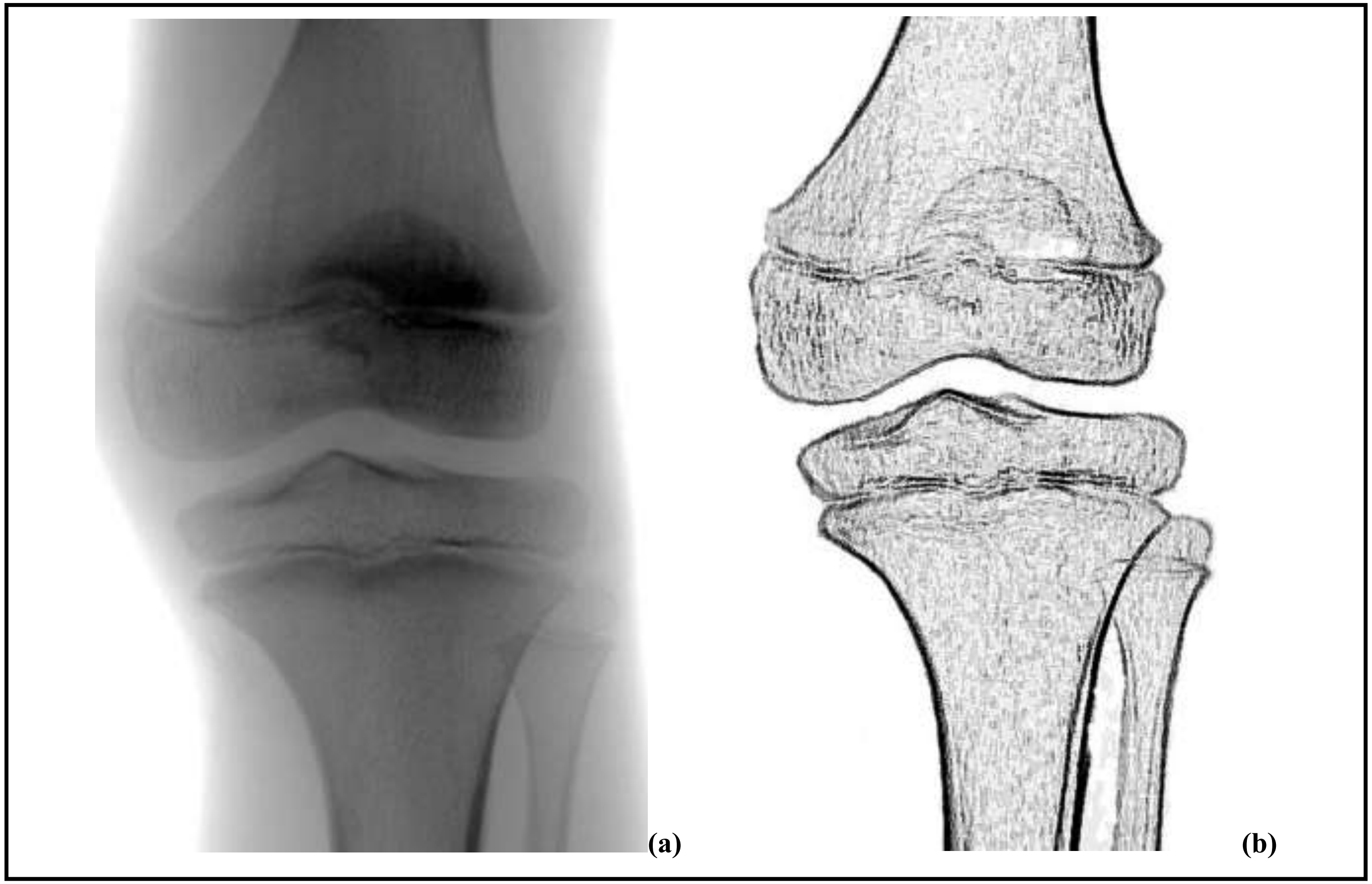


Figure 3.26: *Stage 2 of the knee in an 11 year old male. The epiphyses of the distal femur, proximal tibia and fibula are similar in size to the adjacent shaft and show less than 50% union and hence scored as stage 2.*

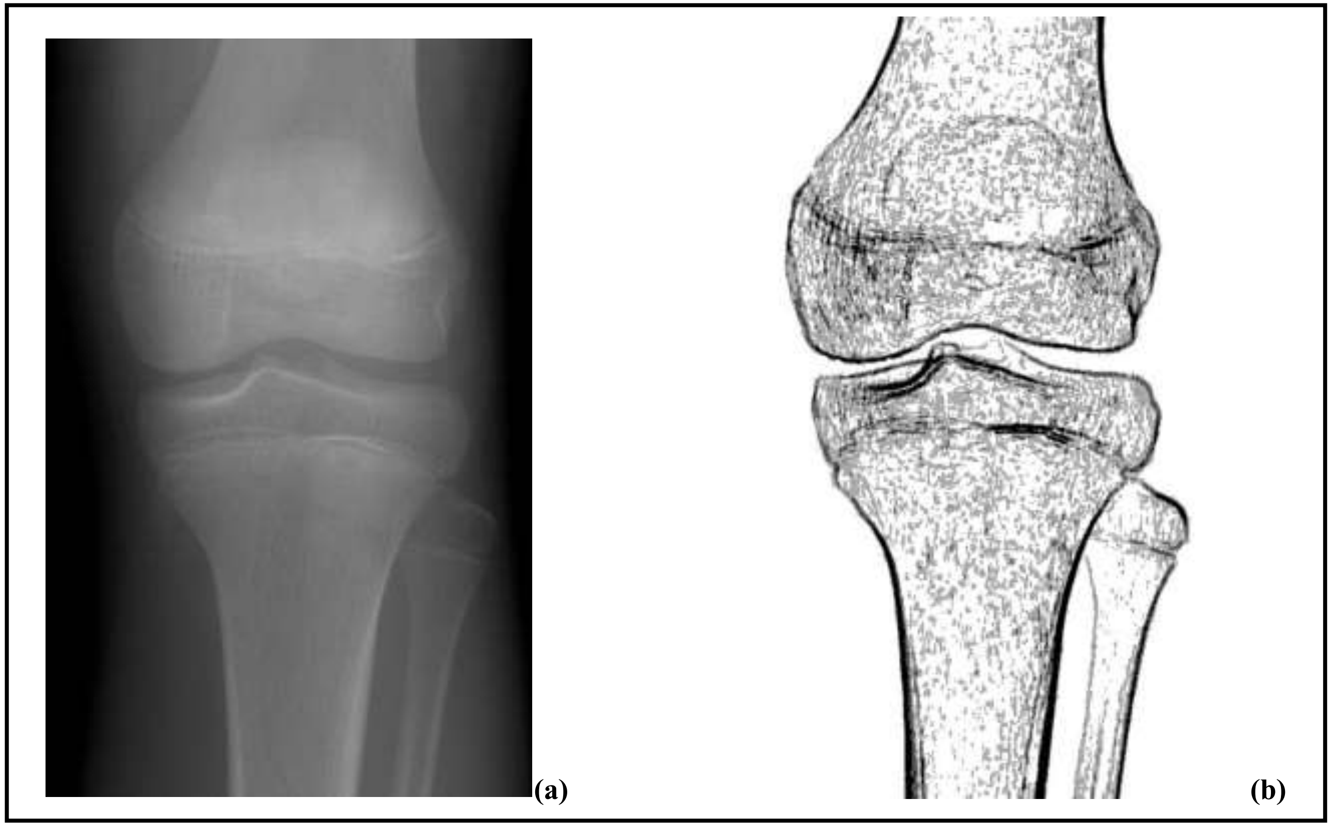


Figure 3.27: *Stage 3 of the knee in a 12.6 year old female. The epiphyses of the distal femur, proximal tibia and proximal fibula closely approximate the shafts showing greater than 50% union and therefore scored as stage 3.*

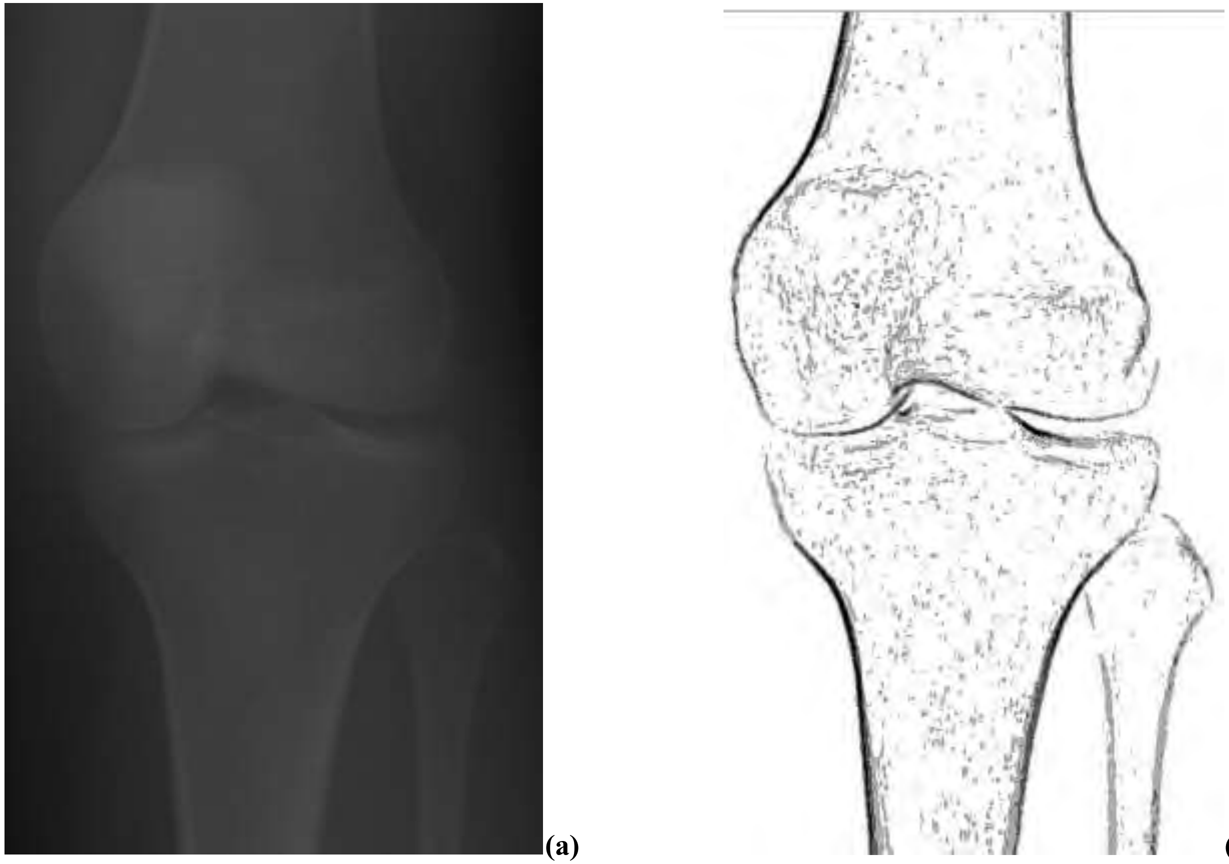


Figure 3.28: *Stage 4 (complete union) at the knee in a 17.5 year old female.*

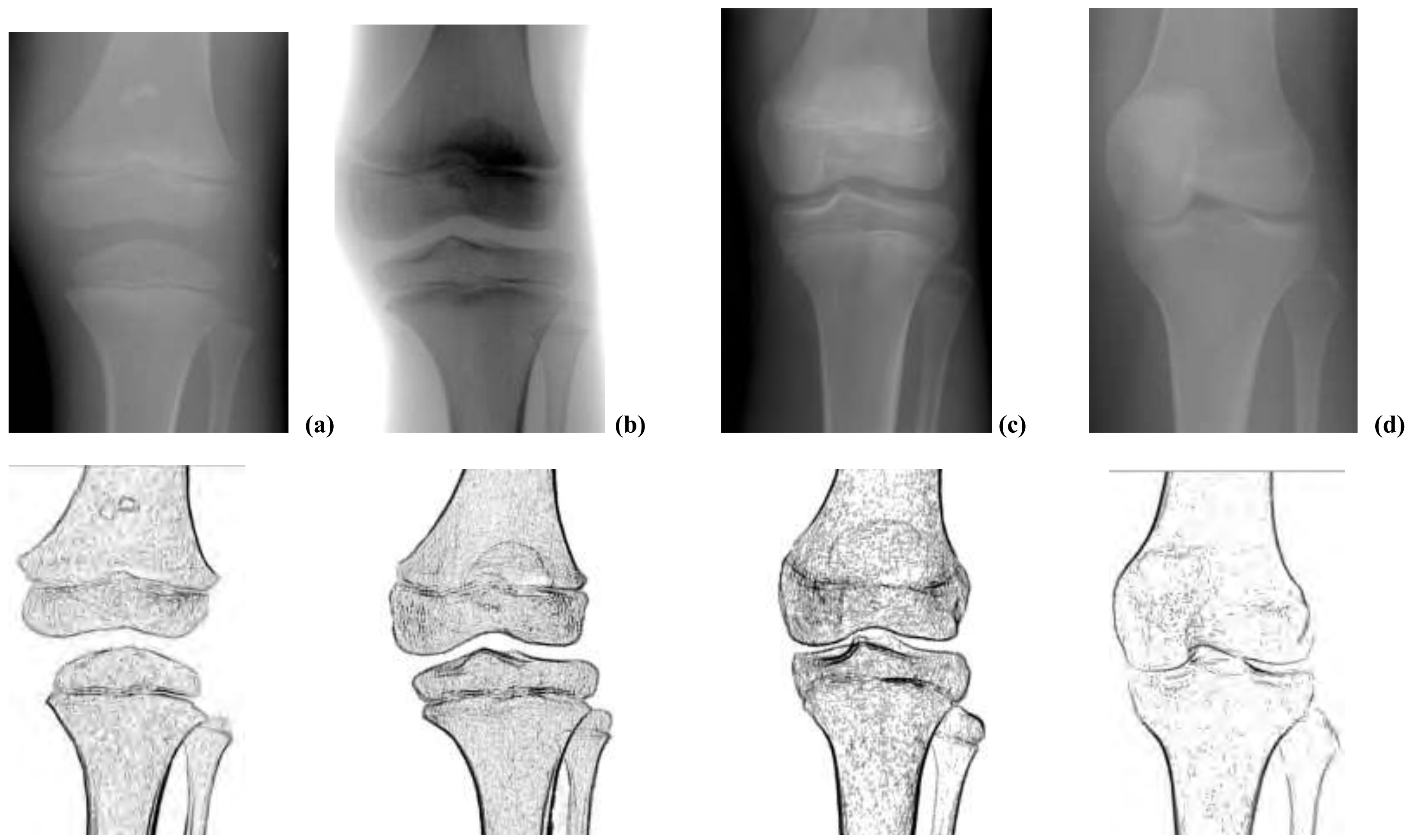
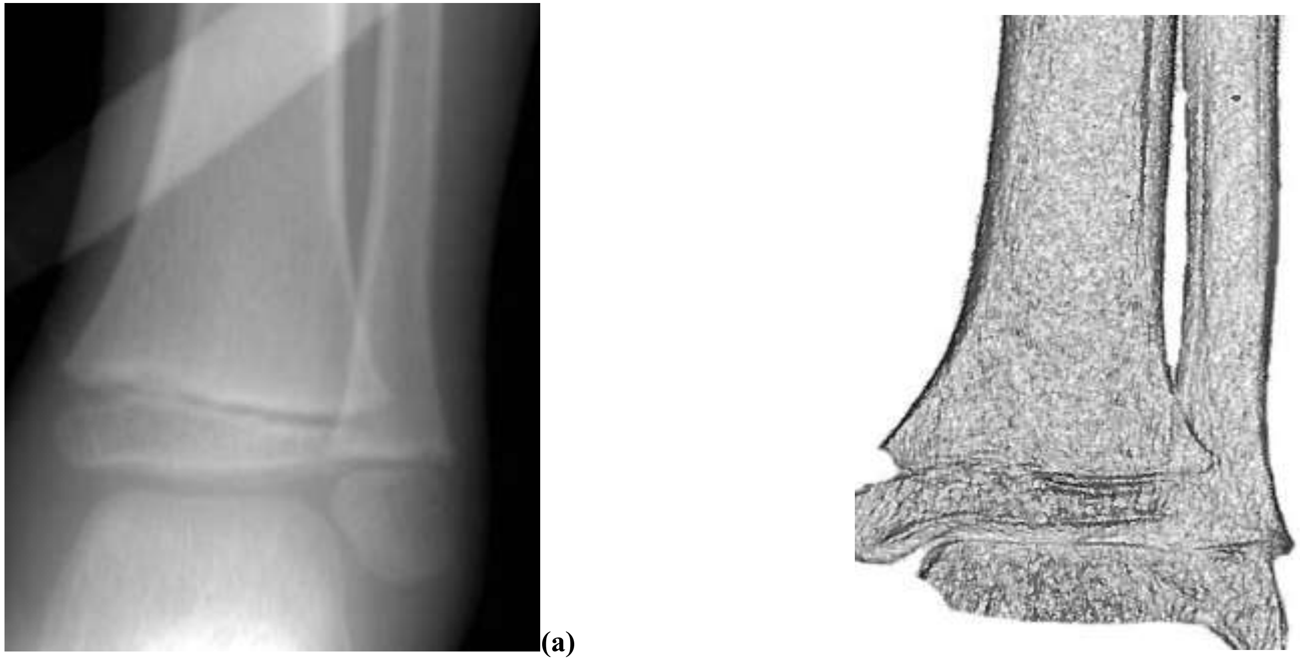


Figure 3.29: *Summary of the progression of union from stage 1 to stage 4 of union at the knee joint. Stage 1(a) is characterised by smaller shape and size of the epiphyses as well as the larger relative gap between epiphyses. As union progresses, the epiphyses grow in size and the gap between the epiphyses and diaphyses narrows until complete union takes place Stage 4 (d).*



(a) (b)

Figure 3.30: *Stage 1 of the ankle in a 7.3 year old male. The epiphyses of the distal tibia and fibula appear smaller in size compared to the adjacent diaphyses. The medial malleolus of the distal tibia has not gained adult form yet and is hence scored as 1. The distal epiphysis is also scored as 1.*

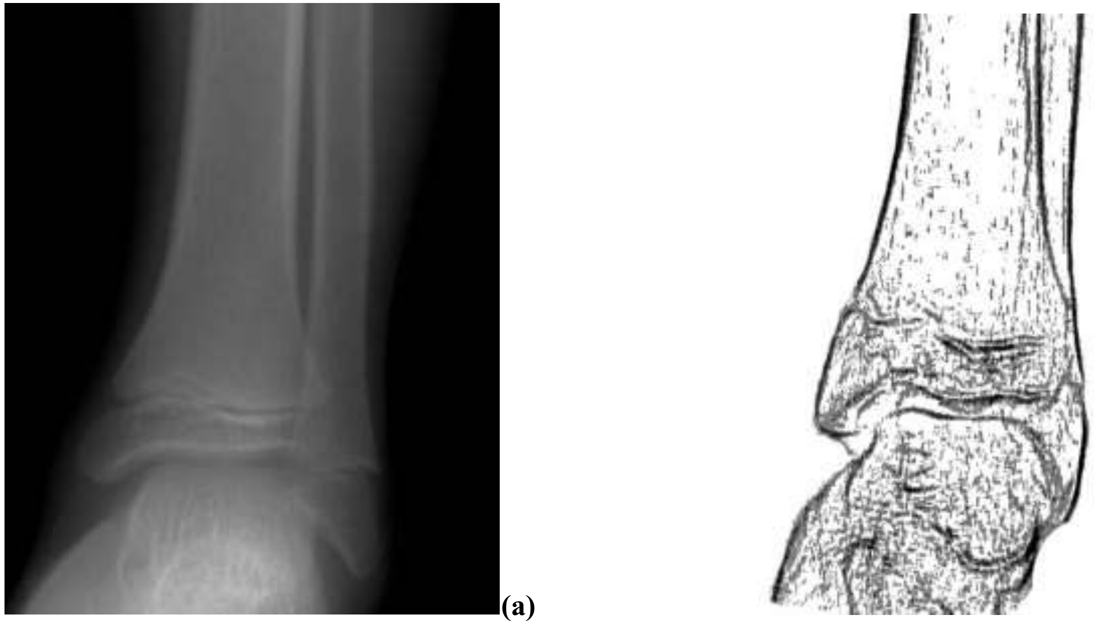

(a) (b)

Figure 3.31: *Stage 2 of the ankle of a male nine years of age. The epiphyses of the distal tibia and distal fibula are of similar size to diaphyses but show less than 50% union. Note that the medial malleolus has now taken shape.*

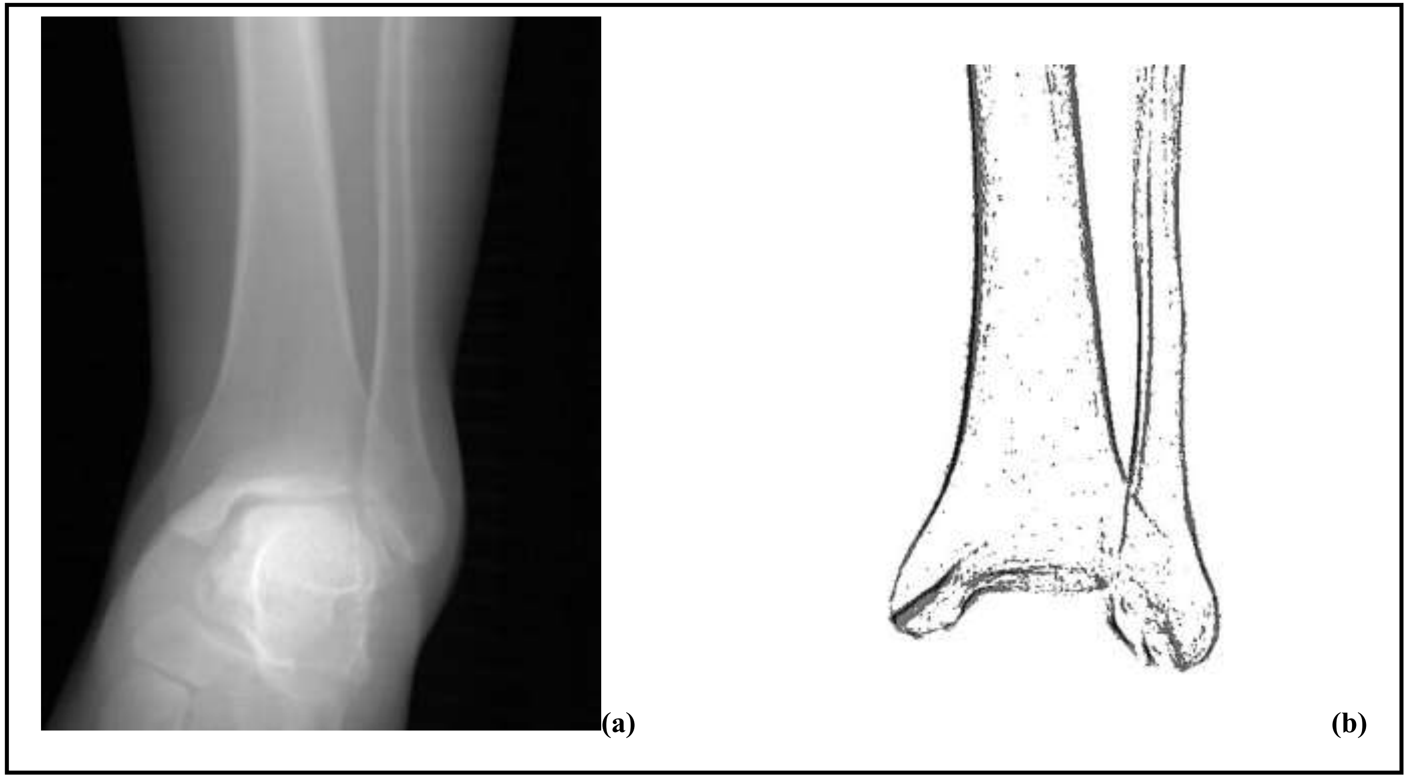
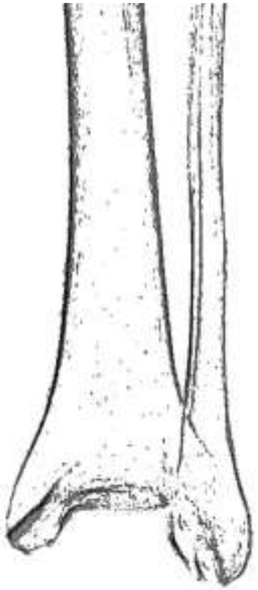


Figure 3.32: *Stage 3 of the ankle in a 12.6 year old female showing greater than 50% union for the distal epiphysis of the tibia and fibula.*

(a)



(b)

Figure 3.33: *Stage 4 (complete union) of the ankle in a 17.5 year old female*.

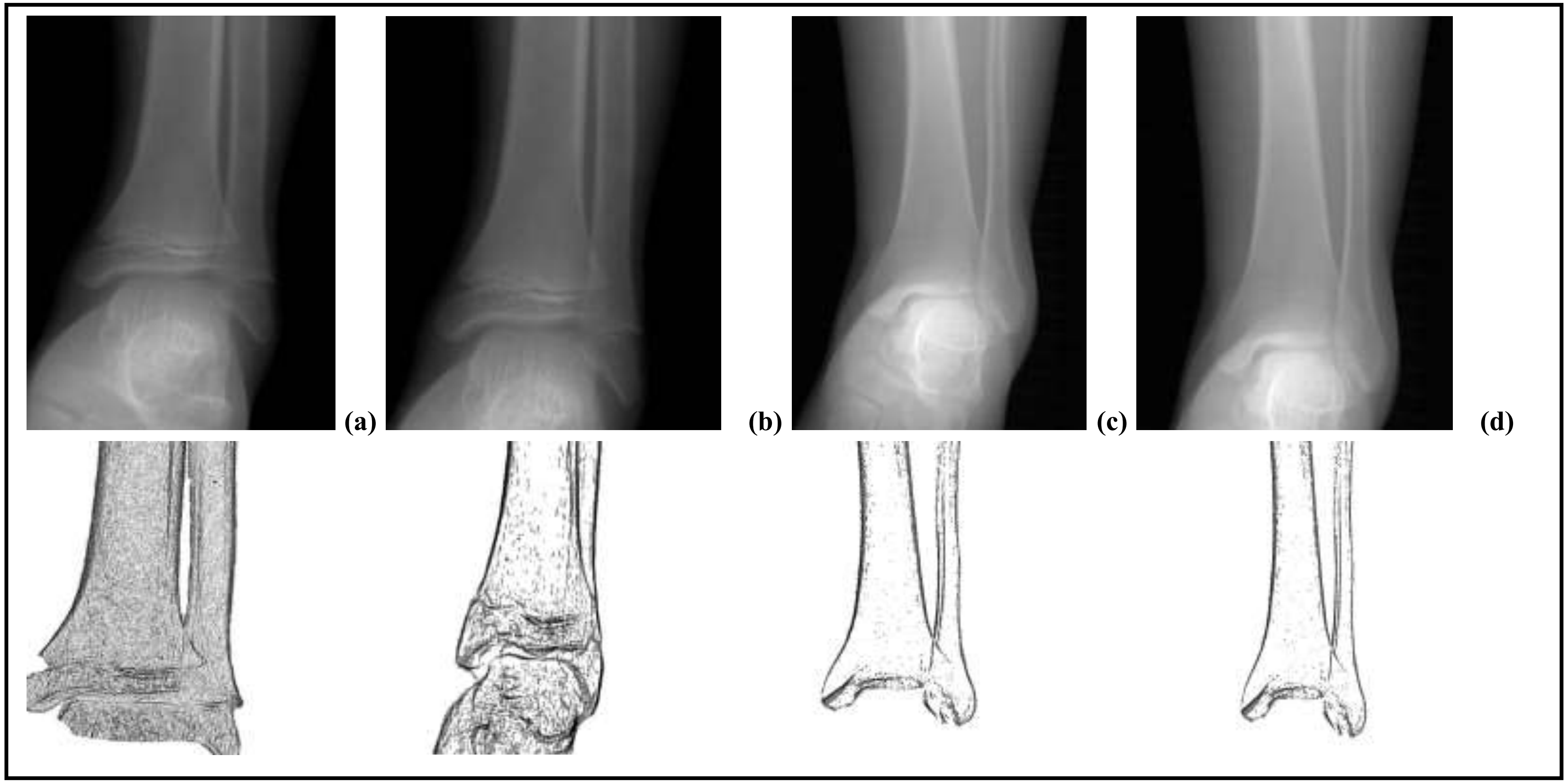


Figure 3.34: *Summary of the progression of union from stage 1 to stage 4 of union at the elbow joint. Stage 1 is characterised by the absence of epiphyses and may include the formation of the epiphysis, if present it is usually smaller in size compared to the adjacent diaphyses. As union progresses, the epiphyses grow in size and the gap between the epiphyses and diaphyses narrows until complete union takes place stage 4 (d).*

3.3.2 Assessment of Union in Skeletal Cases, using stages derived by Ousley *et al*., (2013).

Part one above was carried out to determine radiographic stages for the classification of epiphyseal union in a contemporary population using the major joints of the body. This defines the first aim of the current research which was to determine the age of bone development age at a given chronological age. The second aim is to use the phases derived in part one and attempt to apply them to human skeletal specimens.

3.3.2.1 Methodology

Complete human skeletons housed in the Raymond Dart Collection at the University of the Witwatersrand Medical School were chosen based on their ages. Individuals between the ages of 13-23 years of age were chosen since it represents the active phase of epiphyseal union. Permission was obtained to radiograph the specimens using the Statscan™ system (LODOX ™ Systems, (Pty) Ltd., Sandton, South Africa) which was also used to obtain the radiographs used in the first part of the research. The settings of the machine were not manipulated in order to radiograph the skeletal material; they were taken at the same settings as that of patients who undergo diagnostic procedures at the trauma unit.

On two occasions remains were taken to the trauma unit. They were placed in an anatomical order so it would mimic the human body in anatomical position as if it were fleshed. Additional information relating to geographic origin, age and sex were obtained from the collections" database. On a separate occasion, photographs of each skeletal joint were taken. This would enable comparisons of the radiographic observations to those of the macroscopic observations.

Many of the previous studies suggest that radiographic images cannot be used to determine age in forensic cases. This may be due to the fact that direct observations were carried out between the skeletal/ forensic material and the radiographs of a reference sample; however, no standards have been published to account for the differences if any exists. In the present study radiographs were taken of the skeletal material and scored using the stages derived in part one. After adapting the classification of stages *(Table 3.06)* for macroscopic observations, the scores were compared.

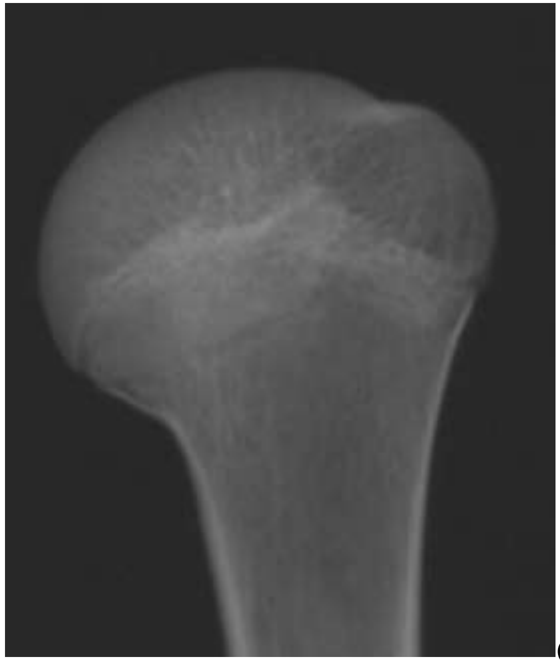
Table 3.06: Stage Utilised in the Analysis of Radiographs and Skeletal Material

Stage	Radiographic Stages*	Macroscopic Stages
Stage 1: Non Union	**Epiphyses** present and not fused. **Both** epiphyses and diaphyses appear as separate structures. **Margins** of the metaphysis are not continuous with the underlying metaphysis because the epiphysis is smaller.	**Epiphysis** completely separate. **Epiphyses** will be smaller in size compared to diaphyses.
Stage 2: Partial Fusion	**Diameters** of the metaphyses and diaphyses are similar in shape and size. **Visible** islands of cartilaginous ossification are observed. **However,** less than 50% of the adjacent ends are touching.	**Epiphyses** completely separate but fits snugly with no change in contour between metaphysis and epiphyses
Stage 3: Greater than 50% union	**Over** 50% of the adjacent ends are in contact. **Visible** islands of caliginous ossification. **Increased** continuity of shape between adjacent structures.	**Partial** fusion with epiphyseal line still very visible. **Gaps** between surfaces are still visible.
Stage 4: Complete Union	**Complete** articulation of epiphyses and diaphyses to form a single structure. **With** or without fusion line.	**Complete** union between adjacent structures

* Ousley *et al.,* (2013)

In all the figures below, (a) represents the radiograph of a bone and (b) represents the skeletal element upon which the assessment and radiograph are based.

(a)



(b)

Figure 3.35: *(a) Gross assessment of union at the shoulder in a 16 year old male from the Dart Collection. (b) The Humerus is a radiograph of (a), although it looks as a stage 3 of union in the radiograph, upon analysis it seems that the epiphysis is a separate component and is classified as stage 2 (less than 50% union).*

Figure 3.36: *Gross assessment of union at the elbow in a 16 year old male. The epiphysis of the medial epicondyle is absent in both the radiograph (a) as well as the gross assessment (b) and hence scored as 1. The trochlea, capitulum, lateral epicondyle as well as the proximal radius in both radiographic and gross examination appear completely fused (Stage 4). The radio dense scar of recent union can be observed at the proximal radius in (a).*


(a)

(b)

Figure 3.37 (i): *Gross assessment at the skeletal hip and iliac crest. The radiograph (a) of the skeletal pelvis (b) showing an absence of the iliac crest, the iliac crest is open and hence scored as stage 1. The head of the femur in (a) is scored as 3 (showing greater than 50% union)and the greater trochanter as stage 2 while the absence of the lesser trochanter is scored as stage 1. The iliac crest in (b) is absent showing a ridge like formation suggesting the epiphysis is open.*

(c)

(d)

Figure 3.37 (ii): *Gross examination of the skeletal femur cont. from 3.37 (i). The head of the femur in (c) shows greater than 50% union with only the margins appearing unfused and is therefore scored as 3. Upon initial inspection of the greater trochanter it appears as if there is greater than 50 % union taking place, however at closer inspection the greater trochanter appears to detach showing that less than 50% of union has taken place hence scoring it as stage 2. The absence of the lesser trochanter is thus scored as stage 1.*

Figure 3.38: *Gross examination of the distal humerus and proximal radius. The distal humerus which includes all epiphysis (medial epicondyle, trochlea, capitulum, lateral epicondyle) is scored as stage 1 due to the absence of these epiphyses (a). The proximal epiphysis of the radius appears to be united but is also smaller in size to the diaphysis and hence scored as stage 1. (b) The distal humerus is also scored as stage 1 upon gross analysis due to the absence of the epiphyses. (c) The glue applied to the proximal epiphysis of the radius is visible. Though the glue makes it appear as if union is taking place, the difference in size of the epiphysis ensures it scored as stage 1.*

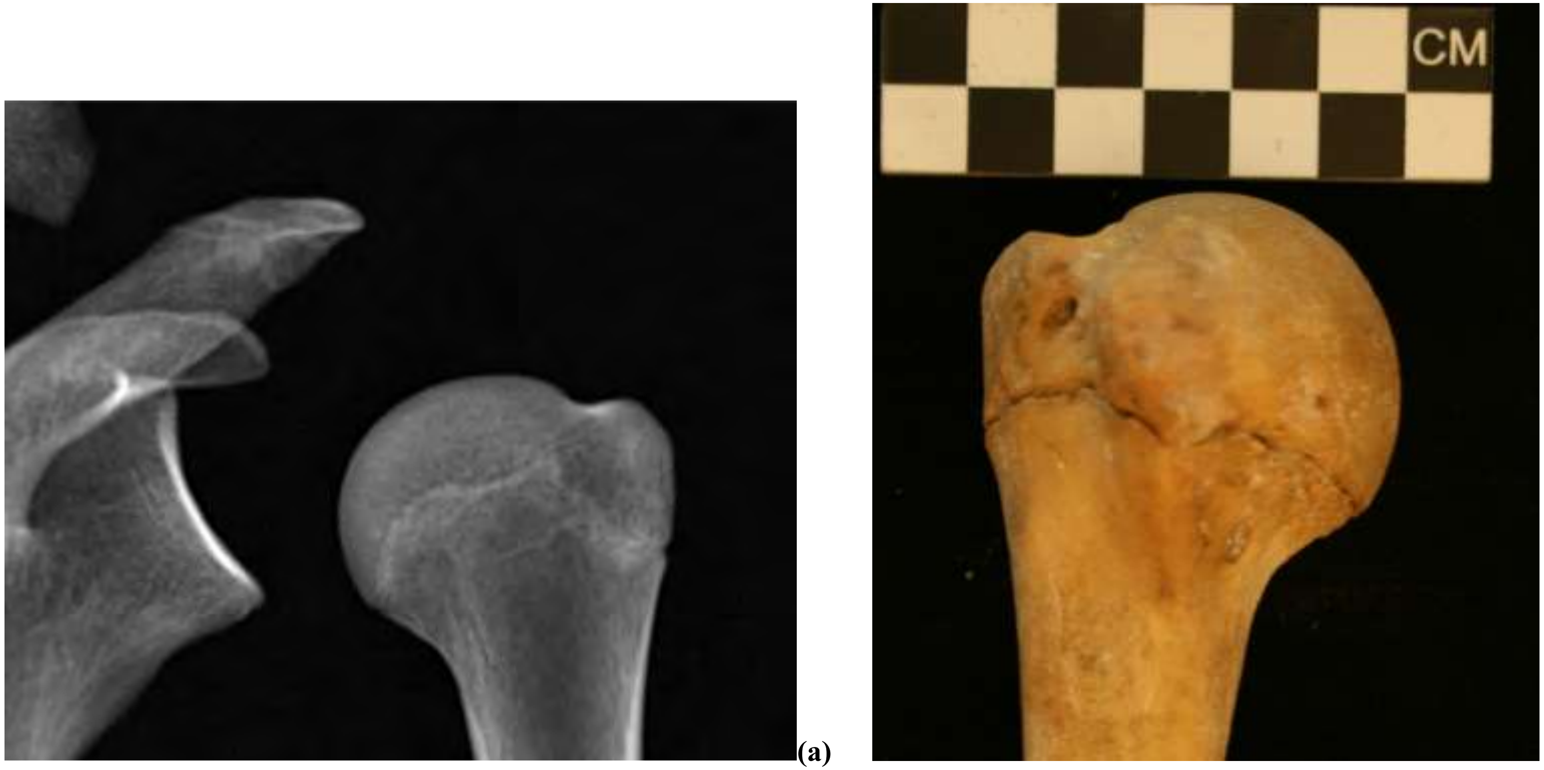
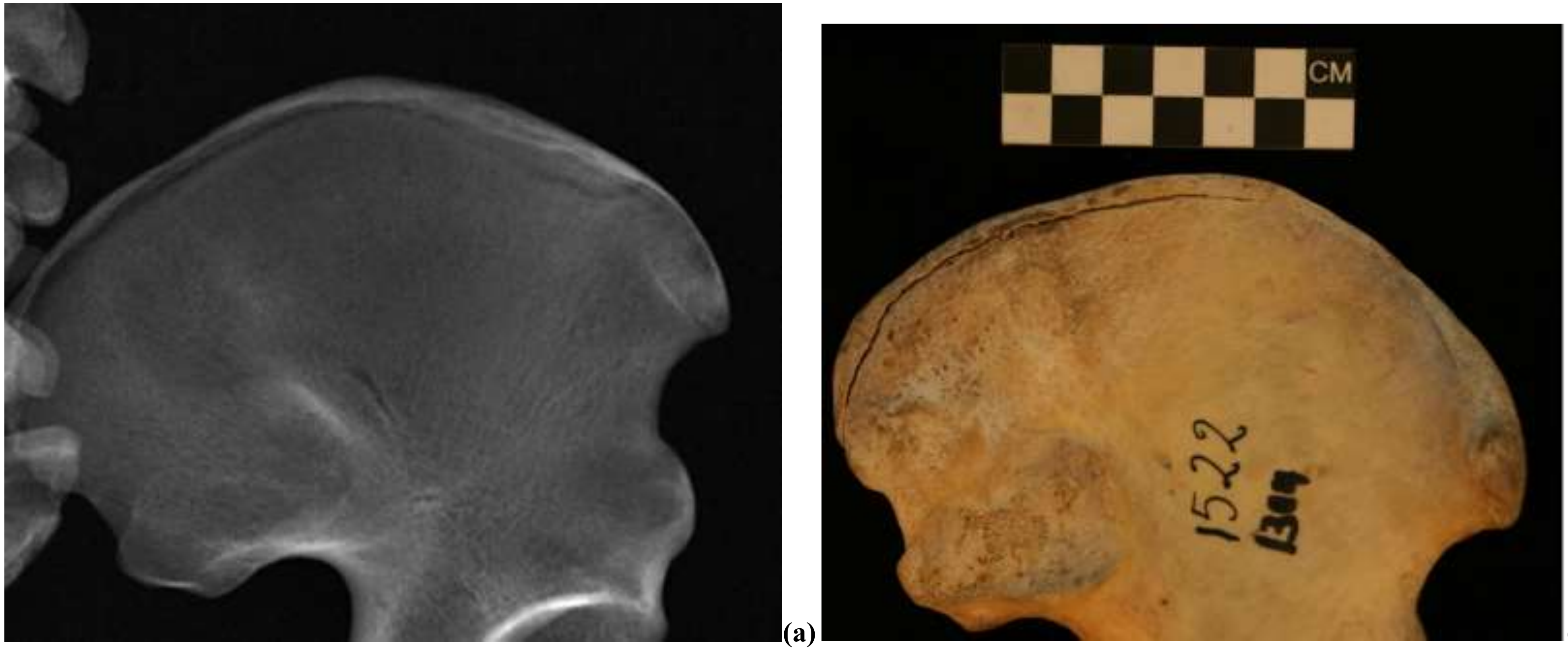


Figure 3.39: *Radiographic and gross examination of the proximal end of a skeletal humerus. (a) The head of the humerus and greater tubercle are scored as stage 3 showing greater than 50%union. (b) Gross examination of the humerus from (a) the head of the humerus and greater tubercle show greater than 50% union thus scored as stage 3.*



(a) (b)

Figure 3.40: *Radiographic and gross examination of the iliac spine. (a) The iliac spine greater than 50% union and thus scored as stage 3, incomplete union may still be observed on the anterior surface of the ilium along the margins. (b) Upon gross examination greater than 50% union is visible at the margins of the epiphysis (stage 3). It however appears as if the anterior iliac spine is slightly ahead that of the posterior iliac spine.*

Figure 3.41: *Radiographic and gross examination of the distal humerus. (a) Left distal humerus showing greater than 50% union (stage 3) of medial epicondyle. (b) Upon close examination of the skeletonised distal humerus the medial epicondyle also shows greater than 50% union and is also scored as stage 3.*

Figure 3.42: *Radiographic and gross examination of the knee (a) Radiograph of distal femur, proximal tibia and fibula (epiphysis absent) held together by adhesive. The epiphyses of the distal femur and proximal tibia are similar in size to the adjacent diaphyses but show less than 50% union and scored as stage 2. The epiphysis of the proximal fibula could not be observed and is hence scored as Not observable (N/0). (b, c) Upon analysis of the distal femur and proximal tibia (skeletal), the epiphysis was separate but held together by adhesive. It was hence scored as stage 2 showing less than 50% union.*

Figure 3.43 (a): *Radiographic and gross examination of the proximal femur. (a) The head of the femur appears completely united except for a small margin on the inferior surface of the head and is therefore scored as stage 3. Greater than 50% union at the greater trochanter is visible radiographically. (b) Upon gross examination, the head of the femur appears to be completely united (stage 4) whereas the greater trochanter shows greater than 50% union (stage 3).*

Figure 3.44: *Radiographic and gross examination of the distal ulna and radius. (a) The distal end of the radius is held together with adhesive in the radiograph. However the size of the epiphysis closely approximates the diaphysis and is scored as stage 2. The epiphysis of the distal radius is not observable and scored as such (N/O). (b) The gross examination of the distal radius is also scored as stage 2 while the distal ulna is scored as Not Observable (N/O).*

3.4 Statistical Analysis

Data analysis was carried out using Microsoft excel and IBM © SPSS © Version 22 statistical software packages. Ordinal logistic regressions were run to determine significant differences between sexes, ethnic groups and SES classifications. Ordinal logistic regression is similar to normal regression. It models the relationship between a dependent and one or more independent variables and allows for a view of the fit of the models as well as the significance of the relationships (Bender and Grouven, 1997).

The statistical calculation is quite different to ordinary regression. Ordinary regression uses least squares to find the best fit line and derives co-efficient that predict the change in the dependent variable for one unit of change in the independent variable. Logistic regression estimates the probability of an event occurring. The knowledge of relevant independent variables allows for the prediction of the probability (p) that the event is (l) occurring. Unlike linear regression which suggests that the relationship between the independent and dependent variables the same assumptions are not made in logistic regression.

The output of such ordinal regression results in the reporting of the Wald test which is a parametric statistical test. It may be used whenever a relationship within or between data items can be expressed as a statistical model with parameters to be estimated from a sample. The Wald test can be used to test the true value of the parameter based on the sample estimate. In testing one particular regression coefficient, it is equivalent to the t-test for the normal distribution, but in this case a t-test would not be appropriate since the response variable is categorical rather than numerical.

The 95% Confidence interval (95% CI) are used to express the uncertainty in the estimated regression coefficients. The estimates are based on a particular sample; its use on a different sample would yield different answers.

Data were modelled using ordinal logistic regression which utilises the Logs, odds and probabilities of achieving a score. Threshold refers to the intercepts of the dependent variables whereas Location refers to the independent variables (predictor variables). The estimate refers to the co-efficient. The number of coefficients displayed is one less than the number of categories of the variable. In this case, the coefficient is for the value of one. Category 2 (females) is the reference category and has a coefficient of 0. The Wald test is used whenever a relationship within or between data items can be expressed as a statistical model with parameters to be estimated from a sample, the Wald test can be used to test the true value of the parameter based on the sample estimate test can be used to test the true value of the parameter based on the sample estimate. Data are significantly different at $p < 0.05$. The 95% confidence interval (95% CI) is used to express the uncertainty in the estimated regression coefficients. The results for an unknown from a large sample suggest that it should fit between the 95% CI.

CHAPTER 4: RESULTS

4.1 Descriptive Statistics: General Distribution of Sample

The sample comprised of 2151 individuals of whom 445 individuals were females (26%) and the males comprise 1290 individuals (74%) of the sample (*Figure 4.01*). The distribution of their ages can be found in *Table 4.01* and *Figure 4.02* below.

***Table 4.01*: Distribution of Sample According to Sex and Age**

Females			Males		
Age Category	**Age Range**	**N**	**Age Category**	**Age Range**	**N**
6 years	6.0 - 6.99	12	6 years	6.0 - 6.99	17
7 years	7.0 - 7.99	58	7 years	7.0 - 7.99	98
8 years	8.0 - 8.99	73	8 years	8.0 - 8.99	99
9 years	9.0 - 9.99	55	9 years	9.0 - 9.99	79
10 years	10.0 - 10.99	39	10 years	10.0 - 10.99	73
11 years	11.0 - 11.99	51	11 years	11.0 - 11.99	86
12 years	12.0 - 12.99	37	12 years	12.0 - 12.99	77
13 years	13.0 - 13.99	6	13 years	13.0 - 13.99	31
14 years	14.0 - 14.99	9	14 years	14.0 - 14.99	20
15 years	15.0 - 15.99	4	15 years	15.0 - 15.99	29
16 years	16.0 - 16.99	4	16 years	16.0 - 16.99	32
17 years	17.0 - 17.99	9	17 years	17.0 - 17.99	66
18 years	18.0 - 18.99	8	18 years	18.0 - 18.99	67
19 years	19.0 - 19.99	12	19 years	19.0 - 19.99	92
20 years	20.0 - 20.99	13	20 years	20.0 - 20.99	92
21 years	21.0 - 21.99	19	21 years	21.0 - 21.99	108
22 years	22.0 - 22.99	15	22 years	22.0 - 22.99	83
23 years	23.0 - 23.99	18	23 years	23.0 - 23.99	90
24 years	24.0 - 24.99	8	24 years	24.0 - 24.99	70
25 years	25.0 - 25.99	5	25 years	25.0 - 25.99	82
Total		**455**			**1661**

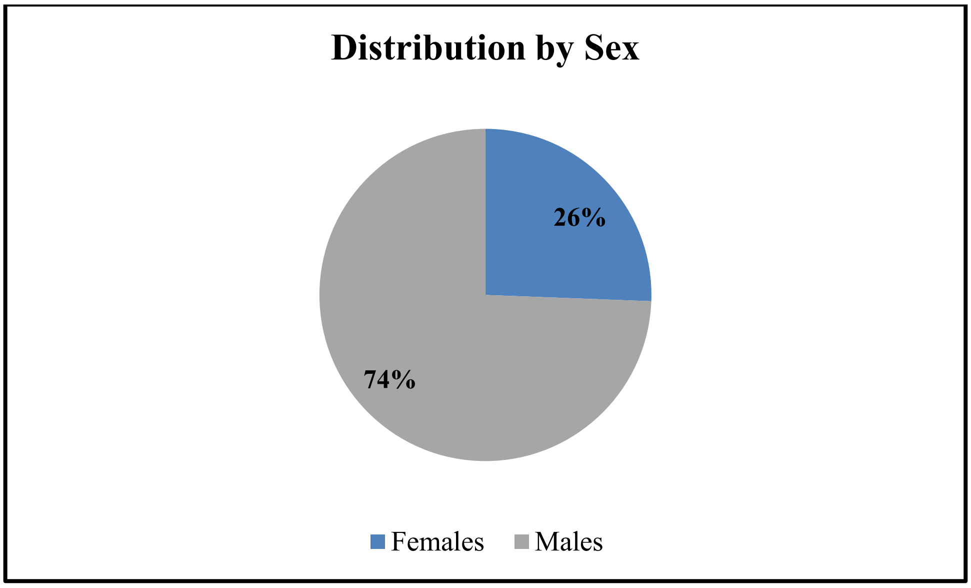


Figure 4.01: *Distribution of the sample by sex*

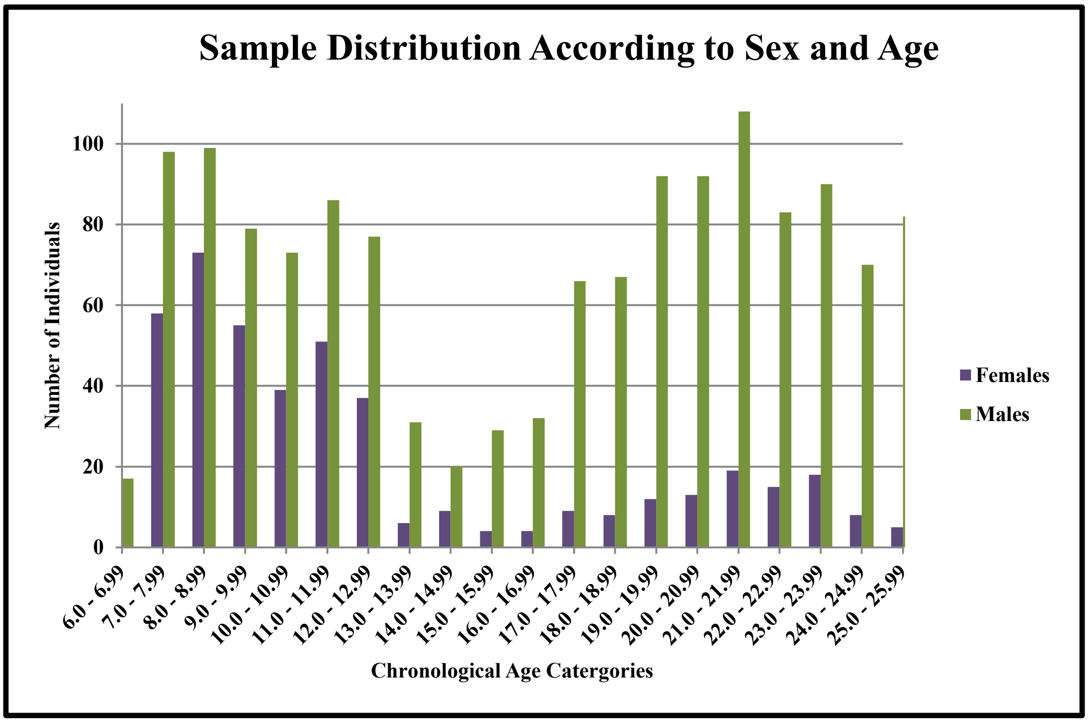


Figure 4.02: *Sample distribution according to age and sex showing higher numbers of males for each chronological age range.*

The age range for the samples in males and females are between six years and 24 years. There appears to be significantly less females compared to males. The number of females peak at ages seven, nine and 11 years respectively. The bimodal distribution in males is evident with less than 20 individuals at age six, a peak at eight years and gradual decrease up to 14 years showing positive skewing. The distribution once again reaches a peak at 21 years of age and gradually decreases. The data are not normally distributed. The genetic background is as follows; Black individuals constitute 52.5% (911) of the sample followed by Cape Coloured at 35.9% (622). 2.4% (41) of the sample is White, while Indians make up 0.8% (14) of the sample (*Figure 4.03*).

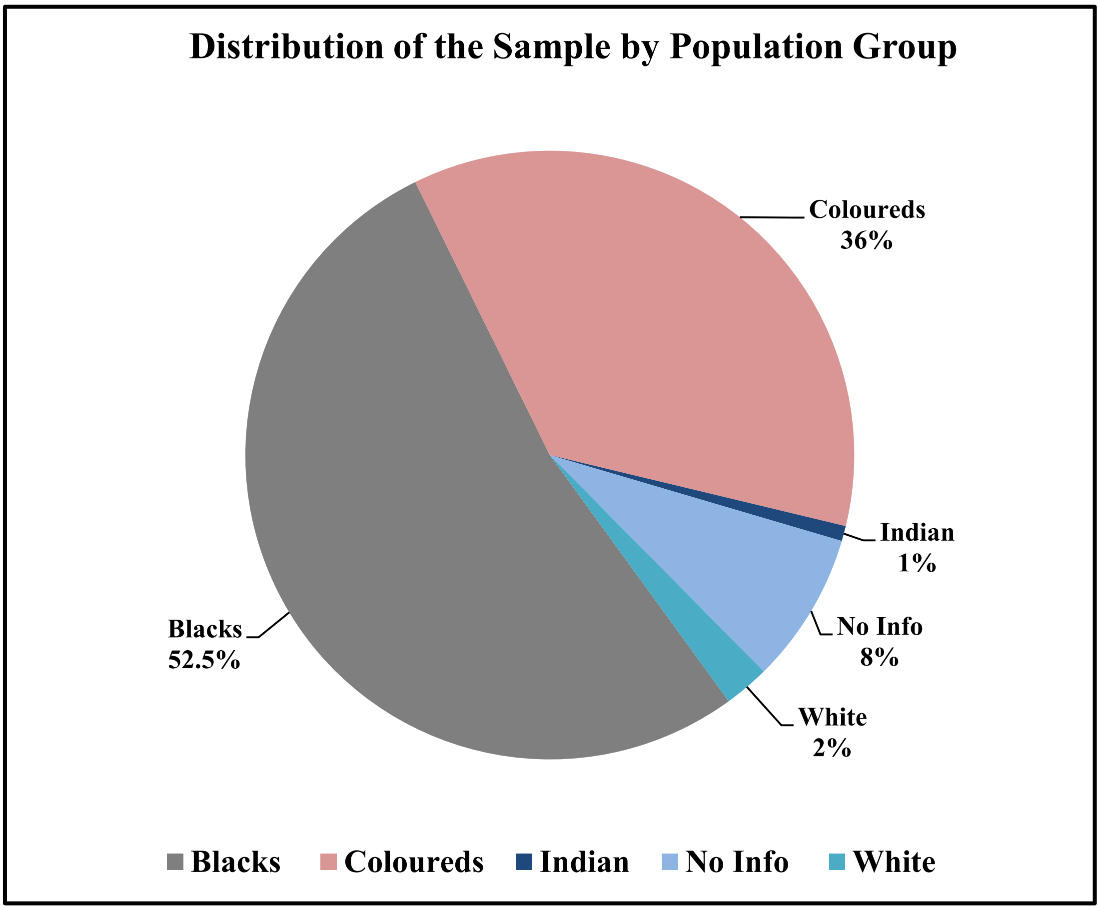


Figure 4.03: *Distribution of the sample by genetic background*

4.2 Chronological Age of Union.

4.2.1 Elbow

4.2.1.1 Medial Epicondyle

The bones which constitute the elbow have been assessed in order of the way they were observed in the radiograph (medial to lateral and proximal to distal). The elbow is made up of six components, only five of these were visible in the anterior plane of the radiograph. These are the medial epicondyle, trochlea, capitulum, lateral epicondyle and proximal radius. The data begin with a minimum age of six years as this is the point at which data collection was initiated. *Table 4.02* summarises the progression of union in males and females for the medial epicondyle of the elbow. It summarises the percentage of individuals at any given stage of union.

Union at the medial epicondyle begins earlier in females compared to males (*Table 4.02*). This is visible in *Figures 4.04 and 4.*05 which shows that union (stage 2) in 50% of females is observed as early as six years old. Union in 40% of males however is first observed at 10 years old. Females appear to be ahead of males at all stages. While females first show greater than 50% union at eight years, this is only seen at 11 years in males. Complete union on the other hand is first observed in less than 10 % of females at the age of 11 years and 13 years in males.

It is apparent from the figures that the number of individuals who progress from one stage to another increase with an increase in age until the entire sample shows complete union. An overlap between stages is also observed suggesting that one stage does not cease before the next stage is initiated. Complete union (stage 4) in males is considered as the age at which 95% of the sample appears in stage 4 due to the considerable lag to 100%. Complete union in females is however classified as the age at which 100% of the sample appears in stage 4. Complete union of the medial epicondyle occurs at 17 years in males and 15 years in females.

Table 4.02: Chronological age for stages 1 to 4 of the Medial Epicondyle in Males and Females

	Males				*Females*			
Stage	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Age								
6	100.00%	0.00%	0.00%	0.00%	50.00%	50.00%	0.00%	0.00%
7	93.60%	6.40%	0.00%	0.00%	63.30%	36.70%	0.00%	0.00%
8	92.60%	7.40%	0.00%	0.00%	50.00%	46.40%	3.60%	0.00%
9	79.70%	20.30%	0.00%	0.00%	38.60%	52.60%	8.80%	0.00%
10	61.30%	38.70%	0.00%	0.00%	18.80%	65.60%	15.60%	0.00%
11	32.80%	62.10%	5.20%	0.00%	7.70%	51.30%	33.30%	7.70%
12	17.50%	68.30%	14.30%	0.00%	2.40%	29.30%	43.90%	24.40%
13	13.20%	50.00%	23.70%	13.20%	0.00%	23.50%	35.30%	41.20%
14	0.00%	16.70%	44.40%	38.90%	11.10%	11.10%	0.00%	77.80%
15	0.00%	8.30%	16.70%	75.00%	0.00%	0.00%	0.00%	100.00%
16	0.00%	0.00%	8.70%	91.30%	0.00%	0.00%	0.00%	100.00%
17	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
18	0.00%	0.00%	1.60%	98.40%	0.00%	0.00%	0.00%	100.00%
19	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
20	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
21	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
22	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
23	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
24	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%

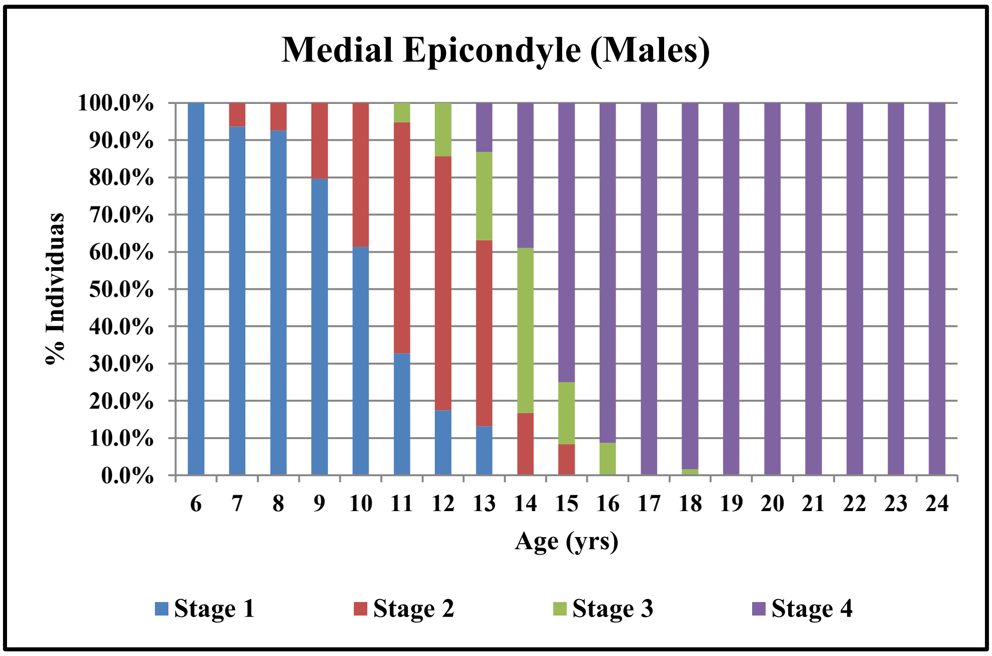


Figure 4.04: *Progression of union at the medial epicondyle in males. Stage 1 begins around six years and extends till 13 years with an overlap in stage 2. Stage 2 and 3 terminate at age 17 when 100% of males reach stage 4.*

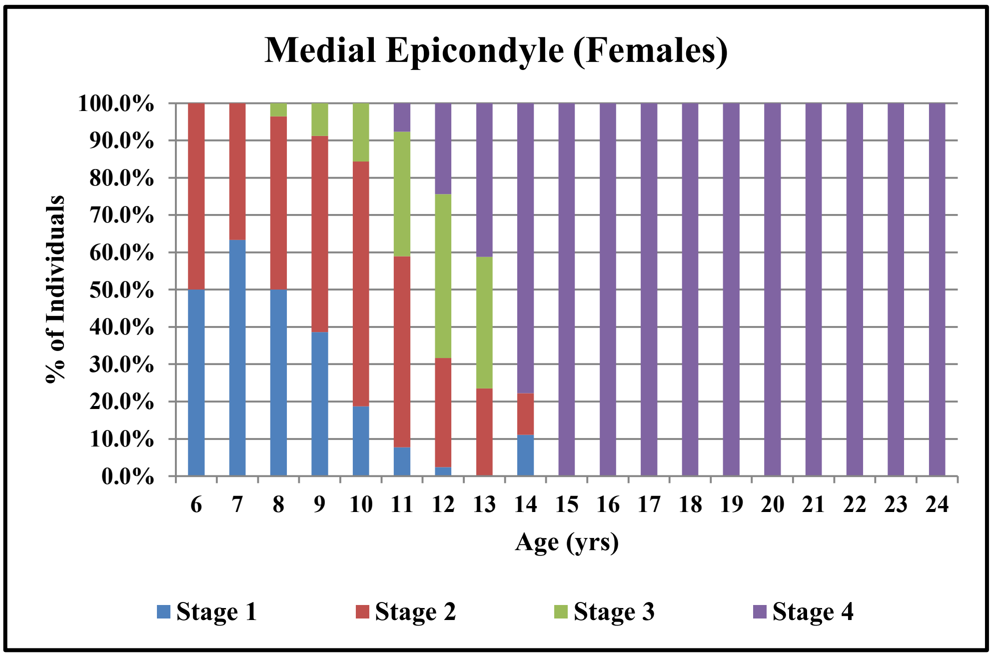


Figure 4.05: *Progression of union at the medial epicondyle in females. A larger percentage of females appear in stage 1 from age six. Stage 1 in females extends between 6 - 12 years, stage 2 between 6 - 14 years, stage 3 8 - 13 years followed by stage 4 (complete union) at age 15 years.*

4.2.1.2 Trochlea

Progression of union from stage 1 to 4 in males and females is presented in *Table 4.03.* In males union (stage 2) begins around six years of age while females begin union at seven years (*Figure 4.06 and 4.07*). Overlap exists between the adjacent stages in males and females and active union (stage 2 and 3) takes place between six to 16 years in males and seven to 14 years in females until complete union at 15 years in males and females.

Table 4.03: Chronological age for stages 1 to 4 at the Trochlea in Males and Females

	Males				***Females***			
Stage	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Age								
6	75.00%	25.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%
7	100.00%	0.00%	0.00%	0.00%	96.70%	3.30%	0.00%	0.00%
8	95.80%	4.20%	0.00%	0.00%	87.50%	7.10%	3.60%	1.80%
9	96.60%	3.40%	0.00%	0.00%	68.40%	24.60%	5.30%	1.80%
10	90.70%	8.00%	1.30%	0.00%	46.90%	28.10%	25.00%	0.00%
11	63.80%	31.00%	5.20%	0.00%	23.10%	12.80%	35.90%	28.20%
12	28.60%	33.30%	34.90%	3.20%	9.80%	7.30%	19.50%	63.40%
13	28.90%	26.30%	23.70%	21.10%	0.00%	0.00%	23.50%	76.50%
14	11.10%	0.00%	27.80%	61.10%	11.10%	0.00%	11.10%	77.80%
15	0.00%	0.00%	4.20%	95.80%	0.00%	0.00%	0.00%	100.00%
16	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
17	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
18	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
19	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
20	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
21	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
22	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
23	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
24	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%

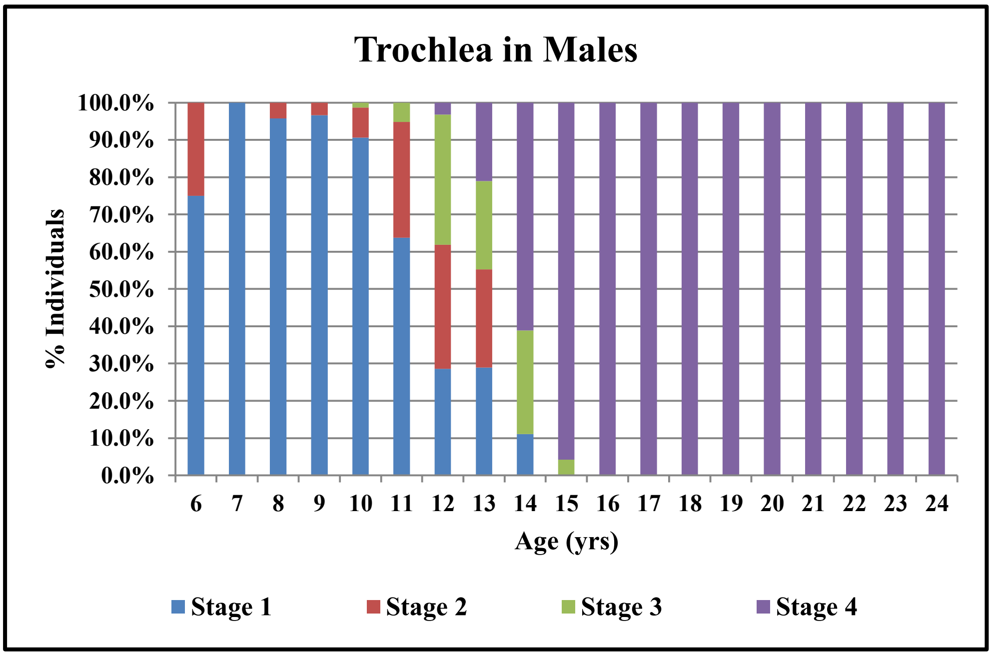


Figure 4.06: *Progression of union at the trochlea in males. A prolonged stage 1 in males extends between 6 - 14 years of age. Stage 2 begins around six and ends at age 13, overlapping with stage 3 between 10 to 15 years. Stage 4 is reached by 16 years in 100% of individuals.*

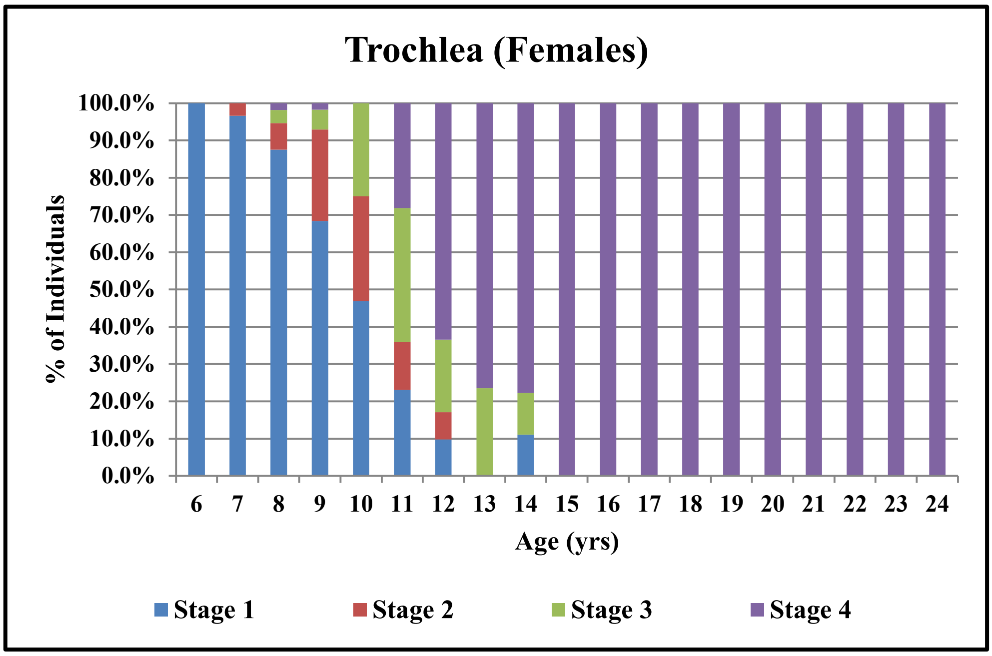


Figure 4.07: *Progression of union at the trochlea in females. Stage 1 is observed between 6 - 12 years in females. Stage 2 is observed between 7 to 12 years overlapping with stage 3 which is observed between 8 and 14 years. Stage 4 in 100% females is occurs at 15 years of age.*

4.2.1.3 Capitulum

At age six, 75% males are observed in stage 2 compared to 100% of females (*Table 4.04*). At age 10 years 68.8% of females are observed in stage 3 compared to only 12% of males at the same age while complete union is observed at 17 years in males and 15 years in females.

Table 4.04: Chronological age for stages 1 to 4 at the Capitulum in Males and Females

	Males				***Females***			
Stage	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Age								
6	25.00%	75.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%
7	46.80%	51.10%	2.10%	0.00%	10.00%	80.00%	10.00%	0.00%
8	30.50%	68.40%	1.10%	0.00%	8.90%	73.20%	16.10%	1.80%
9	16.90%	81.40%	1.70%	0.00%	5.30%	63.20%	29.80%	1.80%
10	14.70%	73.30%	12.00%	0.00%	0.00%	31.30%	68.80%	0.00%
11	6.90%	69.00%	24.10%	0.00%	0.00%	10.30%	53.80%	35.90%
12	0.00%	36.50%	60.30%	3.20%	0.00%	4.90%	29.30%	65.90%
13	0.00%	23.70%	52.60%	23.70%	0.00%	0.00%	23.50%	76.50%
14	0.00%	0.00%	38.90%	61.10%	0.00%	11.10%	0.00%	88.90%
15	0.00%	0.00%	4.20%	95.80%	0.00%	0.00%	0.00%	100.00%
16	0.00%	0.00%	4.30%	95.70%	0.00%	0.00%	0.00%	100.00%
17	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
18	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
19	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
20	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
21	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
22	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
23	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
24	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%

Males appear to be slightly delayed compared to females when stage 4 is observed in 35 % of females around age 11 compared to 23.7% of males at age 13 years *(Figure 4.08 and 4.09)*. A 14 year old female outlier is visible in *Figure 4.09* who appears to be in stage 2 of union.

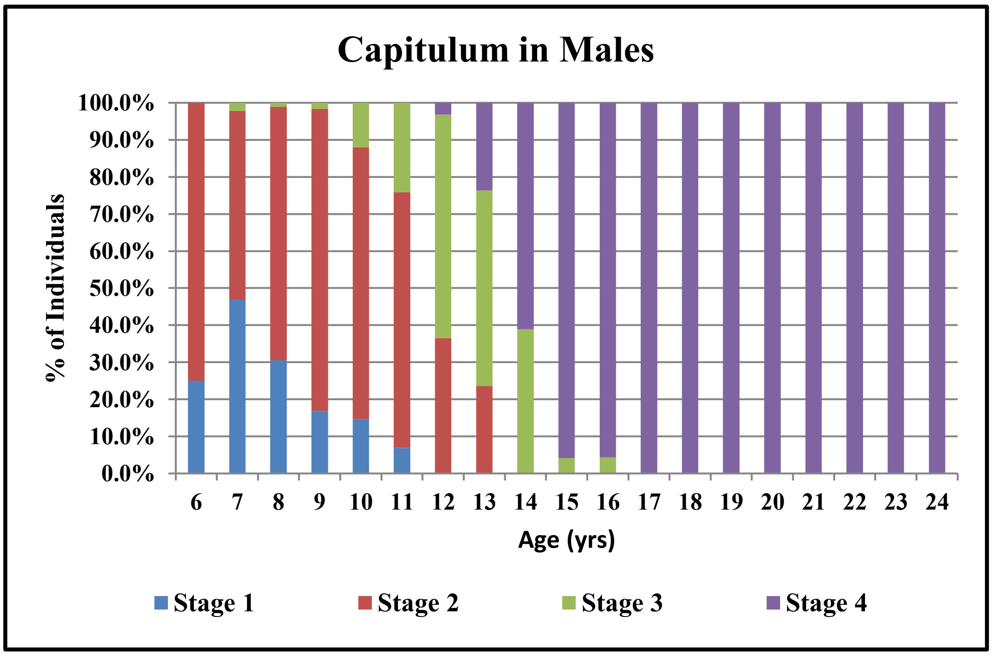


Figure 4.08: *Progression of union at the capitulum in males. Stage 2 of union appears at six years and is observed until 11 years. Stage 3 is first observed at age eight years till 16 years (4.3%). Stage 4 is observed at 17 years in 100% of males.*

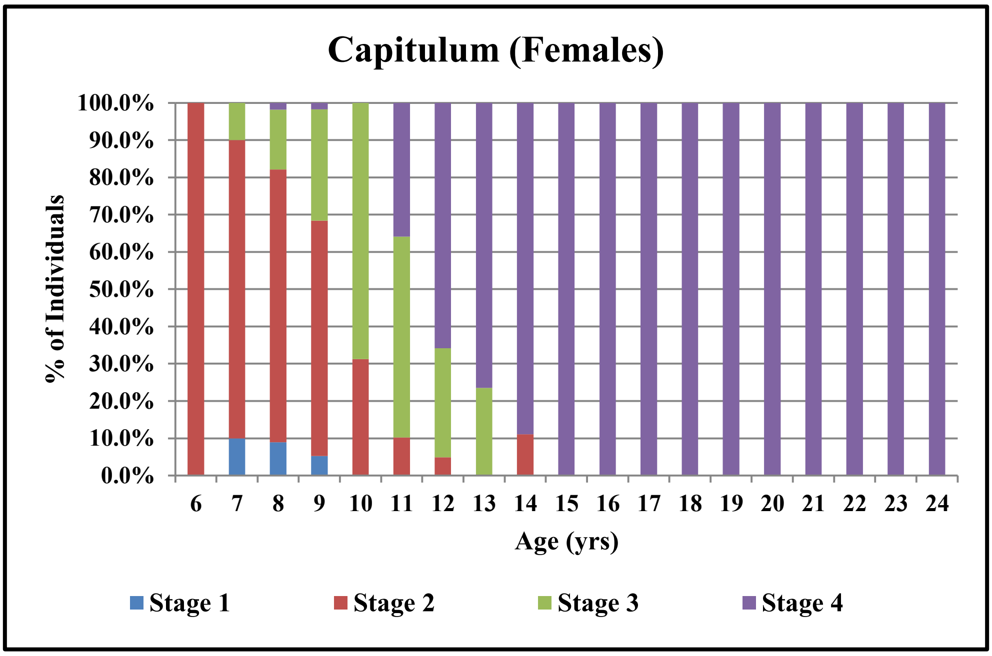


Figure 4.09: *Progression of union at the capitulum in females. Stage 2 in females is observed at six years of age. Stage 3 is first observed at seven years and terminates around 13 years. Stage 4 in 100% of females appears at 15 years.*

4.2.1.4 Lateral Epicondyle

The epiphysis of the lateral epicondyle appears and begins union later than the rest of the epiphyses in this area in both males and females. 100% of males are observed in stage 1 till nine years, while 100% of females are observed in stage 1 till seven years (*Table 4.05*). Stage 4 is first observed at age 12 in males and 11 years in females. Complete union is observed at 17 years in males and 15 years in females (*Figure 4.10 and 4.11*). Females appear to be 2 years in advance of males. A single female outlier is present at 14 years of age who appears to be in stage 1.

Table 4.05: Chronological age for stages 1 to 4 at the Lateral Epicondyle in Males and Females

	Males				***Females***			
Stage	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Age								
6	100.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%
7	100.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%
8	100.00%	0.00%	0.00%	0.00%	96.40%	1.80%	0.00%	1.80%
9	100.00%	0.00%	0.00%	0.00%	84.20%	8.80%	7.00%	0.00%
10	98.70%	0.00%	1.30%	0.00%	71.90%	15.60%	12.50%	0.00%
11	91.40%	6.90%	1.70%	0.00%	28.20%	15.40%	33.30%	23.10%
12	65.10%	17.50%	15.90%	1.60%	12.20%	4.90%	41.50%	41.50%
13	47.40%	15.80%	15.80%	21.10%	0.00%	0.00%	29.40%	70.60%
14	16.70%	5.60%	22.20%	55.60%	11.10%	0.00%	11.10%	77.80%
15	0.00%	0.00%	12.50%	87.50%	0.00%	0.00%	0.00%	100.00%
16	0.00%	0.00%	4.30%	95.70%	0.00%	0.00%	0.00%	100.00%
17	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
18	0.00%	0.00%	1.60%	98.40%	0.00%	0.00%	0.00%	100.00%
19	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
20	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
21	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
22	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
23	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
24	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%

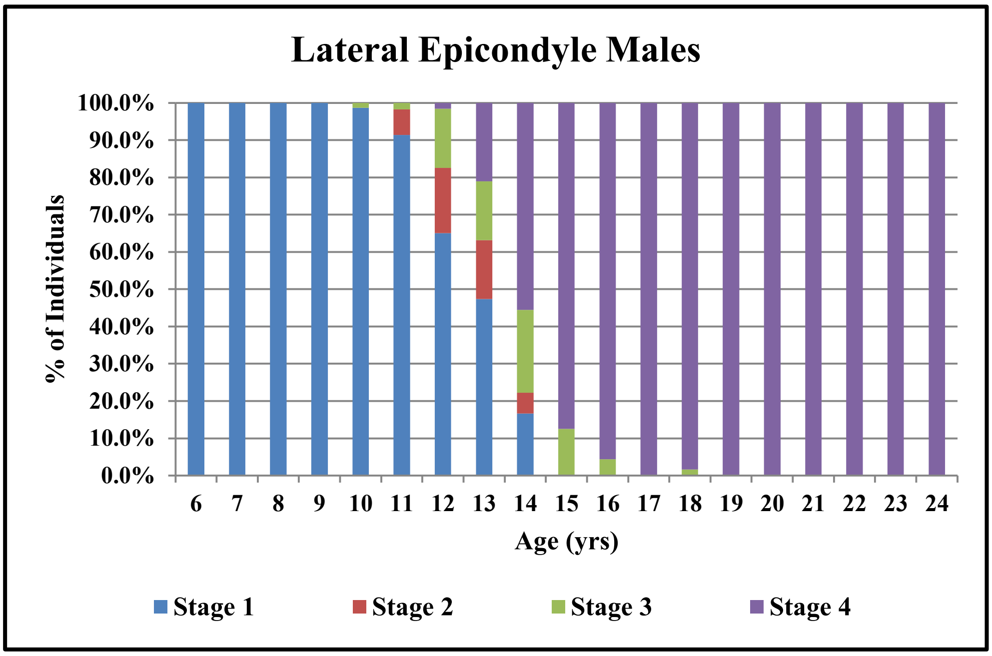


Figure 4.10: *Progression of union at the lateral epicondyle in males. Prolonged stage 1 (6 - 14 years) followed by stage 2 between 11 - 14 years. Stage 3 is observed between 10 - 16 years and stage in 100% of individuals is observed at age 17 years.*

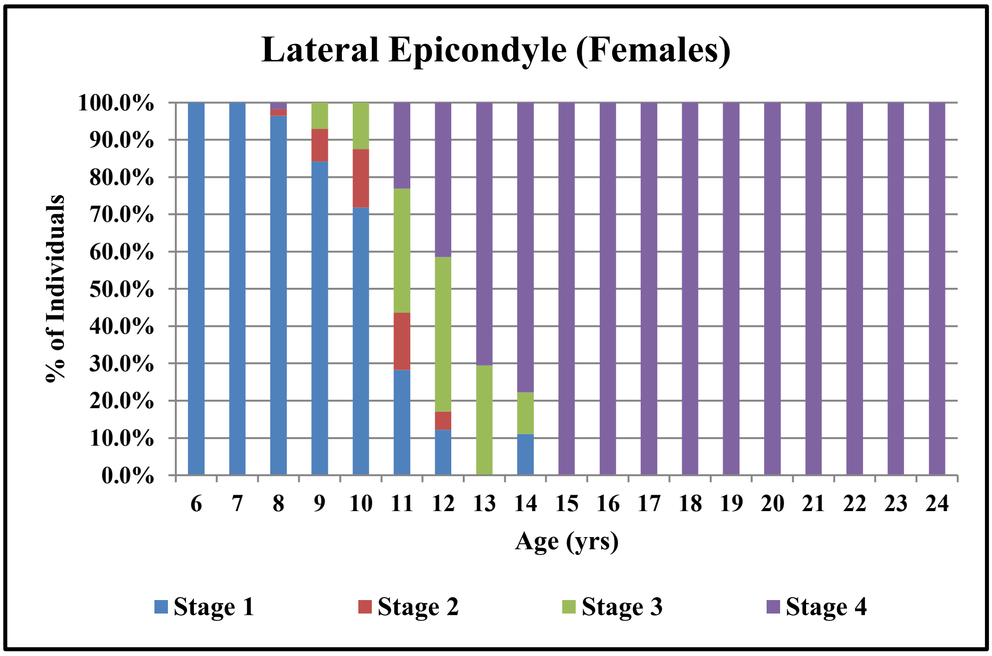


Figure 4.11: *Progression of union at the lateral epicondyle in females. Stage 1 extends between 6 - 12 years, stage 2 is observed between 8 - 12 years; while stage 3 is observed between 9 - 14 years. Stage 4 in 100% of individuals is visible at 15 years in females.*

4.2.1.5 Proximal Radius

Union at the proximal radius begins earlier in females (six years) compared to males (eight years) when 25% of females begin union at six years, 100% of males still show non-union (*Table 4.06*). Stage 2 in males is first observed at eight years when 6.3% appear in this stage.

Table 4.06: Chronological age for stages 1 to 4 at the Proximal Radius in Males and Females

	Males				***Females***			
Stage	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Age								
6	100.00%	0.00%	0.00%	0.00%	75.00%	25.00%	0.00%	0.00%
7	100.00%	0.00%	0.00%	0.00%	86.70%	13.30%	0.00%	0.00%
8	93.70%	6.30%	0.00%	0.00%	73.20%	25.00%	1.80%	0.00%
9	81.40%	18.60%	0.00%	0.00%	42.10%	45.60%	12.30%	0.00%
10	64.00%	36.00%	0.00%	0.00%	18.80%	56.30%	25.00%	0.00%
11	27.60%	72.40%	0.00%	0.00%	7.70%	33.30%	43.60%	15.40%
12	6.30%	73.00%	20.60%	0.00%	2.40%	19.50%	36.60%	41.50%
13	15.80%	42.10%	28.90%	13.20%	0.00%	5.90%	35.30%	58.80%
14	0.00%	27.80%	22.20%	50.00%	0.00%	11.10%	11.10%	77.80%
15	0.00%	4.20%	12.50%	83.30%	0.00%	0.00%	12.50%	87.50%
16	0.00%	0.00%	8.70%	91.30%	0.00%	0.00%	0.00%	100.00%
17	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
18	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
19	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
20	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
21	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
22	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
23	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
24	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%

Complete union is first observed at age 13 (13.2% of individuals) in males and age 11 in females (15.4% of individuals) (*Figure 4.12 and 4.13*) with complete union occurring at 17 years in males and 16 years in females. Stages 2, 3 and 4 are observed earlier in females than males. While stage 1 is terminated at age 13 in males it is terminated at age 12 in females. In males stage 3 has the shortest duration compared to the other stages spanning between 12 to 16 years.

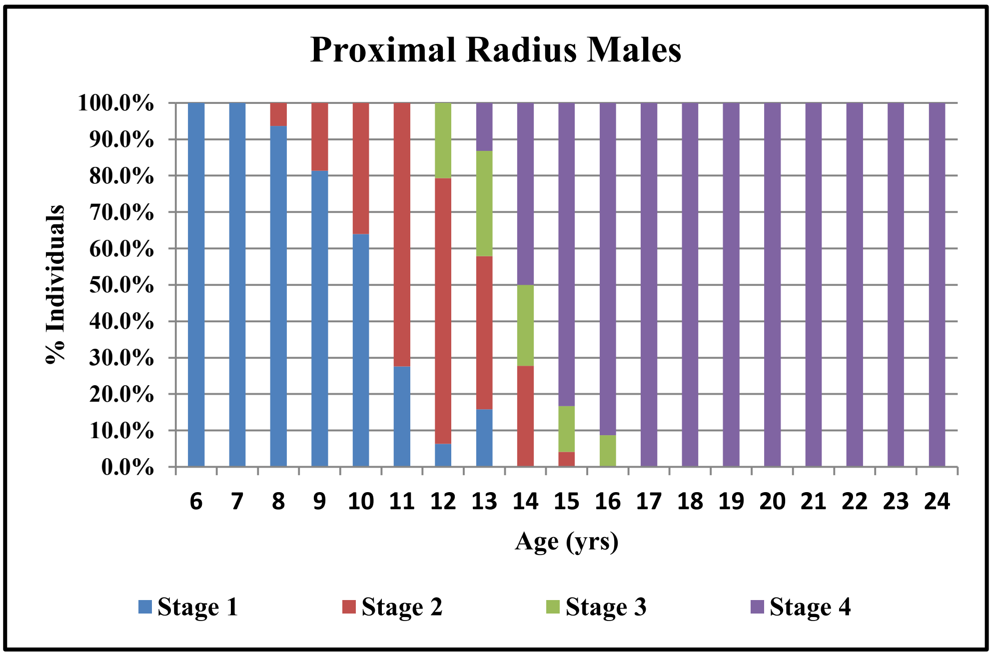


Figure 4.12: *Progression of union at the proximal radius in males. Stage 1 lies between 6 - 13 years, while stage 2 begins at eight years and terminates at 15. Stages 1, 2 and 3 overlap at age 13 years. Stage 4 in 100% of individuals is seen at 17 years of age.*

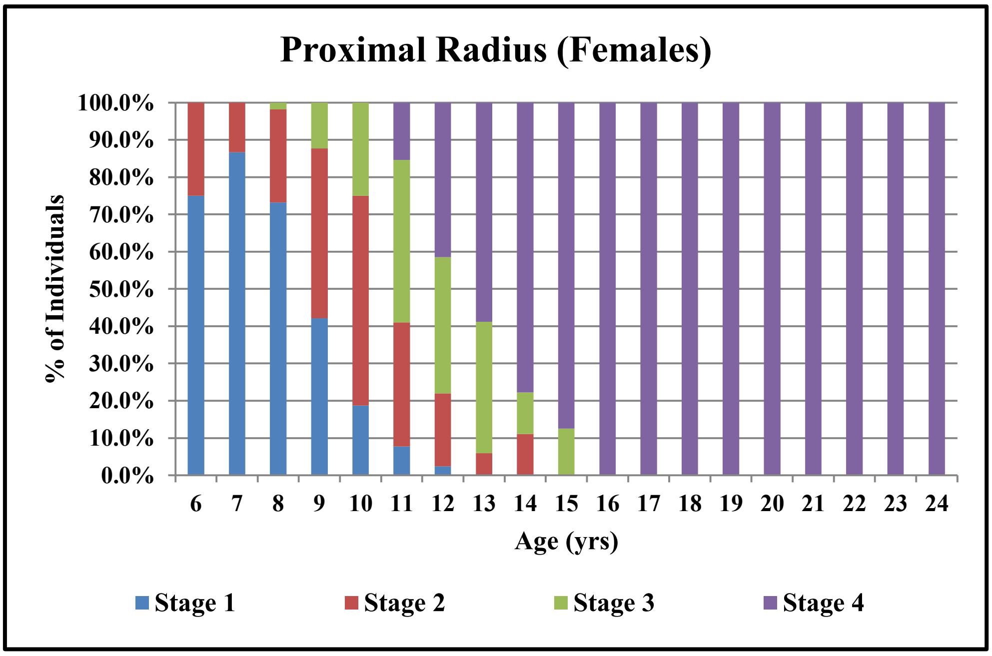


Figure 4.13: *Progression of union at the proximal radius in females. The stages in females appear to be less prolonged. Stage 1 is observed between 6 - 12 years, stage 2 between 6 - 14 years and stage 3 between 8 - 15 years. Stage 4 is first observed at 11 years and reaches complete union at 15 years when 100% of individuals are in this stage.*

The sequence of complete union in males and females appears to be the same *(Figure 4.14 and 4.15)*. Complete union is first observed at the trochlea followed by the capitulum, lateral epicondyle (LE), proximal radius (Prox Rad) and finally the medial epicondyle (ME). The data in females appears to be more erratic due to smaller sample sizes. There appears to be consistency in the age of complete union when greater than 95% of individuals show complete union and enables the bones to be clustered into one joint called the elbow). *Table 4.07* below is a representation of the mean percentage fusion of the five elements.

Table 4.07: Chronological age of Union at the Elbow in Males and Females

	Males				Females			
Age	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**
6	100% (4)	0% (0)	0% (0)	0% (0)	100% (4)	0% (0)	0% (0)	0% (0)
7	100% (47)	0% (0)	0% (0)	0% (0)	97% (29)	3% (1)	0% (0)	0% (0)
8	100% (95)	0% (0)	0% (0)	0% (0)	95% (53)	4% (2)	2% (1)	0% (0)
9	100% (59)	0% (0)	0% (0)	0% (0)	74% (42)	21% (12)	5% (3)	0% (0)
10	96% (72)	4% (3)	0% (0)	0% (0)	44% (14)	53% (17)	3% (1)	0% (0)
11	81% (47)	19% (11)	0% (0)	0% (0)	18% (7)	41% (16)	36% (14)	5% (2)
12	43% (27)	49% (31)	8% (5)	0% (0)	10% (4)	20% (8)	49% (20)	22% (9)
13	31% (12)	41% (16)	18% (7)	10% (4)	0% (0)	12% (2)	47% (8)	41% (7)
14	5% (1)	26% (5)	37% (7)	32% (6)	11% (1)	0% (0)	11% (1)	78% (7)
15	0% (0)	4% (1)	20% (5)	76% (19)	0% (0)	0% (0)	0% (1)	88% (7)
16	0% (0)	0% (0)	9% (2)	91% (21)	0% (0)	0% (0)	0% (0)	100% (3)
17	0% (0)	0% (0)	0% (0)	100% (59)	0% (0)	0% (0)	0% (0)	100% (5)
18	0% (0)	0% (0)	2% (1)	98% (60)	0% (0)	0% (0)	0% (0)	100% (9)
19	0% (0)	0% (0)	0% (0)	100% (89)	0% (0)	0% (0)	0% (0)	100% (10)
20	0% (0)	0% (0)	0% (0)	100% (86)	0% (0)	0% (0)	0% (0)	100% (9)
21	0% (0)	0% (0)	0% (0)	100% (94)	0% (0)	0% (0)	0% (0)	100% (21)
22	0% (0)	0% (0)	0% (0)	100% (102)	0% (0)	0% (0)	0% (0)	100% (16)
23	0% (0)	0% (0)	0% (0)	100% (82)	0% (0)	0% (0)	0% (0)	100% (18)
24	0% (0)	0% (0)	0% (0)	100% (94)	0% (0)	0% (0)	0% (0)	100% (9)

*

Percentage (# N)

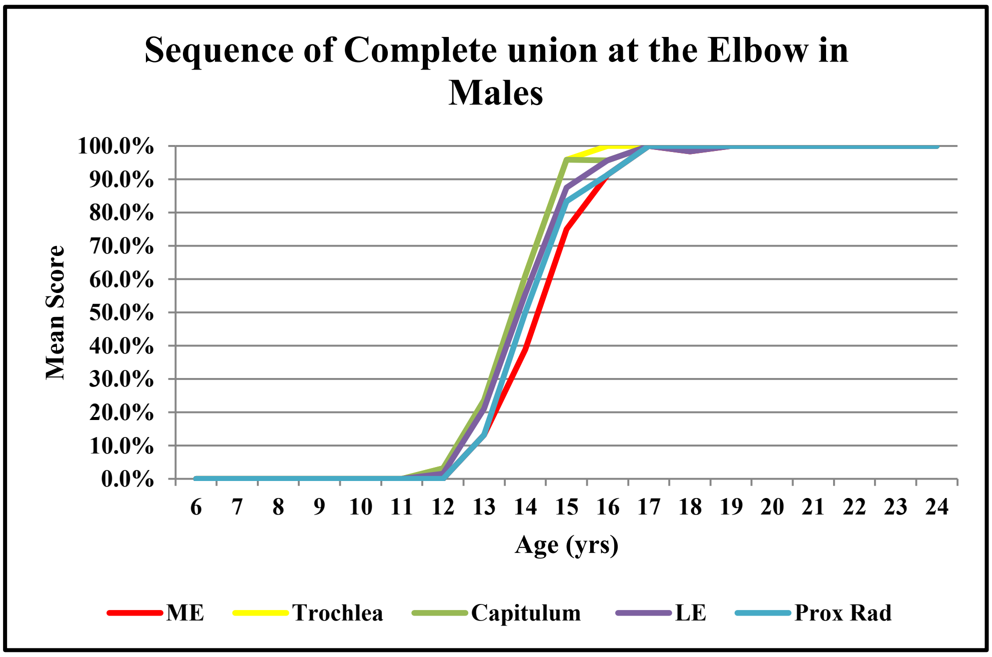


Figure 4.14: *Sequence of union of the elbow in males. The trochlea is the first to complete union followed by the capitulum, lateral epicondyle (LE), proximal radius (prox rad) and finally the medial epicondyle (ME).*

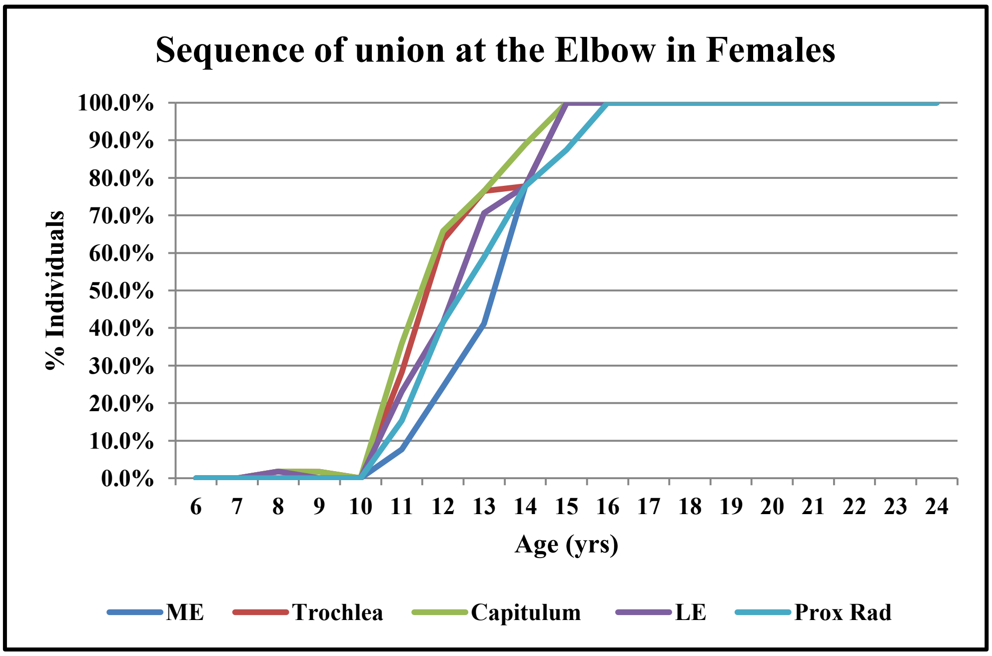


Figure 4.15: *Sequence of union of the elbow in females. The capitulum is the first to complete union followed by the trochlea, lateral epicondyle (LE), medial epicondyle (ME) and followed by the proximal radius (prox rad) at age 16 years.*

4.2.2 Hip

4.2.2.1 Head of Femur

The hip consists of a number of components however; there are three visible epiphysis (aside from iliac crest). Union at the head of the femur is observed at six years in both males and females (*Table 4.08*). At age six females appear to be in advance of males as 75% of females appear in stage 2 and union has progressed to stage 3 in 25% of females. Compared to 100% of males in stage 2 (*Figure 4.16 and 4.17*).

Table 4.08: Chronological age for stages 1 to 4 at the Head of Femur in Males and Females

	Males				***Females***			
Stage	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Age								
6	0.00%	100.00%	0.00%	0.00%	0.00%	75.00%	25.00%	0.00%
7	0.00%	92.70%	7.30%	0.00%	0.00%	80.00%	20.00%	0.00%
8	1.80%	85.70%	12.50%	0.00%	0.00%	53.70%	46.30%	0.00%
9	0.00%	76.00%	24.00%	0.00%	0.00%	27.90%	72.10%	0.00%
10	0.00%	57.30%	42.70%	0.00%	0.00%	2.30%	97.70%	0.00%
11	0.00%	27.80%	72.20%	0.00%	0.00%	2.20%	97.80%	0.00%
12	0.00%	20.20%	79.80%	0.00%	0.00%	2.20%	86.70%	11.10%
13	0.00%	17.60%	74.50%	7.80%	0.00%	5.60%	72.20%	22.20%
14	0.00%	0.00%	73.90%	26.10%	0.00%	0.00%	55.60%	44.40%
15	0.00%	0.00%	44.80%	55.20%	0.00%	0.00%	0.00%	100.00%
16	0.00%	0.00%	16.70%	83.30%	0.00%	0.00%	0.00%	100.00%
17	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
18	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
19	0.00%	0.00%	1.10%	98.90%	0.00%	0.00%	0.00%	100.00%
20	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	10.00%	90.00%
21	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
22	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
23	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
24	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%

Stage 2 in males appears to be more prolonged between 6 - 13 years compared to 6 - 9 years in females. Stage 3 of union is observed earlier in females and is terminated by age 14 years.

Stage 4 is first observed in males at 13 years in males and 12 years in females with complete union occurring at 17 years in males and 15 years in females (*Figure 4.16 and 4.17*). A single female outlier aged 20 years is visible. This female appears to be in stage 3 of union while complete union was observed at 15 years.

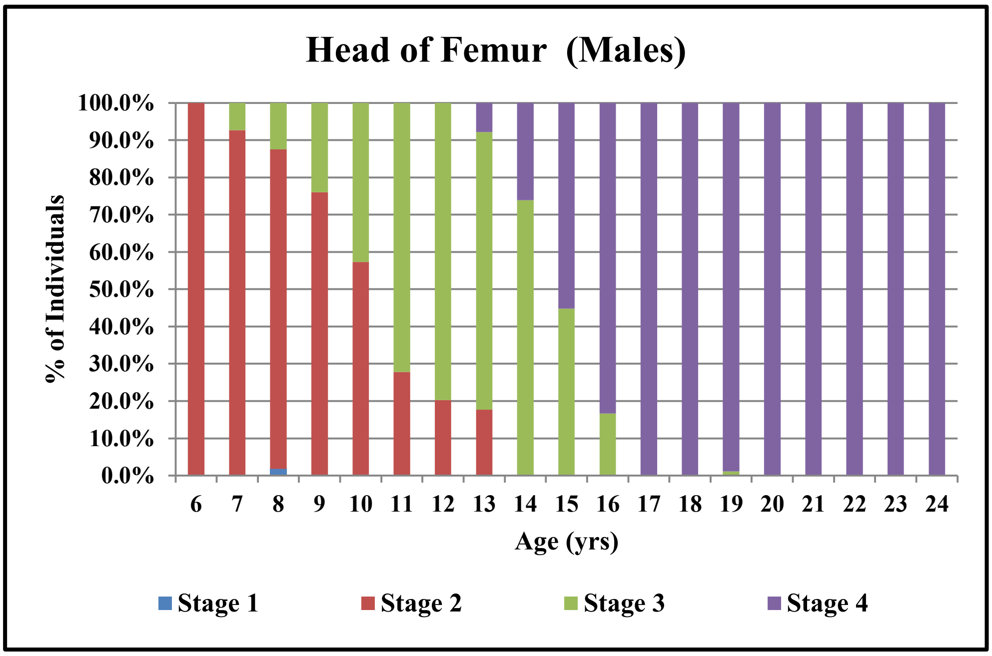


Figure 4.16: *Progression of union at the head of the femur in males* showing a visible absence *of stage 1. Stage 2 extends between 6 - 13 years. Stage 3 overlaps with stage 2 between 7 - 13 years and is terminated at age 16. Stage 4 in 100% of individuals is reached at 17 years.*

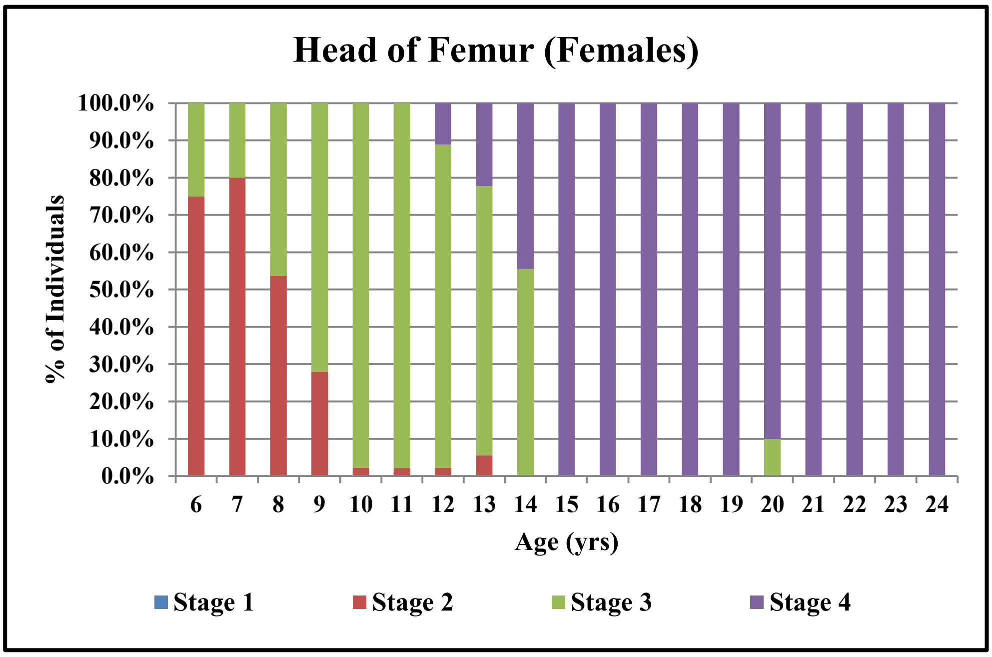


Figure 4.17: *Progression of union at the head of the femur in females.* There is a *visible absence of stage 1 and short duration for stage 2. Stage 2 extends between 6 - 13 years. Stage 3 overlaps with stage 2 between 6 - 9 years and is terminated at age 14. Stage 4 in 100% of individuals is reached at 15 years.*

4.2.2.2 Greater Trochanter

Stage 2 in 25% of males and females is observed six years (*Table 4.09*). Stage 2 is terminated at age 14 years in males and females (*Figure 4.18 and 4.19*). Stage 3 is first observed in females at age eight and terminates at age 14 years. Complete union in females is observed at 15 years (*Figure 4.19*) whereas fusion in greater than 95% of males is observed at age 18 years (complete union may be considered at this age) (*Figure 4.18).* Variation in the rate of maturation is evident in males who show a lag in reaching 100% union due to one or two males who still appear in stage 3. Two male outliers are visible; the first appears in stage 1 at 16 years and the second at 20 years who appears to be in stage 2 of union. The presence of two female outliers is also visible at age 20 years (*Figure 4.19*).

Table 4.09: Chronological age for stages 1 to 4 at the Greater Trochanter in Males and Females

	Males				*Females*			
Stage	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Age								
6	75.00%	25.00%	0.00%	0.00%	75.00%	25.00%	0.00%	0.00%
7	89.10%	10.90%	0.00%	0.00%	68.60%	31.40%	0.00%	0.00%
8	84.80%	15.20%	0.00%	0.00%	44.80%	53.70%	1.50%	0.00%
9	72.00%	28.00%	0.00%	0.00%	23.50%	73.50%	2.90%	0.00%
10	44.90%	55.10%	0.00%	0.00%	4.50%	90.90%	4.50%	0.00%
11	15.30%	84.70%	0.00%	0.00%	0.00%	84.80%	15.20%	0.00%
12	14.30%	82.10%	3.60%	0.00%	0.00%	44.40%	46.70%	8.90%
13	3.90%	80.40%	9.80%	5.90%	0.00%	33.30%	61.10%	5.60%
14	0.00%	56.50%	30.40%	13.00%	0.00%	11.10%	44.40%	44.40%
15	0.00%	10.30%	51.70%	37.90%	0.00%	0.00%	0.00%	100.00%
16	4.20%	0.00%	25.00%	70.80%	0.00%	0.00%	0.00%	100.00%
17	0.00%	0.00%	5.10%	94.90%	0.00%	0.00%	0.00%	100.00%
18	0.00%	0.00%	1.60%	98.40%	0.00%	0.00%	0.00%	100.00%
19	0.00%	0.00%	1.10%	98.90%	0.00%	0.00%	0.00%	100.00%
20	0.00%	1.20%	0.00%	98.80%	0.00%	10.00%	0.00%	90.00%
21	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
22	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
23	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
24	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%

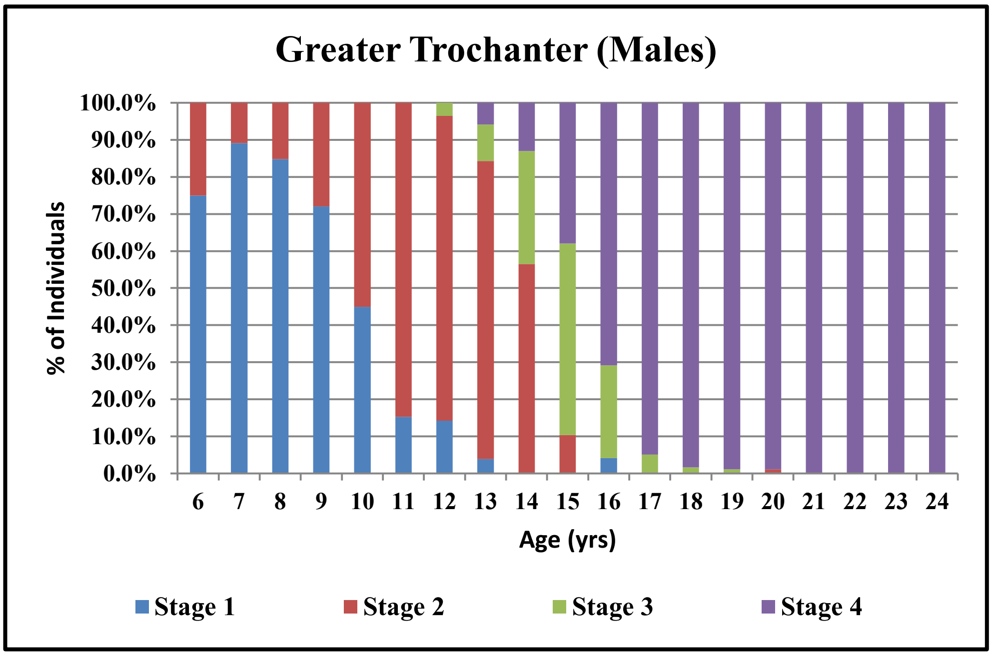


Figure 4.18: *Progression of union at the greater trochanter in males. Stage 1 in males is apparent till 13 years of age. Stage 2 begins at six years and continues till age 15. Stage 3 is first noticed at age 12 years and terminates at age 19. Stage 4 is achieved at 18 years.*

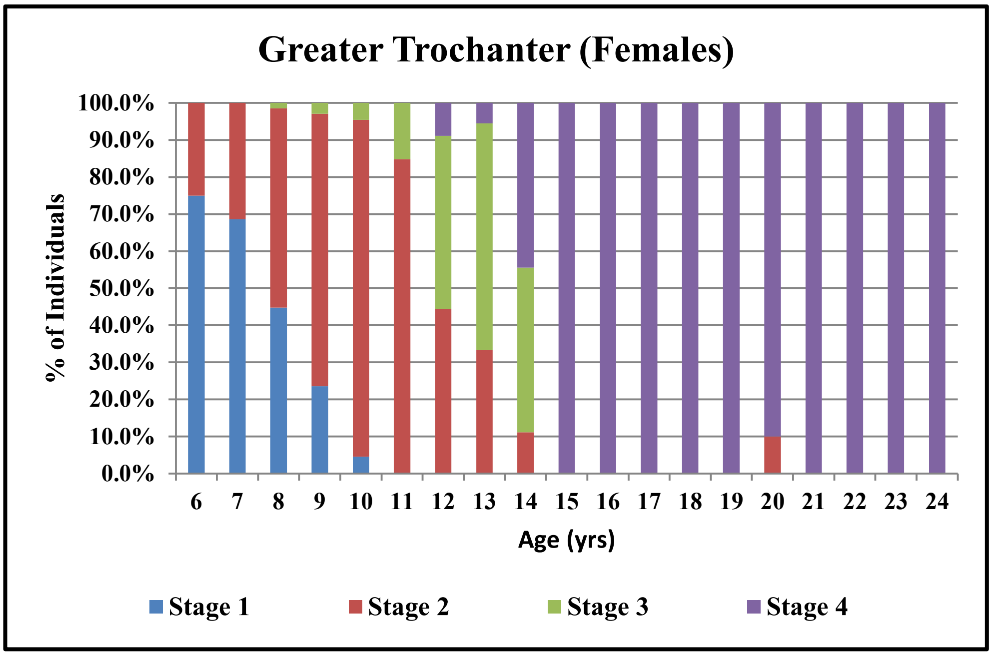


Figure 4.19: *Progression of union at the greater trochanter in females. Stage 1 in females appears between 6 - 10 years. It overlaps with stage 2 which begins at 6 and ends at 14 years. Stage 3 first noticed at age nine years and is terminated by age 15 years. Stage 4 is achieved in 100% of females at age 15.*

4.2.2.3 Lesser Trochanter

Stage 2 is observed at eight years in both males and females when 1.8% males and 6% of females fall within this stage (*Table 4.10*). Complete union is first observed at 13 years in males (5.9%) and 12 years in females (6.7%). Complete union occurs around 18 years in males (98.4%) and 15 years in females.

Table 4.10: Chronological age for stages 1 to 4 at the Lesser Trochanter in Males and Females

	Males				***Females***			
Stage	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Age								
6	100.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%
7	100.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%
8	98.20%	1.80%	0.00%	0.00%	94.00%	6.00%	0.00%	0.00%
9	96.00%	4.00%	0.00%	0.00%	88.20%	11.80%	0.00%	0.00%
10	93.30%	6.70%	0.00%	0.00%	65.90%	34.10%	0.00%	0.00%
11	81.90%	18.10%	0.00%	0.00%	60.90%	32.60%	6.50%	0.00%
12	65.50%	31.00%	3.60%	0.00%	48.90%	24.40%	20.00%	6.70%
13	54.90%	35.30%	3.90%	5.90%	27.80%	50.00%	11.10%	11.10%
14	26.10%	47.80%	17.40%	8.70%	11.10%	22.20%	22.20%	44.40%
15	6.90%	13.80%	41.40%	37.90%	0.00%	0.00%	0.00%	100.00%
16	4.20%	0.00%	25.00%	70.80%	0.00%	0.00%	0.00%	100.00%
17	0.00%	0.00%	6.80%	93.20%	0.00%	0.00%	0.00%	100.00%
18	0.00%	0.00%	1.60%	98.40%	0.00%	0.00%	0.00%	100.00%
19	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
20	0.00%	0.00%	0.00%	100.00%	10.00%	0.00%	0.00%	90.00%
21	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
22	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
23	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
24	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%

Stage 1 in both males and females appears prolonged, the oldest male to show non-union is 16 years old while the oldest female is 14 years old (*Figure 4.20 and 4.21*). A female outlier 20 years of age is visible in stage 2 of union compared to the rest of the females who complete union at age 15.

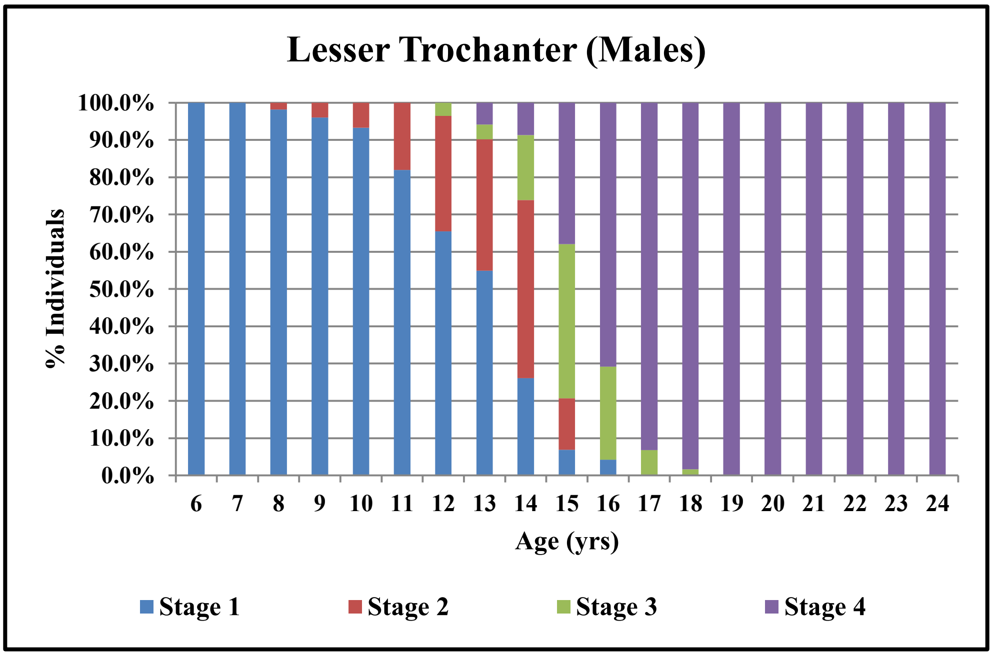


Figure 4.20: *Progression of union at lesser trochanter in males. Stage 1 is prolonged (6 - 16 years) in males. Stage 2 appears to be relatively shorter extending between 8 - 15 years of age. Stage 3 between 12 - 17 years and Stage 4 in 100% of individuals is reached at 19 years.*

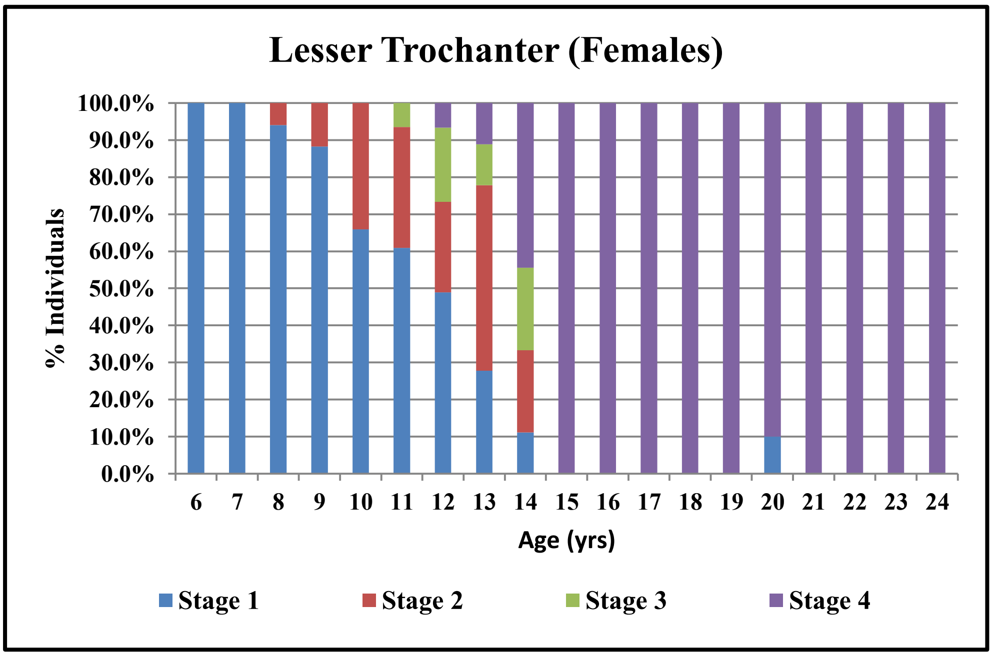


Figure 4.21: *Progression of union at lesser trochanter in females. Stage 1 in females also appears prolonged whereas stages 2 and 3 seem relatively shorter. Stage 1 for the lesser trochanter is 6 - 14 years, stage 2 (8 - 14) years whereas a stage 3 is visible between 11 - 14 years. 100% of females reach stage 4 at age 15 years.*

The sequence of union in males and females appears to be similar. In males, the head of the femur (HoF) appears to reach complete union ahead of the greater and lesser trochanters (GT & LT) (*Table 4.11*) (*Figure 4.22*). The head of the femur in males completes union at 17 years while the greater and lesser trochanters complete union at 18 years (greater than 95%). In females all the components complete union at 15 years of age (*Figure 4.23*). These bones are clustered and called hip.

Table 4.11: Chronological age of Union at the Hip in Males and Females

	Males				**Females**			
Age	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**
6	100% (4)	0% (0)	0% (0)	0% (0)	100% (4)	0% (0)	0% (0)	0% (0)
7	93% (51)	7% (4)	0% (0)	0% (0)	83% (29)	17% (6)	0% (0)	0% (0)
8	92% (103)	8% (9)	0% (0)	0% (0)	54% (36)	46%(31)	0% (0)	0% (0)
9	81% (61)	19% (14)	0% (0)	0% (0)	35% (24)	65%(44)	0% (0)	0% (0)
10	57% (51)	43% (38)	0% (0)	0% (0)	7% (3)	93%(41)	0% (0)	0% (0)
11	29% (21)	71% (51)	0% (0)	0% (0)	2% (1)	96% 44)	2% (1)	0% (0)
12	19% (16)	80% (67)	1% (1)	0% (0)	2% (1)	71%(32)	20% (9)	7% (3)
13	15% (8)	75% (39)	4% (2)	6% (3)	0% (0)	72% 13)	22% (4)	6% (1)
14	0% (0)	63% (15)	29% (7)	8% (2)	0% (0)	33% (3)	22% (2)	44% (4)
15	0% (0)	20% (6)	43%(13)	37% (11)	0% (0)	0% (0)	0% (0)	100% (8)
16	4% (1)	0% (0)	29% (7)	67% (16)	0% (0)	0% (0)	0% (0)	100% (3)
17	0% (0)	0% (0)	7% (4)	93% (55)	0% (0)	0% (0)	0% (0)	100% (5)
18	0% (0)	0% (0)	2% (1)	98% (60)	0% (0)	0% (0)	0% (0)	100% (9)
19	0% (0)	0% (0)	2% (2)	98% (87)	0% (0)	0% (0)	0% (0)	100% (10)
20	0% (0)	0% (0)	1% (1)	99% (85)	0% (0)	10% (1)	0% (0)	90% (9)
21	0% (0)	0% (0)	0% (0)	100% (94)	0% (0)	0% (0)	0% (0)	100% (21)
22	0% (0)	0% (0)	0% (0)	100% (102)	0% (0)	0% (0)	0% (0)	100% (16)
23	0% (0)	0% (0)	0% (0)	100% (82)	0% (0)	0% (0)	0% (0)	100% (18)
24	0% (0)	0% (0)	0% (0)	100% (94)	0% (0)	0% (0)	0% (0)	100% (9)

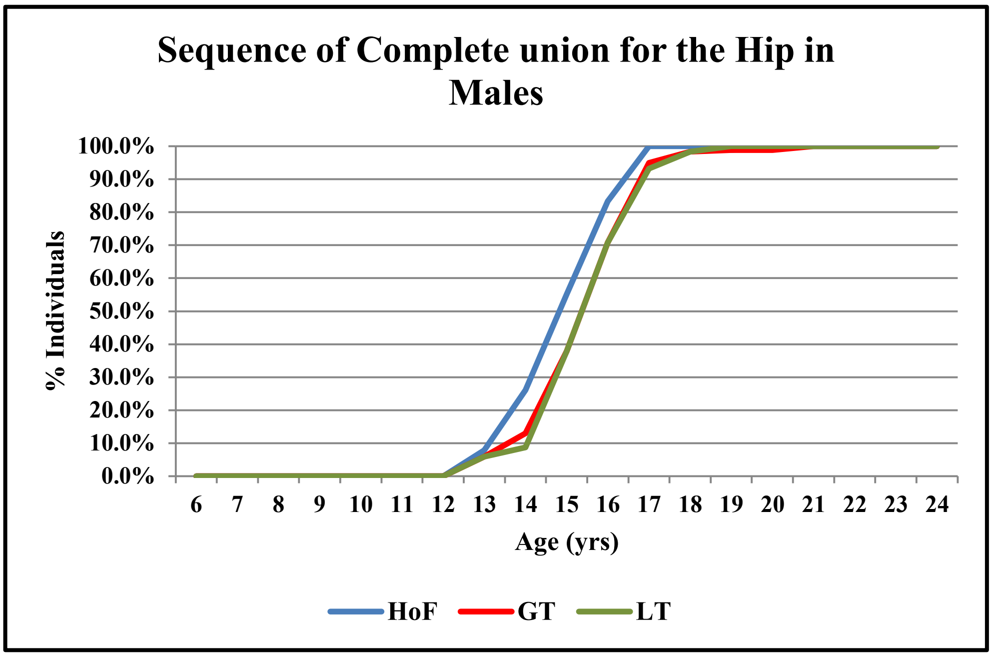


Figure 4.22: *Sequence of union at the hip in males. The head of the femur (HoF) appears to be slightly in advance of the greater (GT) and lesser trochanters (LT). The head achieves complete union at 17 years while the latter accomplishes union at age 18.*

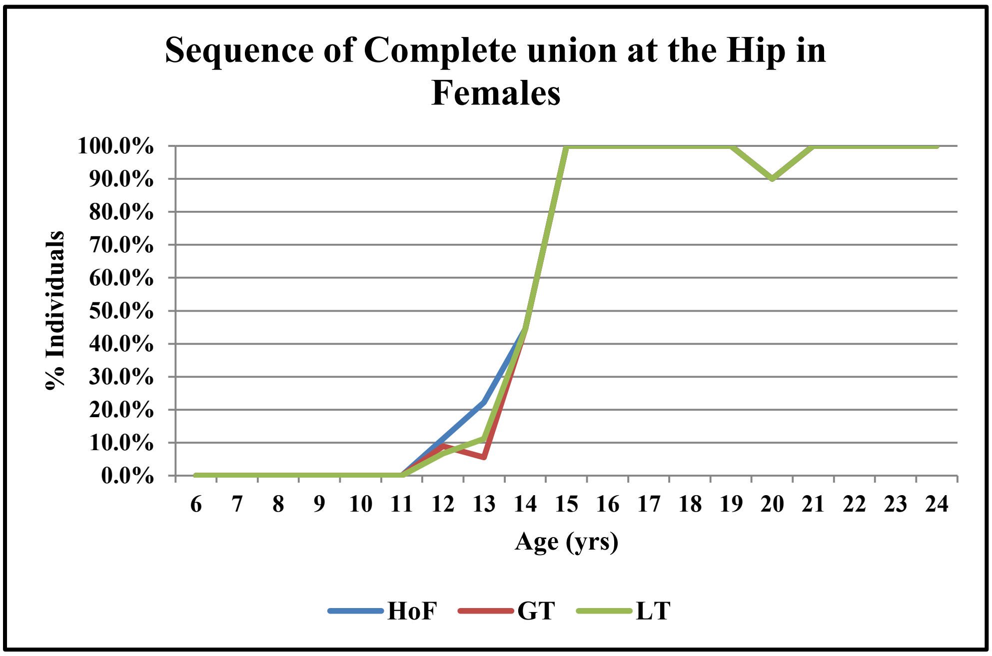


Figure 4.23: *Sequence of union at the hip in females. The head of the femur (HoF), greater (GT) and lesser (LT) trochanters in females follow a similar pattern and reach complete union at age 15.*

4.2.3 Ankle

4.2.3.1 Distal Tibia and Distal Fibula

The ankle comprises of the distal tibia and fibula and commences union after the hip and elbow. The epiphyses begin union by age six years in both males and females (*Table 4.12 and Table 4.13*). Females are in advance of males at all stages. Between ages 6 - 9 years 100% females show union and transition into stage 3 begins as early as 10 years. In males however the first signs of transition into stage 3 are seen at 12 years (*Figure 4.24 to Figure 4.27*).

Table 4.12: Chronological age for stages 1 to 4 at the Distal Tibia in Males and Females

	Males				***Females***			
Stage	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Age								
6	50.00%	50.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%
7	1.90%	98.10%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%
8	2.70%	97.30%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%
9	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%
10	0.00%	100.00%	0.00%	0.00%	0.00%	97.70%	2.30%	0.00%
11	0.00%	100.00%	0.00%	0.00%	0.00%	95.70%	4.30%	0.00%
12	0.00%	97.60%	2.40%	0.00%	0.00%	59.10%	34.10%	6.80%
13	0.00%	84.00%	10.00%	6.00%	0.00%	55.60%	38.90%	5.60%
14	0.00%	47.80%	39.10%	13.00%	0.00%	22.20%	44.40%	33.30%
15	0.00%	10.70%	57.10%	32.10%	0.00%	0.00%	0.00%	100.00%
16	0.00%	4.30%	26.10%	69.60%	0.00%	0.00%	0.00%	100.00%
17	0.00%	0.00%	8.60%	91.40%	0.00%	0.00%	0.00%	100.00%
18	0.00%	0.00%	1.70%	98.30%	0.00%	0.00%	0.00%	100.00%
19	0.00%	0.00%	1.10%	98.90%	0.00%	0.00%	0.00%	100.00%
20	0.00%	0.00%	0.00%	100.00%	0.00%	10.00%	0.00%	90.00%
21	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
22	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
23	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
24	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%

Table 4.13: Chronological age for stages 1 to 4 at the Distal Fibula in Males and Females

	Males				*Females*			
Stage	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Age								
6	50.00%	50.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%
7	1.90%	98.10%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%
8	1.80%	98.20%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%
9	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%
10	1.10%	98.90%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%
11	0.00%	100.00%	0.00%	0.00%	0.00%	97.80%	2.20%	0.00%
12	0.00%	98.80%	1.20%	0.00%	0.00%	63.60%	29.50%	6.80%
13	0.00%	88.00%	6.00%	6.00%	0.00%	61.10%	33.30%	5.60%
14	0.00%	52.20%	43.50%	4.30%	0.00%	22.20%	44.40%	33.30%
15	0.00%	10.70%	57.10%	32.10%	0.00%	0.00%	0.00%	100.00%
16	0.00%	4.30%	21.70%	73.90%	0.00%	0.00%	0.00%	100.00%
17	0.00%	0.00%	8.60%	91.40%	0.00%	0.00%	0.00%	100.00%
18	0.00%	0.00%	1.70%	98.30%	0.00%	0.00%	0.00%	100.00%
19	0.00%	0.00%	1.10%	98.90%	0.00%	0.00%	0.00%	100.00%
20	0.00%	0.00%	0.00%	100.00%	0.00%	10.00%	0.00%	90.00%
21	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
22	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
23	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
24	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%

A female outlier is visible at age 20 years at both the distal tibia *(Figure 4.25)* and distal fibula (*Figure 4.27*).Complete union of the distal tibia and fibula in males takes place at 18 years (98.3%) and 15 years in females. Males show a three year delay in complete union compared to females. In males 100% of the sample reaches complete union of the distal tibia and fibula at 20 years.

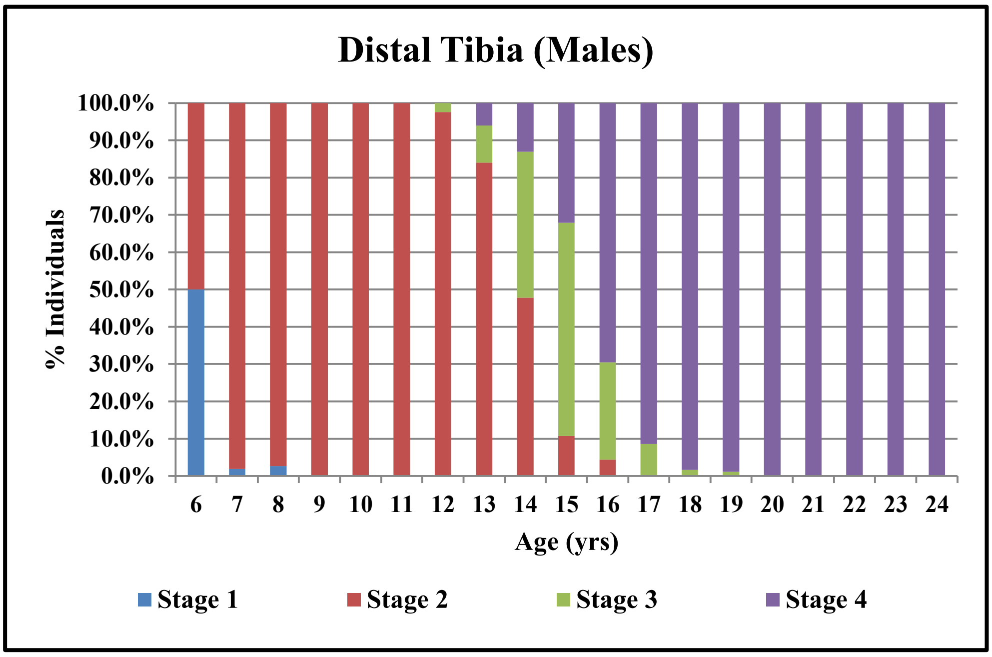


Figure 4.24: *Progression of union at the distal tibia in males. Males show non-union between 6 - 8 years, union begins early at seven years and concludes around 16 years. By age 18 greater than 95% of individuals have completed union.*

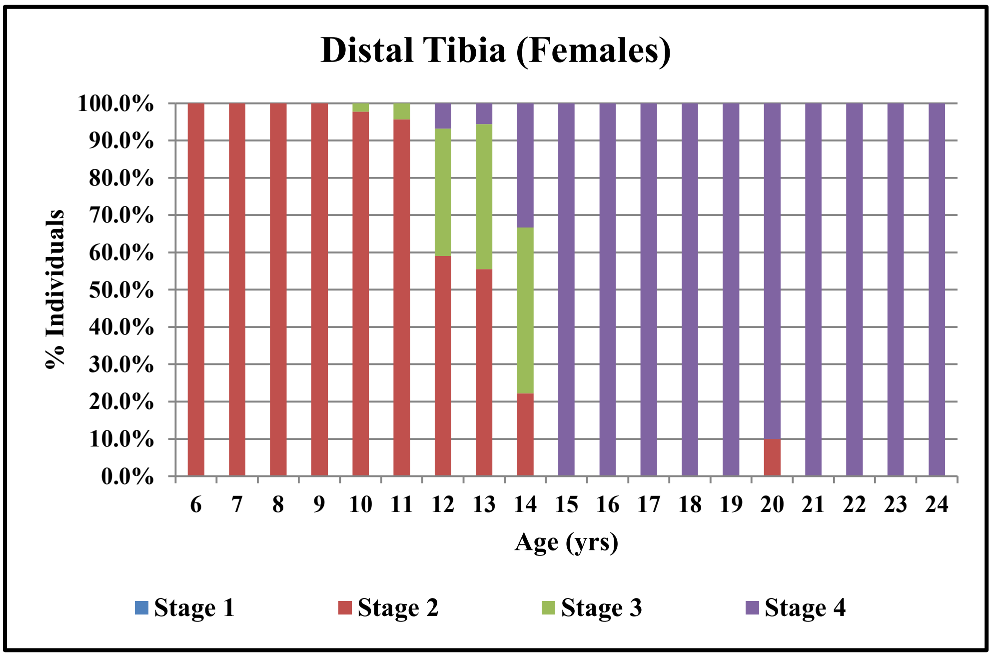


Figure 4.25: *Progression of union at the distal tibia in females showing prolonged stage 2 (6 - 14 years, stage 3 briefly overlaps with stage 2 between 10 - 14 years and is itself terminated at 14 years. The first signs of complete union are at 10 years and complete union (100% of individuals) at 15 years.*

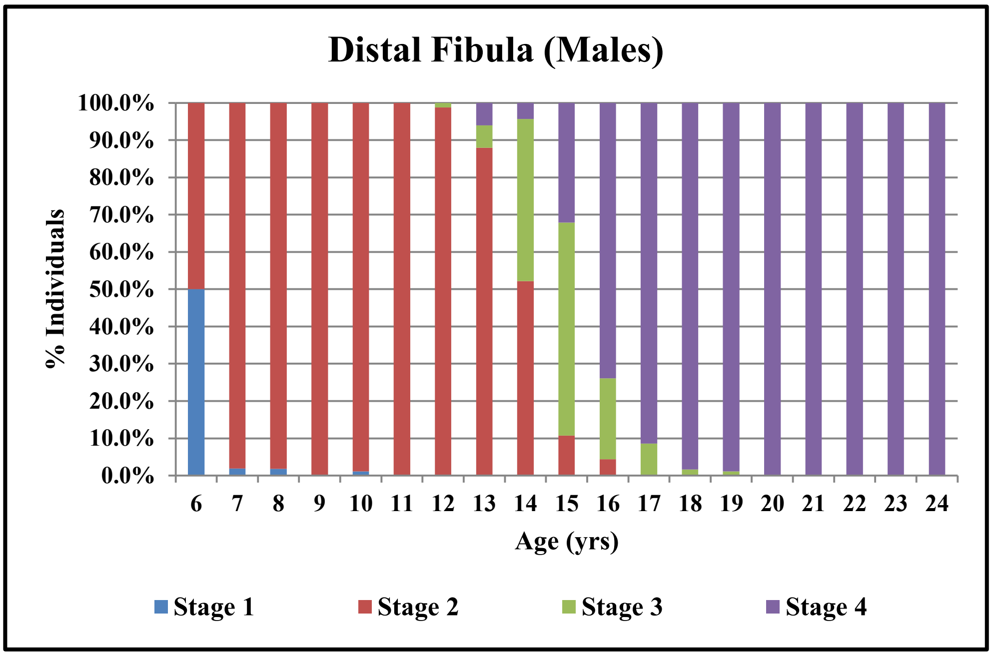


Figure 4.26: *Progression of union at the distal fibula in males. Stage 1 is apparent at six years of age. Stage 2 is apparent between 6 – 16 years and stage 3 (12 - 18). At age 18 years greater than 95% of individuals appear to have completed union.*

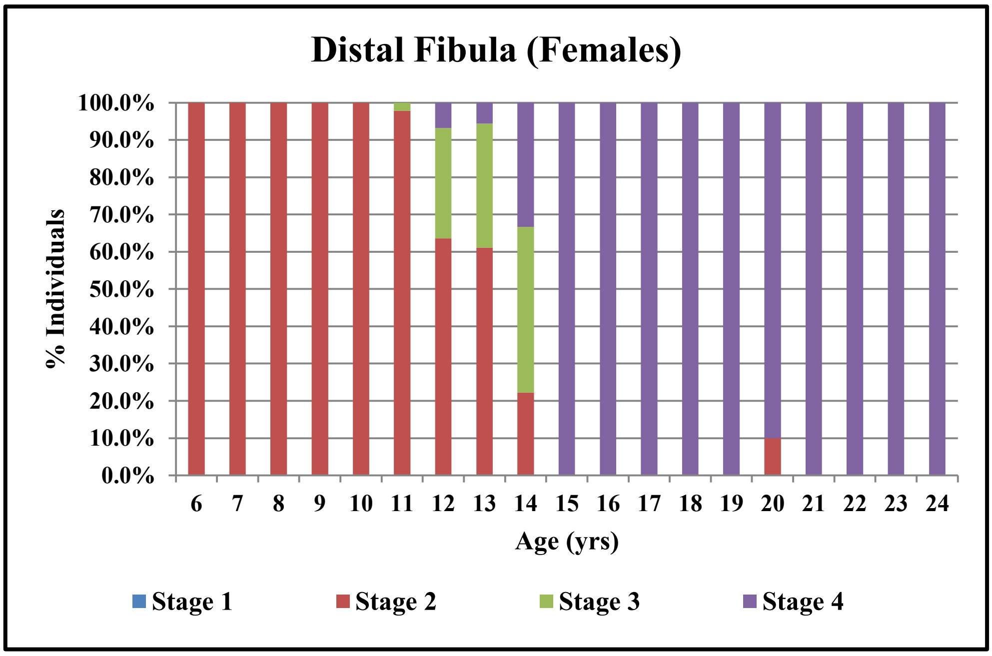


Figure 4.27: *Progression of union at the distal fibula in females. A prolonged stage 2 is visible between 6 - 14 years. Stage 3 overlaps between 11 - 14 years and stage 4 of 100% of individuals is achieved by 15 years.*

Both the distal tibia and fibula in males follow the exact sequence showing no significant differences in age and pattern of union (*Figure 4.28*). Therefore they can be grouped into one joint called the ankle (*Table 4.14*). In females (*Figure 4.29*), both the distal tibia and fibula follow the exact sequence resulting in lack of differentiation between the two curves.

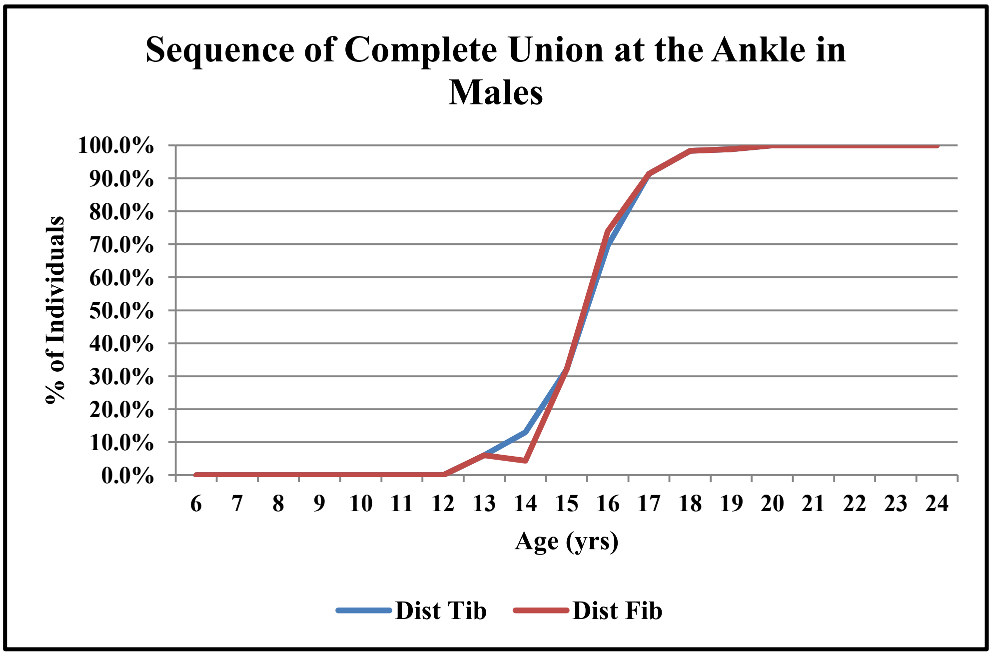


Figure 4.28: *Sequence of complete union at the Ankle in males showing no significant differences in the pattern or timing of union.*

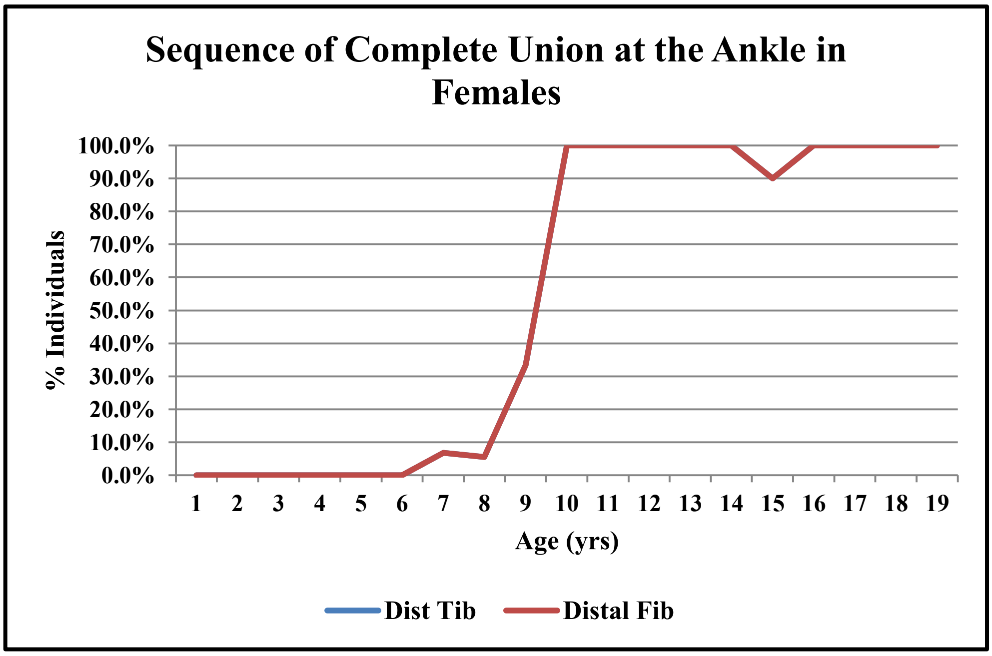


Figure 4.29: *Sequence of complete union at the ankle in females showing no differentiation in the pattern and timing of stage 4.*

Table 4.14: Chronological age of Union at the Ankle in Males and Females

	Males				Females			
Age	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**
6	50% (2)	50% (2)	0% (0)	0% (0)	0% (0)	100% (4)	0% (0)	0% (0)
7	2% (1)	98% (51)	0% (0)	0% (0)	0% (0)	100% (35)	0% (0)	0% (0)
8	3% (3)	97% (108)	0% (0)	0% (0)	0% (0)	100% (65)	0% (0)	0% (0)
9	0% (0)	100% (73)	0% (0)	0% (0)	0% (0)	100% (67)	0% (0)	0% (0)
10	1% (1)	99% (87)	0% (0)	0% (0)	0% (0)	100% (44)	0% (0)	0% (0)
11	0% (0)	100% (71)	0% (0)	0% (0)	0% (0)	98% (45)	2% (1)	0% (0)
12	0% (0)	99% (82)	1% (1)	0% (0)	0% (0)	64% (28)	30% (13)	7% (3)
13	0% (0)	88% (45)	6% (3)	0% (0)	0% (0)	61% (11)	33% (6)	6% (1)
14	0% (0)	50% (12)	46%(11)	4% (1)	0% (0)	22% (2)	44% (4)	33% (3)
15	0% (0)	10% (3)	55%(16)	34% (10)	0% (0)	0% (0)	0% (0)	100% (8)
16	0% (0)	4% (1)	26% (6)	70% (16)	0% (0)	0% (0)	0% (0)	100% (3)
17	0% (0)	0% (0)	9% (5)	91% (53)	0% (0)	0% (0)	0% (0)	100% (5)
18	0% (0)	0% (0)	2% (1)	98% (59)	0% (0)	0% (0)	0% (0)	100% (9)
19	0% (0)	0% (0)	1% (1)	99% (88)	0% (0)	0% (0)	0% (0)	100% 10)
20	0% (0)	0% (0)	0% (0)	100%(86)	0% (0)	10% (1)	0% (0)	90% (9)
21	0% (0)	0% (0)	0% (0)	100%(94)	0% (0)	0% (0)	0% (0)	100%(21)
22	0% (0)	0% (0)	0% (0)	100% 102)	0% (0)	0% (0)	0% (0)	100% 15)
23	0% (0)	0% (0)	0% (0)	100% (82)	0% (0)	0% (0)	0% (0)	100% 18)
24	0% (0)	0% (0)	0% (0)	100% (94)	0% (0)	0% (0)	0% (0)	100% (9)

4.2.4 Knee

The knee comprises of three epiphyses which include the distal femur, proximal tibia and proximal fibula.

4.2.4.1 Distal Femur

Union (stage 2) of the distal femur is observed as early as six years in both males (*Table 4.15*) (*Figure 4.30*) and females (*Figure 4.31*). A larger percentage of males appear to be in stage 1 compared to females and stage 3 is first observed at nine years in males (13.5%) and eight years in females (20.9%). Outliers are also apparent in females at 20 and 22 years respectively (*Figure 4.31*). Complete union is visible at 15 years in females and 19 years in males when greater than 95% of males show maturity.

Table 4.15: Chronological age for stages 1 to 4 at the Distal Femur in Males and Females

	Males				*Females*			
Stage	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Age								
6	50.00%	50.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%
7	50.90%	47.30%	1.80%	0.00%	34.30%	65.70%	0.00%	0.00%
8	38.40%	59.80%	1.80%	0.00%	9.00%	70.10%	20.90%	0.00%
9	17.60%	68.90%	13.50%	0.00%	1.50%	57.40%	41.20%	0.00%
10	9.00%	69.70%	21.30%	0.00%	0.00%	27.30%	72.70%	0.00%
11	2.80%	54.90%	42.30%	0.00%	0.00%	17.40%	82.60%	0.00%
12	1.20%	36.10%	62.70%	0.00%	0.00%	13.30%	84.40%	2.20%
13	2.00%	29.40%	62.70%	5.90%	0.00%	0.00%	100.00%	0.00%
14	0.00%	13.00%	78.30%	8.70%	0.00%	11.10%	44.40%	44.40%
15	0.00%	0.00%	65.50%	34.50%	0.00%	0.00%	0.00%	100.00%
16	0.00%	0.00%	47.80%	52.20%	0.00%	0.00%	0.00%	100.00%
17	0.00%	0.00%	13.60%	86.40%	0.00%	0.00%	0.00%	100.00%
18	0.00%	0.00%	6.60%	93.40%	0.00%	0.00%	0.00%	100.00%
19	0.00%	0.00%	2.30%	97.70%	0.00%	0.00%	0.00%	100.00%
20	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	10.00%	90.00%
21	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
22	0.00%	0.00%	1.00%	99.00%	0.00%	0.00%	6.30%	93.80%
23	0.00%	0.00%	1.20%	98.80%	0.00%	0.00%	0.00%	100.00%
24	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%

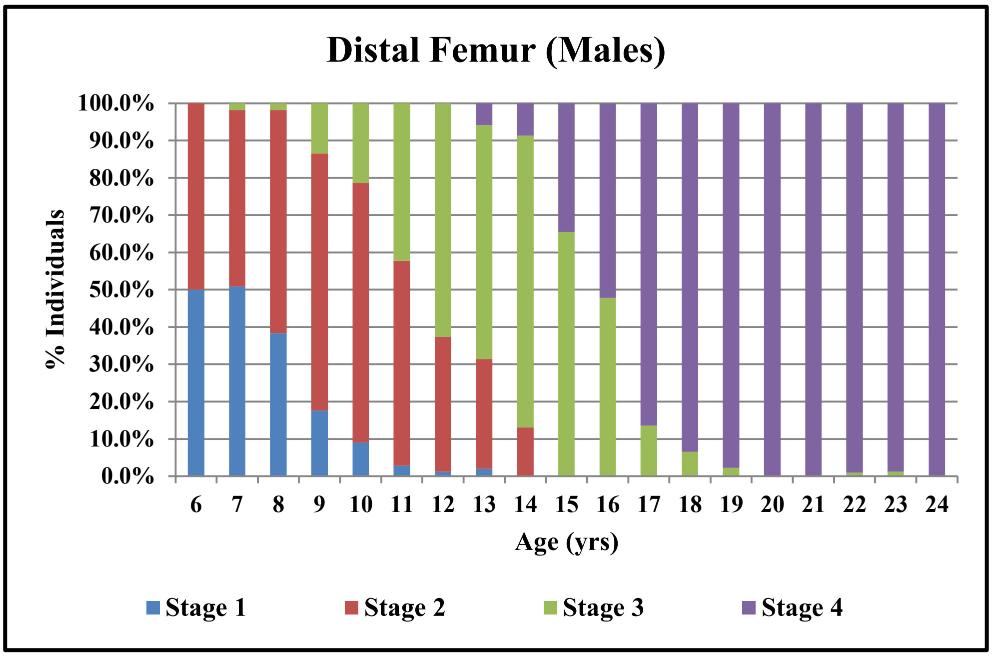


Figure 4.30: *Progression of union at the distal femur in males. Stage 1 extends between 6 - 13 years, stage 2 between 6 - 14 years. Stage 3 of union is first seen at seven years and stage 4 at 13 years. Complete union occurs at 19 years.*

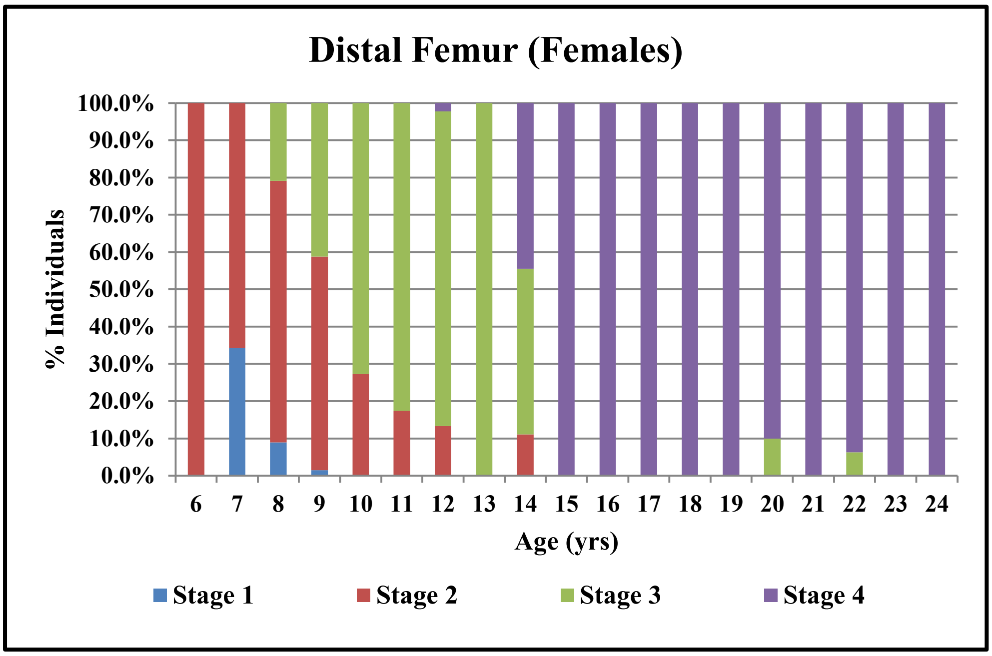


Figure 4.31: *Progression of union at the distal femur in females. Stage 1 is rather brief spanning 3 years (7 - 9 years). Stage 2 is observed between 6-12 years and stage 3 progresses rather rapidly with greater percentages of females in stage 3 for every age compared to males. Stage 4 is first observed at 14 years (44.4%) and complete union is achieved at 15 years (100%).*

4.2.4.2 Proximal Tibia and Proximal Fibula

Stage 1 is more prominent in the proximal tibia and fibula. It is observed as early as six years and is terminated by 13 years in males and nine years in females (*Table 4.16 and Table 4.17*). The beginning of union is first observed at six years in both males (25%) and females (50%). Stage 2 is terminated at 16 years in males and 14 years in females (*Figure 4.32 - Figure 4.35*). Complete union is first observed at age 13 in males (3.9%) and at 14 years in females (22.2%). In females 100% of the sample attains complete union by age 16 years while in males this is only observed at age 19. 100% union in males is however observed at 21 years.

Table 4.16: Chronological age for stages 1 to 4 at the Proximal Tibia in Males and Females

	Males				***Females***			
Stage	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Age								
6	75.00%	25.00%	0.00%	0.00%	50.00%	50.00%	0.00%	0.00%
7	80.00%	20.00%	0.00%	0.00%	77.10%	22.90%	0.00%	0.00%
8	80.40%	19.60%	0.00%	0.00%	35.80%	62.70%	1.50%	0.00%
9	56.80%	43.20%	0.00%	0.00%	14.70%	85.30%	0.00%	0.00%
10	31.50%	68.50%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%
11	8.50%	90.10%	1.40%	0.00%	0.00%	80.40%	19.60%	0.00%
12	6.00%	91.60%	2.40%	0.00%	0.00%	55.60%	44.40%	0.00%
13	2.00%	86.30%	7.80%	3.90%	0.00%	38.90%	61.10%	0.00%
14	0.00%	60.90%	34.80%	4.30%	0.00%	11.10%	66.70%	22.20%
15	0.00%	17.20%	62.10%	20.70%	0.00%	0.00%	25.00%	75.00%
16	0.00%	4.30%	60.90%	34.80%	0.00%	0.00%	0.00%	100.00%
17	0.00%	0.00%	20.30%	79.70%	0.00%	0.00%	0.00%	100.00%
18	0.00%	0.00%	6.60%	93.40%	0.00%	0.00%	0.00%	100.00%
19	0.00%	0.00%	2.30%	97.70%	0.00%	0.00%	0.00%	100.00%
20	0.00%	0.00%	1.20%	98.80%	0.00%	10.00%	0.00%	90.00%
21	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
22	0.00%	0.00%	1.00%	99.00%	0.00%	0.00%	6.30%	93.80%
23	0.00%	0.00%	1.20%	98.80%	0.00%	0.00%	0.00%	100.00%
24	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%

Table 4.17: Chronological age for stages 1 to 4 at the Proximal Fibula in Males and Females

	Males				***Females***			
Stage	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Age								
6	100.00%	0.00%	0.00%	0.00%	75.00%	25.00%	0.00%	0.00%
7	98.10%	1.90%	0.00%	0.00%	97.10%	2.90%	0.00%	0.00%
8	95.50%	4.50%	0.00%	0.00%	83.60%	16.40%	0.00%	0.00%
9	91.90%	8.10%	0.00%	0.00%	54.40%	45.60%	0.00%	0.00%
10	75.00%	25.00%	0.00%	0.00%	45.50%	54.50%	0.00%	0.00%
11	44.90%	53.60%	1.40%	0.00%	15.20%	82.60%	2.20%	0.00%
12	29.30%	70.70%	0.00%	0.00%	4.40%	77.80%	17.80%	0.00%
13	23.50%	68.60%	3.90%	3.90%	0.00%	88.90%	11.10%	0.00%
14	4.30%	69.60%	21.70%	4.30%	0.00%	22.20%	55.60%	22.20%
15	0.00%	34.50%	44.80%	20.70%	0.00%	0.00%	25.00%	75.00%
16	0.00%	8.70%	56.50%	34.80%	0.00%	0.00%	0.00%	100.00%
17	0.00%	0.00%	20.30%	79.70%	0.00%	0.00%	0.00%	100.00%
18	0.00%	0.00%	6.60%	93.40%	0.00%	0.00%	0.00%	100.00%
19	0.00%	0.00%	2.30%	97.70%	0.00%	0.00%	0.00%	100.00%
20	0.00%	0.00%	1.20%	98.80%	0.00%	10.00%	0.00%	90.00%
21	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
22	0.00%	0.00%	1.00%	99.00%	0.00%	0.00%	6.30%	93.80%
23	0.00%	0.00%	1.20%	98.80%	0.00%	0.00%	0.00%	100.00%
24	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%

Non-union (stage 1) in the proximal fibula is seen up to 14 (4.3%) years in males and 12 years in females (4.2%) suggesting that its development is slightly delayed compared to the proximal epiphysis of the tibia. The onset of stage 2 in males appears to be delayed by a year compared to the proximal tibia whereas stage 3 in both males and females progresses rapidly. Complete union is first observed earlier in males at 13 years (3.9%) compared to females at 14 years (22.2%) (*Table 4.17*). Females complete union at 16 years in both proximal tibia and fibula three years earlier than males (19 years). Stage 4 in 100% of males is seen at age 21 although greater than 95% of males appear in stage 4 by age 19 (*Figure 4.32 and 4.34)*. There appears to be two female outliers at ages 20 and 22 respectively (*Figure 4.33 and Figure 4.35*).

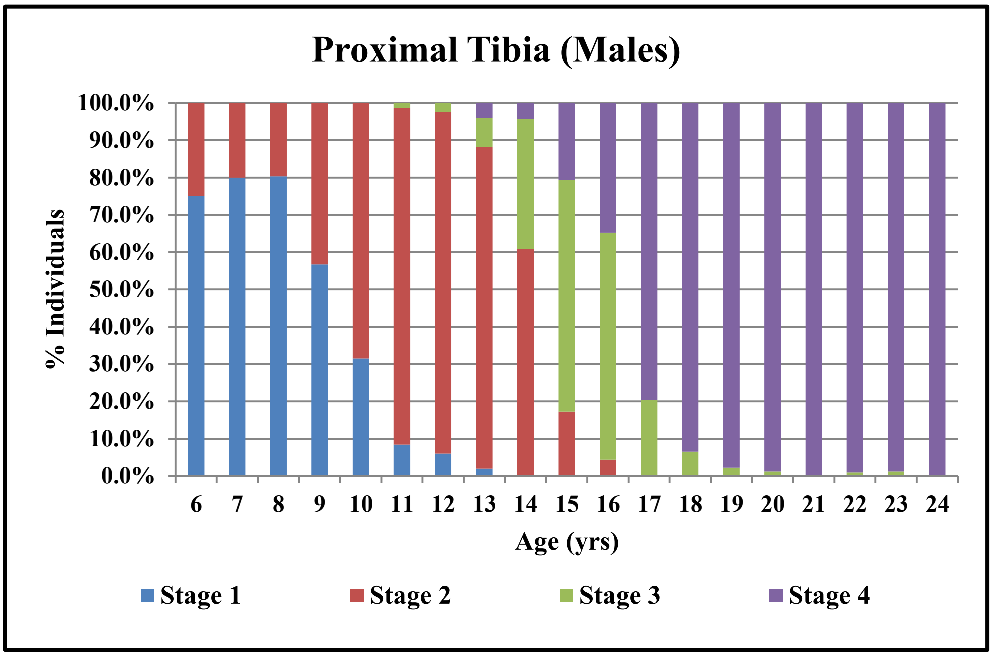


Figure 4.32: *Progression of union at the proximal tibia in males. Stage 1 in males is observed between 6 - 13 years. Stage 2 first observed at six years is completed by 16 years. Stage 3 of union is first seen at 11 years and is completed by 20 years by which time 98.8% have also reached stage 4. Maturity is attained by 21 years.*

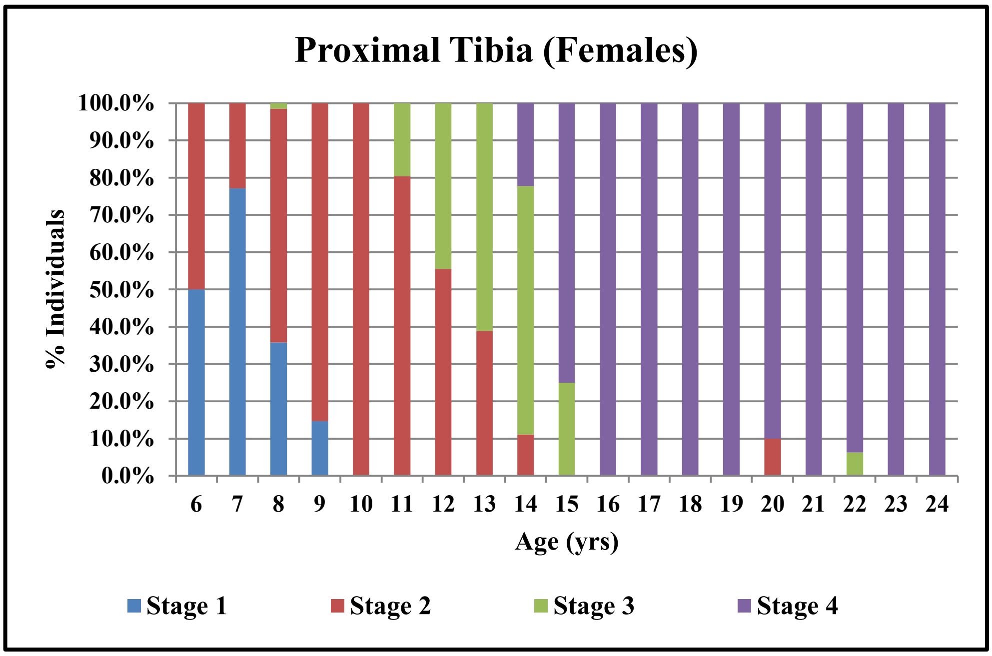


Figure 4.33: *Progression of union at the proximal tibia in females. Stage 1 is observed between 6 - 9 years, stage 2 between 6 - 14 year, stage 3 is completed by 15 years and stage 4 in 100% of females is attained at 16 years.*

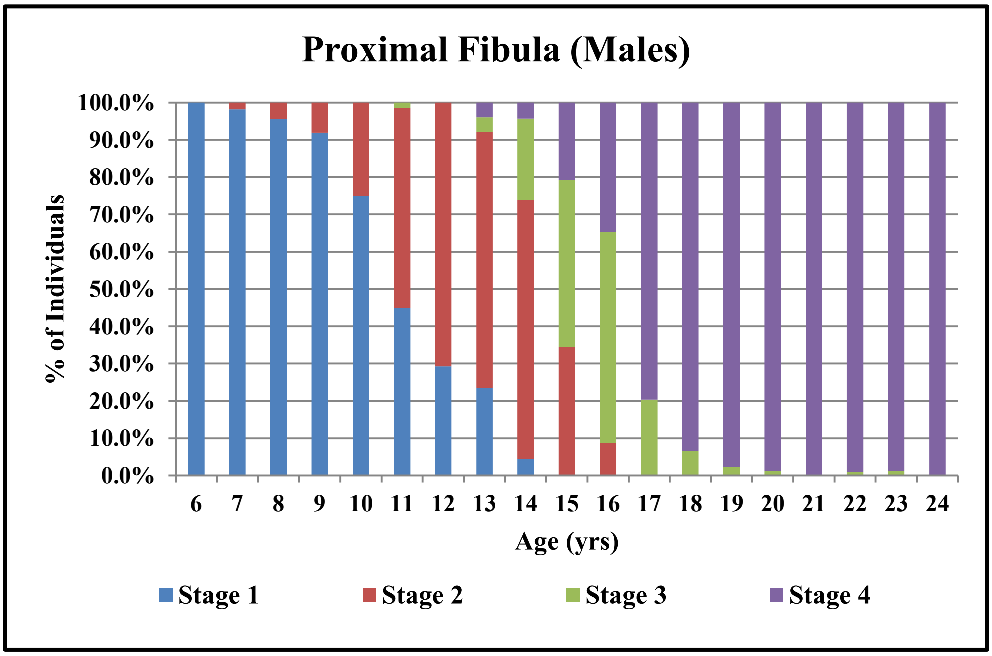


Figure 4.34: *Progression of union at the proximal fibula in males showing a prolonged stage 1 in male. Stage 2 is observed between 6 - 14 years, stage 3 between 13 - 20 years and stage 4 of 100% males at age 21.*

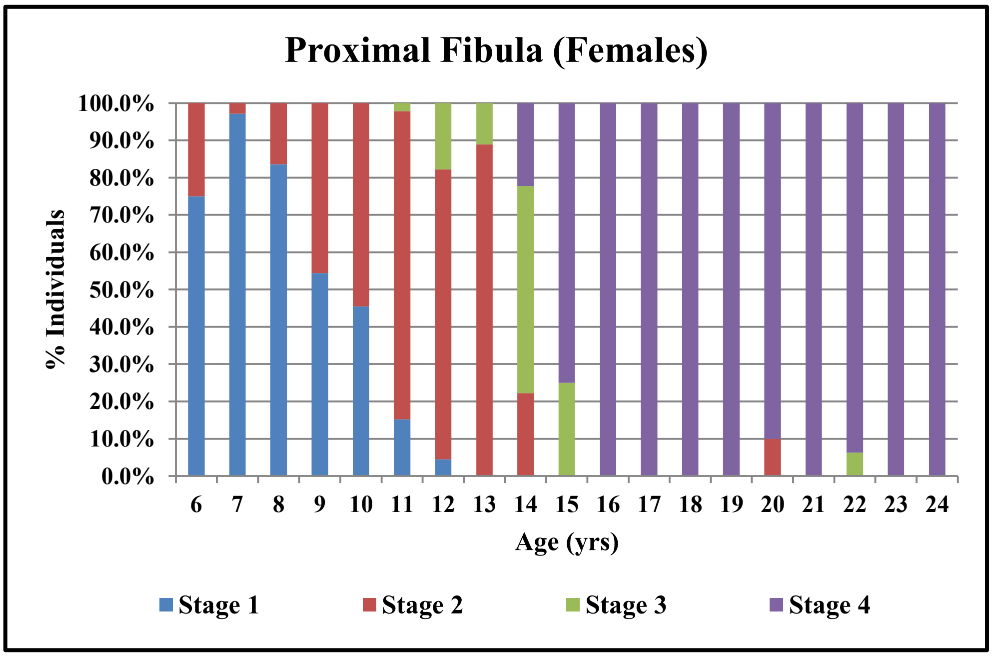


Figure 4.35: *Progression of union at the proximal fibula in females. Stage 1 is observed between 6 - 12 years, stage 2 between 6 - 14 years and stage 3 11 - 15 years. Stage 4 in 100% of females is attained at 16 years.*

The sequence of complete union for males (*Figure 4.36*) and females (*Figure 4.37*) at these three epiphysis is as follows, the distal femur appears to be in advance of the proximal tibia and fibula; however not significantly. The proximal tibia and fibula follow the same pattern and cannot be differentiated in the illustration below. The epiphyses are grouped into a joint called the knee (*Table 4.18*).

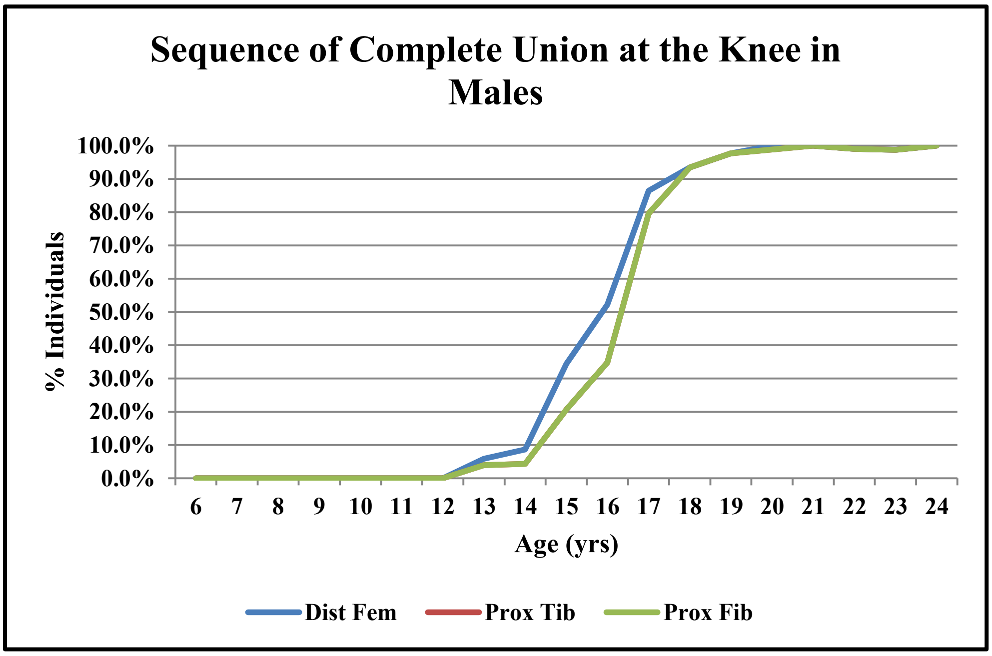


Figure 4.36: *The sequence of complete union (stage 4) in males. The distal femur appears to be slightly advanced compared to the proximal tibia and fibula and are not significant. The proximal tibia and fibula follow the same pattern in time and cannot be differentiated.*

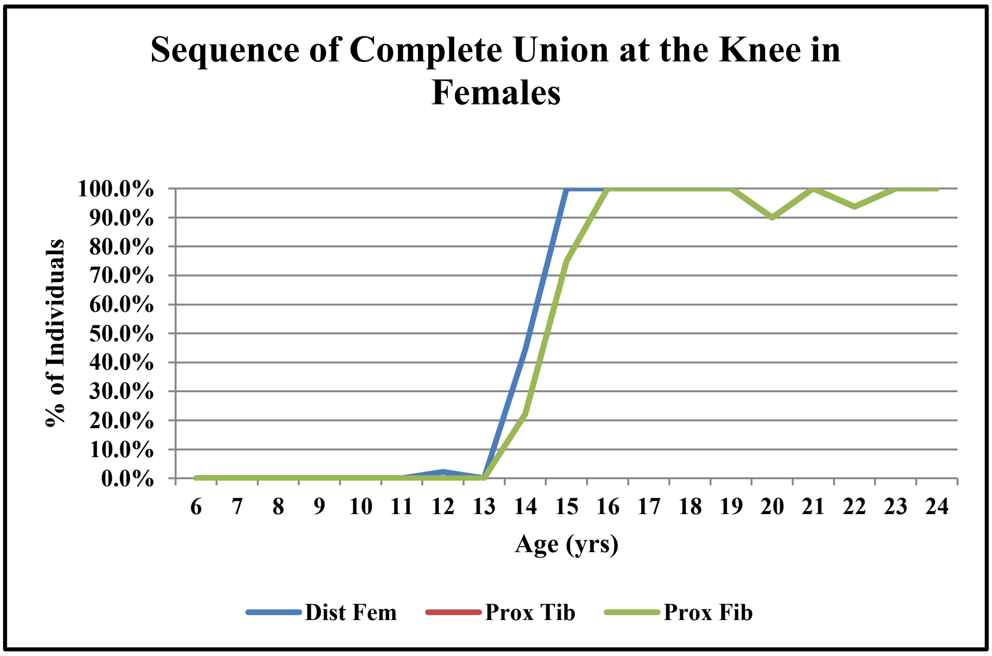


Figure 4.37: *Sequence of complete union (stage 4) in females. The distal femur appears to be slightly advanced compared to the proximal tibia and fibula and are not significant. The proximal tibia and fibula follow the same pattern in time and cannot be differentiated.*

Table 4.18: Chronological age of Union at the Knee in Males and Females

	Males				Females			
Age	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**
6	100% (4)	0% (0)	0% (0)	0% (0)	75% (3)	25% (1)	0% (0)	0% (0)
7	98% (53)	2% (1)	0% (0)	0% (0)	97% (34)	3% (1)	0% (0)	0% (0)
8	96% (107)	4% (5)	0% (0)	0% (0)	70% (47)	30% (20)	0% (0)	0% (0)
9	82% (61)	18% (13)	0% (0)	0% (0)	40% (27)	60% (41)	0% (0)	0% (0)
10	66% (58)	34% (30)	0% (0)	0% (0)	18% (8)	82% (36)	0% (0)	0% (0)
11	38% (26)	62% (43)	0% (0)	0% (0)	7% (3)	91% (42)	2% (1)	0% (0)
12	18% (15)	82% (67)	0% (0)	0% (0)	4% (2)	80% (36)	16% (7)	0% (0)
13	13% (7)	79% (41)	4% (2)	0% (0)	0% (0)	89% (16)	11% (2)	0% (0)
14	4% (1)	67% (16)	25% (6)	4% (1)	0% (0)	22% (2)	56% (5)	22% (2)
15	0% (0)	33% (10)	43% (13)	23% (7)	0% (0)	0% (0)	25% (2)	75% (6)
16	0% (0)	9% (2)	57% (13)	35% (8)	0% (0)	0% (0)	0% (0)	100% (3)
17	0% (0)	0% (0)	20% (12)	80% (47)	0% (0)	0% (0)	0% (0)	100% (5)
18	0% (0)	0% (0)	7% (4)	93% (57)	0% (0)	0% (0)	0% (0)	100% (9)
19	0% (0)	0% (0)	2% (2)	98% (87)	0% (0)	0% (0)	0% (0)	100% (10)
20	0% (0)	0% (0)	1% (1)	99% (85)	0% (0)	10% (1)	0% (0)	90% (9)
21	0% (0)	0% (0)	0% (0)	100% (94)	0% (0)	0% (0)	0% (0)	100% (21)
22	0% (0)	0% (0)	1% (1)	99% (101)	0% (0)	0% (0)	6% (1)	94% (15)
23	0% (0)	0% (0)	1% (1)	99% (81)	0% (0)	0% (0)	0% (0)	100% (18)
24	0% (0)	0% (0)	0% (0)	100% (94)	0% (0)	0% (0)	0% (0)	100% (9)

4.2.5 Wrist

4.2.5.1 Distal Ulna

The wrist is comprised of two epiphyses namely the distal ulna and distal radius. Females commence union (stage 2) at the distal ulna approximately a year ahead of males at seven years when 3.6% of females appear in stage 2 (*Table 4.19*). Stage 2 is first observed at eight years in males (1.2% of individuals). Stage 2 is completed in males around 16 years and 13 years in females (*Figure 4.38 and Figure 4.39*). A 14 year old female outlier is visible in stage 1 of union (*Figure 4.39*). Complete union in males is first noted at 13 years (6.7%) and 12 years in females (2.9%). The age of complete union in males is 20 years and 17 years in females.

Table 4.19: Chronological age for stages 1 to 4 at the Distal Ulna in Males and Females

	Males				*Females*			
Stage	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Age								
6	100.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%
7	100.00%	0.00%	0.00%	0.00%	96.40%	3.60%	0.00%	0.00%
8	98.80%	1.20%	0.00%	0.00%	89.40%	10.60%	0.00%	0.00%
9	92.50%	7.50%	0.00%	0.00%	77.60%	22.40%	0.00%	0.00%
10	88.70%	11.30%	0.00%	0.00%	53.80%	46.20%	0.00%	0.00%
11	69.00%	31.00%	0.00%	0.00%	25.00%	71.90%	3.10%	0.00%
12	53.30%	46.70%	0.00%	0.00%	8.80%	67.60%	20.60%	2.90%
13	33.30%	56.70%	3.30%	6.70%	0.00%	53.80%	46.20%	0.00%
14	0.00%	64.30%	35.70%	0.00%	12.50%	0.00%	75.00%	12.50%
15	0.00%	18.20%	63.60%	18.20%	0.00%	0.00%	37.50%	62.50%
16	0.00%	10.00%	60.00%	30.00%	0.00%	0.00%	33.30%	66.70%
17	0.00%	0.00%	23.70%	76.30%	0.00%	0.00%	0.00%	100.00%
18	0.00%	0.00%	9.80%	90.20%	0.00%	0.00%	0.00%	100.00%
19	0.00%	0.00%	6.80%	93.20%	0.00%	0.00%	0.00%	100.00%
20	0.00%	0.00%	3.50%	96.50%	0.00%	0.00%	0.00%	100.00%
21	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
22	0.00%	0.00%	1.00%	99.00%	0.00%	0.00%	0.00%	100.00%
23	0.00%	0.00%	1.20%	98.80%	0.00%	0.00%	0.00%	100.00%
24	0.00%	0.00%	1.10%	98.90%	0.00%	0.00%	0.00%	100.00%

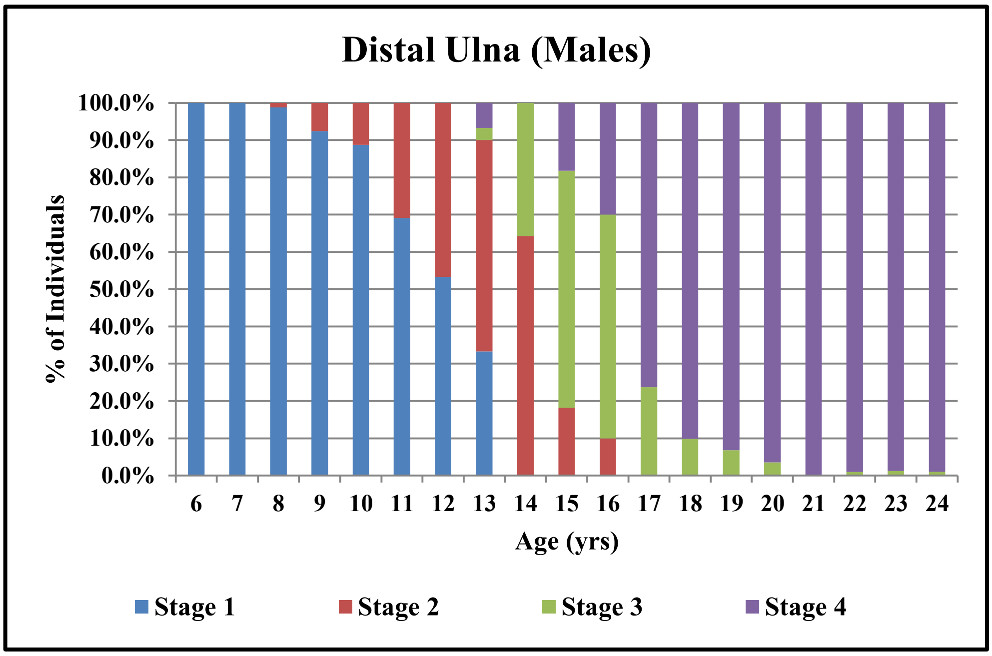


Figure 4.38: *Progression of union at the distal ulna in males. Stage 1 is apparent between 6 - 13 years, stage 2 between 8 - 13 years and stage 3 between 13 - 20 years. Stage 4 is achieved by 100% of males at age 21.*

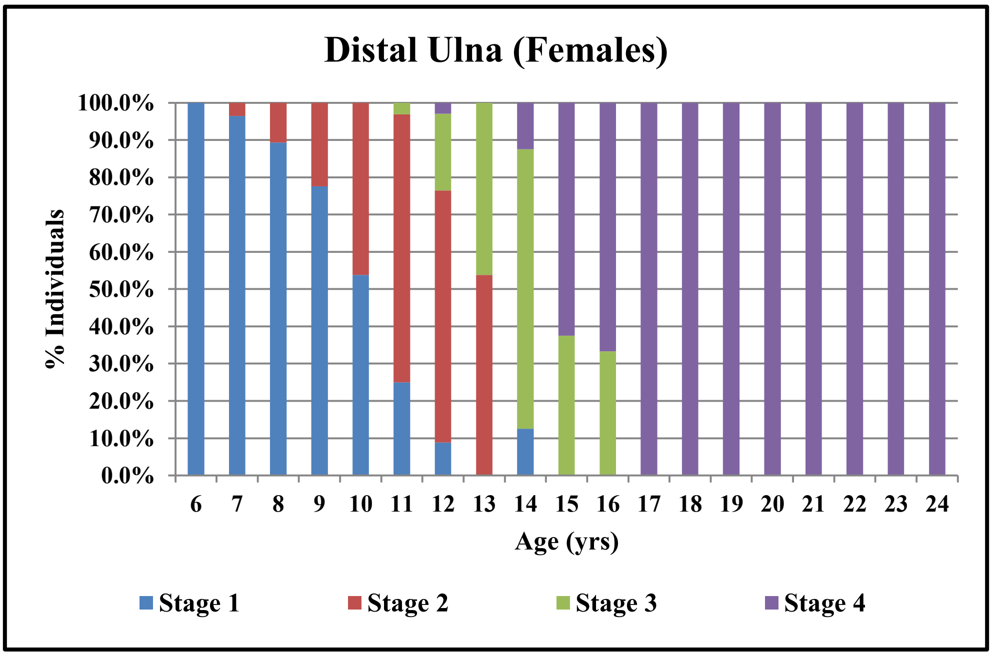


Figure 4.39: *Progression of union at the distal ulna in females. Stage 1 is apparent between 6 - 14 years, stage 2 between 7 - 13 years and stage 3 between 11 - 15 years. Stage 4 is first observed at age 13 and complete union is attained by 17 years.*

4.2.5.2 Distal Radius

The distal radius follows a similar pattern as the ulna. In females however stage 2 is seen at six years of age, a year earlier than the distal ulna. Similar to the distal ulna, complete union in males is accomplished at 20 years and 17 years in females (*Table 4.20*) (*Figures 4.40 and 4.41*). The age of complete union in the distal ulna and radius is a year behind that of the knee.

Table 4.20: Chronological age for stages 1 to 4 at the Distal Radius in Males and Females

	Males				***Females***			
Stage	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Age								
6	100.00%	0.00%	0.00%	0.00%	25.00%	75.00%	0.00%	0.00%
7	93.20%	6.80%	0.00%	0.00%	78.60%	21.40%	0.00%	0.00%
8	90.10%	9.90%	0.00%	0.00%	69.60%	30.40%	0.00%	0.00%
9	73.60%	26.40%	0.00%	0.00%	46.90%	53.10%	0.00%	0.00%
10	58.10%	41.90%	0.00%	0.00%	23.10%	76.90%	0.00%	0.00%
11	40.50%	59.50%	0.00%	0.00%	15.60%	81.30%	3.10%	0.00%
12	21.70%	78.30%	0.00%	0.00%	2.90%	73.50%	20.60%	2.90%
13	23.30%	66.70%	3.30%	6.70%	0.00%	53.80%	46.20%	0.00%
14	0.00%	57.10%	42.90%	0.00%	0.00%	12.50%	75.00%	12.50%
15	0.00%	18.20%	63.60%	18.20%	0.00%	0.00%	37.50%	62.50%
16	0.00%	10.00%	60.00%	30.00%	0.00%	0.00%	33.30%	66.70%
17	0.00%	0.00%	25.40%	74.60%	0.00%	0.00%	0.00%	100.00%
18	0.00%	0.00%	9.80%	90.20%	0.00%	0.00%	0.00%	100.00%
19	0.00%	0.00%	6.80%	93.20%	0.00%	0.00%	0.00%	100.00%
20	0.00%	0.00%	3.50%	96.50%	0.00%	0.00%	0.00%	100.00%
21	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%
22	0.00%	0.00%	1.00%	99.00%	0.00%	0.00%	0.00%	100.00%
23	0.00%	0.00%	1.20%	98.80%	0.00%	0.00%	0.00%	100.00%
24	0.00%	0.00%	1.10%	98.90%	0.00%	0.00%	0.00%	100.00%

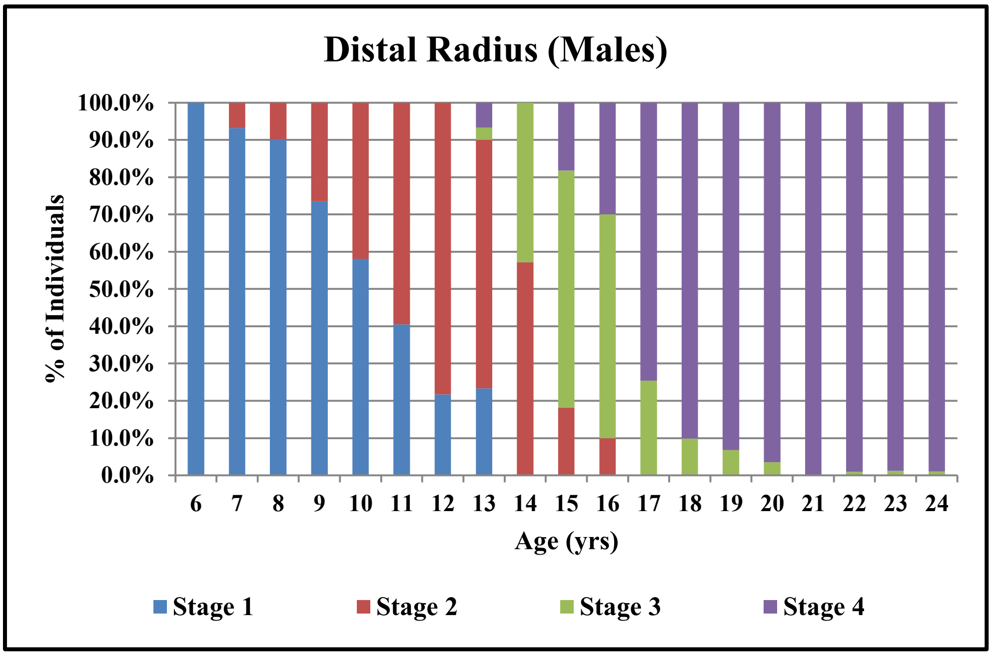


Figure 4.40: *Progression of union at the distal ulna in males. Stage 1 is apparent between 6 - 13 years, stage 2 between 7 - 13 years and stage 3 between 13 - 20 years. Stage 4 is achieved by 100% of males at age 21.*

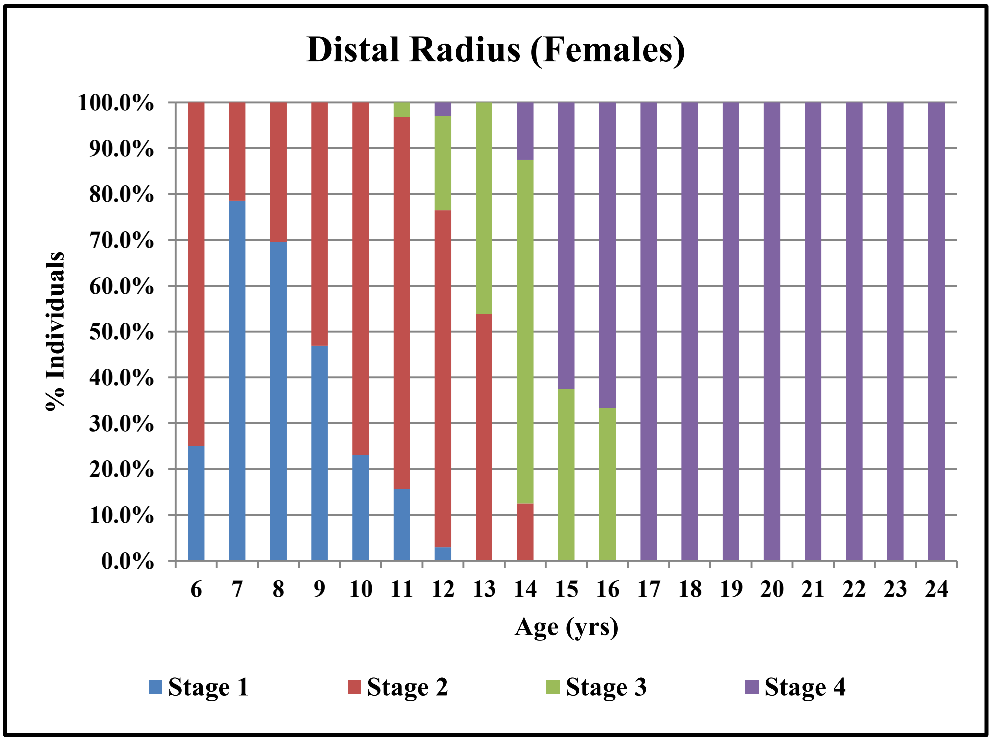


Figure 4.41: *Progression of union at the distal ulna in females. Stage 1 is apparent between 6 - 12 years, stage 2 between 6 - 14 years and stage 3 between 11 - 16 years. Stage 4 is first observed at age 13 and complete union is attained by 17 years.*

The distal ulna and radius in both males and females follows the same pattern (*Figure 4.42 and 4.43*). These patterns show no differentiation in both groups. They can therefore be categorised according to a single joint referred to as the wrist (*Table 4.21*).

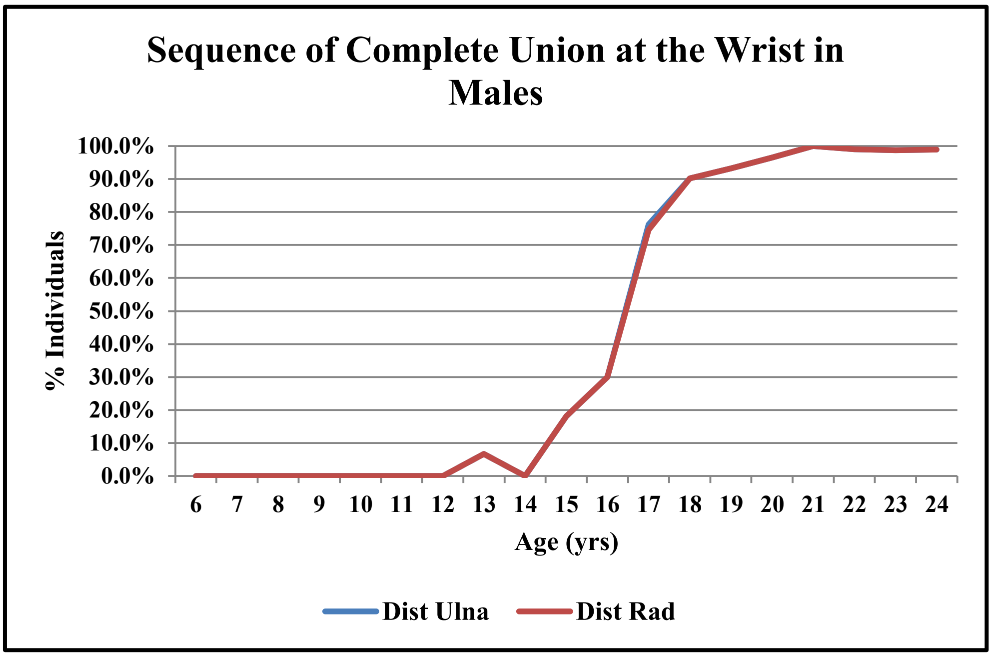


Figure 4.42: *Sequence of complete union of the wrist in males showing no differentiation in the distal ulna and radius.*

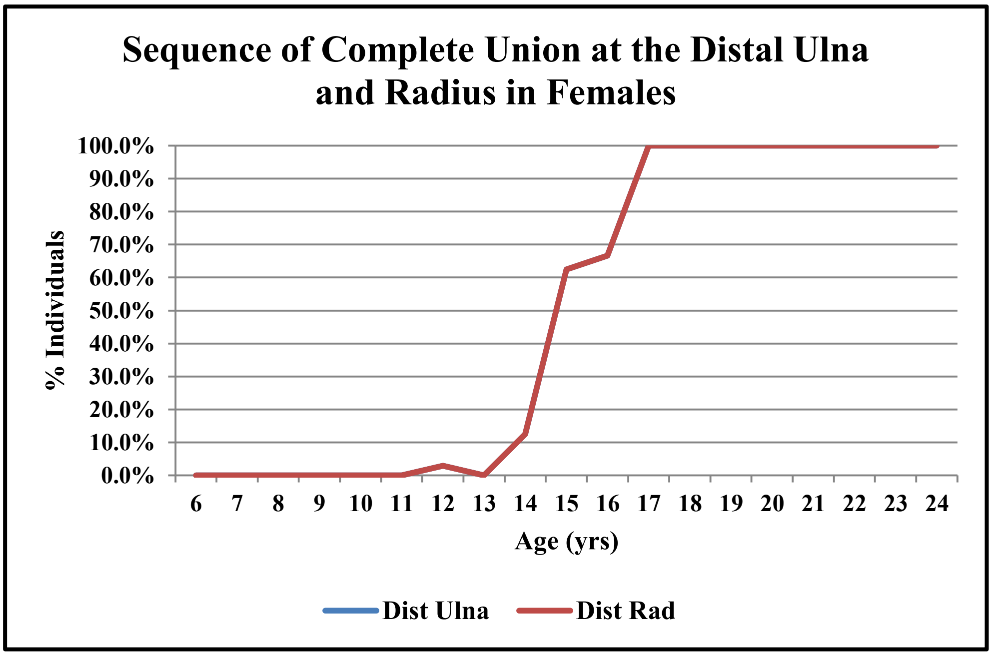


Figure 4.43: *Sequence of complete union of the wrist in females showing no differentiation in the distal ulna and radius.*

Table 4.21: Chronological age of Union at the Wrist in Males and Females

	Males				Females			
Age	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**
6	100% (3)	0% (0)	0% (0)	0% (0)	100% (4)	0% (0)	0% (0)	0% (0)
7	100% (44)	0% (0)	0% (0)	0% (0)	96% (27)	4% (1)	0% (0)	0% (0)
8	100% (81)	0% (0)	0% (0)	0% (0)	89% (41)	11% (5)	0% (0)	0% (0)
9	94% (50)	6% (3)	0% (0)	0% (0)	78% (38)	22% (11)	0% (0)	0% (0)
10	89% (55)	11% (7)	0% (0)	0% (0)	54% (14)	46% (12)	0% (0)	0% (0)
11	71% (30)	29% (12)	0% (0)	0% (0)	28% (9)	69% (22)	3% (1)	0% (0)
12	53% (24)	47% (21)	0% (0)	0% (0)	9% (3)	68% (23)	21% (7)	3% (1)
13	33% (10)	57% (17)	3% (1)	0% (0)	0% (0)	54% (7)	46% (6)	0% (0)
14	0% (0)	60% (9)	40% (6)	0% (0)	13% (1)	0% (0)	75% (6)	13% (1)
15	0% (0)	17% (4)	61% (14)	22% (5)	0% (0)	0% (0)	38% (3)	63% (5)
16	0% (0)	10% (2)	60% (12)	30% (6)	0% (0)	0% (0)	33% (1)	67% (2)
17	0% (0)	0% (0)	25% (15)	75% (44)	0% (0)	0% (0)	0% (0)	100% (5)
18	0% (0)	0% (0)	10% (6)	90% (55)	0% (0)	0% (0)	0% (0)	100% (9)
19	0% (0)	0% (0)	7% (6)	93% (83)	0% (0)	0% (0)	0% (0)	100% (10)
20	0% (0)	0% (0)	3% (3)	97% (83)	0% (0)	0% (0)	0% (0)	100% (9)
21	0% (0)	0% (0)	0% (0)	100% (94)	0% (0)	0% (0)	0% (0)	100% (21)
22	0% (0)	0% (0)	1% (1)	99% (101)	0% (0)	0% (0)	0% (0)	100% (16)
23	0% (0)	0% (0)	1% (1)	99% (81)	0% (0)	0% (0)	0% (0)	100% (18)
24	0% (0)	0% (0)	1% (1)	99% (93)	0% (0)	0% (0)	0% (0)	100% (9)

4.2.6 Shoulder

The shoulder is made up of a number of epiphyses, however; some epiphyses may not be clearly visible in the anterior plane of the radiographs. They are often only visible once greater than 50% union is observed. They have been excluded from the analyses and only the head of the humerus (*Table 4.22*) and greater tubercle (*Table 4.23*) will be reported on.

4.2.6.1 Head of Humerus

Stage 2 of the head of the humerus is characterised by a prolonged stage 2 (*Table 4.22*). While the epiphysis is fully formed by six years union is prolonged.

Table 4.22: Chronological age for stages 1 to 4 at the Head of Humerus in Males and Females

	Males				*Females*			
Stage	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Age								
6	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%
7	0.00%	100.00%	0.00%	0.00%	3.60%	96.40%	0.00%	0.00%
8	1.10%	98.90%	0.00%	0.00%	0.00%	96.40%	3.60%	0.00%
9	0.00%	100.00%	0.00%	0.00%	0.00%	98.20%	1.80%	0.00%
10	0.00%	98.50%	1.50%	0.00%	0.00%	83.90%	16.10%	0.00%
11	0.00%	100.00%	0.00%	0.00%	0.00%	75.00%	25.00%	0.00%
12	0.00%	96.60%	3.40%	0.00%	0.00%	32.50%	67.50%	0.00%
13	0.00%	88.60%	8.60%	2.90%	0.00%	50.00%	50.00%	0.00%
14	0.00%	38.90%	61.10%	0.00%	0.00%	11.10%	88.90%	0.00%
15	0.00%	12.50%	75.00%	12.50%	0.00%	0.00%	75.00%	25.00%
16	0.00%	0.00%	91.70%	8.30%	0.00%	0.00%	66.70%	33.30%
17	0.00%	0.00%	55.90%	44.10%	0.00%	0.00%	0.00%	100.00%
18	0.00%	0.00%	29.50%	70.50%	0.00%	0.00%	0.00%	100.00%
19	0.00%	0.00%	20.50%	79.50%	0.00%	0.00%	10.00%	90.00%
20	0.00%	1.20%	3.60%	95.20%	0.00%	0.00%	0.00%	100.00%
21	0.00%	0.00%	4.30%	95.70%	0.00%	0.00%	0.00%	100.00%
22	0.00%	0.00%	2.00%	98.00%	0.00%	0.00%	6.30%	93.80%
23	0.00%	0.00%	3.70%	96.30%	0.00%	0.00%	5.60%	94.40%
24	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%

In males stage 2 is completed at 15 years and 14 years in females. Complete union in males is seen at age 13 while in females it is seen only at age 15. Complete union for the head of the humerus in males is 22 years while that for females is 17 years (*Table 4.22*) (*Figure 4.44 and 4.45*).

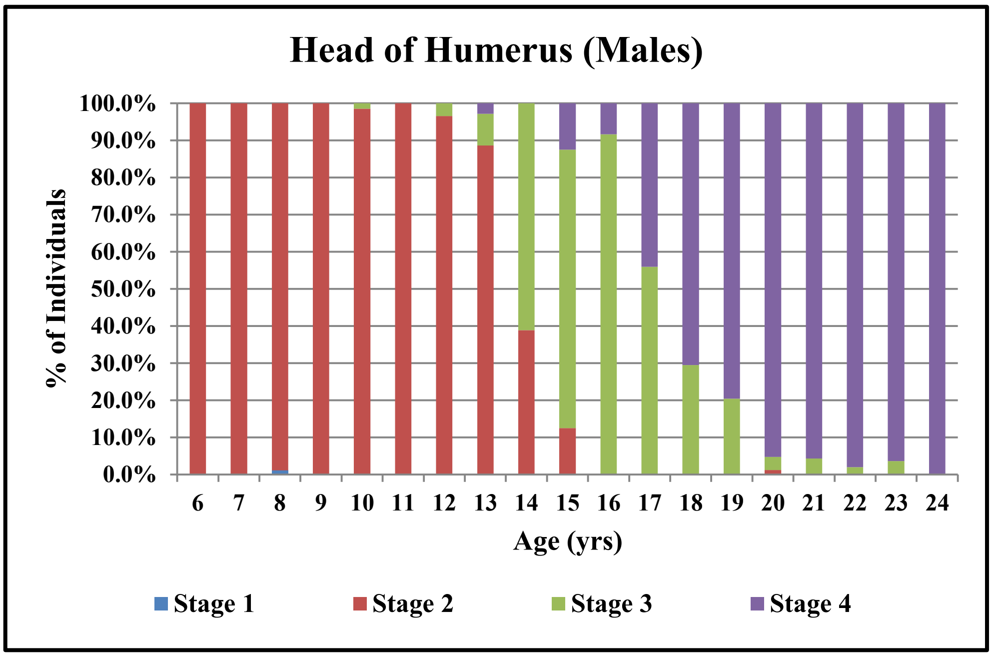


Figure 4.44: *Progression of union at the head of the humerus in males. Stage 2 is prolonged and is complete by 15 years. Stage 3 is observed between 12 – 23 years and complete union (stage 4 in 100% of males) is accomplished by 24 years.*

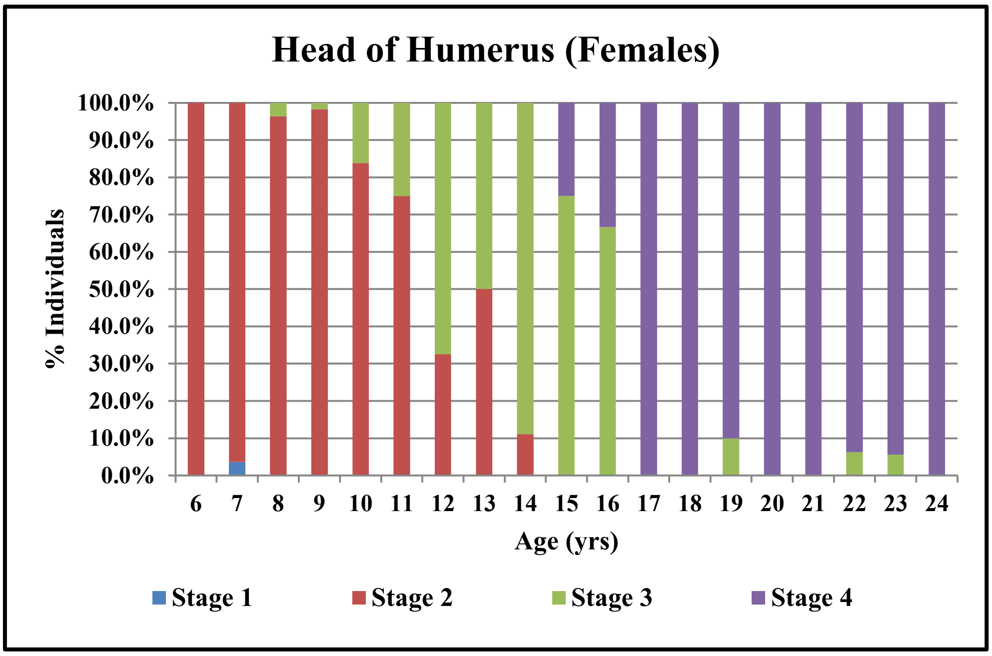


Figure 4.45: *Progression of union at the head of the humerus in females. Stage 2 is complete by 14 years and stage 3 by 16 years. Stage 4 in 100% females is achieved at age 17.*

4.2.6.2 Greater Tubercle

The greater tubercle of the humerus begins union (stage 2) at seven years in males (2.3%) and eight years in females (23.6%) (*Table 4.23*). Stage 2 of union is complete by 15 years in males and 14 years in females. Stage 3 appears to be more prolonged compared to the previous joints accomplishing completion at age 23 in males and 19 years in females (*Figure 4.46 and 4.47*). A single male outlier who appears to in stage 2 of union is visible at age 20 years in males. Complete union is achieved at 22 years in males and 20 years in females.

Table 4.23: Chronological age for stages 1 to 4 at the Greater Tubercle in Males and Females

	Males				*Females*			
Stage	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Age								
6	100.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%
7	97.70%	2.30%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%
8	94.40%	5.60%	0.00%	0.00%	76.40%	23.60%	0.00%	0.00%
9	96.50%	3.50%	0.00%	0.00%	59.60%	40.40%	0.00%	0.00%
10	82.40%	17.60%	0.00%	0.00%	48.40%	45.20%	6.50%	0.00%
11	70.70%	29.30%	0.00%	0.00%	30.00%	50.00%	20.00%	0.00%
12	43.10%	53.40%	3.40%	0.00%	7.50%	32.50%	60.00%	0.00%
13	34.30%	54.30%	8.60%	2.90%	0.00%	50.00%	50.00%	0.00%
14	0.00%	38.90%	61.10%	0.00%	0.00%	11.10%	88.90%	0.00%
15	0.00%	12.50%	75.00%	12.50%	0.00%	0.00%	75.00%	25.00%
16	0.00%	0.00%	91.70%	8.30%	0.00%	0.00%	100.00%	0.00%
17	0.00%	0.00%	59.30%	40.70%	0.00%	0.00%	40.00%	60.00%
18	0.00%	0.00%	31.10%	68.90%	0.00%	0.00%	11.10%	88.90%
19	0.00%	0.00%	22.70%	77.30%	0.00%	0.00%	10.00%	90.00%
20	0.00%	1.20%	3.60%	95.20%	0.00%	0.00%	0.00%	100.00%
21	0.00%	0.00%	4.30%	95.70%	0.00%	0.00%	0.00%	100.00%
22	0.00%	0.00%	3.00%	97.00%	0.00%	0.00%	6.30%	93.80%
23	0.00%	0.00%	3.70%	96.30%	0.00%	0.00%	5.60%	94.40%
24	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%

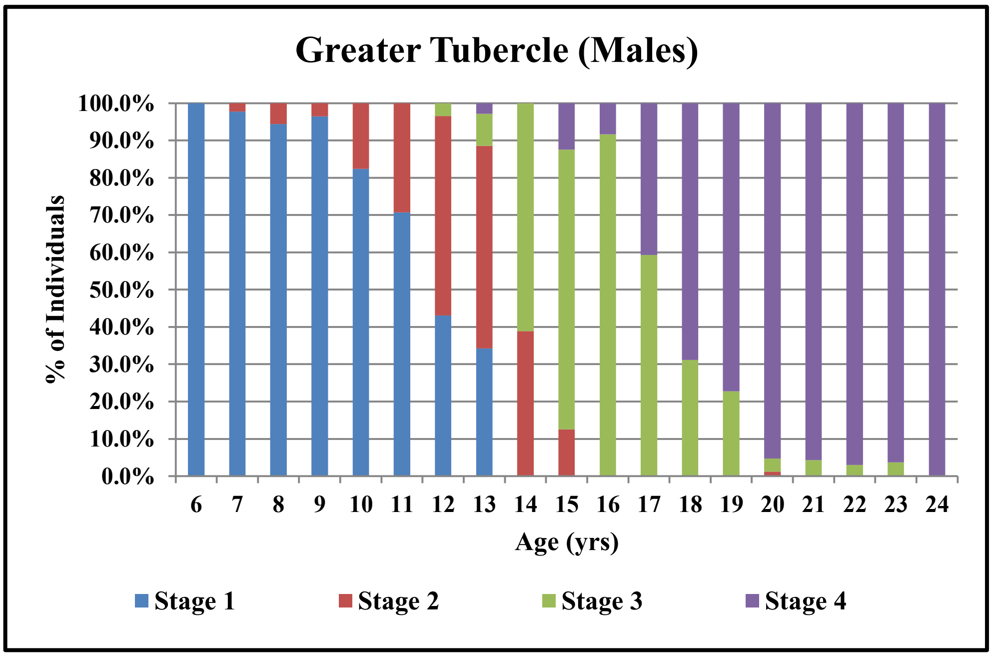


Figure 4.46: *Progression of union at the greater tubercle in males. Stage 1 is observed between 6 - 13 years, stage 2 between 7 - 15 years and stage 3 12 - 23 years. Stage 4 in 100% of individuals is reached at 24 years.*

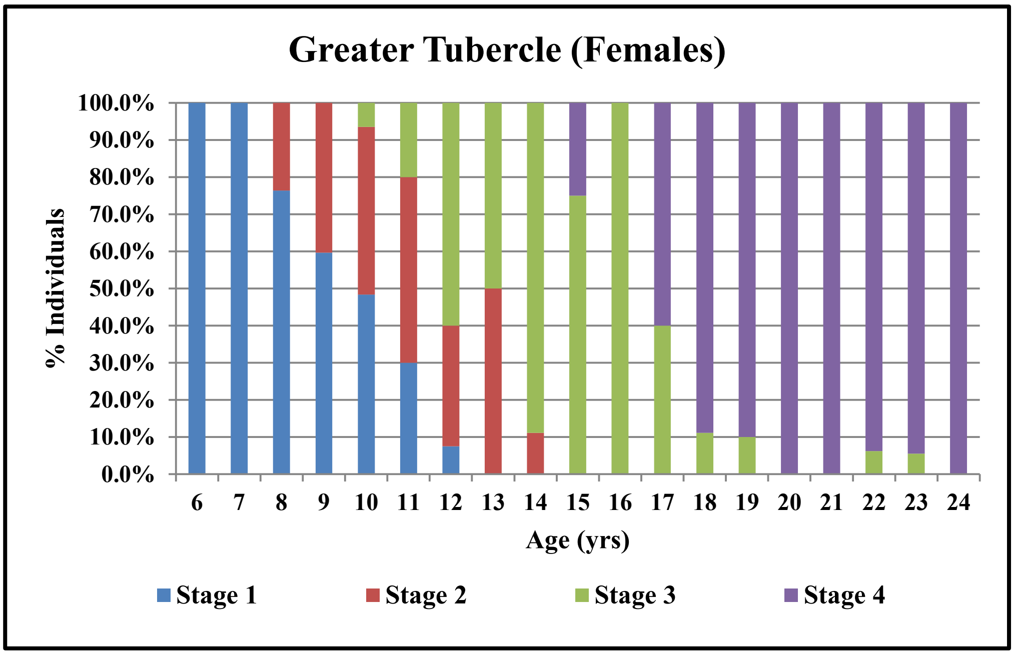


Figure 4.47: *Progression of union at the greater tubercle in females. Stage 1 is observed between 6 - 12 years, stage 2 between 8 - 14 years and stage 3 10 - 19 years. Stage 4 in 100% of females is reached at 20 year.*

In males the epiphysis of the head of the humerus and the greater tubercle follow an identical pattern. Enabling the combination of these epiphyses into a joint classified as the shoulder (*Figure 4.48*) (*Table 4.24*).

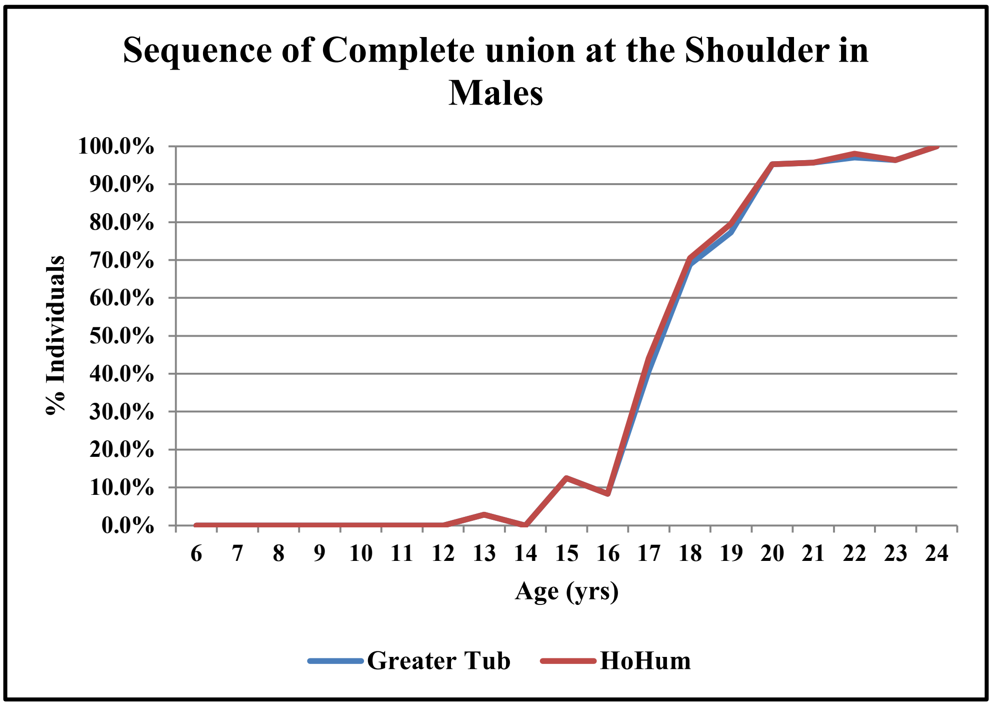


Figure 4.48: *Sequence of complete union at the shoulder in males. The head of the humerus (HoHum) and greater tubercle (Greater Tub) show an identical pattern. Slight differentiation is possible between the two curves.*

In females however; there appears to be greater variability probably due to the sample size (*Figure 4.49*). Conclusion based on the shoulder in females should be done with caution.

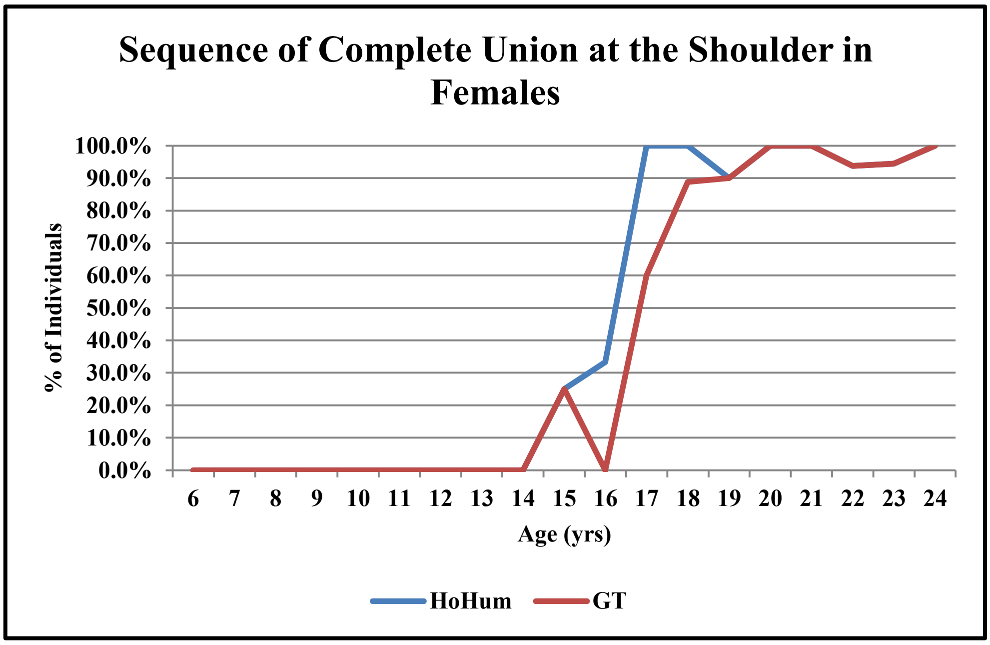


Figure 4.49: *Sequence of complete union at the shoulder in females.* ***.*** *There appears to be considerable variation due to smaller sample sizes.*

Table 4.24: Chronological age of Union at the Shoulder in Males and Females

	Males				Females			
Age	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**
6	100% (3)	0% (0)	0% (0)	0% (0)	100% (4)	0% (0)	0% (0)	0% (0)
7	98% (43)	2% (1)	0% (0)	0% (0)	100% (28)	0% (0)	0% (0)	0% (0)
8	94% (85)	6% (5)	0% (0)	0% (0)	76% (42)	24% (13)	0% (0)	0% (0)
9	96% (55)	4% (2)	0% (0)	0% (0)	60% (34)	40% (23)	0% (0)	0% (0)
10	82% (56)	18% (12)	0% (0)	0% (0)	39% (12)	55% (17)	6% (2)	0% (0)
11	71% (41)	29% (17)	0% (0)	0% (0)	30% (12)	50% (20)	20% (8)	0% (0)
12	43% (25)	53% (31)	3% (2)	0% (0)	8% (3)	33% (13)	60% (24)	0% (0)
13	33% (12)	56% (20)	8% (3)	0% (0)	0% (0)	50% (8)	50% (8)	0% (0)
14	0% (0)	37% (7)	63% (12)	0% (0)	0% (0)	11% (1)	89% (8)	0% (0)
15	0% (0)	12% (3)	72% (18)	16% (4)	0% (0)	0% (0)	75% (6)	25% (2)
16	0% (0)	0% (0)	92% (22)	8% (2)	0% (0)	0% (0)	100% (3)	0% (0)
17	0% (0)	0% (0)	59% (35)	41% (24)	0% (0)	0% (0)	40% (2)	60% (3)
18	0% (0)	0% (0)	31% (19)	69% (42)	0% (0)	0% (0)	11% (1)	89% (8)
19	0% (0)	0% (0)	22% (20)	78% (69)	0% (0)	0% (0)	10% (1)	90% (9)
20	0% (0)	1% (1)	4% (3)	95% (81)	0% (0)	0% (0)	0% (0)	100% (9)
21	0% (0)	0% (0)	4% (4)	96% (90)	0% (0)	0% (0)	0% (0)	100% (21)
22	0% (0)	0% (0)	3% (3)	97% (98)	0% (0)	0% (0)	6% (1)	94% (15)
23	0% (0)	0% (0)	4% (3)	96% (79)	0% (0)	0% (0)	6% (1)	94% (17)
24	0% (0)	0% (0)	0% (0)	100% (94)	0% (0)	0% (0)	0% (0)	100% (9)

4.2.7 Iliac Crest

The iliac crest is the last of the epiphysis to form and unite. Union starts in the centre and move posterior an anterior inferior. This epiphysis is the last to appear; this is evident in *Figure 4.50 and Figure 4.51*. The first signs of union become visible around 13 years in males and 11 years in females. Non-union (stage 1) is prolonged in males and females (*Table 4.25*). Stage 2 of the iliac crest in males and females is characteristically rapid as the active stages (2 and 3) of union take place relatively rapidly. The iliac crest is a single epiphysis and does not form part of any compound joints. Complete union of the crest takes place around 22 years in males and 21 years in females.

Table 4.25: Chronological age for stages 1 to 4 at the Iliac Crest in Males and Females

	Males				*Females*			
Stage	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Age								
6	100.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%
7	100.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%
8	100.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%
9	100.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%
10	100.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%
11	100.00%	0.00%	0.00%	0.00%	97.80%	2.20%	0.00%	0.00%
12	100.00%	0.00%	0.00%	0.00%	80.00%	17.80%	2.20%	0.00%
13	92.20%	3.90%	0.00%	0.00%	83.30%	16.70%	0.00%	0.00%
14	78.30%	13.00%	8.70%	0.00%	44.40%	44.40%	11.10%	0.00%
15	34.50%	41.40%	20.70%	3.40%	12.50%	12.50%	62.50%	12.50%
16	4.20%	37.50%	50.00%	8.30%	0.00%	0.00%	100.00%	0.00%
17	3.40%	8.50%	44.10%	44.10%	0.00%	0.00%	80.00%	20.00%
18	1.60%	1.60%	32.80%	63.90%	0.00%	0.00%	22.20%	77.80%
19	0.00%	1.10%	31.80%	67.00%	0.00%	0.00%	30.00%	70.00%
20	0.00%	1.20%	9.40%	89.40%	10.00%	0.00%	10.00%	80.00%
21	0.00%	0.00%	4.30%	95.70%	0.00%	0.00%	0.00%	100.00%
22	0.00%	0.00%	2.00%	98.00%	0.00%	0.00%	0.00%	100.00%
23	0.00%	0.00%	1.20%	98.80%	0.00%	0.00%	0.00%	100.00%
24	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	100.00%

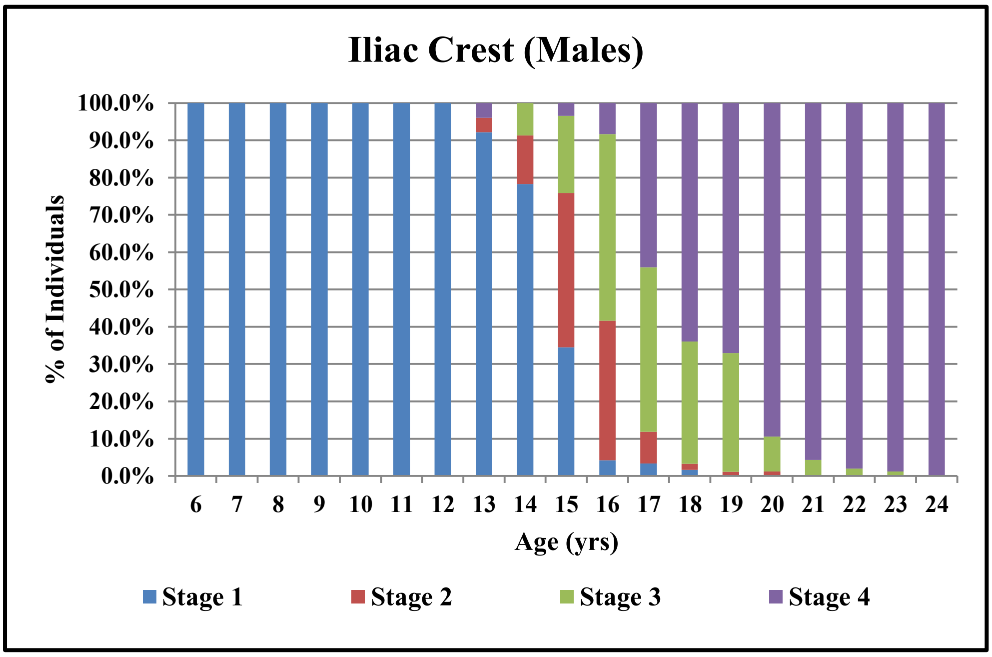


Figure 4.50: *Progression of union at the iliac crest in males. Stage 4 in 100% males is achieved at 24 years.*

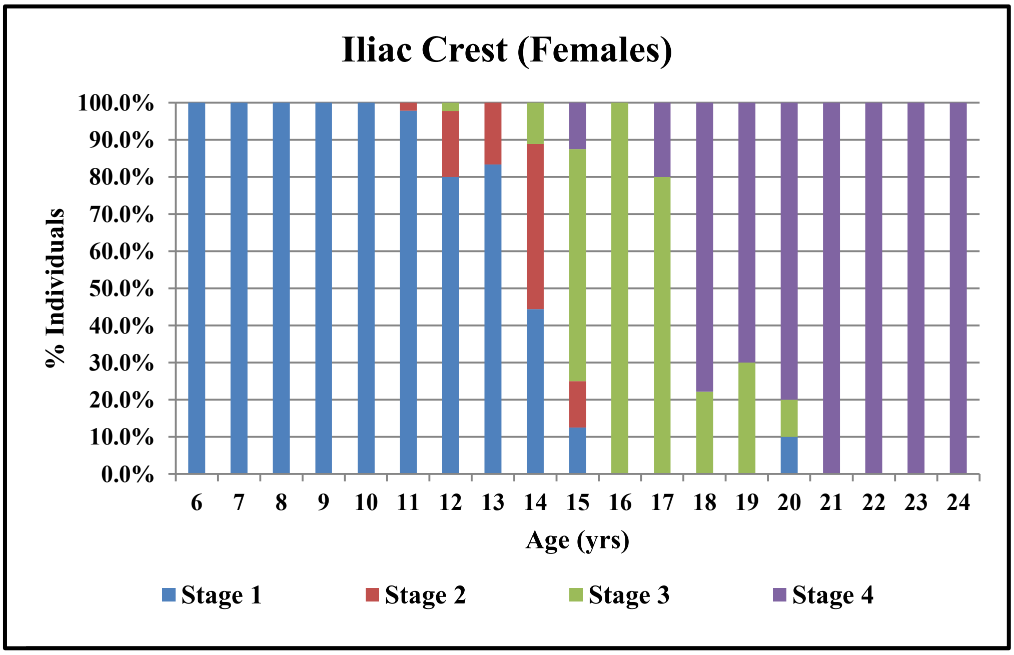


Figure 4.51: *Progression of union at the iliac crest in females. Stage 4 in 100% of females is achieved at 21 years in females.*

4.2.8 Sequence of Union

Schaefer and Black, (2005) and McKern and Stewart (1957) observed the existence of a sequence of union. Ages of complete union for the respective joints were plotted against age and the resultant Figures (*Figure 4.52 and Figure 4.53*) show that the sequence of union is indeed as suggested with union progressing from the elbow to the hip, ankle, knee, wrist and shoulder and completing union at the iliac crest. In males the ankle and hip develop almost simultaneously with the ankle developing slightly faster than the hip. Union however is complete at the same age (*Figure 4.52*). In females (*Figure 4.53*) the hip commences union ahead of the ankle, but the ankle slightly precedes union around 14 years. Complete union takes place at 15 years in both the hip and ankle.

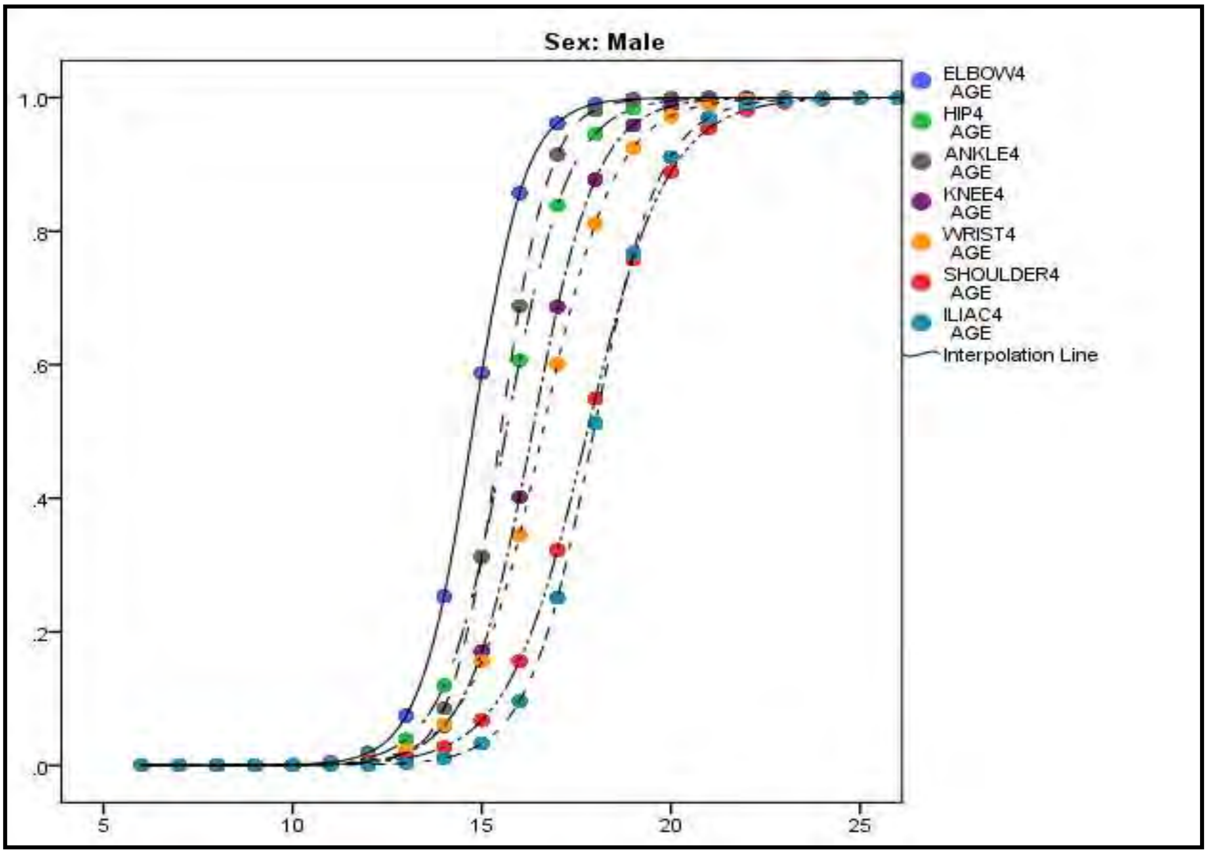


Figure 4.52: *Sequence of complete union of all joints in males. The elbow is the first to complete union followed by the hip, ankle, knee, wrist, shoulder and finally the iliac crest.*

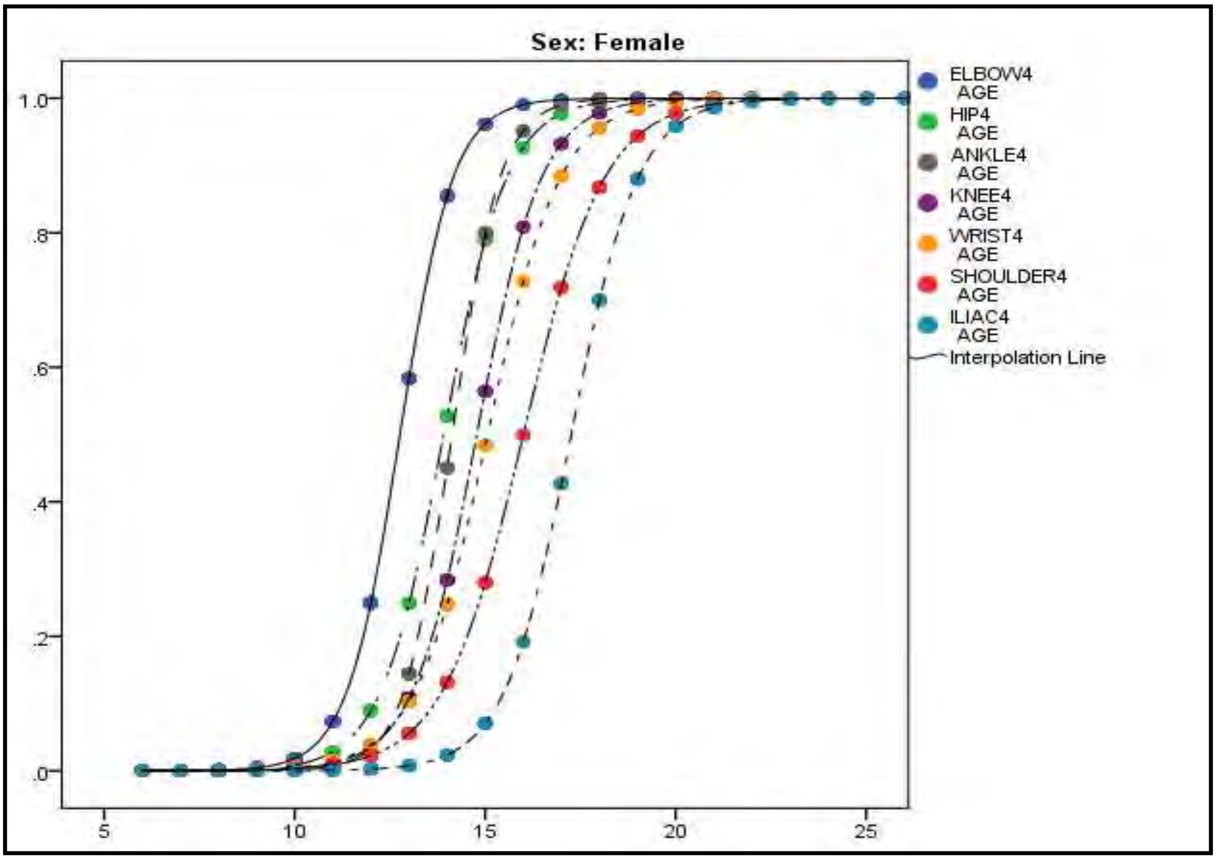


Figure 4.53: *Sequence of complete union of all joints in females. The elbow is the first to complete union followed by the hip, ankle, knee, wrist, shoulder and finally the iliac crest.*

4.3 Point Scores

4.3.1 Point Scores for the Elbow

Table 4.26 below is a summary of the mean fusion scores per age category in Black and Coloured males and females which were obtained by determining the average of the scores at the respective ages. This table suggests that the mean score for a Black male age nine years would be 1.25 ± 0.2 years whereas that in females is 1.71 ± 0.5.

Table 4.26: Mean Scores for the Elbow in Males

	Black Male			Black Female			Coloured Male			Coloured Female		
Age	**N**	**Mean**	**sd**	**N**	**Mean**	**sd**	**N**	**Mean**	**sd**	**N**	**Mean**	**sd**
6	***2***	1.20	0.00	***3***	1.40	0.20	***1***	1.20		***1***	1.20	
7	***22***	1.09	0.12	***16***	1.33	0.26	***19***	1.16	0.14	***11***	1.25	0.18
8	***57***	1.18	0.15	***31***	1.39	0.30	***26***	1.17	0.16	***20***	1.51	0.54
9	***24***	1.25	0.20	***31***	1.71	0.50	***29***	1.26	0.17	***24***	1.64	0.54
10	***25***	1.37	0.29	***8***	1.78	0.47	***41***	1.38	0.26	***19***	1.93	0.45
11	***24***	1.63	0.29	***17***	2.62	0.95	***26***	1.64	0.38	***14***	2.81	0.71
12	***26***	2.09	0.57	***17***	3.11	0.77	***33***	2.04	0.44	***20***	3.30	0.77
13	***16***	2.61	0.86	***6***	3.60	0.63	***17***	2.44	0.95	***9***	3.64	0.44
14	***7***	3.20	0.62	***7***	3.86	0.38	***9***	3.27	0.86	***2***	2.70	1.84
15	***9***	3.73	0.44	***2***	4.00	0.00	***13***	3.91	0.23	***5***	3.96	0.09
16	***13***	3.91	0.24	***3***	4.00	0.00	***7***	4.00	0.00			
17	***39***	4.00	0.00	***2***	4.00	0.00	***13***	4.00	0.00	***3***	4.00	0.00
18	***34***	3.99	0.07	***4***	4.00	0.00	***19***	4.00	0.00	***4***	4.00	0.00
19	***59***	4.00	0.00	***5***	4.00	0.00	***20***	4.00	0.00	***3***	4.00	0.00
20	***56***	4.00	0.00	***5***	4.00	0.00	***18***	4.00	0.00	***3***	4.00	0.00
21	***63***	4.00	0.00	***10***	4.00	0.00	***19***	4.00	0.00	***10***	4.00	0.00
22	***63***	4.00	0.00	***3***	4.00	0.00	***30***	4.00	0.00	***7***	4.00	0.00
23	***48***	4.00	0.00	***12***	4.00	0.00	***24***	4.00	0.00	***5***	4.00	0.00
24	***67***	4.00	0.00	***3***	4.00	0.00	***17***	4.00	0.00	***4***	4.00	0.00

The mean scores per age are higher in females (both Black and Coloured) compared to males for every age category except s years (*Figure 4.54*). The tables allow us to extrapolate the age for a suspected stage of fusion at the elbow. The mean score of complete union at the elbow is 4 and is reached at 17 years in Black males, 15 years in Black females, 16 years in

Coloured males and 17 years in Coloured females (due to lack of Coloured females at 16 years). The mean point scores increase with increasing age until age 15 years in females and 17 years in males at which point they complete union (*Figure 4.54).*

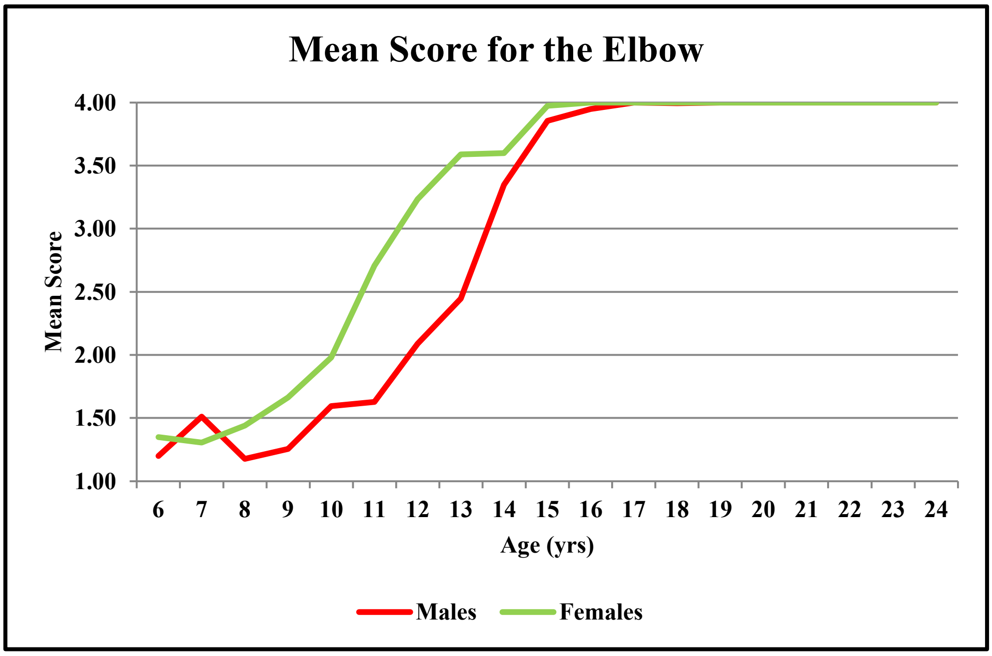


Figure 4.54: *Mean scores for stage 4 of union in males and females showing that females are in advance of males and complete union ahead of them.*

4.3.1.1 Sex Differences in the Mean Score at the Elbow

The results of the ordinal logistic regression for sex differences (*Table 4.27*) suggest that there are significant differences in maturation between males and females ($p < 0.05$) at every stage of union and that males will therefore have a lower score for each stage of union compared to females (-ve sign). There also appears to be a significant relationship between (independent variable) age and the stage (dependent variable) of union ($p < 0.05$). This would be expected; as one progresses to a higher stage on union the age also increases. The Nagelkerke R^2 = 0.897 correlation suggests that there is a strong association between the dependent (stage) and independent variables (age and sex) as reported by. This also suggests that the model predicts 90% of the variability in of the scores.

Table 4.27: Ordinal Logistic Parameter Results at the Elbow in Males and Females

		Estimate	Std. Error	Wald	df	Sig.	95% CI	
							Lower Bound	Upper Bound
Threshold	**Stage 1**	14.285	.718	396.269	1	.000	12.879	15.692
	Stage 2	16.424	.802	418.875	1	.000	14.851	17.997
	Stage 3	18.334	.888	426.448	1	.000	16.594	20.074
Location	**Age**	1.436	.071	409.353	1	.000	1.297	1.575
	Male	-2.855	.240	141.059	1	.000	-3.326	-2.384
	Female	0[a]			0			

Figure 4.55 may be interpreted as follows. The probabilities are listed on the *y axis* while the age appears on the *x axis*. At lower ages the probability of having a stage 4 is 0, but with increasing age the probability of scoring 4 at the elbow increases. The figure also highlights the differences between males and females.

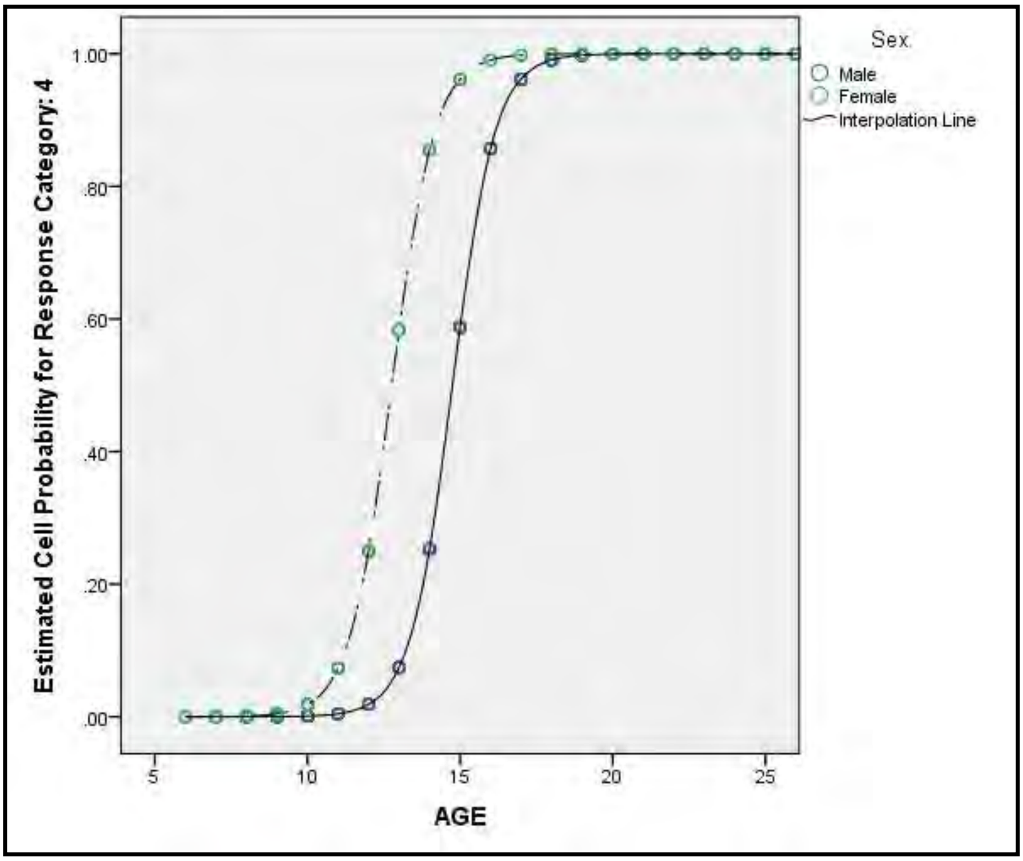


Figure 4.55: *Ordinal logistic regression for stages 4 in males and females at the elbow. The probability of scoring 4 at the lower ages is low, but as age increases the probability also increases until age 15 in females and 17 in males. Significant differences in the age of complete union may be observed herein.*

4.3.1.2 Biological Differences at the Elbow in Males and Females

The results of the ordinal logistic regression for Black and Coloured males and females are presented below (*Table 4.28*). There appears to be no relationship between genetic background and scores per stages for the elbow in males and females ($p > 0.05$). p values of 0.994 were recorded for males and p - values of 0.921 were recorded for females (*Figure 4.56 a; b*) (*Figure 4.57 and 4.58*) suggesting that the relationship is not significant. Black males and females however show lower scores per stage compared to their Coloured counterparts (depicted by the negative sign). These differences are not significant. The significant relationship between age and stages of union are still visible ($p < 0.05$).

Table 4.28: Coefficients for Elbow in Black and Coloured Males and Females

		Coefficient	Std. Error	Wald	df	Sig.	95% CI	
							Lower Bound	Upper Bound
Threshold	Stage 1	17.276	1.193	209.730	1	.000	14.938	19.614
	Stage 2	19.490	1.322	217.380	1	.000	16.899	22.080
	Stage 3	21.032	1.437	214.206	1	.000	18.216	23.849
Location	Age	1.440	.099	210.058	1	.000	1.246	1.635
	Black Males	-.002	.279	.000	1	.994	-.549	.545
	Coloured Males	0^b			0			
Threshold	Stage 1	12.761	1.117	130.553	1	.000	10.572	14.950
	Stage 2	14.638	1.237	139.976	1	.000	12.213	17.063
	Stage 3	16.753	1.360	151.704	1	.000	14.087	19.419
Location	Age	1.281	.110	136.838	1	.000	1.066	1.496
	Black Females	-.029	.291	.010	1	.921	-.598	.541
	Coloured Females	0^b			0			

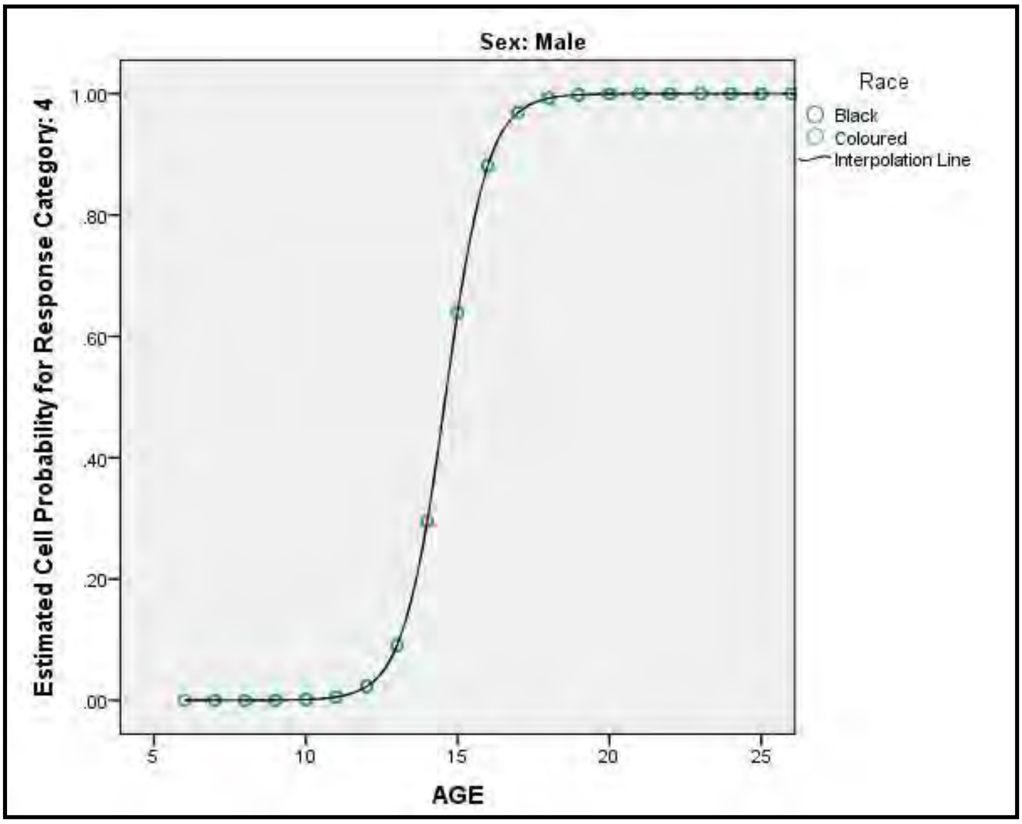


Figure 4.56 (a): *Ordinal logistic regression for stage 4 in black and coloured males at the elbow that shows no significant differences in the probability of being scored as 4.*

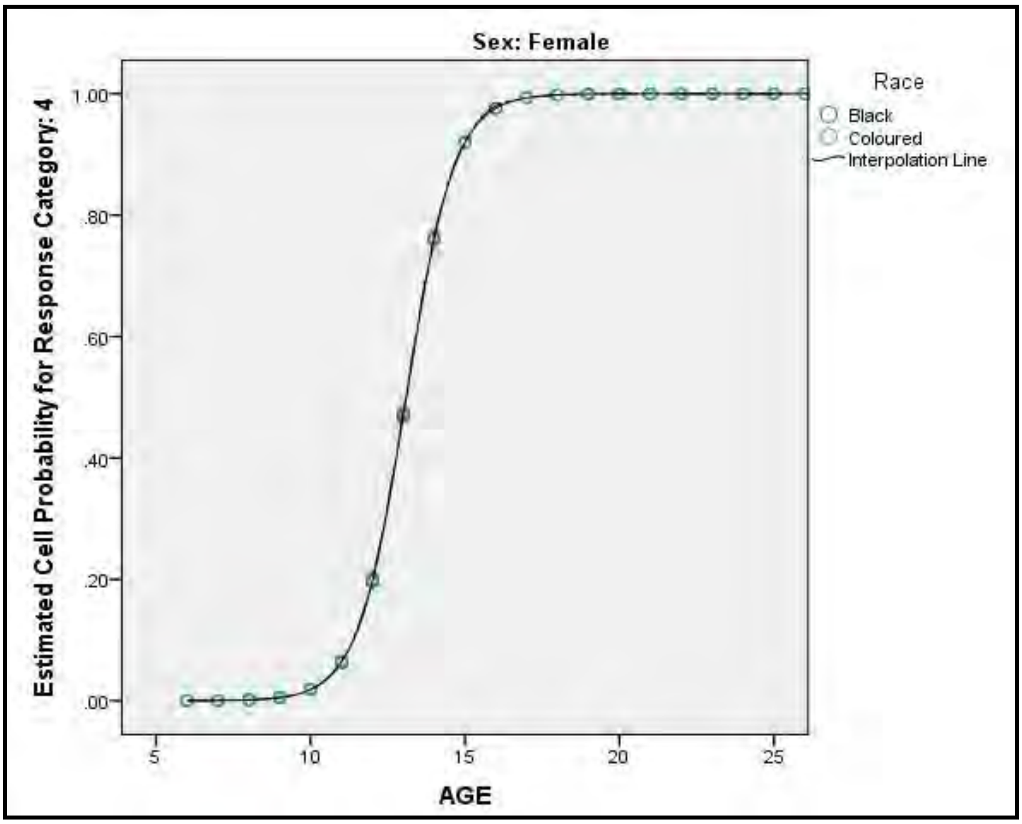


Figure 4.56 (b): *Ordinal logistic regression for stage 4 in black and coloured females at the elbow that shows no significant differences in the mean scores and age between the two groups.*

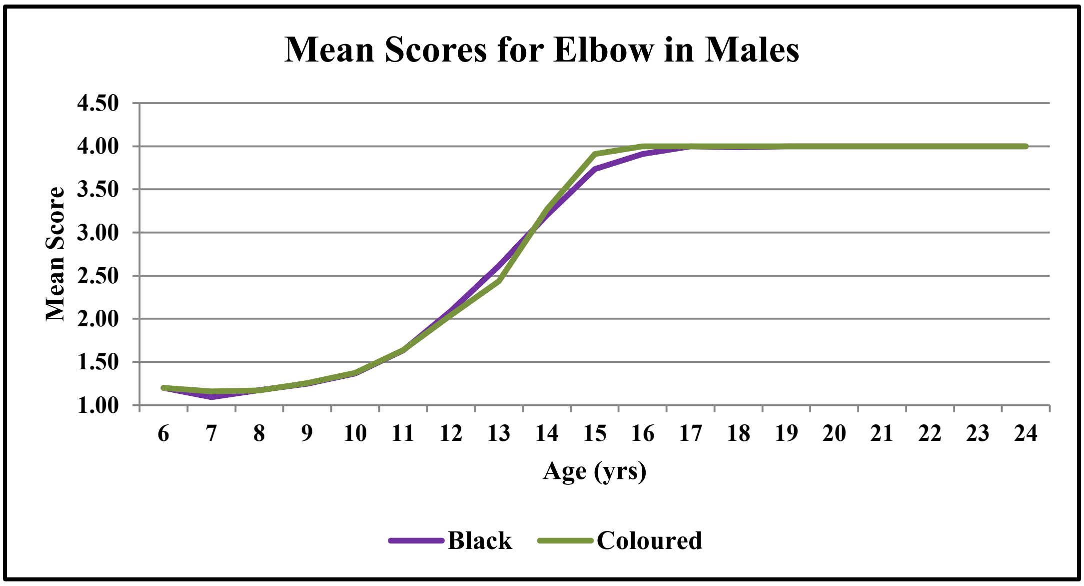


Figure 4.57: *Mean scores at the elbow in black and coloured males showing no significant differences in the timing of union.*

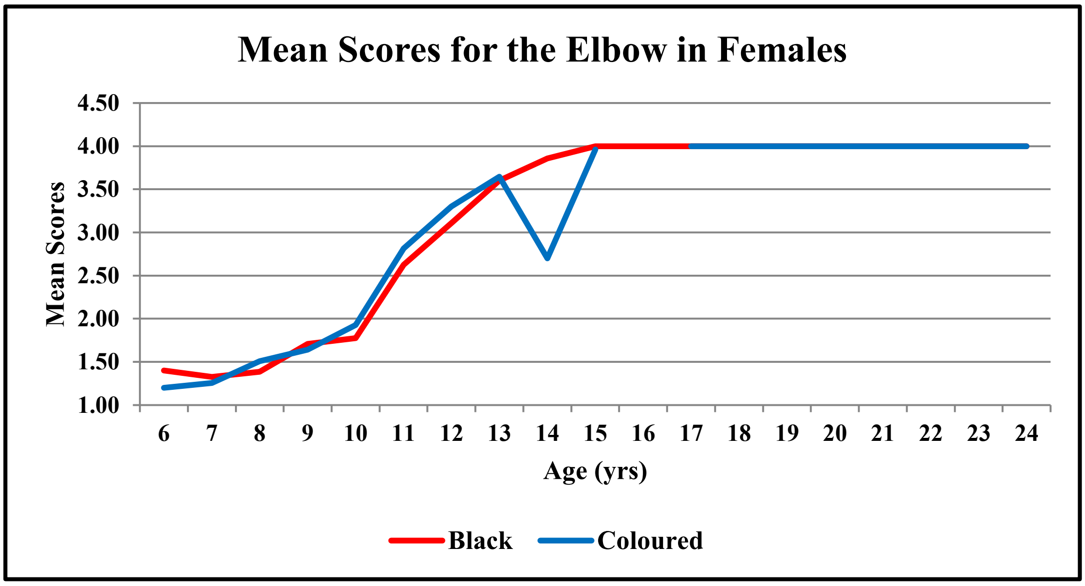


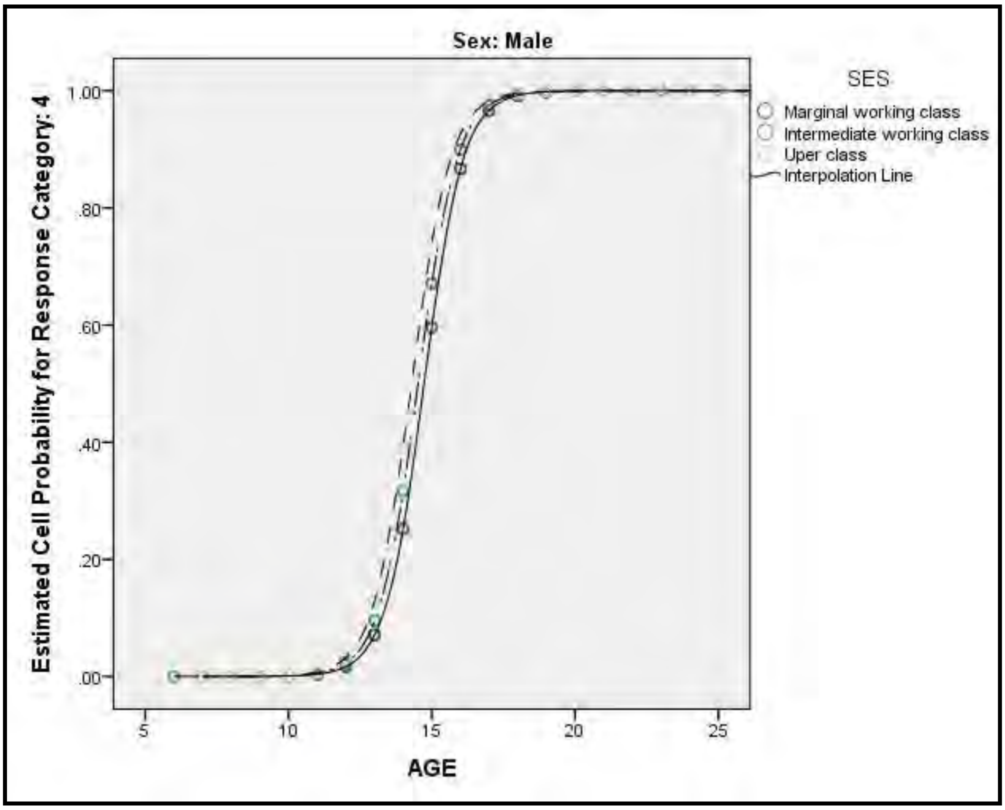
Figure 4.58: *Mean scores at the elbow in black and coloured females showing no significant differences in the timing of union.*

4.3.1.3 The Influence of Socio-Economic Status (SES) on Age of Complete Union at the Elbow in Males and Females.

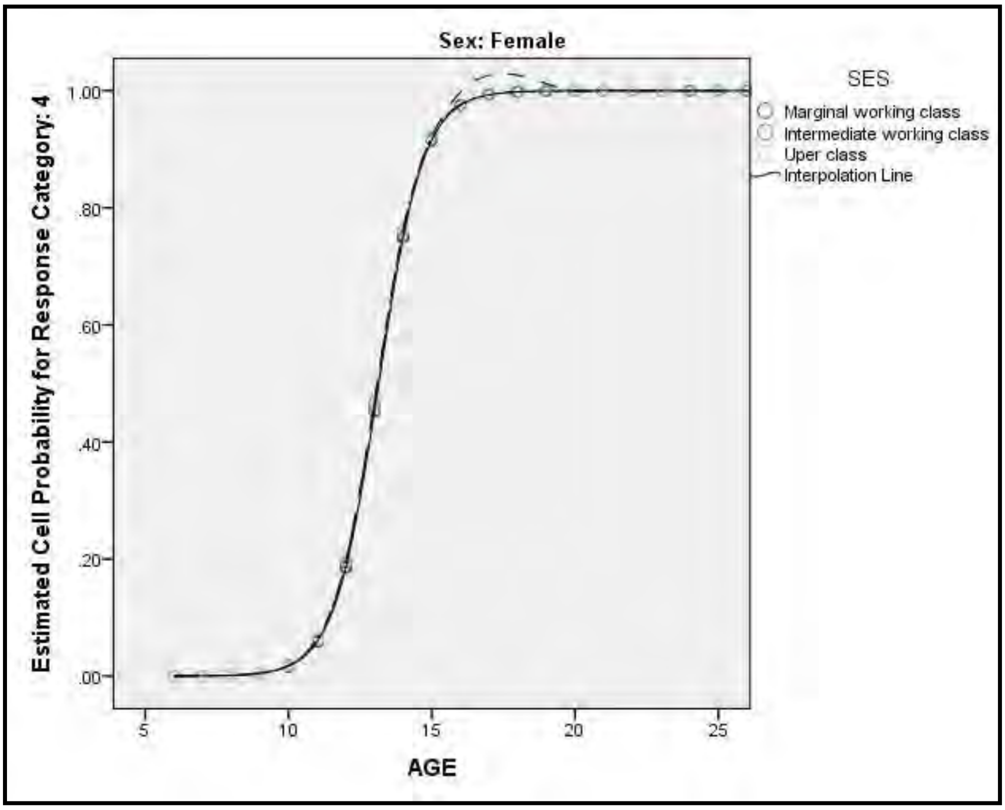
Socio-economic status does not affect the age of complete union in males and females ($p > 0.05$) (*Table 4.29*). In both males and females those individuals who come from the marginal working class (SES 1) (MWC) and intermediate working class (SES 2) (IWC) have lower scores than those who come from the upper class (SES 3) (UC) depicted by the negative signs. These differences are however not significant. The lack of significant difference may be observed in the curves (*Figure 4.59 a and b).*

Table 4.29: Parameters of Ordinal Logistic Regression in the Three Classes of SES

		Estimate	Std. Error	Wald	df	Sig.	95% CI Lower Bound	95% CI Upper Bound
Threshold	Stage 1	17.326	1.273	185.319	1	.000	14.832	19.821
Males	Stage 2	19.555	1.397	195.903	1	.000	16.816	22.293
	Stage 3	21.170	1.512	195.929	1	.000	18.206	24.134
Location	Age	1.481	.103	206.936	1	**.000**	1.279	1.683
	SES 1	-.657	.537	1.495	1	.221	-1.709	.396
	SES 2	-.337	.502	.450	1	.502	-1.322	.648
	SES 3	0[b]			0			
Threshold	Stage 1	12.693	1.224	107.563	1	.000	10.294	15.091
Females	Stage 2	14.613	1.325	121.653	1	.000	12.016	17.210
	Stage 3	16.843	1.434	137.865	1	.000	14.032	19.655
Location	Age	1.287	.106	148.430	1	**.000**	1.080	1.494
	SES 1	-.072	.680	.011	1	.916	-1.404	1.260
	SES 2	-.010	.661	.000	1	.988	-1.306	1.286
	SES 3	0[b]			0			



(a)



(b)

Figure 4.59: *Ordinal logistic regression for stage 4 in males (a) and females (b) at the elbow showing no significant differences in between three classes of SES and stages of union.*

4.3.2 Mean Point Scores for the Hip

The mean point scores for the hip in both biological groups and sexes are presented in *Table 4.30*. The mean scores for females appear to be greater than those of males at each age suggesting that females mature in advance of males (*Figure 4.60*).

Table 4.30: Mean Scores for the Hip in Males and Females

	Black Males			Black Female			Coloured Males			Coloured Female		
Age	N	**Mean**	**sd**	N	**Mean**	**sd**	N	**Mean**	**sd**	N	**Mean**	**sd**
6	***2***	1.50	0.00	***3***	1.56	0.19	***1***	1.67		***1***	1.33	
7	***2***	1.33	0.00	***18***	1.41	0.18	***20***	1.38	0.16	***13***	1.56	0.28
8	***27***	1.42	0.22	***35***	1.68	0.35	***33***	1.44	0.25	***26***	1.74	0.39
9	***64***	1.41	0.19	***36***	1.93	0.28	***39***	1.52	0.28	***29***	1.84	0.33
10	***28***	1.55	0.29	***16***	1.98	0.19	***46***	1.68	0.35	***23***	2.16	0.20
11	***32***	1.74	0.35	***20***	2.15	0.20	***32***	1.92	0.34	***16***	2.29	0.36
12	***29***	1.92	0.28	***18***	2.41	0.57	***43***	2.04	0.33	***23***	2.57	0.58
13	***36***	1.97	0.33	***7***	2.48	0.38	***26***	2.26	0.53	***9***	2.85	0.65
14	***19***	2.23	0.69	***7***	3.29	0.71	***11***	2.70	0.59	***2***	3.17	1.18
15	***10***	2.37	0.48	***2***	4.00	0.00	***16***	3.40	0.65	***5***	4.00	0.00
16	***11***	3.12	0.64	***3***	4.00	0.00	***7***	3.86	0.38			
17	***14***	3.62	0.65	***2***	4.00	0.00	***13***	3.95	0.18	***3***	4.00	0.00
18	***39***	3.96	0.16	***4***	4.00	0.00	***19***	4.00	0.00	***4***	4.00	0.00
19	***34***	3.98	0.11	***5***	4.00	0.00	***20***	4.00	0.00	***3***	4.00	0.00
20	***59***	3.99	0.06	***5***	4.00	0.00	***18***	4.00	0.00	***4***	3.50	1.00
21	***56***	3.99	0.09	***10***	4.00	0.00	***19***	4.00	0.00	***10***	4.00	0.00
22	***63***	4.00	0.00	***3***	4.00	0.00	***30***	4.00	0.00	***7***	4.00	0.00
23	***48***	4.00	0.00	***12***	4.00	0.00	***24***	4.00	0.00	***5***	4.00	0.00
24	***67***	4.00	0.00	***3***	4.00	0.00	***17***	4.00	0.00	***4***	4.00	0.00

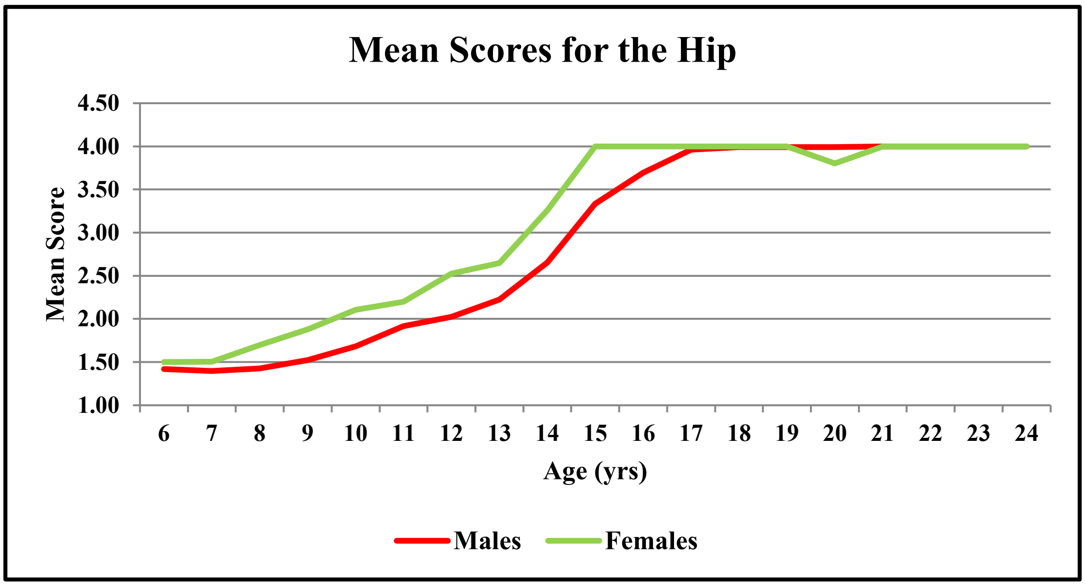


Figure 4.60: *Mean scores for union in the hip in males and females. Females appear to be in advance of males.*

4.3.2.1 Sex Differences in the Ages of Complete Union at the Hip.

There are significant differences between males and females for all stages of union and age ($p < 0.05$) (*Table 4.31*). These differences can be observed in *Figure 4.61* which shows that union in females occurs ahead of males and that the scores in males are lower compared to females at each stage. The model also records low standard errors for differences in sex and predicts 89% of the variability in the model as represented by the Nagelkerke R^{2} of 0.893. The confidence intervals (95% CI) reported for the hip represents the amount of uncertainty expressed by the regression equation. It represents the 95% confidence interval that an unknown individual from a large enough population will have an age between 9.4 and 11.2 years for stage 1 in males.

Table 4.31: Ordinal Logistic Regression Parameters for Sex at the Hip

		Estimate	Std. Error	Wald	df	Sig.	95% CI	
							Lower Bound	Upper Bound
Threshold	**Stage 1**	10.278	.445	532.356	1	.000	9.405	11.151
	Stage 2	15.602	.647	581.899	1	.000	14.334	16.870
	Stage 3	16.882	.698	584.135	1	.000	15.513	18.251
Location	**Age**	1.214	.050	584.587	1	.000	1.115	1.312
	Males	-2.104	.184	130.921	1	.000	-2.465	-1.744
	Females	0[a]			0			

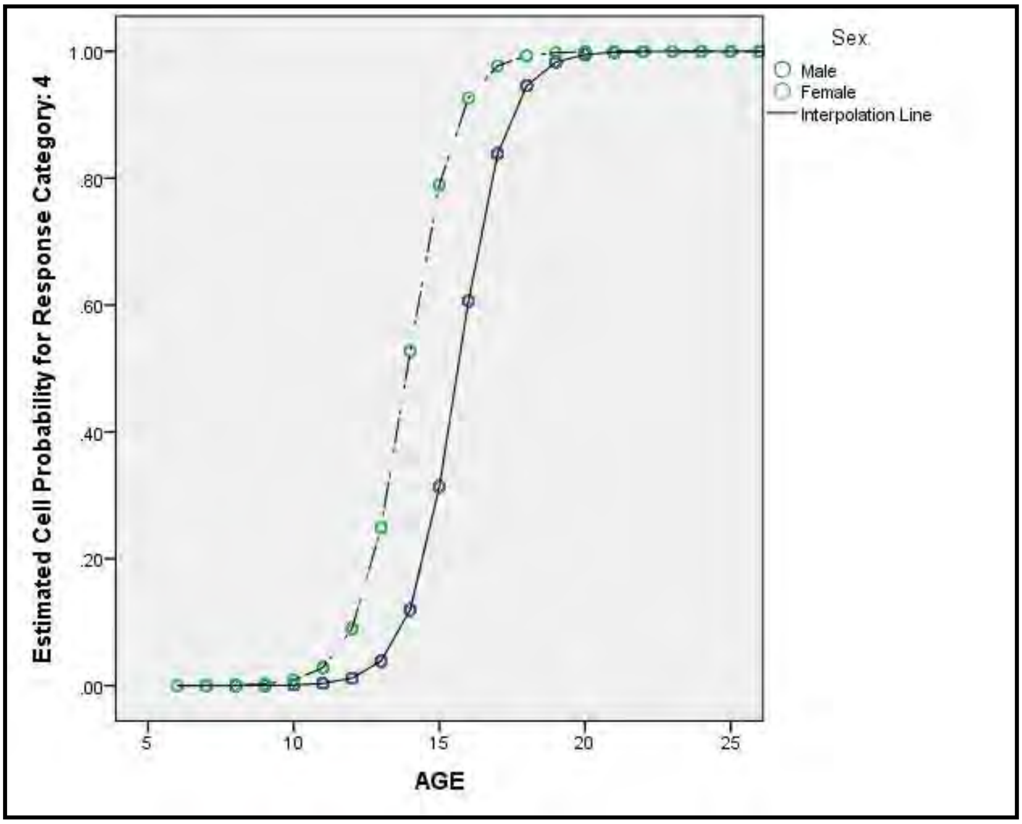


Figure 4.61: *Ordinal logistic regression for stage 4 in males and females at the hip showing significant differences in probability of being scored as stage 4. Females appear to be in advance of males.*

4.3.2.2 Genetic Differences at the Hip in Males and Females.

There is no relationship between the stage of union, age and genetic background suggesting that there are no differences in the models for Black and Coloured males (*Figure 4.62a*) and Black and Coloured females ($p > 0.05$) (*Figure 4.62b*) (*Table 4.32*). The association between age and the stages of union remain significant ($p < 0.05$). Black females have lower scores compared to Coloured females however these were not significant with p-values of 0.421 reported.

Table 4.32: Parameters for Genetic Differences in Males and Females

		Estimate	Std. Error	Wald	df	Sig.	95% CI Lower Bound	95% CI Upper Bound
Threshold	**Stage 1**	11.820	.617	367.011	1	.000	10.611	13.030
	Stage 2	16.554	.855	374.957	1	.000	14.879	18.230
	Stage 3	17.877	.925	373.460	1	.000	16.064	19.690
Location	**Age**	1.147	.058	384.848	1	.000	1.033	1.262
	Black Males	.019	.202	.009	1	.924	-.376	.414
	Coloured Males	0^b			0			
Threshold	**Stage 1**	10.362	1.005	106.250	1	.000	8.392	12.332
	Stage 2	16.586	1.451	130.625	1	.000	13.741	19.430
	Stage 3	17.941	1.540	135.798	1	.000	14.923	20.958
Location	**Age**	1.266	.115	121.640	1	.000	1.041	1.491
	Black Females	-.222	.271	.672	1	.412	-.754	.309
	Coloured Females	0^b			0			

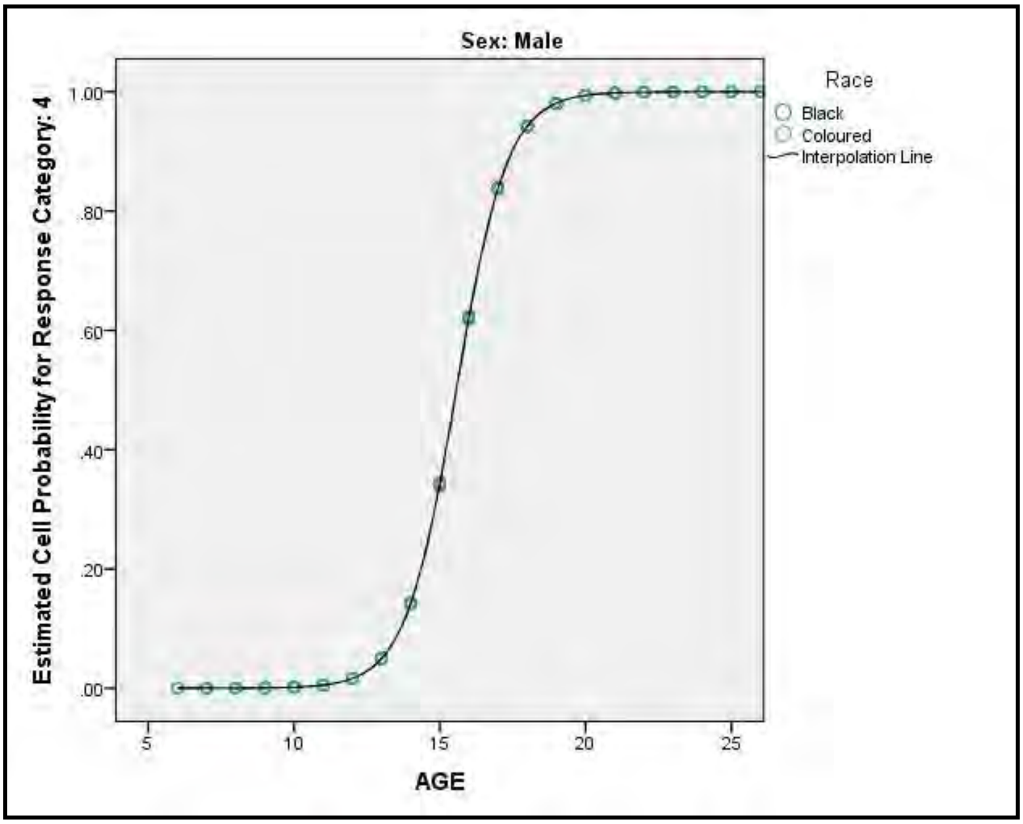


Figure 4.62 (a): *Ordinal logistic regression for stage 4 in black and coloured males at the hip shows no significant differences in stage of union and age between the two groups.*

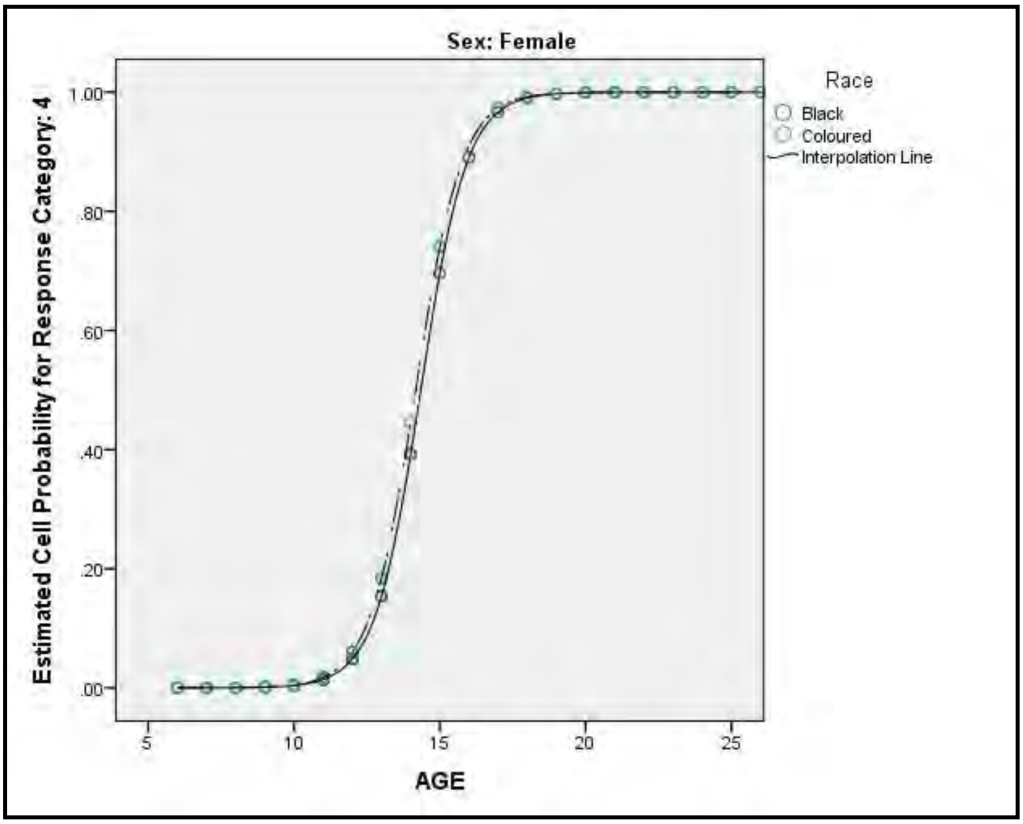


Figure 4.62 (b): *Ordinal logistic regression for stage 4 in black and coloured females at the hip showing no significant differences in the stage of union and age of complete union at the hip.*

There appears to be a trend toward an advance in union (higher mean scores per age) in Coloured males compared to Black males (*Figure 4.63*). The same trend is not observed in females probably due to the sample size (*Figure 4.64).* The differences between the two curves appears to be more defined around 13 years of age. These differences are observed till age 18 at which point both Black and Coloured males show complete union.

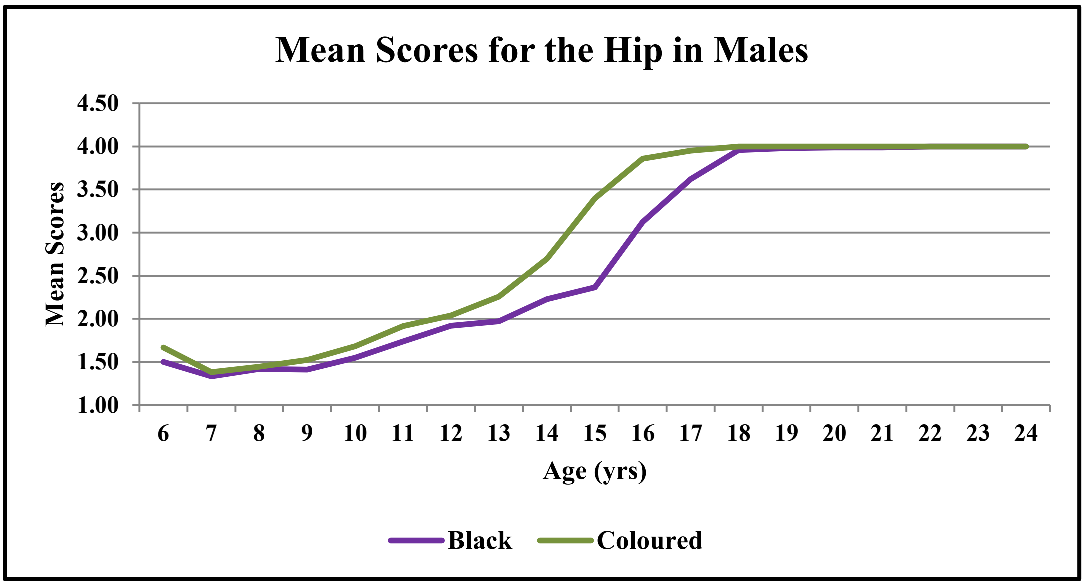


Figure 4.63: *Mean scores in coloured and black males at the hip showing higher mean point scores in coloured males compared to black males between the ages of 12 to 18 years.*

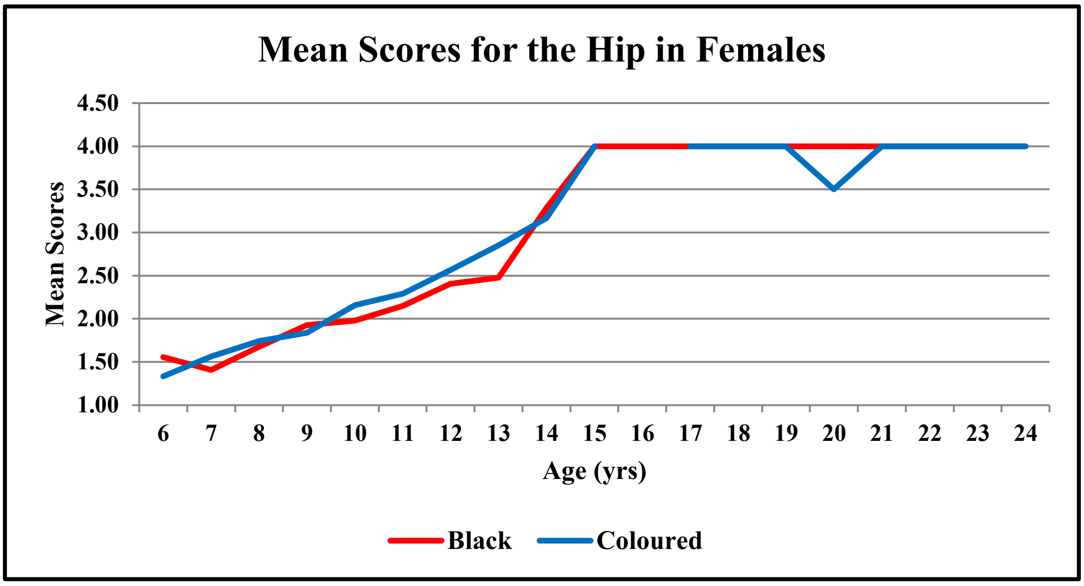


Figure 4.64: *Mean scores in coloured and black females at the hip showing that coloured females are slightly advanced between 10 - 14 years.*

4.3.2.3 The Influence of Socio-Economic Status (SES) on Age of Complete Union at the Hip in Males and Females.

There also appears to be no significant differences in the stage of union and classes of SES ($p > 0.05$) (*Table 4.33*) (*Figure 4.65 a; b*). The mean scores for the marginal working group (SES 1) and intermediate working class (SES 2) in males are lower than those of the upper working class (SES 3); but these differences are not significant (*Table 4.33*). The mean scores of the intermediate working class (SES 2) in females were lower than those of the marginal and upper working classes. These should however be interpreted with caution due to the small sample size.

Table 4.33: Parameters of Ordinal Logistic Regression in the Three Classes of SES

		Estimate	SE	Wald	df	Sig.	95% CI	
							Lower Bound	Upper Bound
Threshold	Stage 1	11.386	.675	284.723	1	.000	10.064	12.709
Males	Stage 2	16.059	.889	326.093	1	.000	14.316	17.802
	Stage 3	17.424	.959	330.290	1	.000	15.545	19.303
Location	Age	1.164	.060	380.914	1	.000	1.047	1.281
	SES 1	-.702	.388	3.266	1	.071	-1.463	.059
	SES 2	-.718	.369	3.782	1	.052	-1.441	.006
	SES 3	0^b			0			
Threshold	Stage 1	10.421	1.057	97.155	1	.000	8.349	12.493
Females	Stage 2	16.593	1.461	128.983	1	.000	13.730	19.457
	Stage 3	17.848	1.535	135.247	1	.000	14.840	20.857
Location	Age	1.257	.112	126.591	1	.000	1.038	1.477
	SES 1	.061	.519	.014	1	.906	-.955	1.078
	SES 2	-.094	.506	.034	1	.853	-1.086	.898
	SES 3	0^b			0			

The absence of any significant differences between the three classes of SES may also be visualised in the graph of probabilities which suggests there is no difference in the probability of reaching stage 4 and age (*Figure 4.65 a and b*).

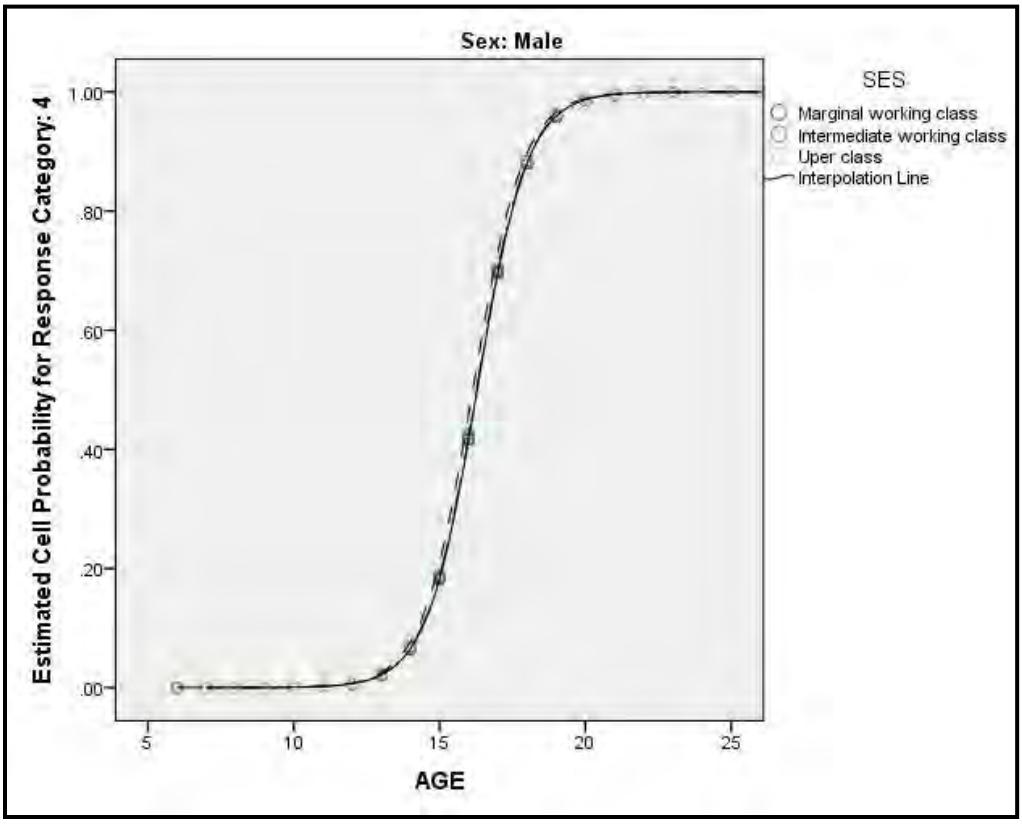


Figure 4.65 (a): *Ordinal logistic regression for stage 4 and SES at the hip in males showing no significant differences in the probability of mean scores and age.*

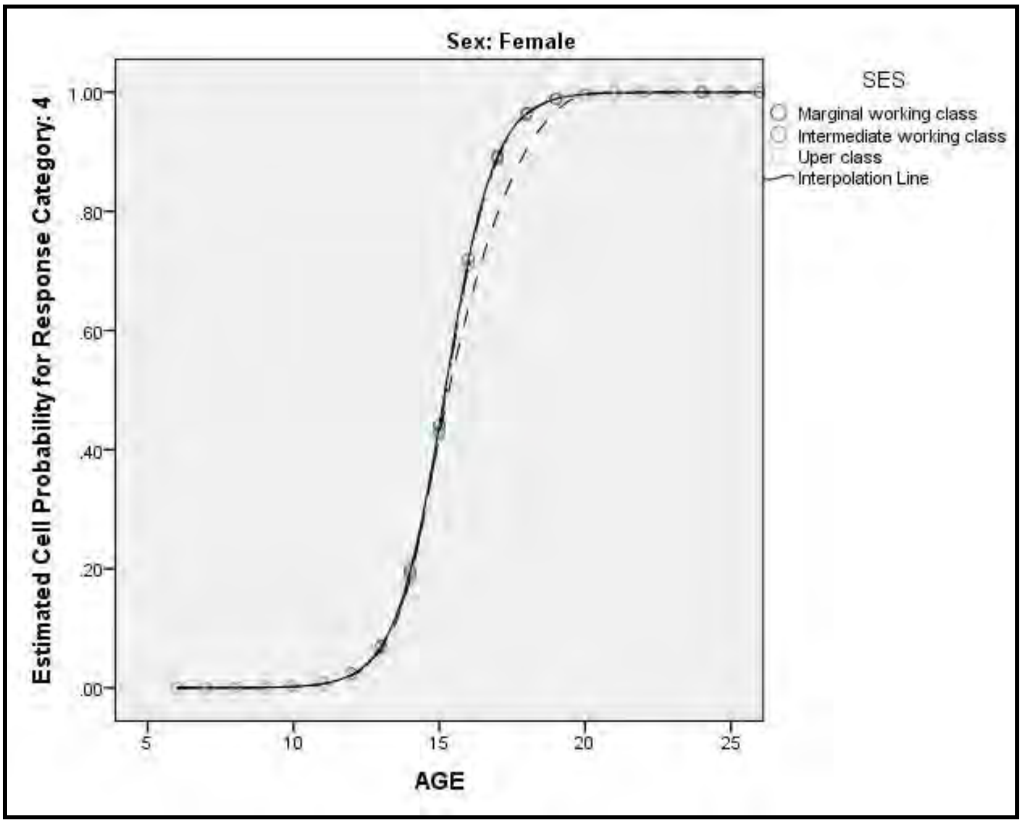


Figure 4.65 (b): *Ordinal logistic regression for stage 4 and SES at the hip in females. No significant differences are observed in females of different SES backgrounds at the hip.*

4.3.3 Mean Point Scores for the Ankle.

The epiphyses of the distal tibia begins union as early as six years of age but experiences a prolonged period of active union (stages 2 and 3) before it completes union at age 18 years in males and 15 years in females. The mean point score for Black males at the ankle at age six is 1.50 ± 0.00 while the mean score for females is 2 ± 0.00 *(Table 4.34*). There is an increase in the mean scores in males and females as age increases. The mean scores are higher for each age in females compared to males suggesting that union in females occurs ahead of males (*Figure 4.66).* The mean scores for the Black and Coloured males and females are presented in *Table 4.34* below.

Table 4.34: Mean Scores for the Ankle in Males and Females

	Black Male			Black Female			Coloured Males			Coloured Female		
Age	**N**	**Mean**	**sd**	**N**	**Mean**	**sd**	**N**	**Mean**	**sd**	**N**	**Mean**	**sd**
6	***2***	1.50	0.00	***3***	2.00	0.00	***1***	1.00		***1***	2.00	
7	***2***	1.50	0.71	***18***	2.00	0.00	***18***	1.94	0.24	***13***	2.00	0.00
8	***26***	2.00	0.00	***34***	2.00	0.00	***32***	1.98	0.09	***25***	2.00	0.00
9	***64***	1.97	0.18	***36***	2.00	0.00	***38***	2.00	0.00	***28***	2.00	0.00
10	***27***	2.00	0.00	***16***	2.00	0.00	***45***	2.00	0.00	***23***	2.00	0.00
11	***32***	1.98	0.09	***20***	2.05	0.22	***31***	2.00	0.00	***16***	2.00	0.00
12	***29***	2.00	0.00	***17***	2.32	0.58	***43***	2.00	0.00	***23***	2.50	0.58
13	***35***	2.01	0.08	***7***	2.21	0.39	***25***	2.20	0.48	***9***	2.67	0.71
14	***19***	2.26	0.65	***7***	3.14	0.69	***11***	2.68	0.56	***2***	3.00	1.41
15	***10***	2.30	0.54	***2***	4.00	0.00	***15***	3.40	0.63	***5***	4.00	0.00
16	***11***	2.91	0.54	***3***	4.00	0.00	***7***	3.71	0.49			
17	***13***	3.62	0.65	***2***	4.00	0.00	***13***	3.92	0.28	***3***	4.00	0.00
18	***39***	3.90	0.31	***4***	4.00	0.00	***18***	4.00	0.00	***4***	4.00	0.00
19	***34***	3.97	0.17	***5***	4.00	0.00	***20***	4.00	0.00	***3***	4.00	0.00
20	***59***	3.98	0.13	***5***	4.00	0.00	***18***	4.00	0.00	***4***	3.50	1.00
21	***56***	4.00	0.00	***10***	4.00	0.00	***19***	4.00	0.00	***10***	4.00	0.00
22	***63***	4.00	0.00	***3***	4.00	0.00	***30***	4.00	0.00	***7***	4.00	0.00
23	***48***	4.00	0.00	***12***	4.00	0.00	***24***	4.00	0.00	***5***	4.00	0.00
24	***67***	4.00	0.00	***3***	4.00	0.00	***17***	4.00	0.00	***4***	4.00	0.00

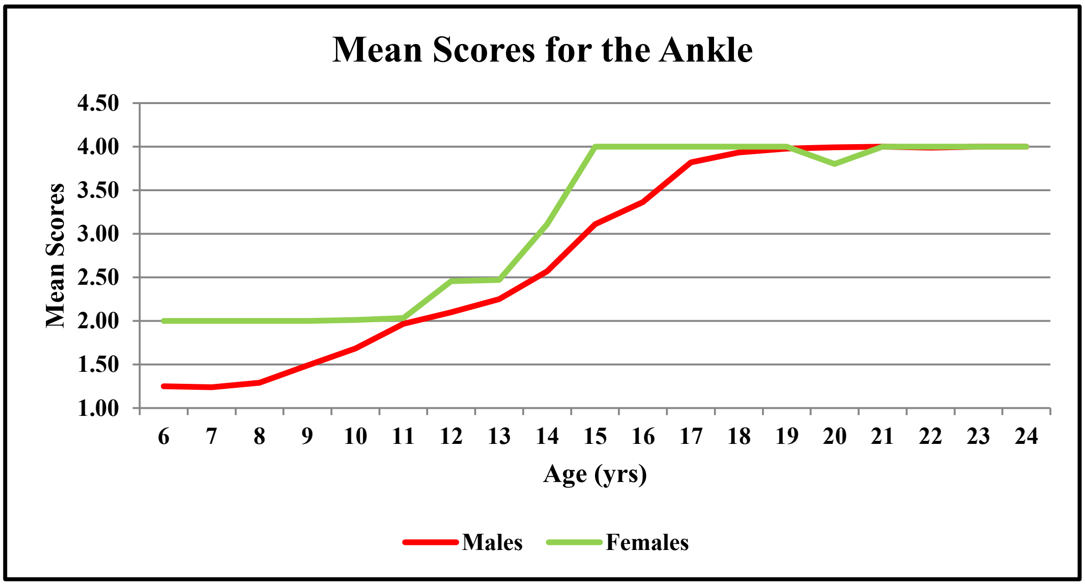


Figure 4.66: *Mean scores for union in the ankle in males and females where females show higher mean scores per age suggesting that they are ahead of males.*

4.3.3.1 Sex Differences in the Ages of Complete Union at the Ankle.

Significant differences in the age of union between males and females are present at all stage ($p<0.05$) (*Table 4.35*) (*Figure 4.67*). Males have lower scores compared to females for all stage (negative sign). There appears to be a strong association between stages of union, age and sex with an R^2 value of 0.937 suggesting that the model predicts 94% of the variability in the scores. The ankle has the highest recorded stand errors for stage 2 and 3 compared to the rest of the joints. The 95% CI for stage 2 in males for the ankle would be 17.3 - 22.6 years.

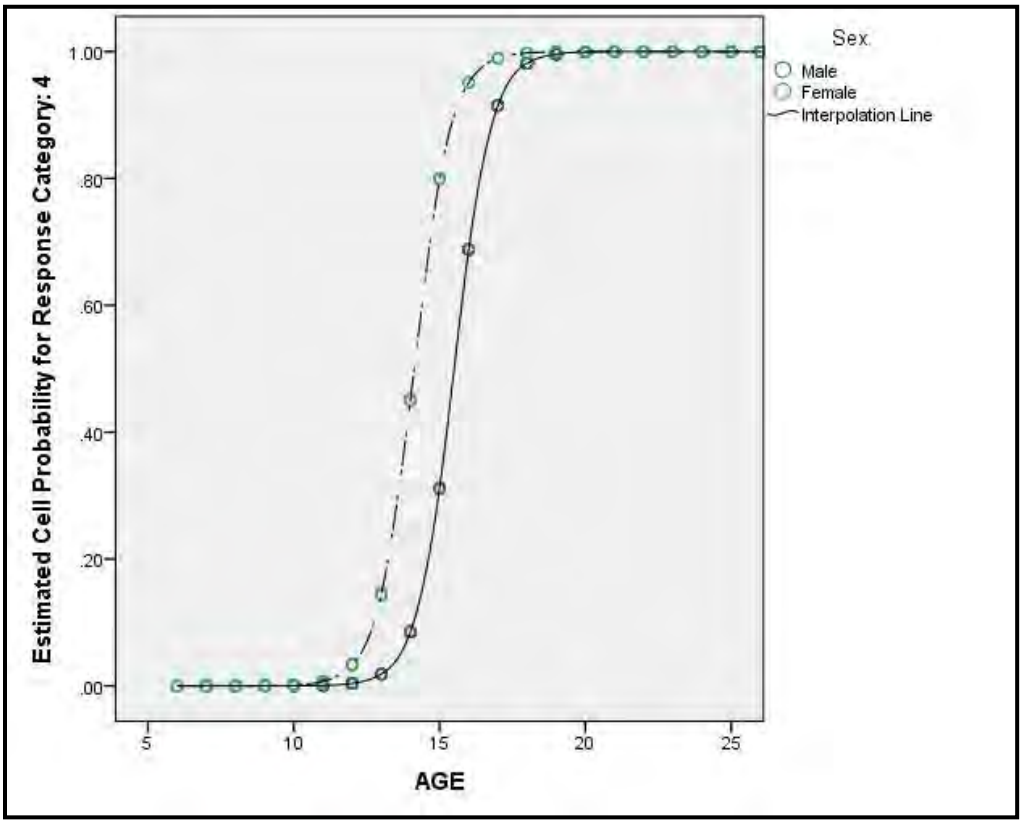


Figure 4.67: *Ordinal logistic regression for stage 4 in males and females at the ankle showing significant differences in probability of being scored as stage 4. Females appear to be in advance of males.*

Table 4.35: Ordinal Logistic Regression Parameters for Sex at the Ankle

		Estimate	SE	Wald	df	Sig.	Lower 95% CI	Upper 95% CI
Threshold	**Stage 1**	6.268	.719	75.932	1	.000	4.858	7.678
	Stage 2	20.228	1.225	272.720	1	.000	17.827	22.629
	Stage 3	22.351	1.357	271.105	1	.000	19.690	25.011
Location	**Age**	1.582	.098	259.546	1	.000	1.390	1.775
	Males	-2.176	.332	42.889	1	.000	-2.827	-1.524
	Females	0[a]			0			

4.3.3.2 Genetic Differences at the Ankle in Males and Females.

No significant differences exist in the differences between Coloured and Black male and female scores ($p > 0.05$) (*Table 4.36*) (*Figure 4.68 a; b*). Similar to the elbow and hip, Black males and females have lower scores per stage compared to the Coloured males and females. The differences are not significant; however the appearance of a trend toward earlier union in Coloured males is apparent (*Figure 4.69*). These differences are more pronounced between the ages of 12 to 18 years. The same trend is not visible in females probably due to the smaller sample size (*Figure 4.70*). Black males will have scores lower than those of Coloured males suggesting that Coloured males do mature in advance of Black males but not significantly so.

Table 4.36: Parameters for Genetic Differences in Males and Females at the Ankle

		Estimate	SE	Wald	df	Sig.	Lower 95% CI	Upper 95% CI
Threshold	**Stage 1**	9.401	1.053	79.771	1	.000	7.338	11.464
	Stage 2	24.270	1.946	155.471	1	.000	20.455	28.085
	Stage 3	26.651	2.151	153.464	1	.000	22.435	30.868
Location	**Age**	1.732	.140	152.837	1	.000	1.458	2.007
	Black Males	-.631	.362	3.040	1	.081	-1.340	.078
	Coloured Males	0^b			0			
Threshold	**Stage 2**	17.624	2.182	65.237	1	.000	13.347	21.900
	Stage 3	19.501	2.347	69.018	1	.000	14.901	24.102
	Age	1.390	.178	60.936	1	.000	1.041	1.739
Location	**Black Females**	-.666	.470	2.007	1	.157	-1.587	.255
	Coloured Females	0^b			0			

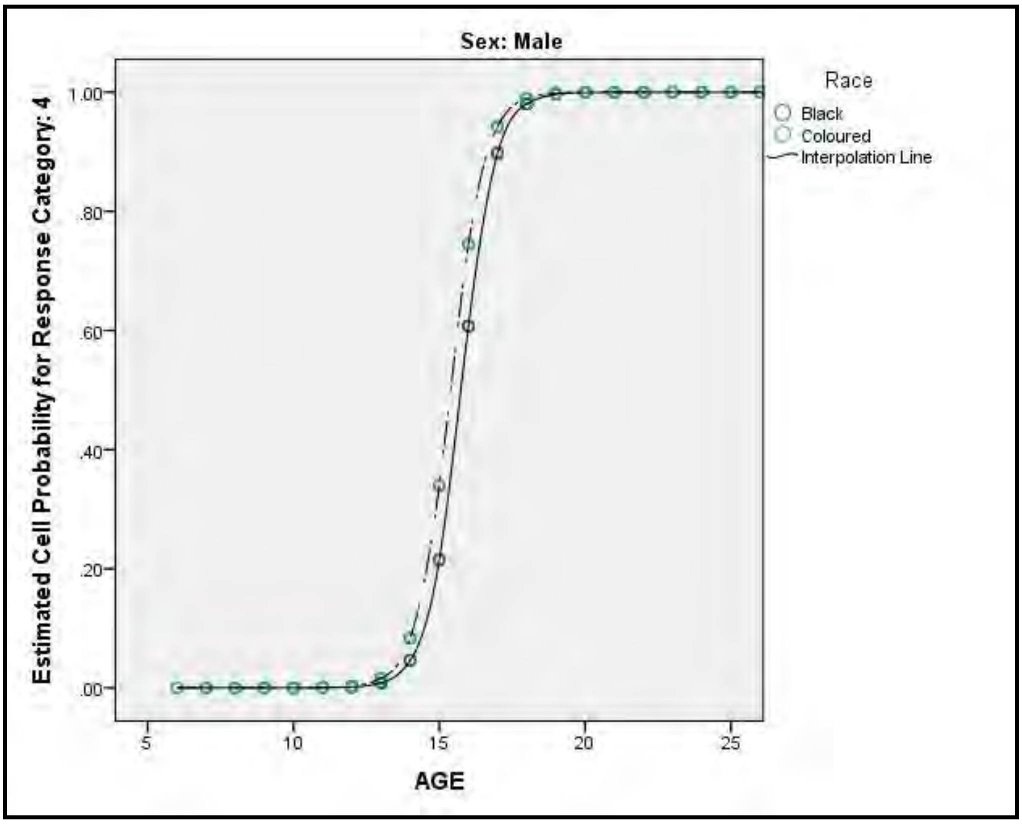


Figure 4.68 (a): *Ordinal logistic regression for stage 4 in black and coloured males at the ankle that shows no significant differences in the models.*

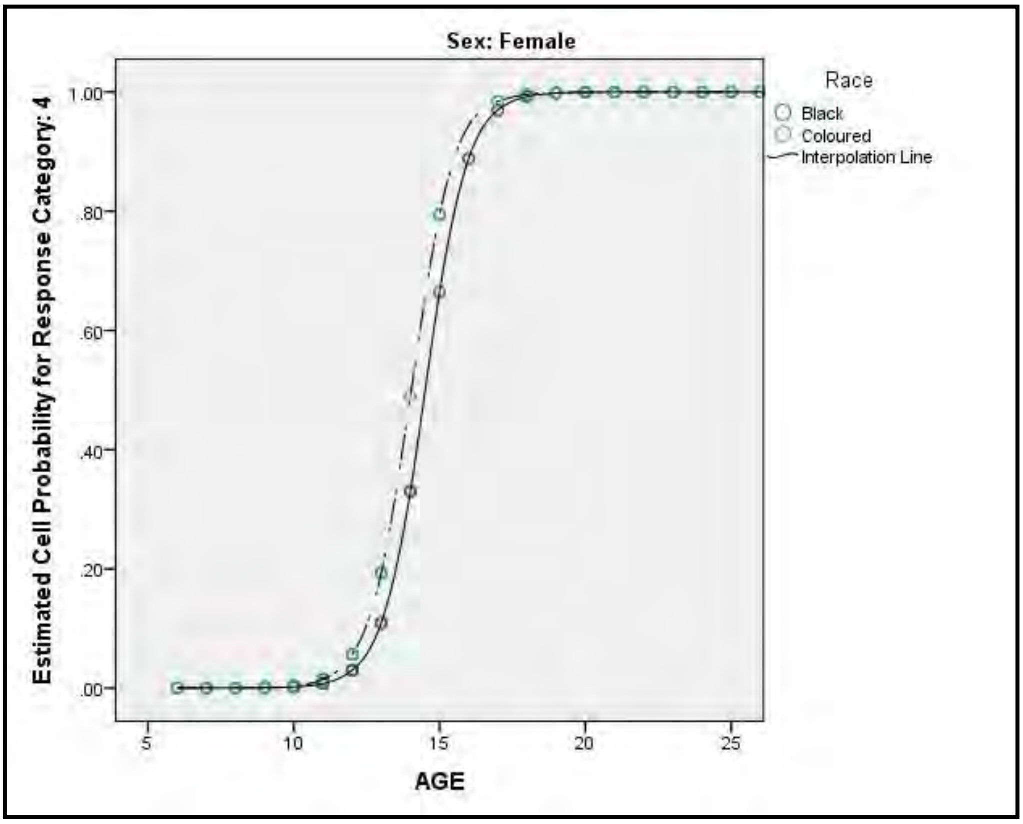


Figure 4.68 (b): *Ordinal logistic regression for stage 4 in black and coloured females at the ankle showing no significant differences are observed in the mean scores and age at the ankle.*

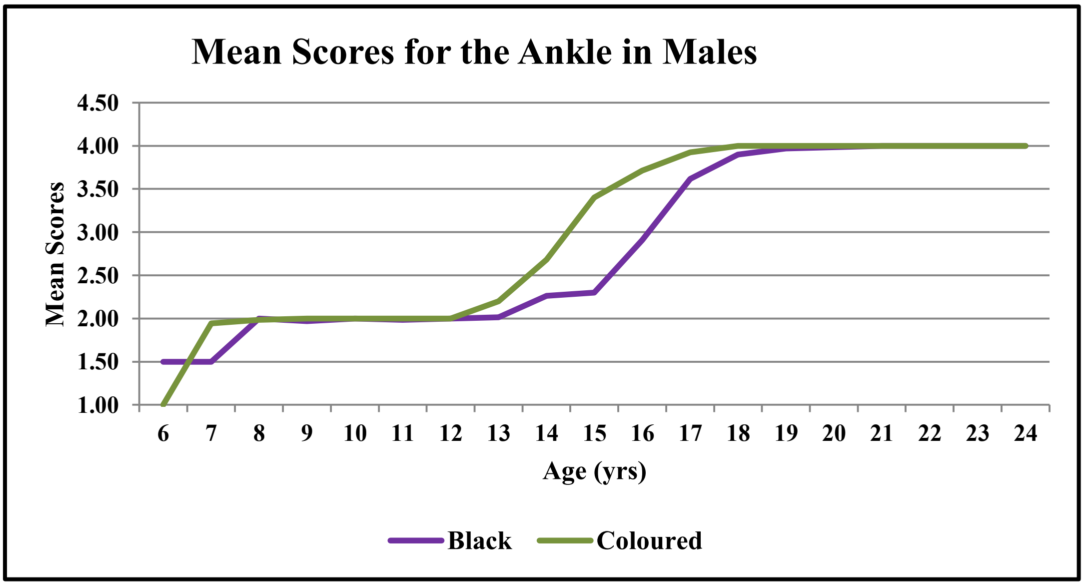


Figure 4.69: *Mean scores for union in the ankle in black and coloured males showing a trend toward advanced union in coloured males compared to black males especially between 12 - 18 years.*

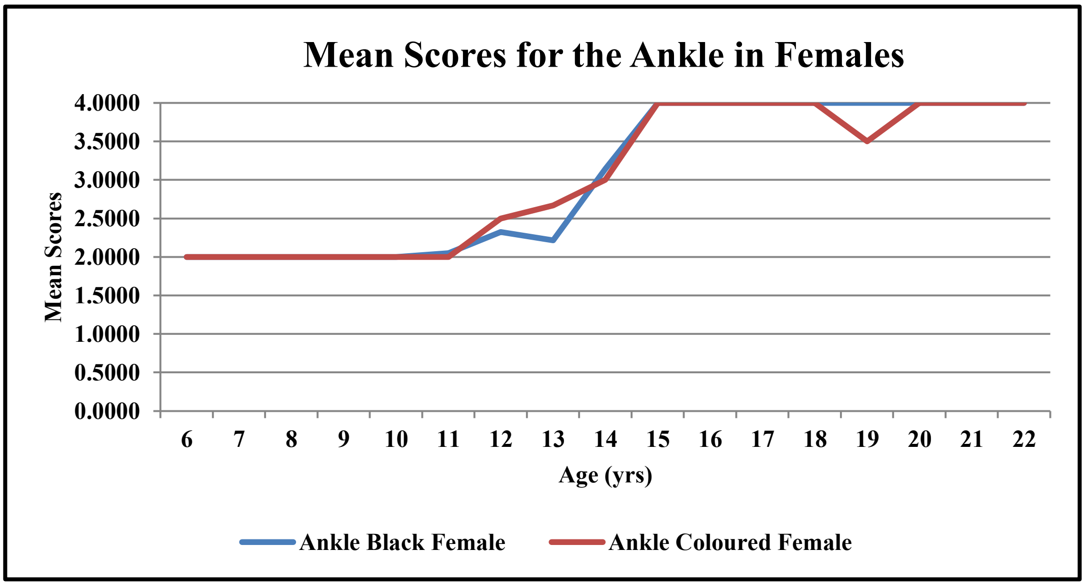


Figure 4.70: *Mean scores for union in the ankle in black and coloured females.*

4.3.3.3 The Influence of Socio-Economic Status (SES) on Age of Complete Union at the Ankle in Males and Females.

There appears to be no significant differences in the models for the three classes of SES ($p > 0.05$) (*Table 4.37*) in males (*Figure 4.71a*) and females (*Figure 4.71b*).

Table 4.37: Parameters of Ordinal Logistic Regression in the Three Classes of SES

		Estimate	SE	Wald	df	Sig.	Lower 95% CI	Upper 95% CI
Threshold-Males	Stage 1	9.117	1.230	54.917	1	.000	6.706	11.529
	Stage 2	23.645	2.018	137.261	1	.000	19.690	27.601
	Stage 3	25.990	2.210	138.352	1	.000	21.659	30.320
Location	Age	1.709	.140	149.444	1	.000	1.435	1.983
	SES 1	-.813	.750	1.175	1	.278	-2.283	.657
	SES 2	-.316	.718	.193	1	.660	-1.724	1.092
	SES 3	0[b]			0			
Threshold-Females	Stage 2	17.810	2.337	58.073	1	.000	13.229	22.390
	Stage 3	19.561	2.468	62.822	1	.000	14.724	24.398
	Age	1.350	.169	63.856	1	.000	1.019	1.681
Location	SES 1	.219	.981	.050	1	.823	-1.704	2.142
	SES 2	.485	.942	.265	1	.606	-1.360	2.330
	SES 3	0[b]			0			

Males who belong to the marginal (SES 1) and intermediate (SES 2) working class have lower scores per stage compared to the upper working (SES 3). These differences are not significant.

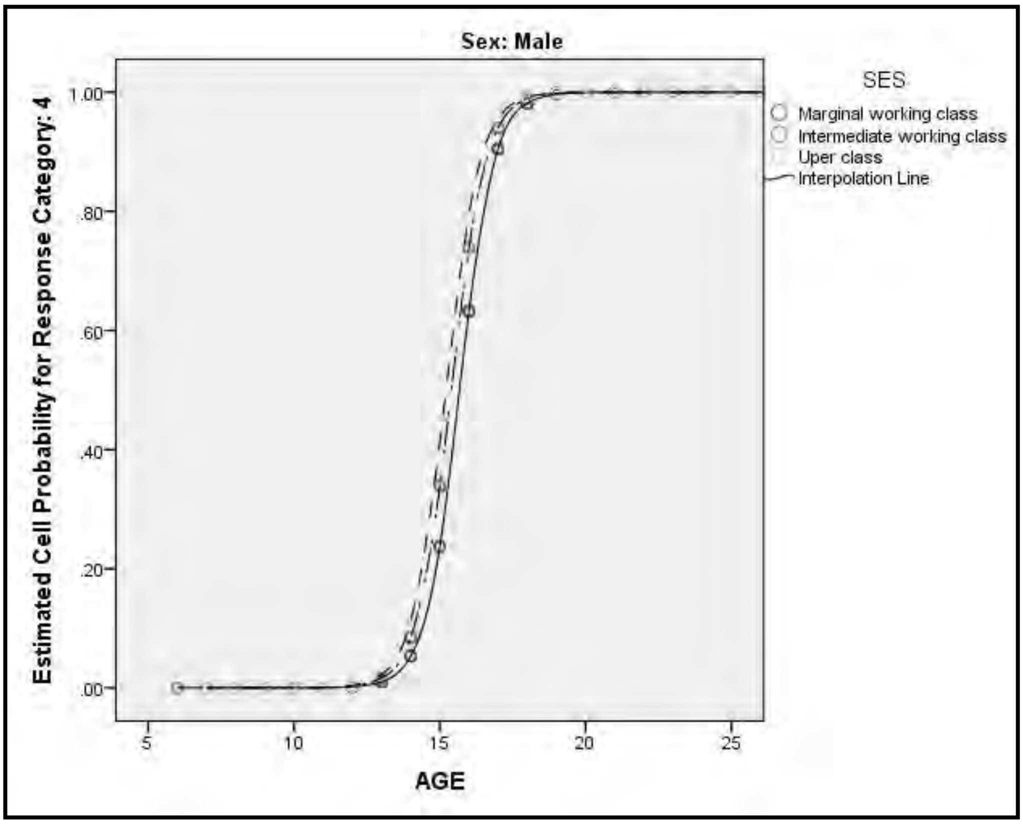


Figure 4.71 (a): *Ordinal logistic regression for stage 4 and SES for the ankle in males showing no significant differences in the probability of being classified in stage 4.*

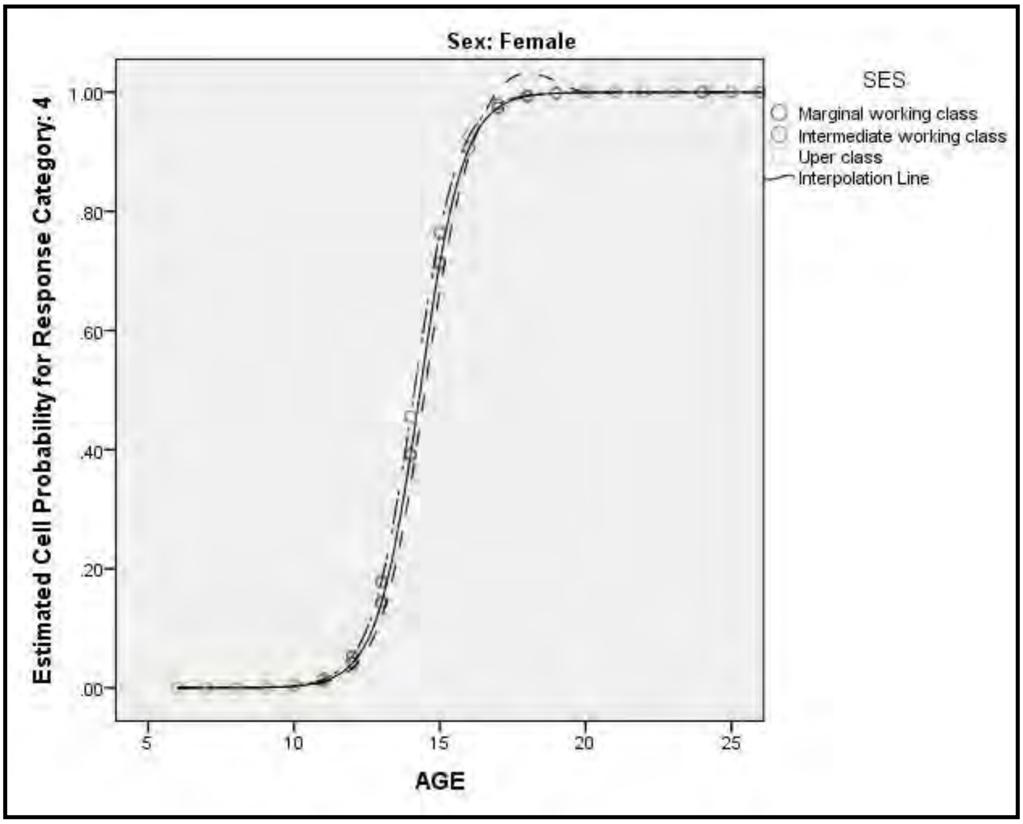


Figure 4.71 (b): *Ordinal logistic regression for stage 4 and SES for the ankle in females showing no significant differences are observed in females of different SES backgrounds at the ankle.*

4.3.4 Mean Scores for the Knee

The mean scores for Black and Coloured males and females for the knee are presented in *Table 4.38*.The mean scores are lower in males compared to females (*Figure 4.72*). Mean point score of 4 which refers to complete union is reached at age 21 in males and 16 years in females.

Table 4.38: Mean Scores for the Knee in Males and Females

	Black Males			Black Female			Coloured Males			Coloured Female		
Age	**N**	**Mean**	**sd**	**N**	**Mean**	**sd**	**N**	**Mean**	**sd**	**N**	**Mean**	**sd**
6	***2***	1.50	0.00	***3***	1.67	0.33	***1***	1.67		***1***	1.33	
7	***2***	1.00	0.00	***18***	1.28	0.24	***19***	1.21	0.28	***13***	1.26	0.31
8	***27***	1.26	0.34	***35***	1.61	0.37	***33***	1.34	0.33	***26***	1.74	0.37
9	***64***	1.25	0.24	***36***	1.93	0.33	***38***	1.44	0.34	***29***	1.90	0.38
10	***28***	1.52	0.34	***16***	2.08	0.29	***45***	1.72	0.36	***23***	2.07	0.25
11	***32***	1.72	0.39	***20***	2.23	0.31	***32***	1.91	0.36	***16***	2.38	0.27
12	***27***	2.01	0.38	***18***	2.44	0.38	***43***	2.13	0.27	***23***	2.51	0.32
13	***34***	2.04	0.33	***7***	2.57	0.16	***26***	2.26	0.46	***9***	2.63	0.26
14	***19***	2.28	0.62	***7***	3.19	0.42	***11***	2.52	0.43	***2***	3.00	1.41
15	***10***	2.40	0.34	***2***	4.00	0.00	***16***	3.21	0.56	***5***	3.87	0.30
16	***11***	2.82	0.50	***3***	4.00	0.00	***7***	3.52	0.60			
17	***13***	3.21	0.44	***2***	4.00	0.00	***13***	3.69	0.42	***3***	4.00	0.00
18	***39***	3.85	0.35	***4***	4.00	0.00	***19***	3.95	0.23	***4***	4.00	0.00
19	***34***	3.91	0.29	***5***	4.00	0.00	***20***	4.00	0.00	***3***	4.00	0.00
20	***59***	3.97	0.18	***5***	4.00	0.00	***18***	4.00	0.00	***4***	3.58	0.83
21	***56***	3.99	0.09	***10***	4.00	0.00	***19***	4.00	0.00	***10***	4.00	0.00
22	***63***	4.00	0.00	***3***	4.00	0.00	***30***	4.00	0.00	***7***	3.86	0.38
23	***48***	4.00	0.00	***12***	4.00	0.00	***24***	4.00	0.00	***5***	4.00	0.00
24	***67***	4.00	0.00	***3***	4.00	0.00	***17***	4.00	0.00	***4***	4.00	0.00

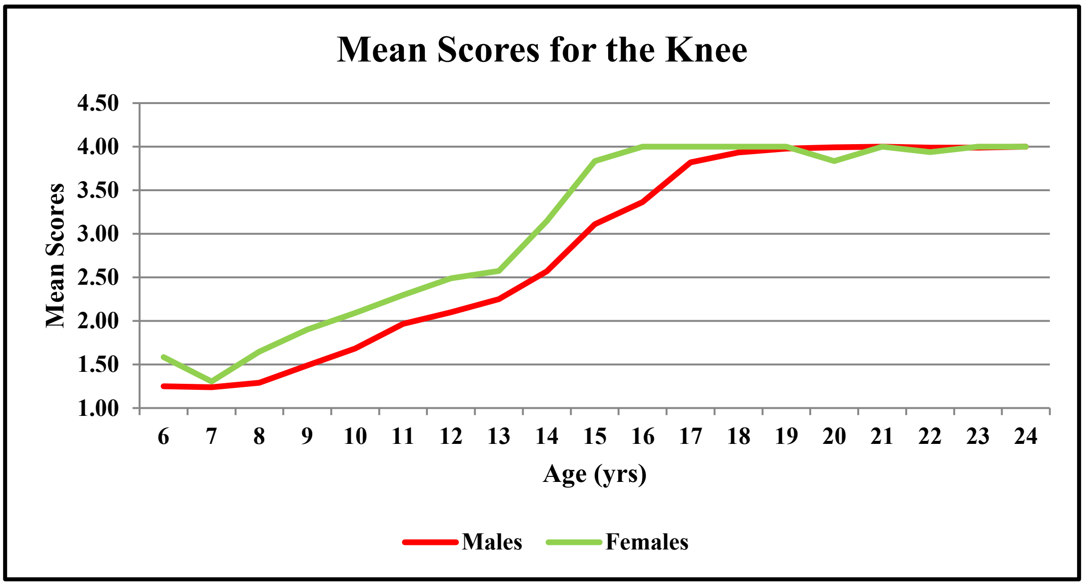


Figure 4.72: *Mean scores at the knee in males and females; females have higher scores at each age compared to males until 18 years.*

4.3.4.1 Sex Differences in the Ages of Complete Union at the Knee.

There are significant differences in the age and stage of union in males and females ($p < 0.05$) (*Table 4.39*). Males attain a lower score for each stage of union compared to females suggesting that union occurs earlier in the females (*Figure 4.72*). The standard errors for the model are low and range between 0.05 and 0.7. The model predicts 90% (Nagelkerke R^2) of variability while the 95% CI in females at the lower age range would be 2.1 years less than that of males whereas the higher age limit would be 1.5 years less than that in males suggesting that the 95% CI for stage 3 in females would be 14.0 to 17.4 years opposed to 16.1 – 18.9 years in males.

Table 4.39: Ordinal Logistic Regression Parameters for Sex at the Knee

		Estimate	Std. Error	Wald	df	Sig.	Lower 95% CI	Upper 95% CI
Threshold	**Stage 1**	10.558	.435	588.582	1	.000	9.705	11.410
	Stage 2	15.707	.632	617.725	1	.000	14.469	16.946
	Stage 3	17.489	.709	609.077	1	.000	16.101	18.878
Location	**Age**	1.183	.047	625.661	1	.000	1.090	1.276
	Males	-1.839	.181	103.475	1	.000	-2.193	-1.485
	Females	0[a]			0			

The probability (1) of achieving a complete union in the knee increases with increasing age. Females achieve the score of 4 earlier than males; they also progress through the stages earlier than males and would therefore appear above males in the logistic regression model (*Figure 4.73*).

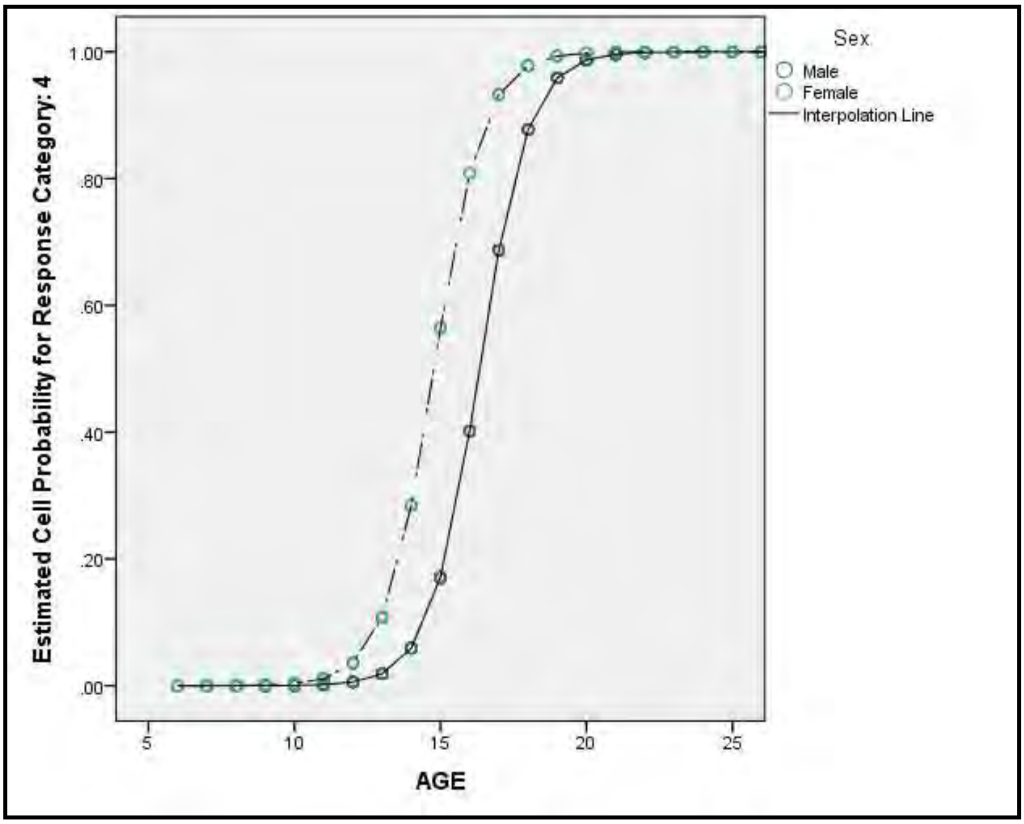


Figure 4.73: *Ordinal logistic regression for stage 4 and sex at the knee showing significant differences between males and females and the probability of being scored as stage 4.*

4.3.4.2 Genetic Differences at the Knee in Males and Females.

There appears to be no significant differences in the ages of union per stage between the two genetic backgrounds in males ($p > 0.05$) and females ($p > 0.05$) (*Table 4.40*) (*Figure 4.74 a and b*). Black males and females have lower scores compared to their Coloured counterparts. Although these do not appear to be significant they point to an apparent trend of earlier union in Coloureds males and females compared to the Black males (*Figure 4.75*) and females (*Figure 4.76*). The model predicts 90% of the variability in males and 85% of the variability in females.

Table 4.40: Parameters for Genetic Differences in Males and Females at the Knee

		Estimate	SE	Wald	df	Sig.	Lower 95% CI	Upper 95% CI
Threshold	**Stage 1**	12.519	.645	377.119	1	.000	11.256	13.783
	Stage 2	17.370	.899	373.348	1	.000	15.608	19.131
	Stage 3	19.278	1.000	371.758	1	.000	17.318	21.237
Location	**Age**	1.187	.060	390.147	1	.000	1.069	1.305
	Black Males	-.170	.203	.699	1	.403	-.567	.228
	Coloured Males	0^b			0			
Threshold	**Stage 1**	9.840	.888	122.765	1	.000	8.099	11.580
	Stage 2	15.514	1.272	148.680	1	.000	13.020	18.008
	Stage 3	17.173	1.403	149.869	1	.000	14.423	19.922
Location	**Age**	1.142	.097	137.480	1	.000	.951	1.333
	Black Females	-.220	.265	.691	1	.406	-.740	.299
	Coloured Females	0^b			0			

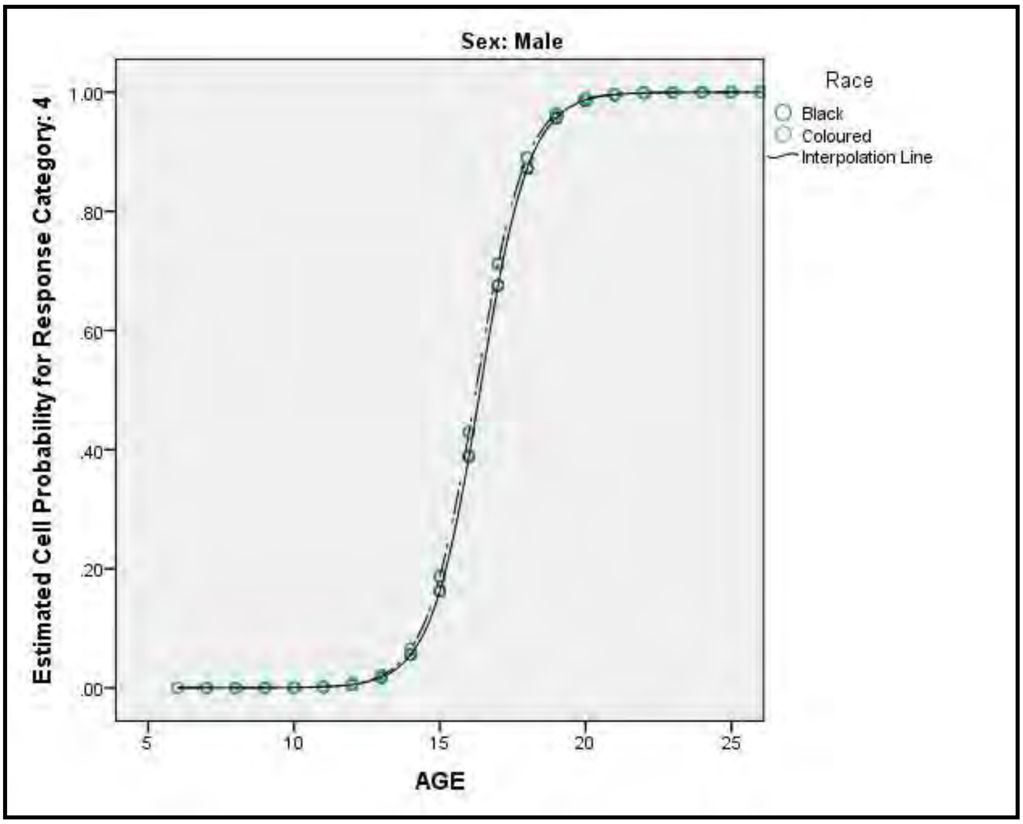


Figure 4.74 (a): *Ordinal logistic regression for stage 4 in black and coloured males at the knee that shows no significant differences in the probability of being scored as 4.*

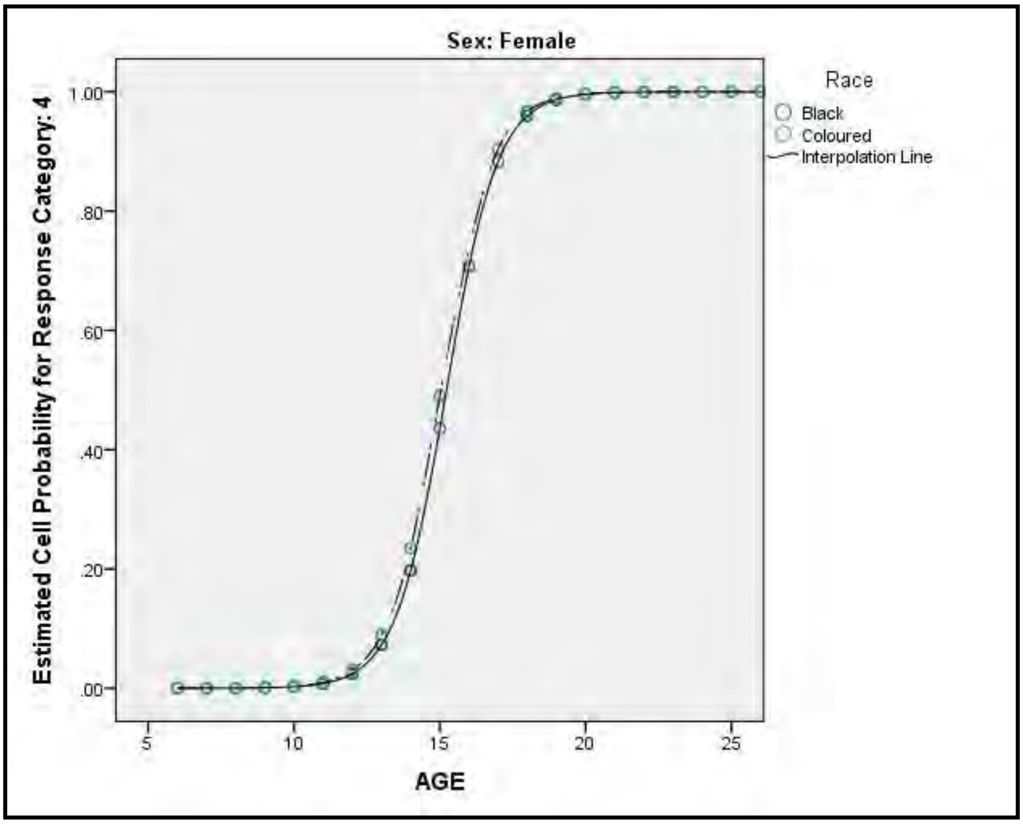


Figure 4.74 (b): *Ordinal logistic regression for stage 4 in black and coloured females at the knee shows no significant difference in the probability of being scored as 4.*

The knee shows a trend of higher mean scores per age in Coloured males compared to Black males (*Figure 4.75*). These differences appear to be more pronounced between 14 and 17 years. At age 17 years the mean score for the knee in Black males is 3.21 and 3.69 in Coloured males. Coloured males reach mean point score of 4 at age 19 whereas Black males reach a mean point score of 4 at age 22 years. However, these are not significant. The same trend is not visible in females probably due to the smaller sample size (*Figure 4.76*).

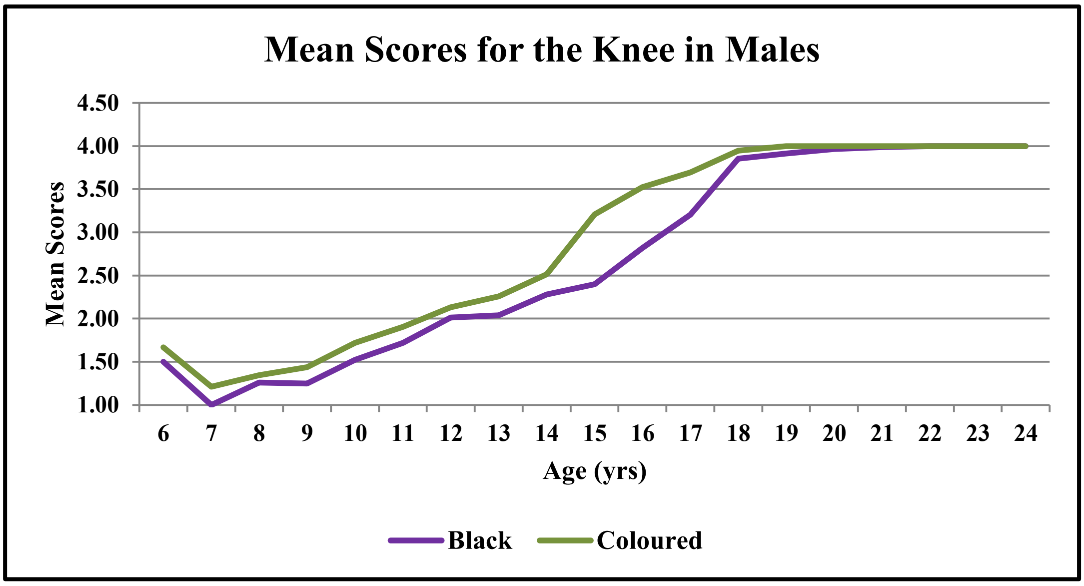


Figure 4.75: *Meas scores for complete union in coloured and black males at the knee. Mean scores in coloured males appear to higher than those in black males for all ages suggesting a trend toward earlier union in coloured males.*

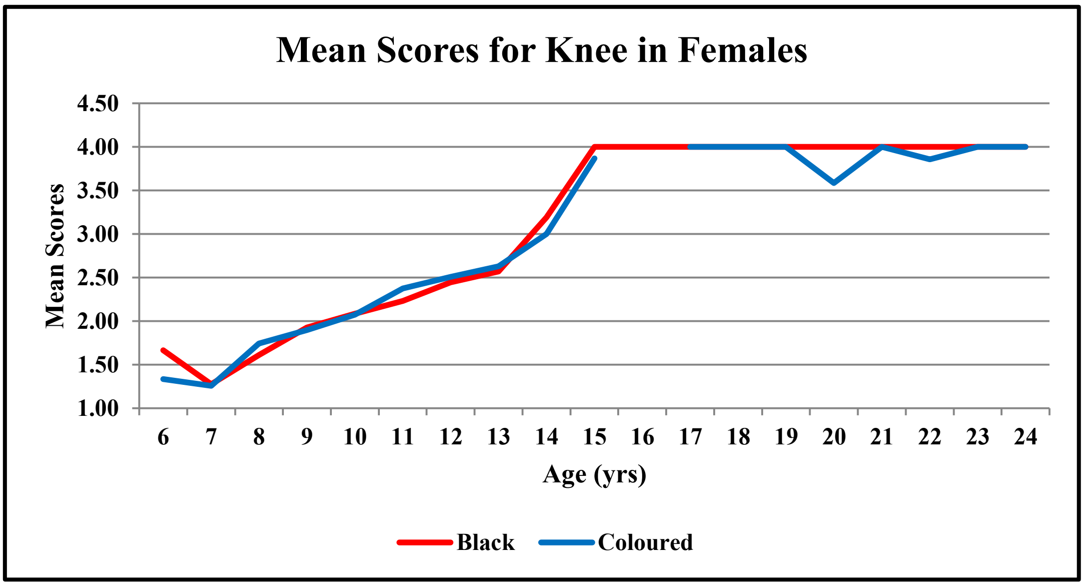


Figure 4.76: *Mean scores for complete union in coloured and black females at the knee. There appear to be no differences between coloured and black females.*

4.3.4.3 The Influence of Socio-Economic Status (SES) on Age of Complete Union at the Knee in Males and Females.

There also appears to be no significant differences in the three classes of SES and age per stage of union in males ($p > 0.05$) and females ($p > 0.05$) (*Table 4.41*).

Table 4.41: Parameters of Ordinal Logistic Regression in the Three Classes of SES

		Estimate	SE	Wald	df	Sig.	Lower 95% CI	Upper 95% CI
Threshold-Males	Stage 1	12.152	.700	301.770	1	.000	10.781	13.523
	Stage 2	16.970	.934	330.203	1	.000	15.140	18.801
	Stage 3	18.765	1.024	335.773	1	.000	16.758	20.772
Location	Age	1.163	.059	391.970	1	.000	1.048	1.278
	SES 1	-.172	.387	.198	1	.657	-.931	.587
	SES 2	-.141	.370	.145	1	.704	-.867	.585
	SES 3	0^b			0			
Threshold-Females	Stage 1	10.373	.988	110.296	1	.000	8.437	12.309
	Stage 2	16.132	1.341	144.722	1	.000	13.504	18.761
	Stage 3	17.981	1.476	148.361	1	.000	15.088	20.874
Location	Age	1.178	.098	143.694	1	.000	.985	1.370
	SES 1	.080	.526	.023	1	.880	-.951	1.111
	SES 2	.030	.513	.003	1	.954	-.975	1.034
	SES 3	0^b			0			

Males who belong to SES 1 and SES 2 have lower scores compared to the upper working class (SES 3) suggesting that the latter group shows non-significant advanced union. The probability of being scored as a stage 4 does not differ between the three classes in males (*Figure 4.77a*) and females (*Figure 4.77b*).

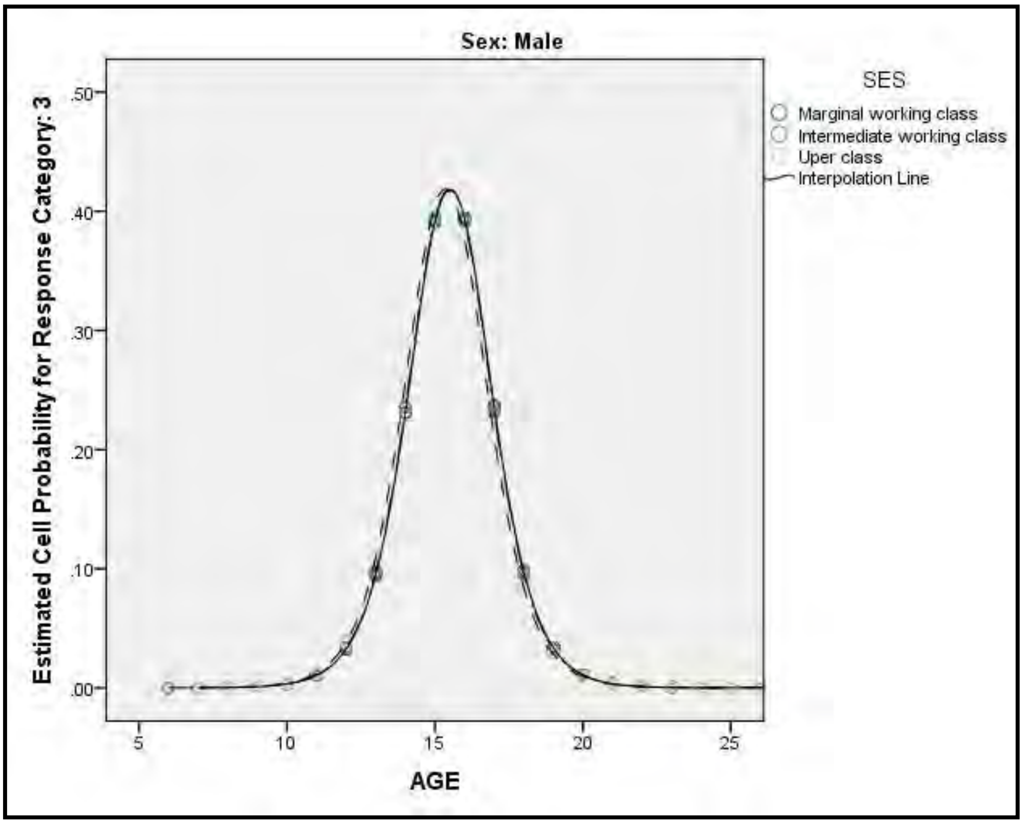


Figure 4.77 (a): *Ordinal logistic regression for three classes of SES at the knee in males showing no significant differences on the effect of SES on maturity.*

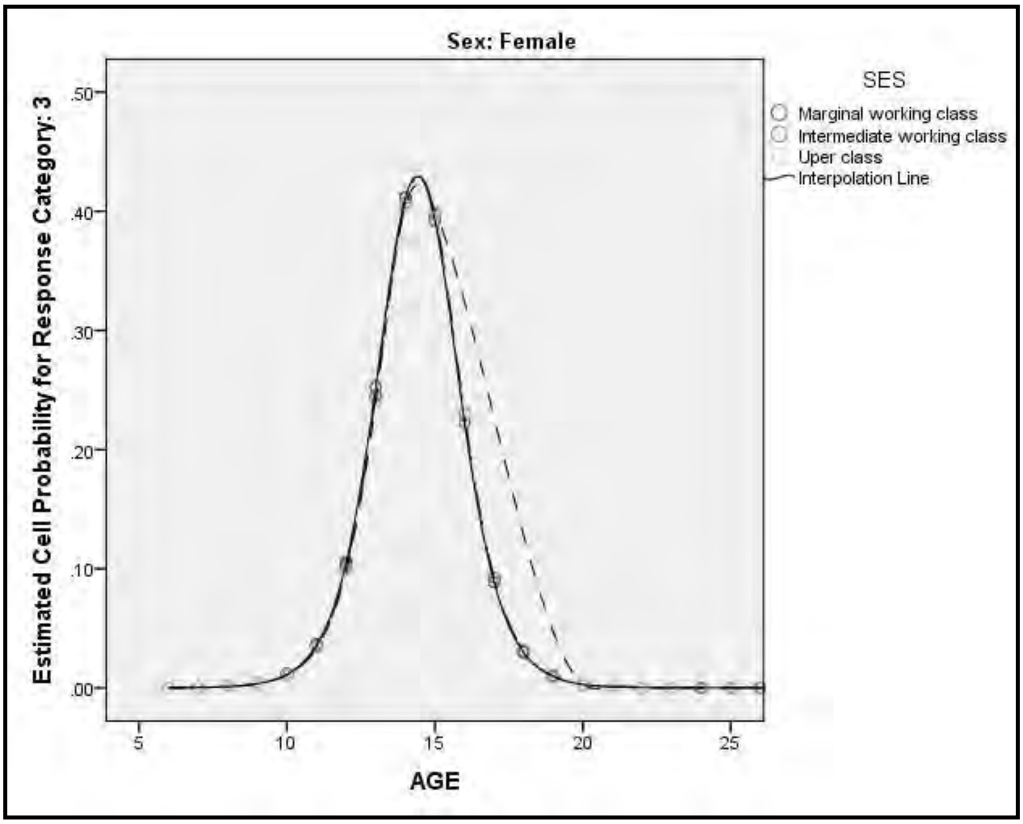


Figure 4.77 (b): *Ordinal logistic regression for three classes of SES at the knee in females showing no significant differences on the effect of SES on maturity.*

4.3.5 Mean Scores at the Wrist

The wrist is the second last joint to complete union in males and females. Like the other joints the mean scores increase with increasing age and females show advanced union compared to males (*Table 4.42*) (*Figure 4.78)*. Females reach a mean point score of 4 at 17 years of age while males reach a mean point score of 4 at 21 years showing a four year difference between the two groups.

Table 4.42: Mean Scores for the Wrist in Males and Females

	Black Males			Black Female			Coloured Males			Coloured Female		
Age	**N**	**Mean**	**sd**	**N**	**Mean**	**sd**	**N**	**Mean**	**sd**	**N**	**Mean**	**sd**
6	***2***	1.50	0.00	***3***	1.33	0.29	***1***	1.00		***1***	1.50	
7	***1***	1.00		***14***	1.07	0.18	***17***	1.03	0.12	***11***	1.09	0.20
8	***21***	1.02	0.11	***27***	1.22	0.35	***24***	1.08	0.19	***16***	1.16	0.30
9	***47***	1.03	0.12	***26***	1.44	0.43	***25***	1.20	0.32	***21***	1.33	0.37
10	***22***	1.16	0.28	***5***	1.70	0.45	***32***	1.28	0.36	***16***	1.50	0.41
11	***21***	1.26	0.37	***13***	1.73	0.56	***19***	1.45	0.40	***13***	1.88	0.30
12	***15***	1.47	0.44	***14***	1.96	0.41	***25***	1.70	0.38	***16***	2.34	0.54
13	***16***	1.50	0.45	***4***	2.75	0.50	***11***	1.86	0.84	***8***	2.38	0.52
14	***14***	2.00	0.76	***6***	3.00	0.00	***7***	2.21	0.39	***2***	2.75	1.77
15	***5***	2.40	0.55	***2***	4.00	0.00	***13***	3.00	0.58	***5***	3.60	0.55
16	***7***	2.86	0.69	***3***	3.67	0.58	***7***	3.29	0.76			
17	***10***	3.00	0.47	***2***	4.00	0.00	***13***	3.54	0.52	***3***	4.00	0.00
18	***39***	3.81	0.39	***4***	4.00	0.00	***19***	3.95	0.23	***4***	4.00	0.00
19	***34***	3.88	0.33	***5***	4.00	0.00	***20***	3.90	0.31	***3***	4.00	0.00
20	***59***	3.93	0.25	***5***	4.00	0.00	***18***	3.94	0.24	***3***	4.00	0.00
21	***56***	3.98	0.13	***10***	4.00	0.00	***19***	4.00	0.00	***10***	4.00	0.00
22	***63***	4.00	0.00	***3***	4.00	0.00	***30***	4.00	0.00	***7***	4.00	0.00
23	***48***	4.00	0.00	***12***	4.00	0.00	***24***	3.96	0.20	***5***	4.00	0.00
24	***67***	3.99	0.12	***3***	4.00	0.00	***17***	4.00	0.00	***4***	4.00	0.00

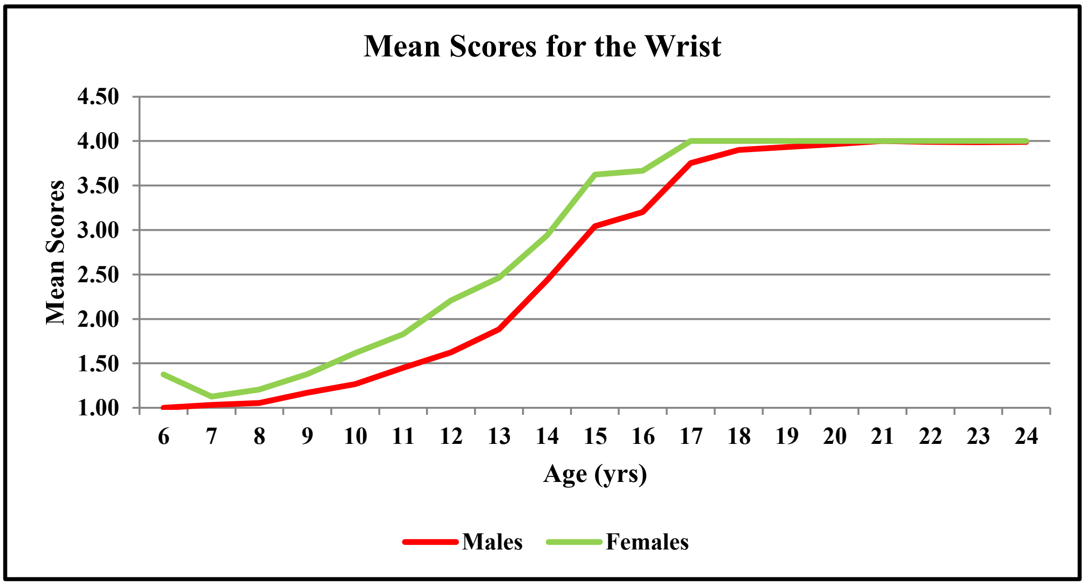


Figure 4.78: *Mean scores at the wrist in males and females; females have higher scores at each age compared to males until 18 years.*

4.3.5.1 Sex Differences in the Ages of Complete Union at the Wrist.

There are significant differences between males and females in the age and all stages of union ($p < 0.05$) (*Table 4.43*) (*Figure 4.79*). These significant differences are apparent in all stages. Males have lower scores per stage compared to females suggesting that females mature earlier. There is also a significant relationship between age and stage of union ($p < 0.05$). The standard errors for sex differences appear to be low. The model predicts 88 % of variability (Nagelkerke R^2). The lower age range for the 95% CI in females is 2. Years less than that of males whereas the limit for the upper age is 1.2 years less than males suggesting that the CI for stage 2 in females for example lies between 10.4 – 13.5 years.

Table 4.43: Ordinal Logistic Regression Parameters for Sex at the Wrist

		Estimate	SE	Wald	df	Sig.	Lower 95% CI	Upper 95% CI
Threshold	**Stage 1**	10.725	.471	518.348	1	.000	9.802	11.649
	Stage 2	13.578	.592	526.446	1	.000	12.418	14.738
	Stage 3	15.814	.700	510.471	1	.000	14.442	17.186
Location	**Age**	1.050	.045	534.925	1	.000	.961	1.139
	Males	-1.626	.210	59.782	1	.000	-2.038	-1.214
	Females	0^a			0			

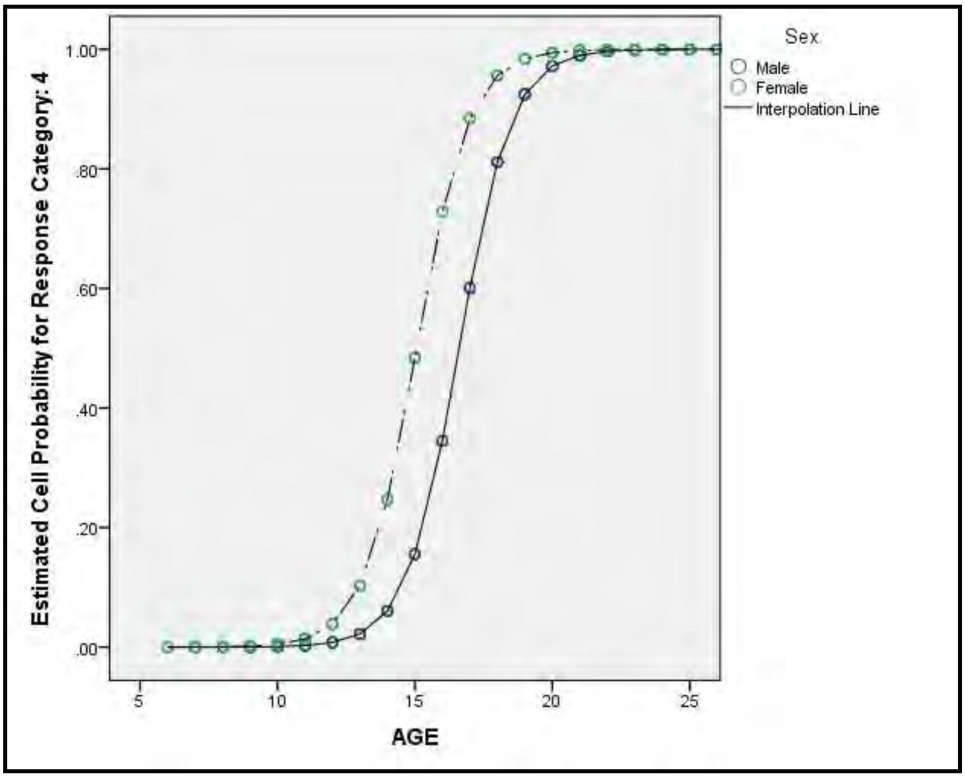


Figure 4.79: *Ordinal logistic regression for complete union in males and females at the wrist showing significant differences in probability of being scored as stage 4.Females appear to be ahead of males.*

4.3.5.2 Genetic Differences at the Wrist in Males and Females.

There are no significant differences between the age of union and genetic background in both Black and Coloured males and females ($p > 0.05$) (*Table 4.44*). There is no difference in the probability of being scored as 4 in Black and Coloured males (*Figure 4.80a*) and females (*Figure 4.80b*).

Table 4.44: Parameters for Genetic Differences in Males and Females at the Wrist

		Estimate	Std. Error	Wald	df	Sig.	Lower 95% CI	Upper 95% CI
Threshold	**Stage 1**	12.086	.679	316.645	1	.000	10.755	13.417
	Stage 2	14.711	.844	304.129	1	.000	13.057	16.364
	Stage 3	16.938	.973	302.911	1	.000	15.031	18.846
Location	**Age**	1.012	.056	326.034	1	.000	.903	1.122
	Black Males	.220	.230	.914	1	.339	-.231	.671
	Coloured Males	0^b			0			
Threshold	**Stage 1**	13.627	1.266	115.779	1	.000	11.144	16.109
	Stage 2	17.268	1.546	124.735	1	.000	14.238	20.298
	Stage 3	20.263	1.829	122.689	1	.000	16.678	23.848
Location	**Age**	1.337	.123	118.212	1	.000	1.096	1.578
	Black Females	.153	.338	.205	1	.651	-.509	.814
	Coloured Females	0^b			0			

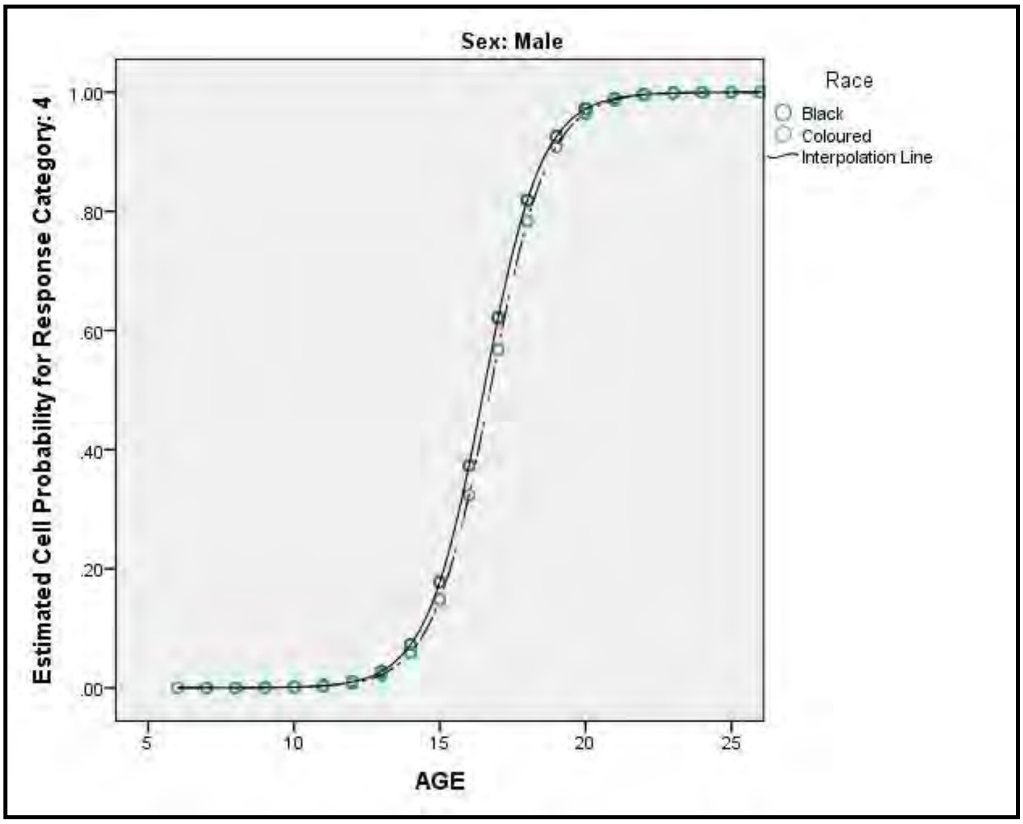


Figure 4.80 (a): *Ordinal logistic regression for complete union at the wrist in black and coloured males that shows no significant differences in probability of being scored as 4.*

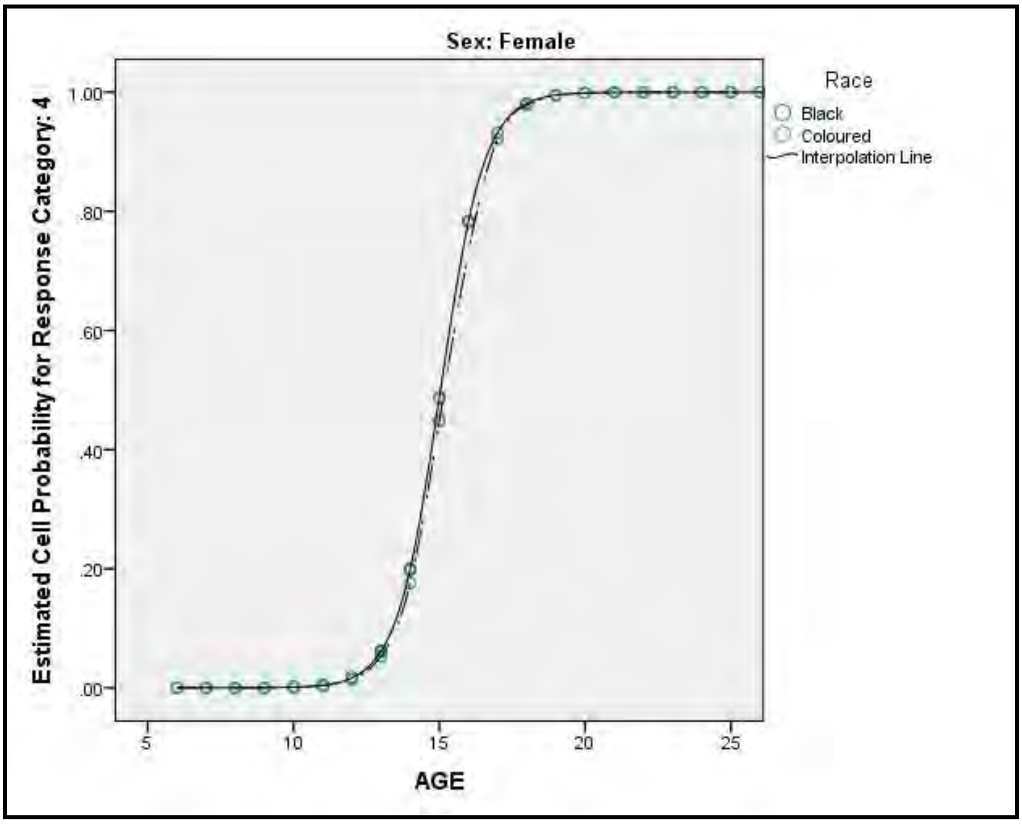


Figure 4.80 (b): *Ordinal logistic regression for complete union in black and coloured females at the wrist* showing *no significant differences in probability of being scored as 4.*

There does however appear to be a trend toward higher mean scores per age in Coloured males compared to Black males (*Figure 4.81*); however the same trend is not visible in the females (*Figure 4.82*).

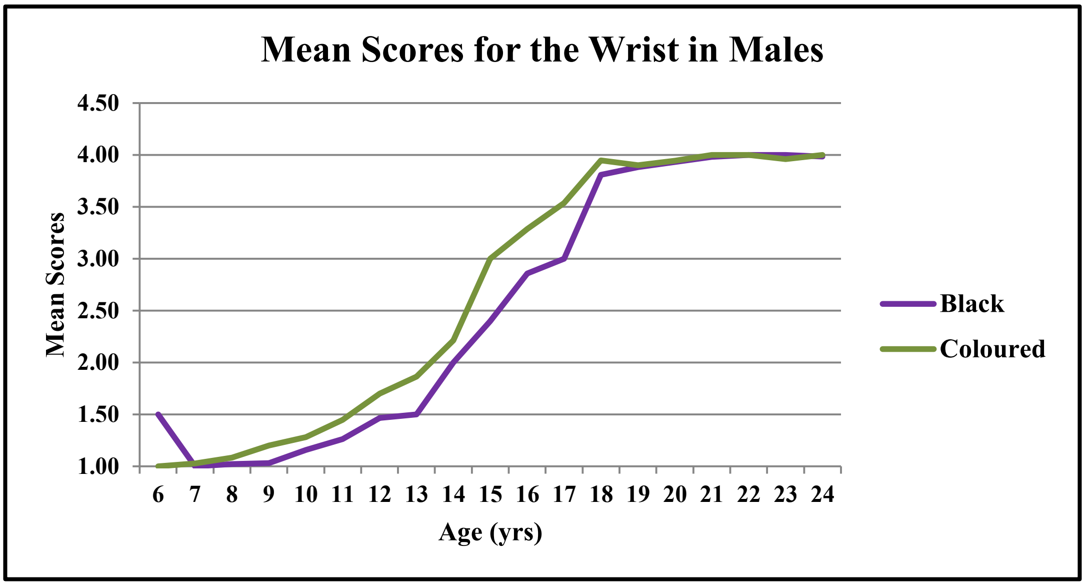


Figure 4.81: *Mean scores for the wrist in black and coloured males; coloured males have higher mean scores than those in black males between 7 to 17 years suggesting a trend toward earlier union in coloured males.*

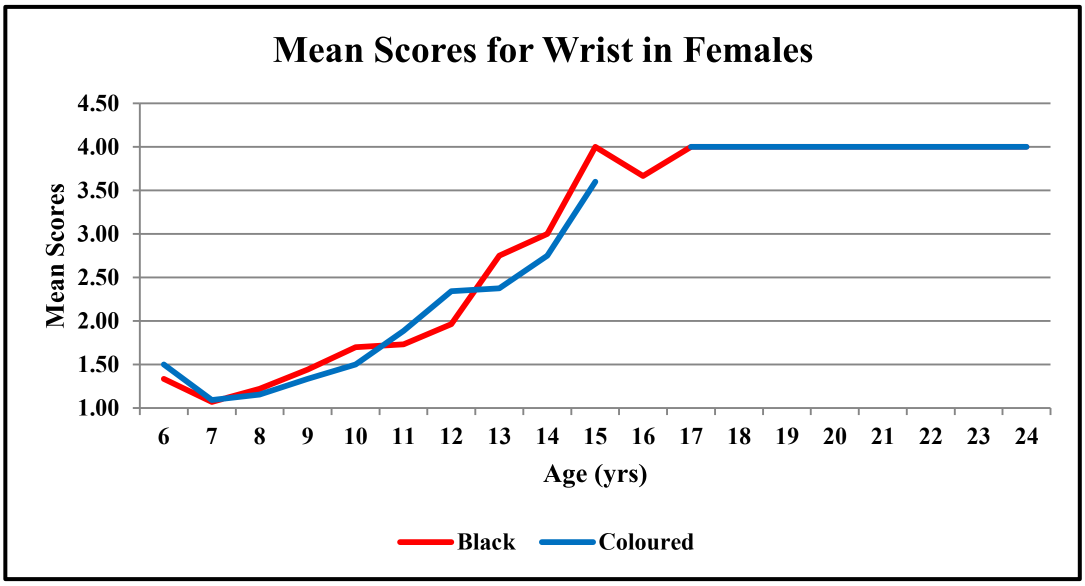


Figure 4.82: *Mean scores for the wrist in black and coloured females, the trend in females appears to be more variable than those in males and probably affected by smaller sample sizes.*

4.3.5.3 The Influence of Socio-Economic Status (SES) on Age of Complete Union at the Wrist in Males and Females.

There are no significant differences between the three classes of SES and union times at the wrist in males ($p > 0.05$) (*Figure 4.83a*) and females ($p > 0.05$) (*Figure 4.83b)* (*Table 4.45*).

Table 4.45: Parameters of Ordinal Logistic Regression in the Three Classes of SES

		Estimate	Std. Error	Wald	df	Sig.	Lower 95% CI	Upper 95% CI
Threshold-Males	Stage 1	13.170	.867	230.636	1	.000	11.470	14.869
	Stage 2	16.026	1.031	241.590	1	.000	14.005	18.047
	Stage 3	18.374	1.164	249.259	1	.000	16.093	20.655
Location	Age	1.096	.063	307.513	1	.000	.974	1.219
	SES 1	.296	.506	.342	1	.559	-.695	1.287
	SES 2	.161	.492	.106	1	.744	-.804	1.125
	SES 3	0^b			0			
Threshold-Females	Stage 1	11.921	1.215	96.254	1	.000	9.539	14.302
	Stage 2	15.604	1.448	116.178	1	.000	12.767	18.441
	Stage 3	18.406	1.680	120.015	1	.000	15.113	21.699
Location	Age	1.267	.112	127.149	1	.000	1.047	1.488
	SES 1	-.799	.666	1.441	1	.230	-2.104	.506
	SES 2	-.884	.644	1.888	1	.169	-2.146	.377
	SES 3	0^b			0			

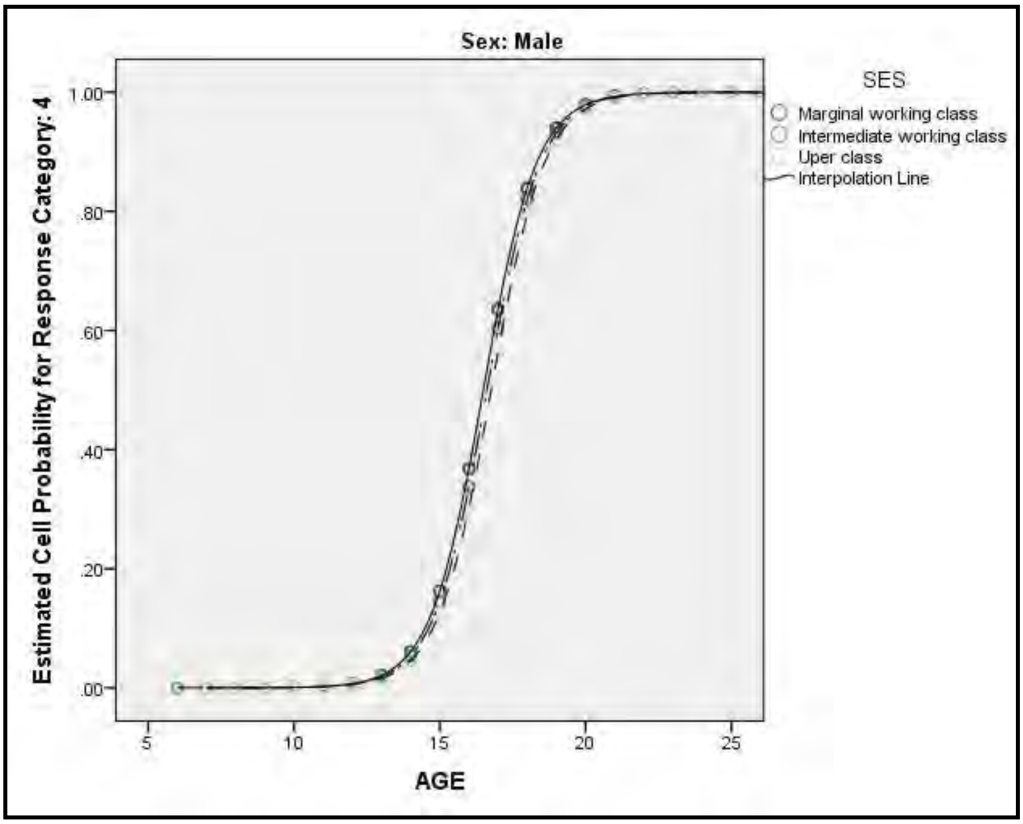


Figure 4.83 (a): *Ordinal Logistic Regression for complete union and SES in males showing no significant differences in the probability of being scored as 4 suggesting that SES does not have an effect on age at maturity.*

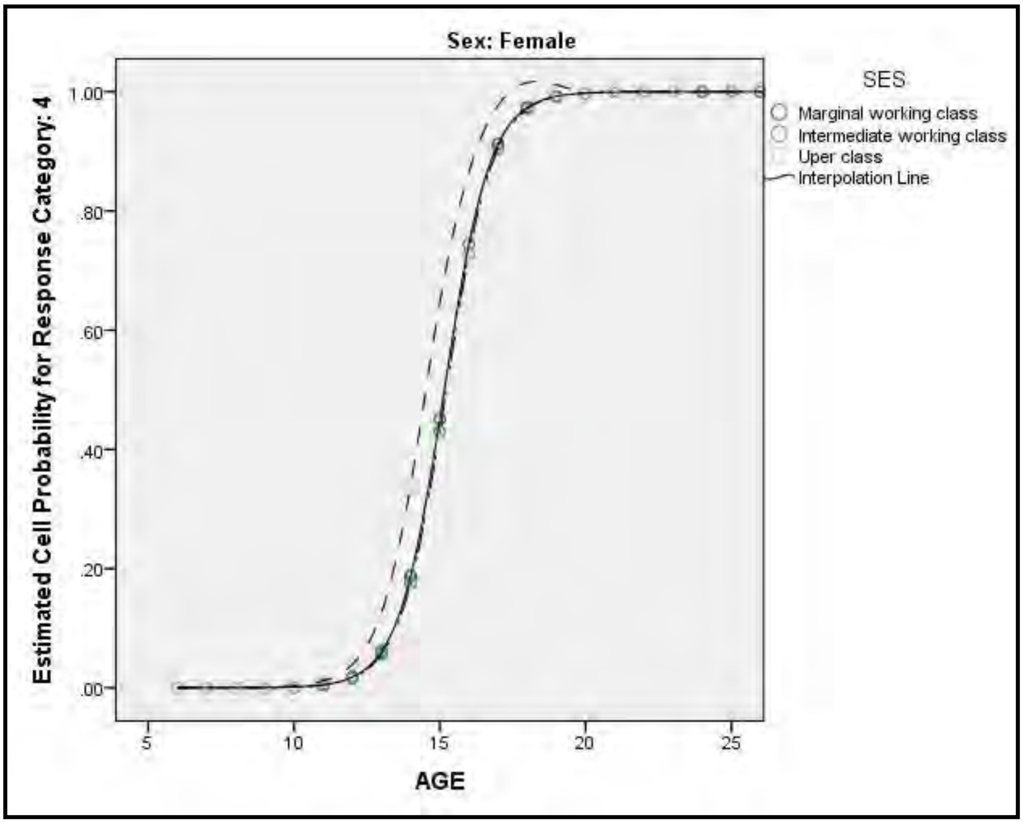


Figure 4.83 (b): *Ordinal Logistic Regression for complete union and SES in females. No significant differences are observed in females of different SES backgrounds at the wrist suggesting the lack of relationship between SES and maturity.*

4.3.6 Mean Scores at the Shoulder

This is the last of the joints to unite at 20 years in females and 22 years in males. The mean point scores increase with increasing chronological age up to age 20 years in females and 22 years at which point they reach complete union. The mean scores are higher in females compared to males for each age suggesting that females mature earlier than males (*Table 4.46*); however they appear to be more variable possibly due to the size of the sample (*Figure 4.84*).

Table 4.46: Mean Scores for the Shoulder in Males and Females

	Black Males			Black Female			Coloured Males			Coloured Female		
Age	**N**	**Mean**	**sd**	**N**	**Mean**	**sd**	**N**	**Mean**	**sd**	**N**	**Mean**	**sd**
6	***2***	1.50	0.00	***3***	1.50	0.00	***18***	1.50	0.00	***1***	1.50	
7	***20***	1.50	0.00	***16***	1.47	0.13	***24***	1.58	0.19	***10***	1.50	0.00
8	***54***	1.49	0.07	***31***	1.63	0.26	***27***	1.52	0.10	***19***	1.63	0.28
9	***24***	1.50	0.00	***30***	1.75	0.29	***38***	1.61	0.21	***24***	1.69	0.25
10	***21***	1.57	0.24	***8***	1.75	0.27	***25***	1.66	0.24	***18***	1.94	0.45
11	***25***	1.64	0.23	***18***	2.00	0.62	***28***	1.84	0.24	***14***	2.14	0.53
12	***26***	1.73	0.35	***16***	2.50	0.55	***16***	1.88	0.39	***20***	2.70	0.52
13	***14***	2.11	0.74	***6***	2.67	0.52	***9***	2.56	0.53	***8***	2.50	0.53
14	***7***	2.57	0.53	***7***	3.00	0.00	***13***	3.15	0.38	***2***	2.50	0.71
15	***9***	2.67	0.50	***2***	3.50	0.71	***7***	3.14	0.38	***5***	3.20	0.45
16	***14***	3.00	0.00	***3***	3.17	0.29	***13***	3.38	0.51			
17	***39***	3.38	0.48	***2***	3.75	0.35	***19***	3.84	0.37	***3***	3.83	0.29
18	***34***	3.63	0.48	***4***	3.88	0.25	***20***	3.70	0.47	***4***	4.00	0.00
19	***59***	3.81	0.38	***5***	3.80	0.45	***18***	3.94	0.24	***3***	4.00	0.00
20	***55***	3.93	0.33	***5***	4.00	0.00	***19***	4.00	0.00	***3***	4.00	0.00
21	***63***	3.94	0.25	***10***	4.00	0.00	***29***	4.00	0.00	***10***	4.00	0.00
22	***63***	3.98	0.14	***3***	4.00	0.00	***24***	3.96	0.20	***7***	3.86	0.38
23	***48***	3.96	0.20	***12***	4.00	0.00	***24***	3.96	0.20	***5***	4.00	0.00
24	***67***	4.00	0.00	***3***	4.00	0.00	***17***	4.00	0.00	***4***	4.00	0.00

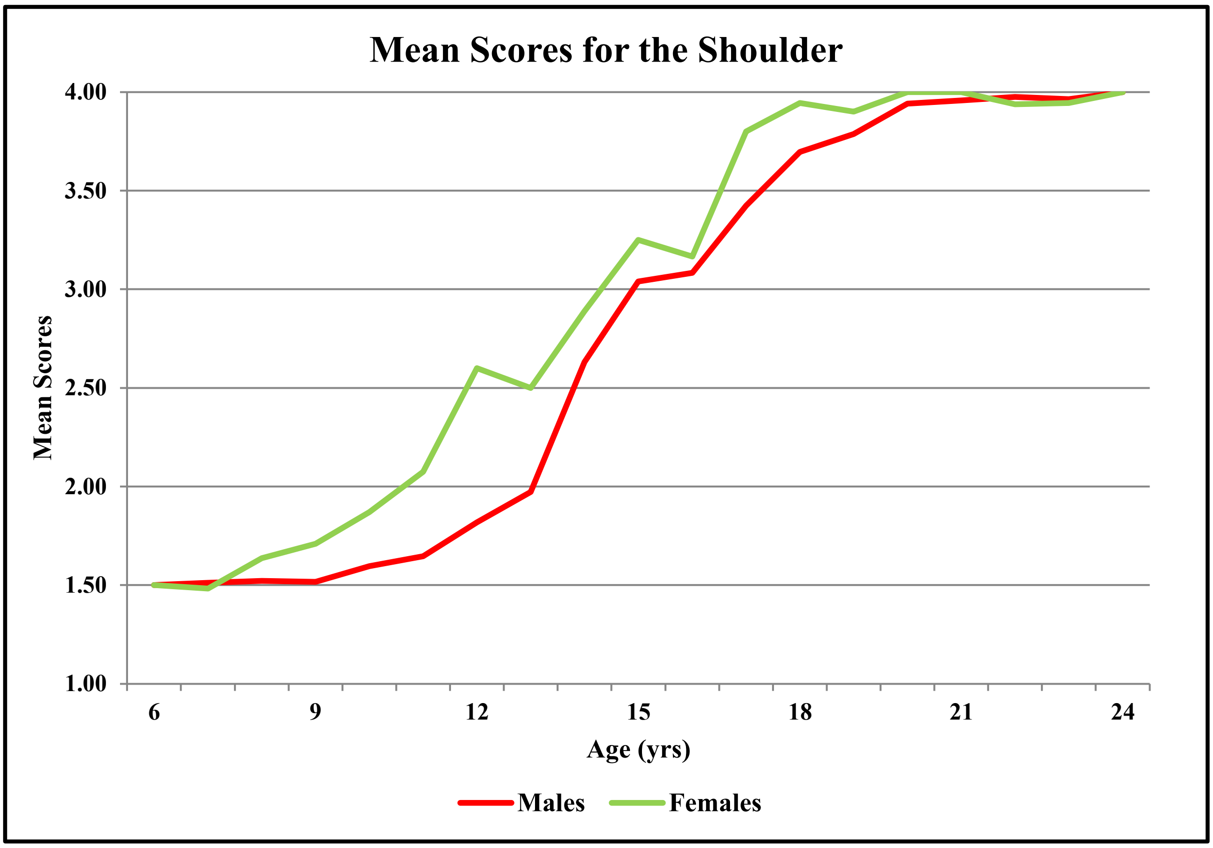


Figure 4.84: *Mean scores in the Shoulder for males and females. Females mature earlier than males.*

4.3.6.1 Sex Differences in the Ages of Complete Union at the Shoulder

Significant differences exist in the age and all stages of union between males and females ($p < 0.05$) (*Table 4.47*). Males have lower scores at each stage compared to females (*Figure 4.85*). The standard errors for the models for sex differences appear to be low. The Nagelkerke R^2 for the shoulder is suggesting that the model explains 87% of variability for the shoulder.

Table 4.47: Ordinal Logistic Regression Parameters for Sex at the Shoulder

		Estimate	SE	Wald	df	Sig.	Lower 95% CI	Upper 95% CI
Threshold	**Stage 1**	9.114	.365	621.915	1	.000	8.398	9.830
	Stage 2	11.570	.442	686.457	1	.000	10.704	12.435
	Stage 3	15.064	.598	633.814	1	.000	13.892	16.237
Location	**Age**	.941	.036	690.441	1	.000	.871	1.012
	Males	-1.680	.176	90.743	1	.000	-2.026	-1.335
	Females	0[a]			0			

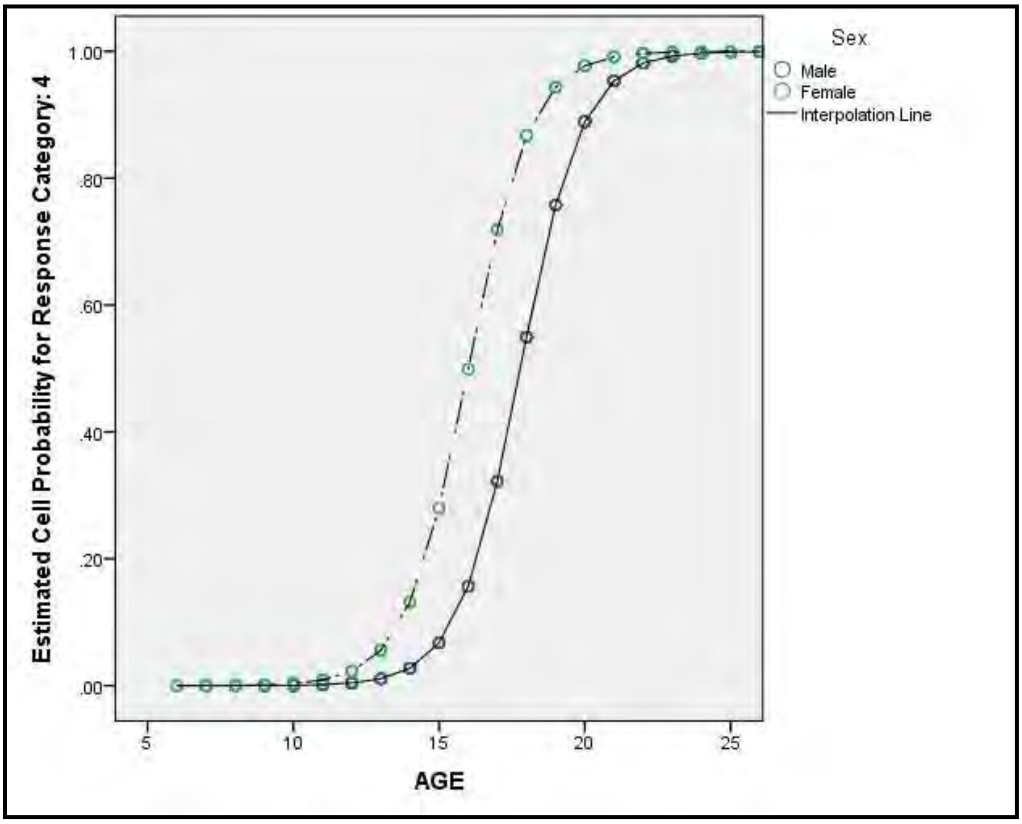


Figure 4.85: *Ordinal Logistic Regression for complete union at the shoulder in males and females showing significant differences in probability of being scored as* stage *4.*

4.3.6.2 Genetic Differences at the Shoulder in Males and Females.

No significant differences exist in the age of union for all stages in Black and Coloured males ($p > 0.05$) and Black and Coloured females (*Table 4.48*) *(Figure 4.86 a and b).* Black males and females obtain lower scores for all stages compared to Coloured males and females. These are not significant and highlight the apparent trend toward slightly earlier maturation in Coloureds and Blacks (*Figure 4.87*) and (*Figure 4.88*).

Table 4.48: Parameters for Genetic Differences in Males and Females at the Shoulder

		Estimate	SE	Wald	df	Sig.	Lower 95% CI	Upper 95% CI
Threshold	**Stage 1**	10.880	.542	403.359	1	.000	9.818	11.941
	Stage 2	13.165	.651	409.316	1	.000	11.889	14.440
	Stage 3	16.492	.824	400.620	1	.000	14.877	18.107
Location	**Age**	.945	.046	428.829	1	.000	.855	1.034
	Black Males	-.399	.197	4.093	1	.043	-.785	-.012
	Coloured Males	0^b			0			
Threshold	**Stage 1**	9.724	.827	138.293	1	.000	8.103	11.344
	Stage 2	12.354	.969	162.535	1	.000	10.455	14.253
	Stage 3	17.304	1.457	141.065	1	.000	14.449	20.160
Location	**Age**	1.030	.083	153.237	1	.000	.867	1.194
	Black Females	-.198	.266	.553	1	.457	-.720	.324
	Coloured Females	0^b			0			

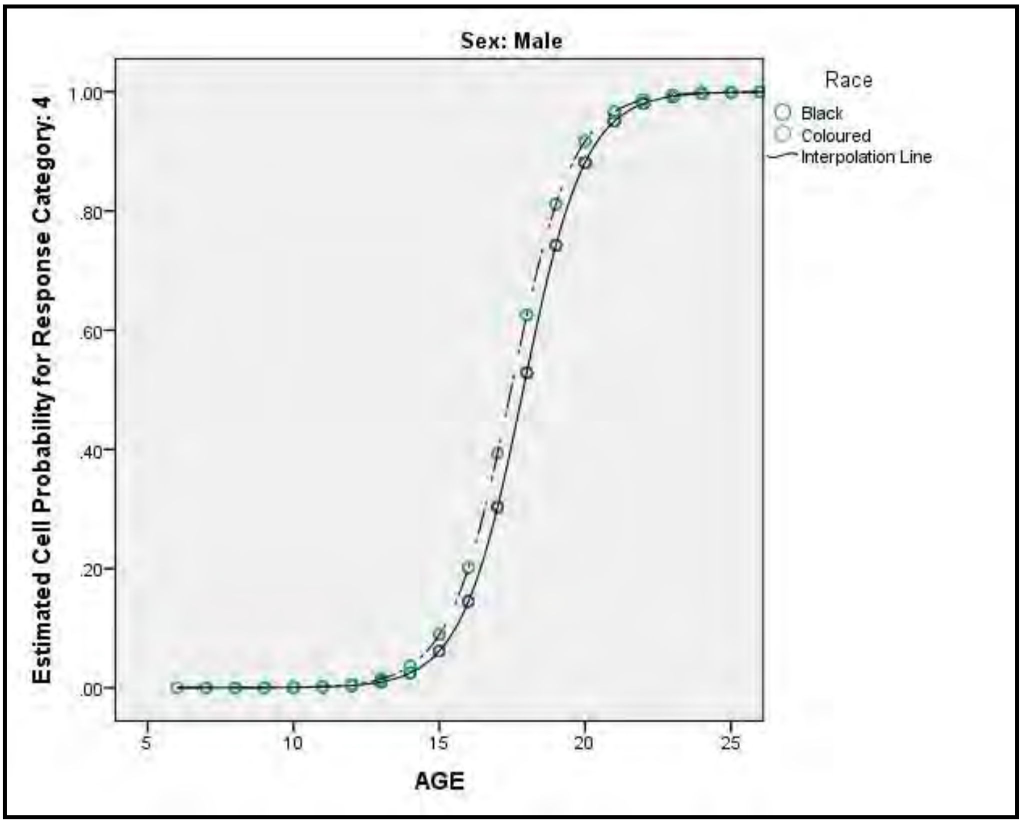


Figure 4.86 (a): *Ordinal Logistic Regression for complete union in black and coloured males at the shoulder that shows no significant differences in being scored as 4.*

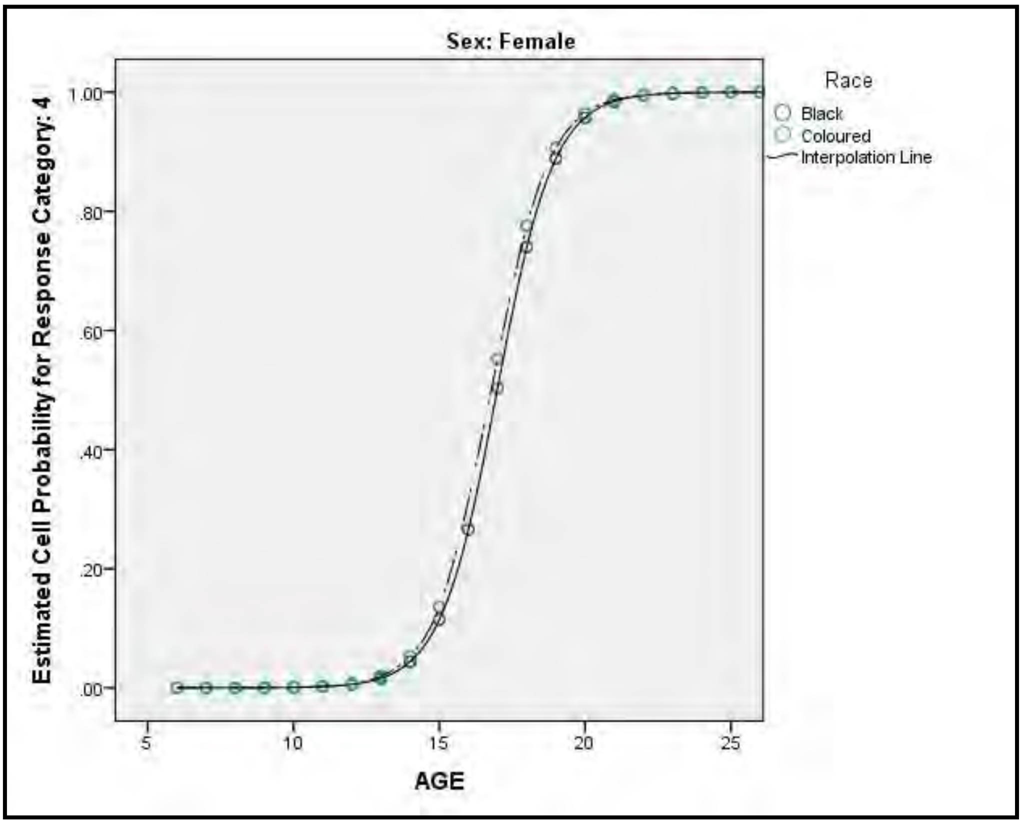


Figure 4.86 (b): *Ordinal Logistic Regression for Stage 4 in black and coloured females at the shoulder that shows no significant differences in being scored as 4.*

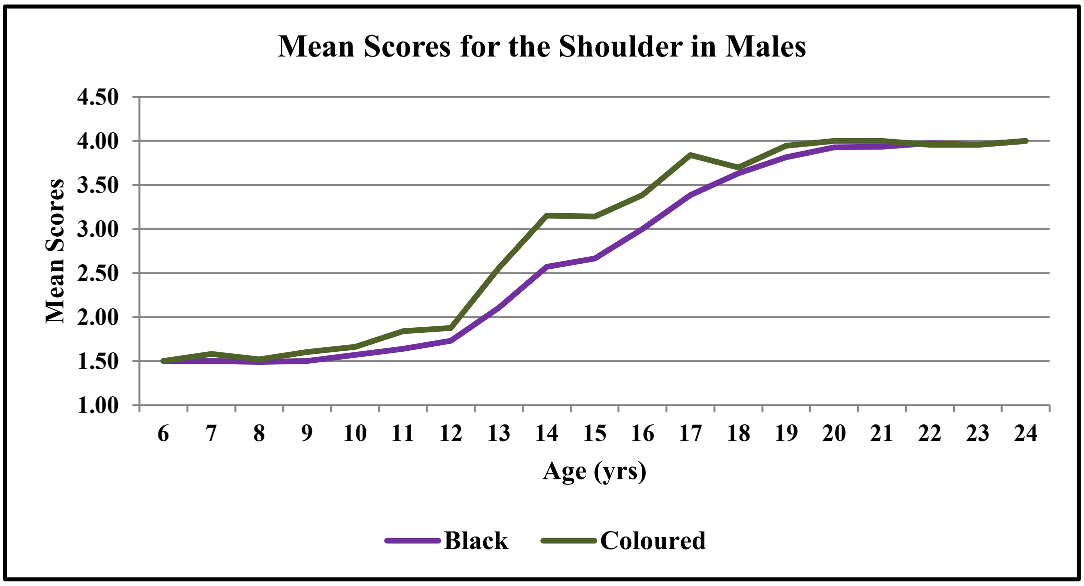


Figure 4.87: *Mean scores for complete union at the shoulder in black and coloured males; coloured males appear to have higher scores than those in black males for all ages suggesting a trend toward earlier maturation in coloured males.*

The trend observed in males is more pronounced between the ages of 12 and 18 years. These trends have not been observed in females.

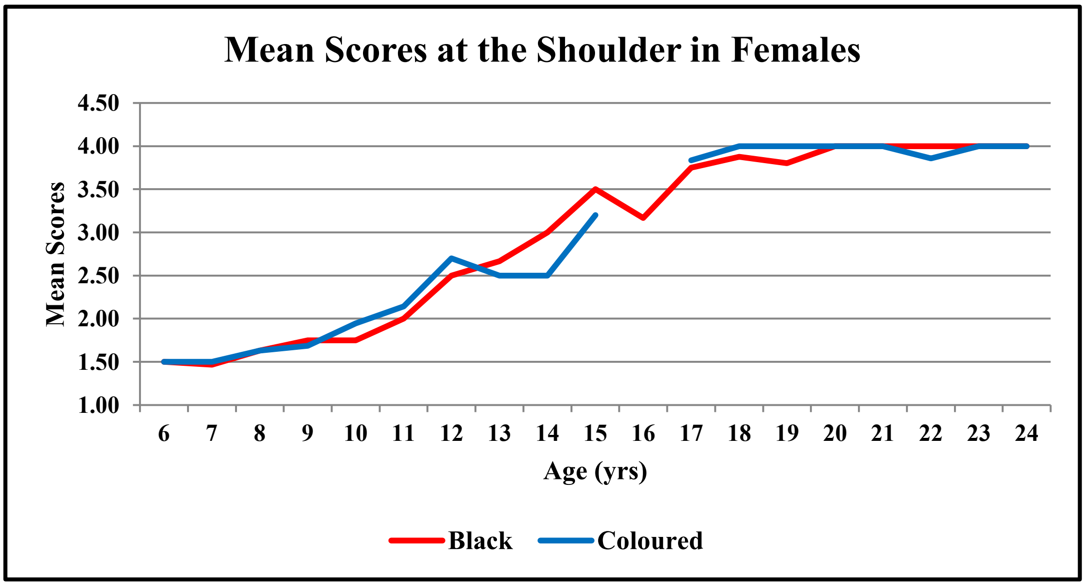


Figure 4.88: *Mean scores for complete union at the shoulder in black and coloured females; there appears to be greater variability probably due to sample size.*

4.3.6.3 The Influence of Socio-Economic Status (SES) on Age of Complete Union at the Shoulder in Males and Females.

There are no significant differences in the three classes of SES in males (*Figure 4.89a*) and females ($p > 0.05$) (*Table 4.49*) (*Figure 4.89b*). In males, the marginal working class (SES 1) shows lower scores compared to the other groups. In females however both SES 1 and SES 2 show lower scores compared to SES 3 (upper working class).

Table 4.49: Parameters of Ordinal Logistic Regression in the Three Classes of SES

		Estimate	Std. Error	Wald	df	Sig.	Lower 95% CI	Upper 95% CI
Threshold-Males	Stage 1	10.991	.643	292.368	1	.000	9.731	12.251
	Stage 2	13.392	.743	324.840	1	.000	11.936	14.849
	Stage 3	16.775	.915	335.969	1	.000	14.981	18.568
Location	Age	.953	.047	418.965	1	.000	.862	1.044
	SES 1	-.136	.393	.120	1	.729	-.907	.634
	SES 2	.001	.384	.000	1	.998	-.751	.753
	SES 3	0^b			0			
Threshold-Females	Stage 1	9.391	.908	107.072	1	.000	7.612	11.170
	Stage 2	12.079	1.024	139.167	1	.000	10.072	14.085
	Stage 3	16.987	1.460	135.470	1	.000	14.127	19.848
Location	Age	.998	.078	163.347	1	.000	.845	1.151
	SES 1	-.154	.586	.069	1	.793	-1.302	.995
	SES 2	-.029	.572	.003	1	.959	-1.150	1.092
	SES 3	0^b			0			

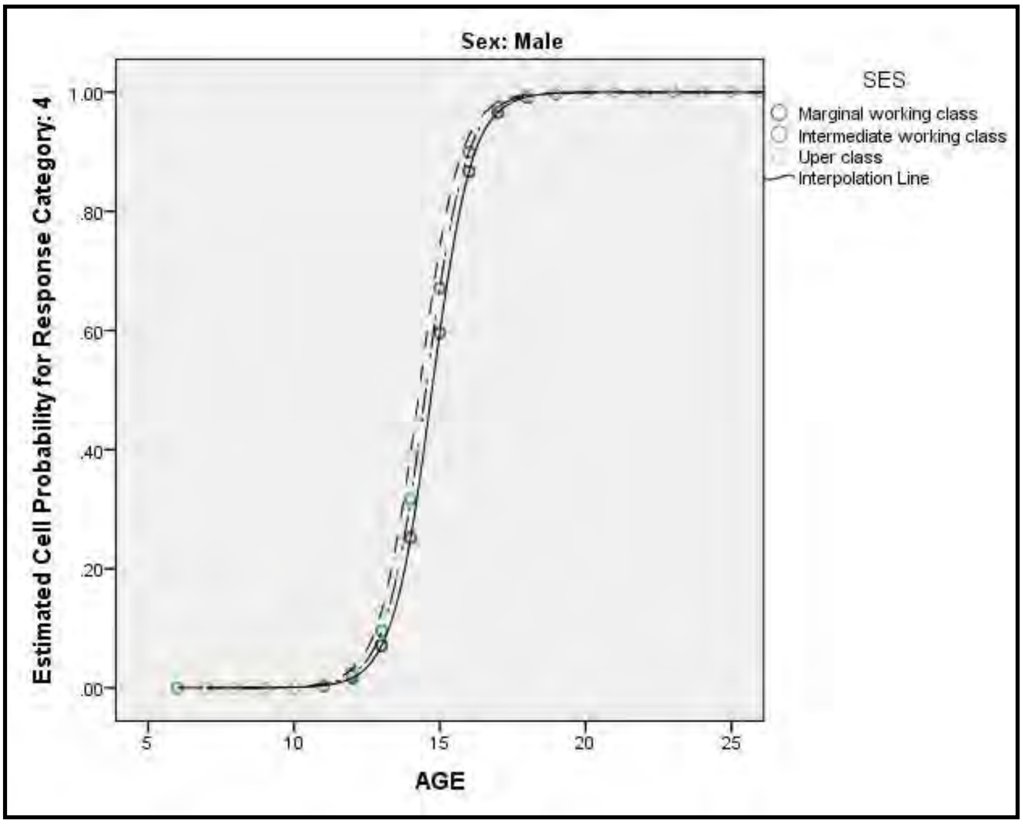


Figure 4.89 (a): *Ordinal Logistic Regression for complete union and SES in males showing no significant differences in the three classes of SES and the probability of scoring 4.*

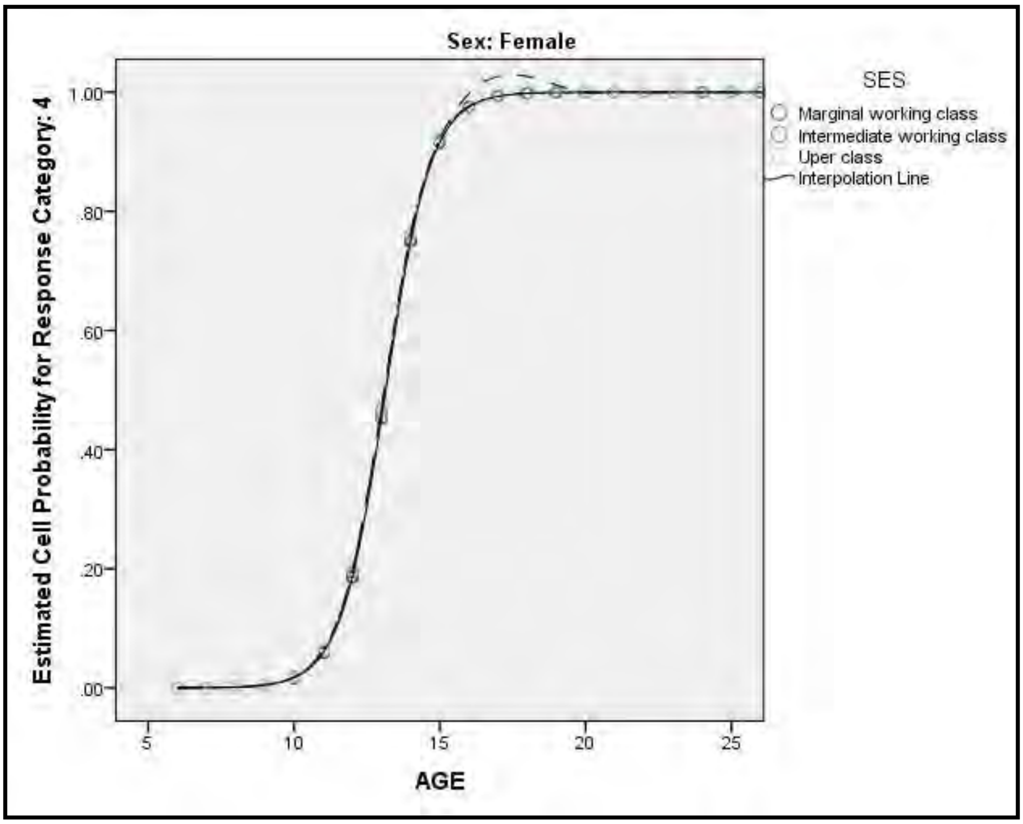


Figure 4.89 (b): *Ordinal Logistic Regression for complete union in females at the shoulder showing no significant differences in the three classes of SES and the probability of scoring 4.*

4.3.7 Mean Scores at the Iliac Crest

The union of the iliac crest takes place in stages but is one compound epiphysis. The mean scores per age are presented in *Table 4.50* below. The mean scores increase with increasing age (*Figure 4.90*). Greater variability due to smaller sample size is observed in females.

Table 4.50: Mean Scores for the Iliac Crest in Males and Females

	Black Males			Black Female			Coloured Males			Coloured Female		
Age	**N**	**Mean**	**sd**	**N**	**Mean**	**sd**	**N**	**Mean**	**sd**	**N**	**Mean**	**sd**
6	***2***	1.00	0.00	***3***	1.00	0.00	***1***	1.00		***1***	1.00	
7	***2***	1.00	0.00	***18***	1.00	0.00	***20***	1.00	0.00	***13***	1.00	0.00
8	***27***	1.00	0.00	***35***	1.00	0.00	***33***	1.00	0.00	***26***	1.00	0.00
9	***64***	1.00	0.00	***36***	1.00	0.00	***39***	1.00	0.00	***29***	1.00	0.00
10	***28***	1.00	0.00	***16***	1.00	0.00	***47***	1.00	0.00	***23***	1.00	0.00
11	***33***	1.00	0.00	***20***	1.00	0.00	***32***	1.00	0.00	***16***	1.06	0.25
12	***29***	1.00	0.00	***18***	1.11	0.32	***43***	1.00	0.00	***23***	1.26	0.45
13	***36***	1.00	0.00	***7***	1.14	0.38	***26***	1.15	0.61	***9***	1.22	0.44
14	***19***	1.21	0.71	***7***	1.57	0.53	***11***	1.36	0.67	***2***	2.00	1.41
15	***10***	1.00	0.00	***2***	3.50	0.71	***16***	2.06	1.00	***5***	2.60	0.89
16	***11***	1.82	0.60	***3***	3.00	0.00	***7***	3.00	0.58			
17	***14***	2.36	0.63	***2***	3.00	0.00	***13***	3.08	0.76	***3***	3.33	0.58
18	***39***	3.33	0.81	***4***	3.75	0.50	***19***	3.53	0.61	***4***	4.00	0.00
19	***34***	3.56	0.66	***5***	3.40	0.55	***20***	3.65	0.49	***3***	4.00	0.00
20	***59***	3.66	0.51	***5***	4.00	0.00	***18***	3.94	0.24	***4***	3.00	1.41
21	***56***	3.86	0.40	***10***	4.00	0.00	***19***	3.95	0.23	***10***	4.00	0.00
22	***63***	3.97	0.18	***3***	4.00	0.00	***30***	4.00	0.00	***7***	4.00	0.00
23	***48***	4.00	0.00	***12***	4.00	0.00	***24***	3.96	0.20	***5***	4.00	0.00
24	***67***	4.00	0.00	***3***	4.00	0.00	***17***	4.00	0.00	***4***	4.00	0.00

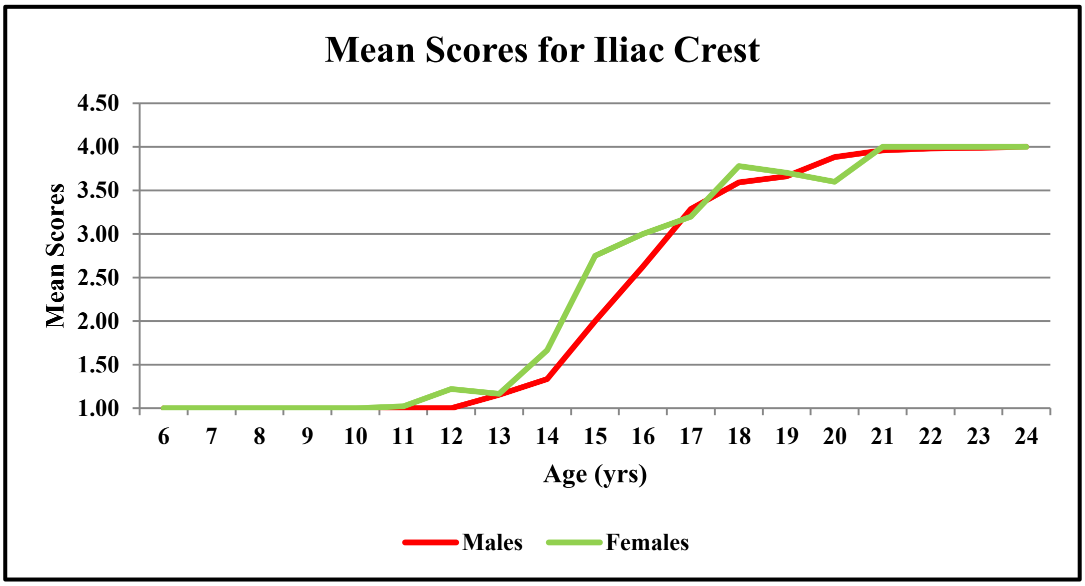


Figure 4.90: *Mean scores in the iliac crest in males and females.*

4.3.7.1 Sex Differences in the Ages of Complete Union at the Iliac Crest

Significant differences are observed in for the ages of union for each stage in males and females ($p < 0.05$) (*Table 4.51*) (*Figure 4.91*). The scores in males per stage are lower than those in females suggesting that females mature ahead of males. The model explains 91% of the variability.

Table 4.51: Ordinal Logistic Regression Parameters for Sex at the Iliac Crest

		Estimate	SE	Wald	df	Sig.	Lower 95% CI	Upper 95% CI
Threshold	**Stage 1**	15.893	.708	503.784	1	.000	14.505	17.281
	Stage 2	17.232	.774	495.800	1	.000	15.715	18.749
	Stage 3	19.713	.883	498.143	1	.000	17.982	21.444
Location	**Age**	1.142	.051	505.203	1	.000	1.043	1.242
	Males	-.800	.261	9.412	1	.002	-1.311	-.289
	Females	0[a]			0			

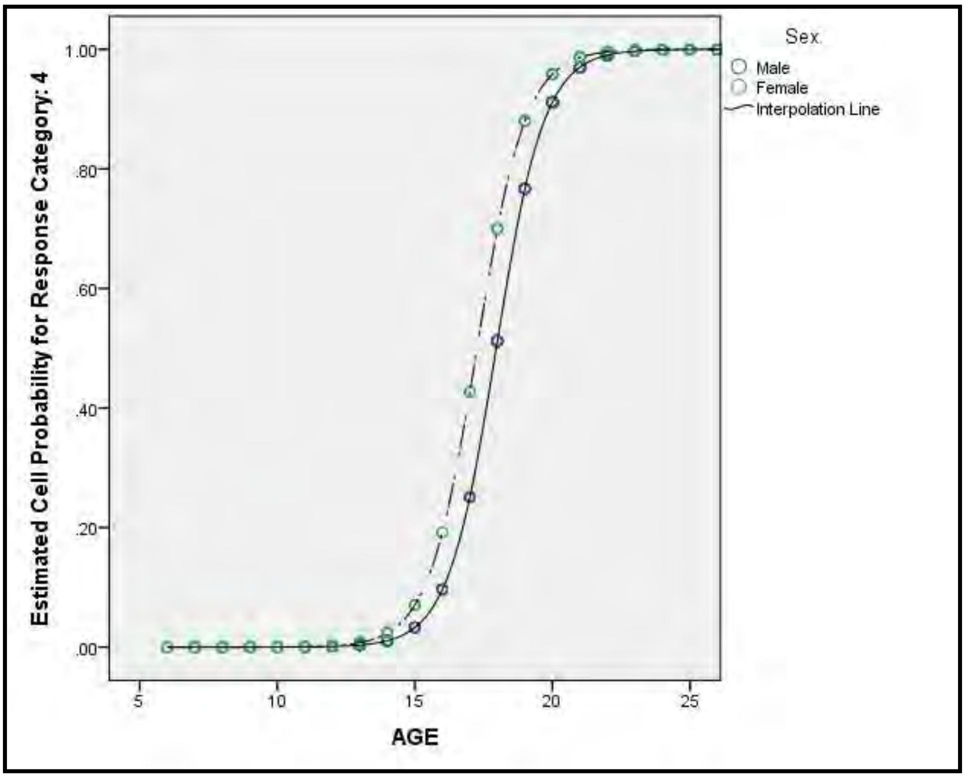


Figure 4.91: *Ordinal Logistic Regression for complete union in males and females at the iliac crest showing significant differences in probability of being scored as stage 4.*

4.3.7.2 Genetic Differences at the Iliac Crest in Males and Females.

There are no significant differences in the age of union between Black and Coloured males ($p > 0.05$) and Coloured and Black females ($p > 0.05$) (*Table 4.52*) (*Figure 4.92a and b*). Black males and females record lower scores compared to Coloured males and females, suggesting that the; latter mature earlier. However; these differences are not significantly (*Figure 4.93*). The trend is more visible in females compared to males (*Figure 4.94*).

Table 4.52: Parameters for Genetic Differences in Males and Females at the Iliac Crest

		Estimate	Std. Error	Wald	df	Sig.	Lower 95% CI	Upper 95% CI
Threshold	**Stage 1**	17.506	.990	312.382	1	.000	15.565	19.447
	Stage 2	18.783	1.063	312.352	1	.000	16.700	20.866
	Stage 3	21.221	1.182	322.376	1	.000	18.904	23.537
Location	**Age**	1.183	.065	327.074	1	.000	1.055	1.312
	Black Males	-.005	.244	.000	1	.984	-.482	.473
	Coloured Males	0[b]			0			
Threshold	**Stage 1**	16.837	1.772	90.265	1	.000	13.364	20.311
	Stage 2	18.586	1.946	91.223	1	.000	14.772	22.400
	Stage 3	22.081	2.476	79.552	1	.000	17.229	26.934
Location	**Age**	1.268	.139	83.162	1	.000	.996	1.541
	Black Females	-.739	.455	2.640	1	.104	-1.630	.152
	Coloured Females	0[b]			0			

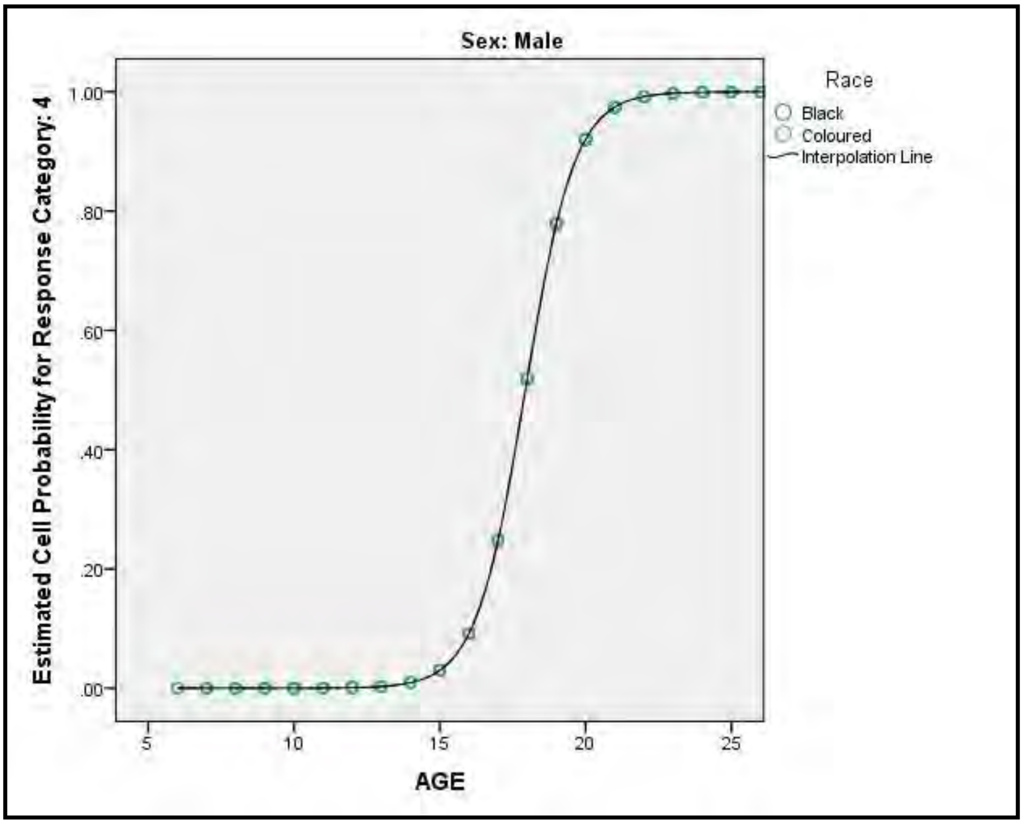


Figure 4.92 (a): *Ordinal Logistic Regression for complete union at the iliac crest in black and coloured males that shows no significant differences in the two models.*

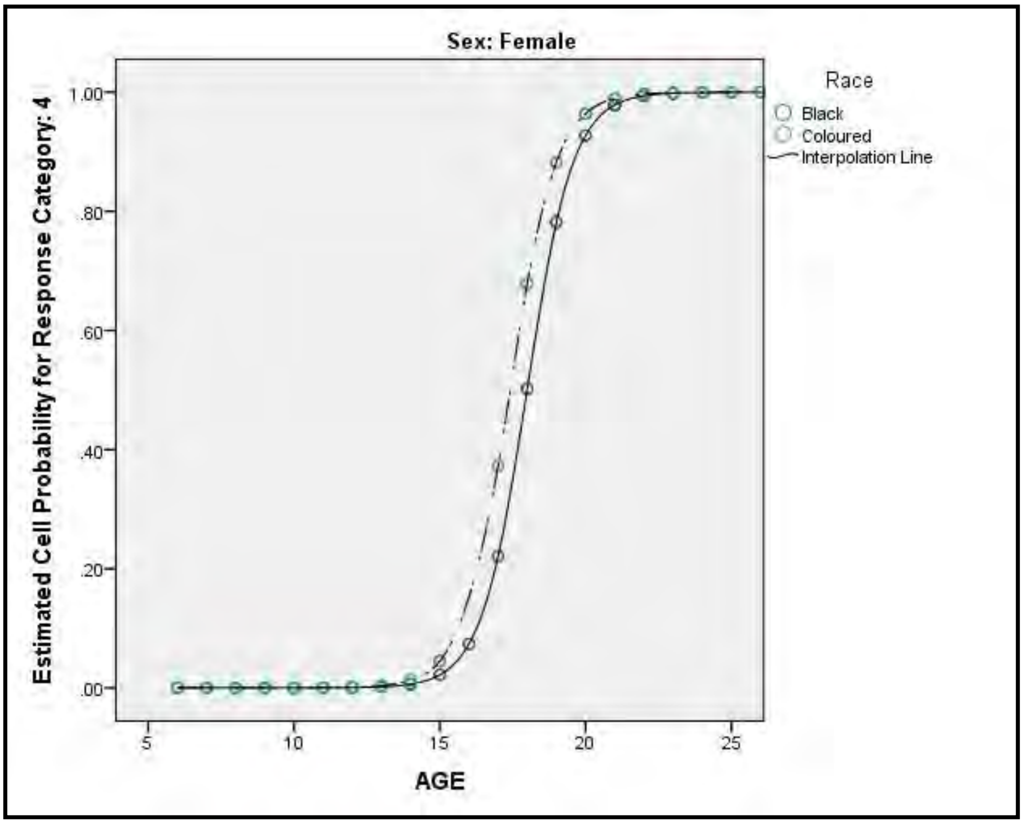


Figure 4.92 (b): *Ordinal Logistic Regression for complete union at the iliac crest in black and coloured females that shows no significant differences in the two models.*

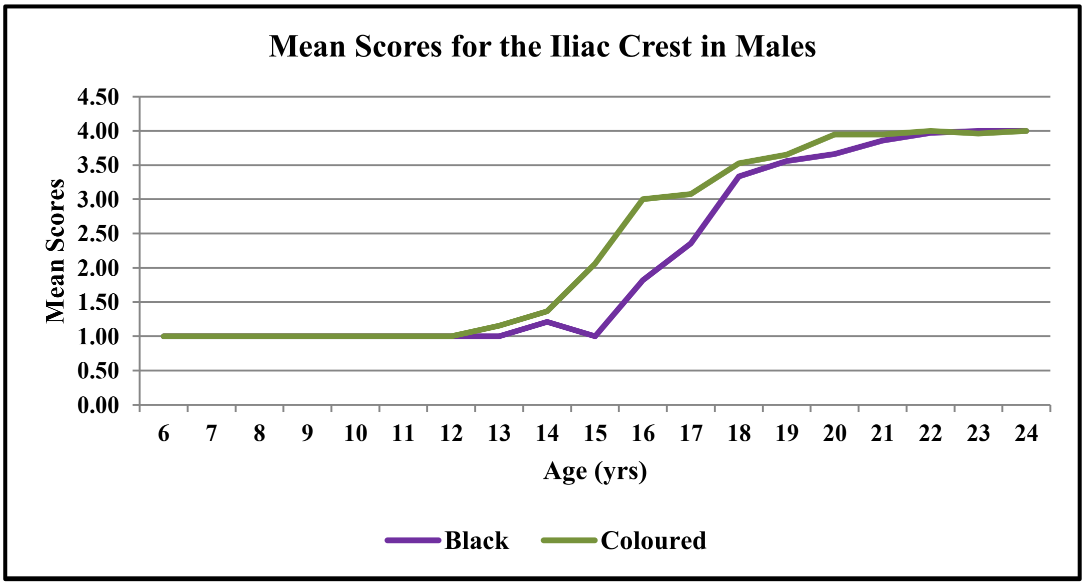


Figure 4.93: *Mean scores for union in the iliac crest in black and coloured males showing pronounced differences between 15 and 18 years.*

Coloured males appear to be in advance of Black males showing a trend toward higher mean scores (*Figure 4.93*). These differences are most pronounced between 15 and 18 years. Black males reach mean point score of 4 at the iliac crest at age 23 years whereas Coloured males reach mean score of 4 for the iliac crest at age 22 years. The same is not the case in females (*Figure 4.94*).

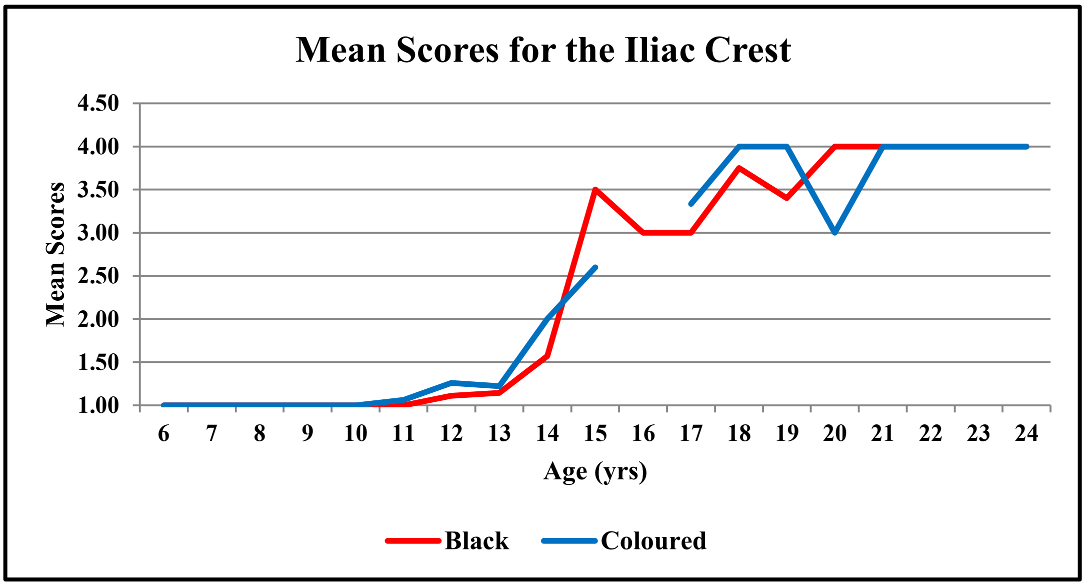


Figure 4.94: *Mean scores for union in the iliac crest in black and coloured females showing an erratic pattern.*

4.3.7.3 The Influence of Socio-Economic Status (SES) on Age of Complete Union at the Iliac Crest in Males and Females.

Belonging to the marginal working class, intermediate working class or upper class has no significance on the age of union in males and females ($p > 0.01$) (*Table 4.53*) (*Figure 4.95a and b*). The intermediate working class in males however shows lower scores compared to the marginal and upper working class. Both the marginal (SES 1) and intermediate (SES 2) working classes in females show lower mean scores compared to the upper working class females (SES 3).

Table 4.53: Parameters of Ordinal Logistic Regression in the Three Classes of SES

		Estimate	SE	Wald	df	Sig.	Lower 95% CI	Upper 95% CI
Threshold-Males	Stage 1	16.357	1.022	256.205	1	.000	14.354	18.360
	Stage 2	17.482	1.079	262.438	1	.000	15.366	19.597
	Stage 3	19.983	1.195	279.662	1	.000	17.641	22.325
Location	Age	1.109	.060	341.922	1	.000	.991	1.226
	SES 1	.078	.530	.022	1	.883	-.960	1.117
	SES 2	-.155	.526	.087	1	.768	-1.186	.876
	SES 3	0[b]			0			
Threshold-Females	Stage 1	15.818	1.793	77.831	1	.000	12.303	19.332
	Stage 2	17.525	1.939	81.705	1	.000	13.725	21.325
	Stage 3	21.122	2.468	73.231	1	.000	16.284	25.959
Location	Age	1.231	.131	87.970	1	.000	.974	1.488
	SES 1	-1.026	.875	1.374	1	.241	-2.741	.689
	SES 2	-.993	.841	1.394	1	.238	-2.640	.655
	SES 3	0[b]			0			

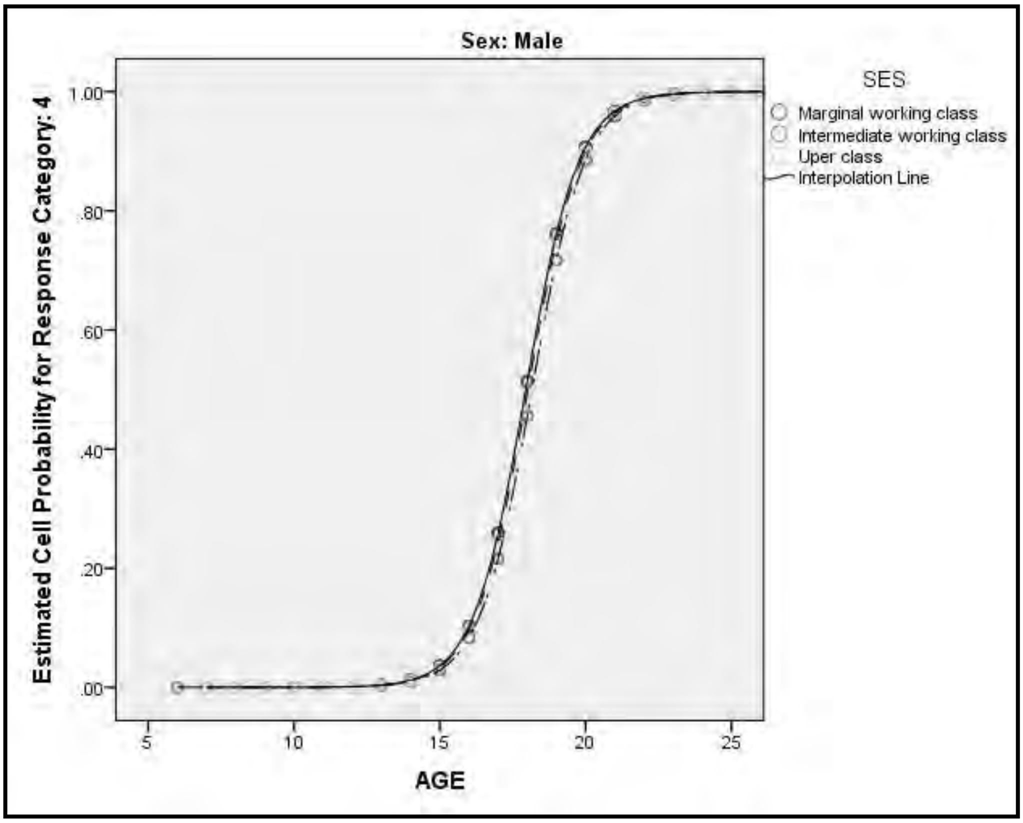


Figure 4.95 (a): *Ordinal Logistic Regression complete union and SES at the iliac crest in males showing no significant differences between the three classes of SES and the probability of being scored as 4.*

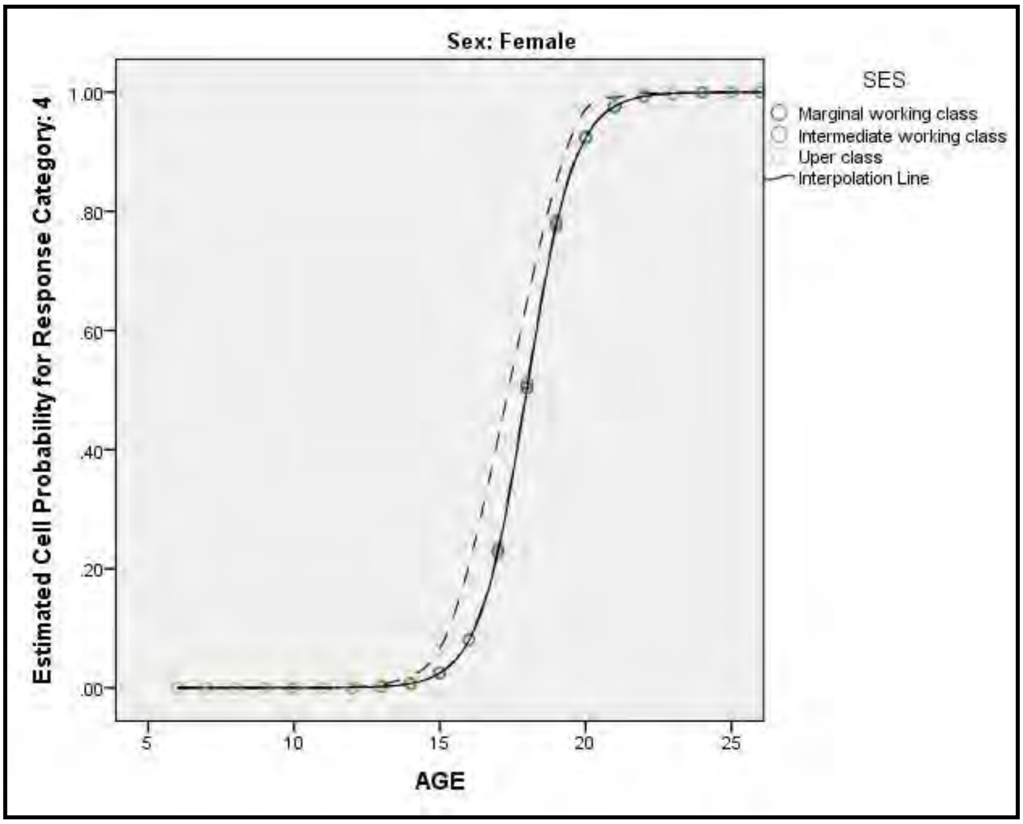


Figure 4.95 (b): *Ordinal Logistic Regression complete union and SES in at the iliac crest in females showing no significant differences between the three classes of SES and the probability of being scored as 4.*

4.4 Summary of Ages of Complete Union in Males and Females

Figure 4.96 below represent the time for complete union in males and females and is only a depiction of the stage 4 when union is first observed (1%) to the age at which union is observed in 100% of individuals.

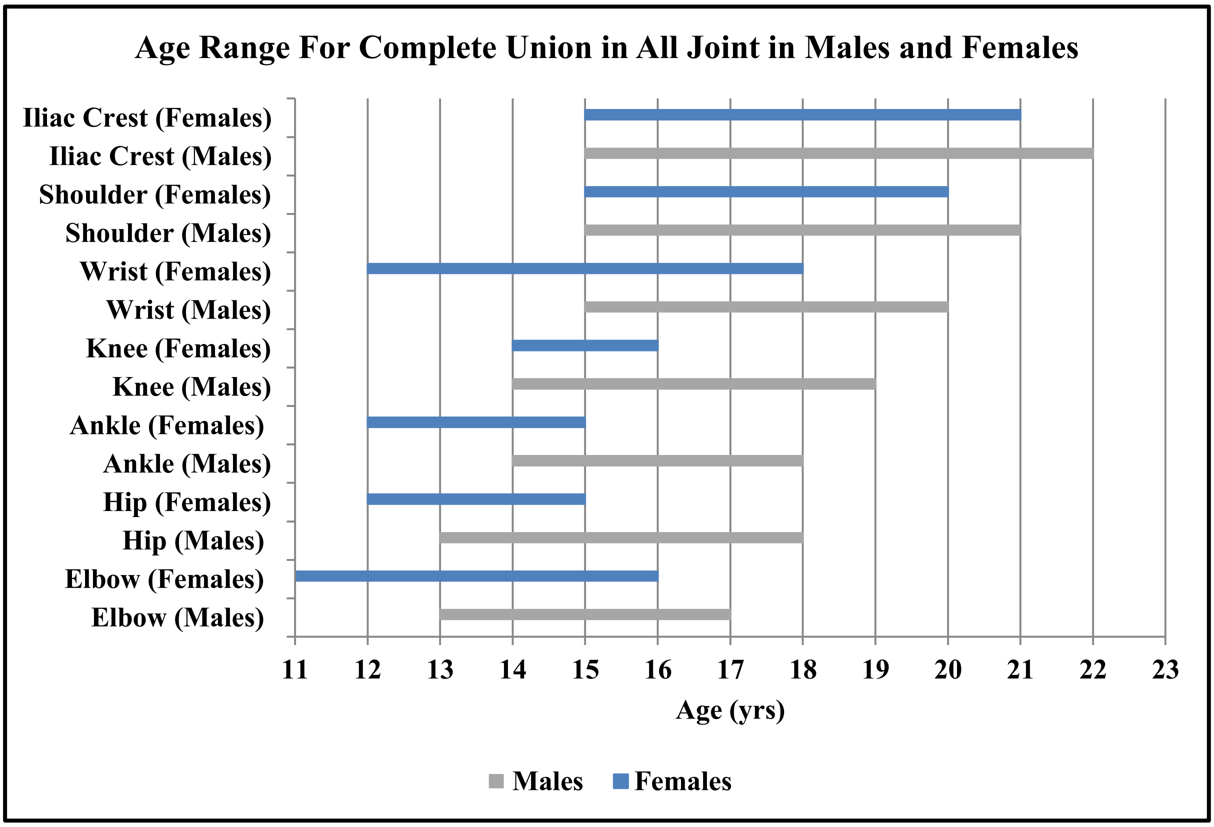


Figure 4.96: *Summary of union times in all joints in males and females. The range depicts the age at which 1% of the sample show union to age at which 100% of individuals show complete union.*

4.5 Intra Observer Error

Results of the tests for intra observer error *(Table 4.54)* show that there is a relatively low intra observer error and high agreement in the scoring methodology. Kappa values are significantly different from 0 ($p < 0.05$). Kappa = 0 would imply that the two measurements gave completely independent answers, which no one would realistically expect.

Table 4.54: Test for Intra observer Error

Bone	% Agreement	Kappa	Std Error	p
Medial Epicondyle	94.27%	0.8929	0.0516	0.000
Trochlea	96.88%	0.9364	0.0581	0.000
Capitulum	96.35%	0.9285	0.0538	0.000
Lateral Epicondyle	98.96%	0.9786	0.0631	0.000
Proximal Radius	95.31%	0.911	0.0517	0.000
Head of Femur	91.00%	0.8378	0.0518	0.000
Greater Trochanter	95.50%	0.9217	0.049	0.000
Lesser Trochanter	97.50%	0.9528	0.0589	0.000
Distal Tibia	99.00%	0.9799	0.0666	0.000
Distal Fibula	99.00%	0.9799	0.0666	0.000
Distal Femur	91.46%	0.8543	0.048	0.000
Proximal Tibia	95.48%	0.9239	0.048	0.000
Proximal Fibula	95.48%	0.9232	0.0496	0.000
Distal Ulna	95.56%	0.9188	0.0536	0.000
Distal Radius	95.53%	0.9201	0.0499	0.000
Head of Humerus	97.91%	0.9633	0.0569	0.000
Greater Tubercle	93.72%	0.8979	0.0489	0.000

The level of agreement between the radiographic specimens and those of the skeletal seem to be high (*Table 4.55*). Identical observations were found on the lateral epicondyle, distal tibia and distal fibula. Lower levels of agreement we observed at the head of the femur.

Table 4.55: Test for Agreement between Skeletal observations and Radiographic

Bone	% Agreement	Kappa	Std Error	Prob > Z
Medial Epicondyle	96.77%	0.8329	0.0998	0.000
Trochlea	100.00%			
Capitulum	100.00%			
Lateral Epicondyle	100.00%	1	0.127	0.000
Proximal Radius	94.92%	0.3833	0.1025	0.000
Head of Femur	96.83%	0.6557	0.0927	0.000
Greater Trochanter	96.77%	0.7862	0.1064	0.000
Lesser Trochanter	98.39%	0.8826	0.0986	0.000
Distal Tibia	100.00%	1	0.0992	0.000
Distal Fibula	100.00%	1	0.103	0.000
Distal Femur	95.24%	0.7812	0.0953	0.000
Proximal Tibia	98.41%	0.9266	0.1006	0.000
Proximal Fibula	96.49%	0.7361	0.1058	0.000
Distal Ulna	90.91%	0.7449	0.0982	0.000
Distal Radius	91.07%	0.7263	0.0964	0.000
Head of Humerus	91.80%	0.8012	0.1051	0.000
Greater Tubercle	93.44%	0.8439	0.1061	0.000

There appears to be a high percentage of agreement between the assessment of gross observations of skeletal material and the radiographic assessment of the skeletal material. Identical observations were obtained for the trochlea, capitulum, distal tibia and fibula. Significance levels reflected by Prob Z suggest that the kappa is significantly different from 0. Kappa values equal to 0 suggest that the answers were completely different which not the case is.

CHAPTER 5: DISCUSSION

5.1 Introduction

To date reference standards used most frequently to study epiphyseal union are those derived by Greulich and Pyle (1959) (GP) and Tanner and Whitehouse (1975) (TW2). Standards for epiphyseal union utilising radiographs of individual joints have been published worldwide (Banerjee and Agarwal, 1998; Crowder and Austin, 2005 and O‟Connor *et al*., 2008). Standards derived from gross examination of complete skeletons have also been published on samples which do not represent contemporary populations (Stevenson, 1932; McKern and Stewart, 1957; Buikstra and Ubelaker, 1994; Schaefer and Black, 2005; Coqueugniot and Weaver, 2007 and Cardoso, 2008 a and b and Vuvic *et al*., 2014). The authors of these studies caution against the use of standards derived on one sample and applying them to a sample from a different origin both because of genetic differences and the effects of secular trend.

The South African sample is unique since South African populations have experienced major changes in socio-political circumstances which directly affected their access to resources such as adequate nutrition and healthcare facilities. After the demise of apartheid and the subsequent increased accessibility to resources, there has been an observed secular trend towards earlier maturation, increased height and earlier menarche in females (Hawley, 2009). This highlights the need to develop standards of epiphyseal union based specifically on South African children.

Results of the current research show that complete union of all the epiphyses in South African females takes place two to four years earlier in females compared to males (21.7 years and 24.2 years to final completion respectively). Non-significant differences in the age of union were observed between two specific population groups and between groups of different socio-economic status (SES). Variations in the patterns of union between males and females were observed at certain joints. Results showed a trend toward higher mean scores per age category in Coloured males compared to Black males with prevalent differences between the ages of 13 to 18 years. A trend toward advanced maturity in Coloured females compared to Black females was not observed.

5.2 Definition of Complete Union

The definition of complete union and variation in methodology employed in skeletal maturation research may result in inconsistencies when comparing results of different studies. The obvious external reasons for differences in age of maturation are environmental, biological, and socio-economic, but differences in methodology and a lack of consistency in the definition of complete union could also account for observed differences in the age of maturity between populations. Union is classified as the stage at which there is no differentiation between the epiphysis and the adjacent diaphysis. The lack of consistency in the reporting of complete union is visible in the literature relating to epiphyseal union. Flecker (1932) and Galstaun (1937) both reported the age of maturity as complete union in the radiographic assessment of skeletal maturity but do not state the definition of complete union. Other studies report maturity at either the 50 % union (Baumann *et al*., 2009); the 85% union (Saksena and Vyas, 1969) or the 100% union state (Banerjee and Agarwal, 1998; Crowder and Austin, 2005 and O‟ Connor *et al*., 2008) while Crowder and Austin (2005) suggest that union is one standard deviation less than the mean age of union. O‟ Connor *et al*., (2008) and Baumann *et al*., (2009) on the other hand classify the stage of complete union as the age at which the epiphyseal scar has been obliterated others represent the age of complete union regardless of the appearance of the scar (Crowder and Austin, 2005 and the present study). The prolonged appearance of the scar results in the relatively higher ages at maturity.

Stages of union however, vary between studies; while some studies concentrate on the beginning and ending (Galstaun, 1937; Flecker, 1932 and Hansman, 1962), some on only the end of union (McKern and Stewart, 1957, Banerjee and Agarwal, 1998 and Schaefer and Black, 2005) other studies aim to determine the variation (Coqueugniot and Weaver, 2007; Cardoso, 2008a and b and O‟Connor *et al*., 2008) of the mean age at which complete union is observed at each joint. The study of variation is of great importance since individuals do not manifest age related changes in exactly the same way in different parts of the body. Study of these stages helps us in understanding the variation in union which is exhibited across all populations and within them as well.

Available studies are often not relevant to contemporary populations due to the effects of secular trends in maturity (Cameron *et al*., 1992; Hennenberg and Louw, 1995; Frietas *et al*., 2004; Jones *et al*., 2009 and Hawley *et al*., 2009). Despite numerous cautionary notes on the application of standards derived on radiographs to gross observations of skeletal material (Krogman and Iscan, 1986; Ubelaker, 1987; Sorg, 1989; Coqueugniot and Weaver, 2007; Cardoso, 2008a and Schaefer, 2008) some researchers publish comparisons of radiographs to ages of epiphyseal union observed on studies utilising skeletal observations (Crowder and Austin, 2005 and O‟ Connor *et al*., 2008). To remedy this methodological issue radiographic observation of skeletal material should be compared to observations carried out during gross inspection and their validity should be determined. This is considered below in section 5.6.

The age of union is defined in the present study as the age at which 95% of males and females show complete union. Females reach maturity more precisely showing little difference between the age at 95% and 100%. This is not true for males who show a lag in a few individuals compared to the rest of the group resulting in a more drawn out timing of final union. The lag may be explained by the continued growth in males post puberty due to the effects of testosterone (Loesch *et al*., 1995) and appears to be a feature of African Child growth (Dembetembe and Morris, 2010).

5.3. The Pattern of Union of the Respective Epiphyses at the Joints

5.3.1 Elbow

In females the epiphyses of the distal humerus complete union at 15 years with the proximal radius completing union a year behind those of the distal humerus. This difference is not significant. In females there appears to be greater variability in the period leading up to complete union (*Figure 4.15* in the previous section showing the sequential changes leading to union) compared to males in which there appears to be uniformity in the development of the epiphyses. This variability may be due to the effects of menarche in females (Scheuer *et al*., 2000). The elbow is the first joint to complete union in females and does so soon after the initiation of menarche and completion of the growth spurt in females. The differences herein are reflected by the variation of the onset of puberty between individual women. This variability may also indeed be influenced by the relatively smaller sample size in females.

In males the observed sequence of union was the capitulum followed by the trochlea, lateral epicondyle, proximal radius and finally medial epicondyle. This is the observed sequence of union in other studies (Flecker, 1932 and Hansman, 1962). The medial epicondyle in both males (*Figure 4.14)* and females (*Figure 4.15*) is one of the earliest epiphyses to form, but it is the last epiphysis to complete union and does so at the same age as the rest of the epiphyses suggesting that it is slower to develop (Flecker, 1932; Hansman 1962, Scheuer *et al*., 2000). Scheuer and colleagues (2000) suggested that its delayed development may be due to the variability in the age of appearance of this epiphysis. In the present sample the epiphysis was first observed around eight years in most individuals, there were some individuals aged 9 - 11 years in which the medial epicondyle had not been observed.

Galstaun (1937), Flecker (1942) and Hansman (1962 report that the epiphyses of the distal humerus form a compound epiphysis before its union with the distal shaft; however, this was not observed in the South African sample.

5.3.2 Hip

The head of the femur completes union a year ahead of the greater and lesser trochanters in South African males. American males (Hansman, 1962) show no difference in the age of union of these three epiphyses, but union at the greater trochanter in Australian males begins a year later than the head of the femur even though complete union occurs at the same time (Flecker, 1932).

On the contrary the greater trochanter in American females is seen to complete union one year later than the head of the femur and 0.5 years later in the Australian females. Complete union at all the epiphyses of the hip in the South African females takes place at 15 years. These observations are contrary to that reported by Scheuer and colleagues (2000) suggested that the maturity of the greater trochanter is always slightly in advance of the head. The earlier union of the head of the femur in South African males may in part be explained by the earlier appearance of this secondary centre (Davies and Parsons, 1927; Flecker, 1932 and Hansman, 1962).

Although the epiphysis of the lesser trochanter appears later than the rest of the epiphysis in this location; complete union takes place at the same time as the greater trochanter in both males and females. Reported ages of union in the literature are scarce since its observations are said to be variable (Scheuer *et al*., 2000).

5.3.3 Knee

The distal femoral epiphysis in females begins union two years earlier than the proximal tibia and fibula and is completed a year ahead of the rest of the epiphyses. Hansman (1962) reported the same ages for the beginning and termination of union in females but Flecker (1932) reports that complete union at the proximal tibia appears a year ahead of the distal femur and proximal tibia. The distal epiphysis of the femur in males completes union at the same time as the proximal tibia and fibula but develops faster than the adjacent epiphyses of the joint. Further variations in the patterns of union were observed by O‟Connor and colleagues (2008) and Hansman (1962) who found that the fibula begins union after the distal tibia and fibula.

The distal epiphysis of the femur is one of the first long bone epiphyses to appear. Its early appearance and development may explain the advanced development seen in males and females. It is also possible that the observed pattern of variability in union in females might be a statistical error caused by the fewer number of females between 13 to 18 years.

5.3.4 Wrist

Although the scope of the current research did not extend to the observations of appearance of the secondary centres; during analyses of the radiographs the epiphysis of the distal ulna was observed to appear later than the distal radius. This observation was also made by Davies and Parsons (1929); Flecker (1932); Hansman (1962) and Greulich and Pyle (1959) who report a delay of one to two years in the appearance of the secondary centre for the distal ulna. Although the appearance of the secondary centre appears to be delayed; fusion is said to precede that of the distal radius (Paterson, 1929; Flecker, 1932 and Hansman, 1962). This was not observed in the South African sample; instead union of the distal ulna and radius occur at the same time in males and females.

Due to the variability in union times of the different bones within a joint the average fusion values for joints are less precise but are still valuable when looking at complete joints.

Individual variability in epiphyseal union sequence is more important in skeletonised cases where single bones are seen.

5.4 The Maturation Status of South African Children

Skeletal maturity studies performed on South African children are scarce but clues to changing patterns of age of maturity can be seen in other non-skeletal data. A reduction in infant mortality rates, decrease in the age of onset of menarche in females and reduction in age at skeletal maturity (Hawley *et al*., 2009) have been observed in the literature signifying improved quality of life in South African individuals during recent decades.

The mean age of menarche for urban South African females prior to 1994 was 13.9 years (Chaning Pearce and Solomon, 1970) and 12.4 years post-apartheid (Jones *et al*., 2009). Age of menarche is considered to be an important indicator on the health of the population as well as an indicator of the socio-economic stratification (Cameron *et al*., 1992; Crowder and Austin, 2005 and Jones *et al*., 2009). Progressive declines are thought to occur due to improvements in environmental conditions (Hennenberg and Louw, 1995 and Cameron *et al*, 1992). Accompanied with the improvements in socio-economic position, the relationship between weight and onset of menarche suggests that the intake of foods with higher concentrations of fat decreases the age of menarche (Roots, 1973, Swerdoff, 1978) and Crowder and Austin, 2005).

Differences in height and weight attributed to biological differences have been observed in Black, White, Coloured and Indian South Africans (Kotze and Vivier, 1986). This study found that while White South Africans compared favourably with American children of the same age, Black children were found to have lower weight and height for age compared to all the populations groups.

Other methods of age estimation involve measurements of long bones. Stull and colleagues (2013) found that population differences existed in the lengths of long bones of South Africans compared to Americans born in the early 1900‟s. Subsequently prediction intervals for univariate and multivariate equations formulated in their 2014 research of contemporary South Africans were as wide as one month to seven years in its accuracy of age estimation. The study found that the prediction intervals of these multivariate equations were limited to use in individuals 12 years and younger as the multivariate models had lower prediction intervals for older children (Stull *et al*., 2014). The study found that there was larger variation in diaphyseal length in older children and less variation in the younger children especially during adolescence (Stull *et al*., 2014). This has been attributed to the variation which exists in the initiation of the growth spurt in males and females. The study failed to find significant differences in males and females which should be expected especially since females enter the growth spurt earlier than males. Neither do they differentiate between the different ethnic groups but expect that the prediction intervals would be improved if this was done.

Although Black children showed the slowest growth rates, their permanent teeth erupt earlier than all the other groups. Indians showed the second highest growth in weight and height but their permanent dentition erupted the last (Kotze and Vivier, 1986) suggesting that dental eruption was less influenced by environment or socio-economic status (SES).

Biological differences and differences due to differing genetic backgrounds have been observed in relation to the eruption of permanent dentition (Kotze and Vivier, 1986 and Gillett, 1998). Gillett (1998) specifically mentions the creation of population specific standards due to the substantial variation in timing of tooth emergence among populations with differing genetic backgrounds which are primarily due to heredity. Although not a new finding; these studies also observe the biological difference in age of emergence of the permanent dentition and note that this is observed earlier in females compared to males

(Phillips and Van Wyk Kotze, 2009 a and b). These observed differences are also noted in studies dealing with epiphyseal maturation. The magnitude of these increases are higher in females compared to males (Hawley *et al*., 2009 and Anholts *et al*., 2013) which is probably due to the shorter period of growth in females compared to males.

5.4.1 Comparison of Radiographic Age Assessment in South Africans to Other World Populations

Radiographic studies dealing with epiphyseal union have been published for all the joints of the body (Davies and Parsons, 1927; Paterson, 1929; Flecker, 1932; Stevenson, 1932; Galstaun, 1937 and Hansman, 1962), but contemporary studies based on epiphyseal union are concentrated on single joints rather than multiple joints due to limitations involved in acquiring large samples. Contemporary studies for individual joints have been published for the wrist (Banerjee and Agarwal, 1998; Baumann *et al*., 2009 and Dembetembe and Morris, 2013), knee (O" Connor *et al*., 2008) and ankle (Banerjee and Agarwal, 1998 and Crowder and Austin, 2005).

The samples from these studies originate from varying socio-economic backgrounds and constituted of different population groups. The American samples utilised in the longitudinal growth study in Denver originated from populations with favourable and stable economic and education background (Hansman, 1962). Similarly, samples from Germany (Baumann *et al*., 2009) and Delhi (Banerjee and Agarwal, 1998) originate from large economic hubs and reflect relatively well-off individuals. This may explain the earlier age of maturity at the wrist and ankle in Indians from Delhi compared to American and British samples.

The South African sample represents predominantly state hospital patients who could not afford medical insurance and were not as well off as those from the rest of their fellow citizens. Comparisons were conducted between studies which reported on similar stage of complete union. Flecker"s (1932) Australian sample was excluded as these did not have clear information regarding the age of complete union. Galstaun (1937) on the other hand was inconsistent in reporting the age of union while Baumann *et al*., (2009) reported on the age of 50% union which is not consistent with the comparisons of 100% union carried out between similar studies.

5.4.1.1 Males

Variability in the initiation of and completion of union is evident across world populations and can be observed in *Figure 5.01*. American males from 1962 (Hansman) tend to mature later at the elbow, hip, ankle and knee compared to Irish, Indian and South African males. Comparisons between two samples which originated from the United States shows that the ankle appears to fuse a year earlier (19 years) in the 2005 study (Crowder and Austin 2005) compared to the 20 year average reported by Hansman (1962), highlighting within population differences due possibly to the effects of secular trends in growth. Yet both samples of American males show one to two years delays in maturity compared to Indian and South African males respectively who show complete union at 18 years.

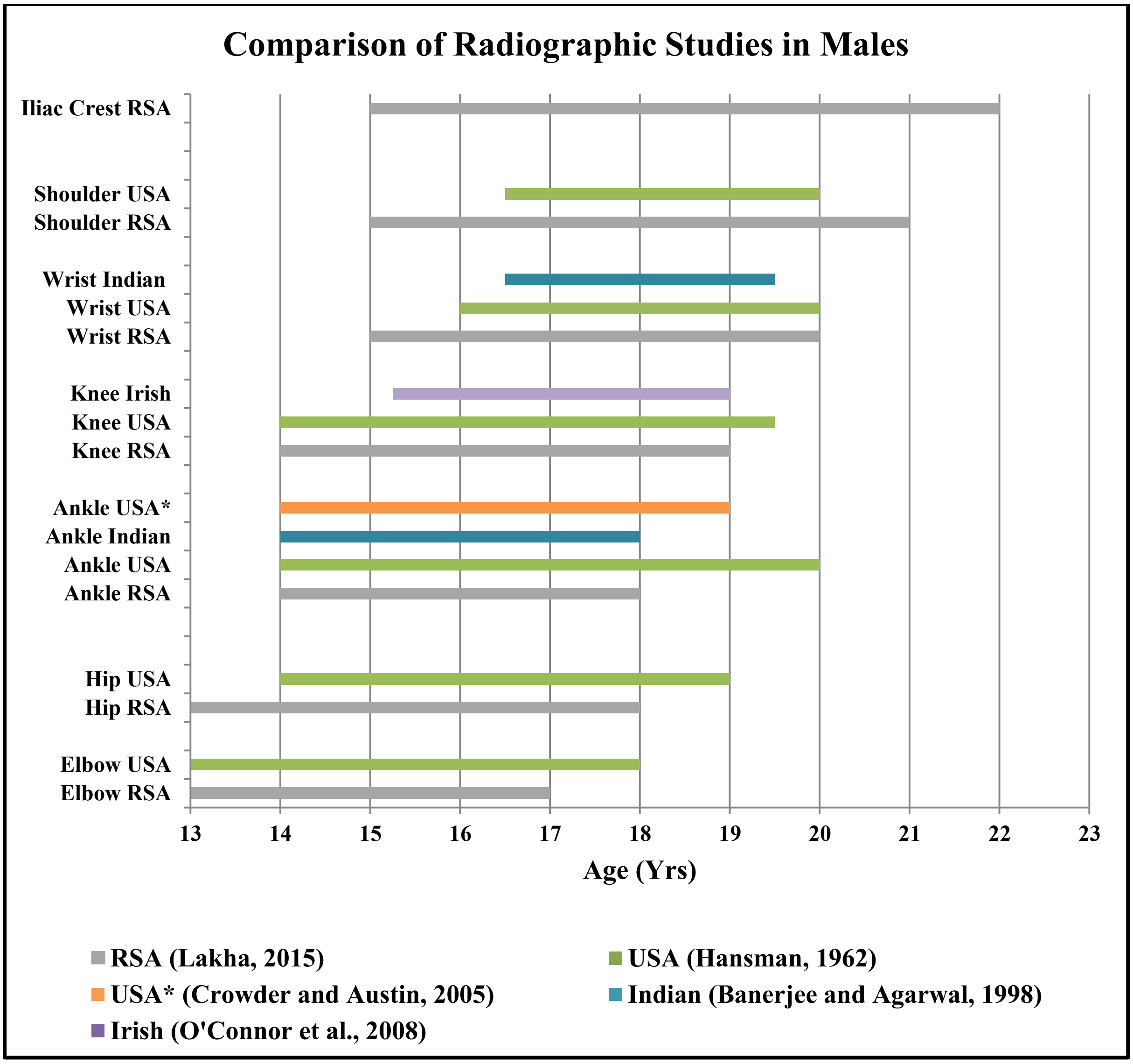


Figure 5.01: *Comparisons of radiographic age range of skeletal maturation in males. The left side of each bar represents the first evidence of fusion while the right side is the age at complete union.*

Irish males show shorter durations of union at the knee compared to both American (Hansman, 1962) and South African males. Although the Irish males begin union later than both comparative samples; complete union in South African males occurs at 19 years, the same as in the Irish (O‟Connor *et al*., 2008).

Indian males on the other hand begin union at the ankle at the same age as the American and South African samples but completes union at the same age as the South African males and two years earlier compared to Hansman (1962) whose sample showed completed union at 20 years and one year earlier than that of the Americans of Crowder and Austin. Indian males however show the shortest duration for union at the wrist with union initiating at 16.5 years and complete in three years at 19.5 years.

Dembetembe and Morris (2012) is the only other South African study to which data can be directly compared. Their age of complete union for the wrist in males was 21 years; a year delayed compared the present data. There are three possible reasons for this difference. The first is that while Dembetembe and Morris (2012) utilise the GP (1959) standards, the present study utilises a four stage scoring system. Secondly, while Dembetembe and Morris classify union in 100% individuals the present study uses the 95% mark. This could account for the observed difference of one year. Finally the sample size in the present study is considerably larger than that of the former study. The one observation similar in both studies however is that African male tend to show prolonged periods of maturity for the wrist. This is clearly a population difference in comparison to other world samples. Although this is primarily visible at the wrist the present study also shows prolonged periods of maturity at the shoulder and Iliac crest, suggesting this may be a general case of growth distinctiveness in African males.

5.4.1.2 Females

Similar to those observations made in males, American females from 2005 (Crowder and Austin) complete union at the ankle a year earlier (16 years) compared to the 17 years seen in an earlier study conducted by Hansman in 1962. American females from Hansman (1962) show prolonged periods in which epiphyseal fusion occurs compared to Irish, Indian and South African females across all joints.

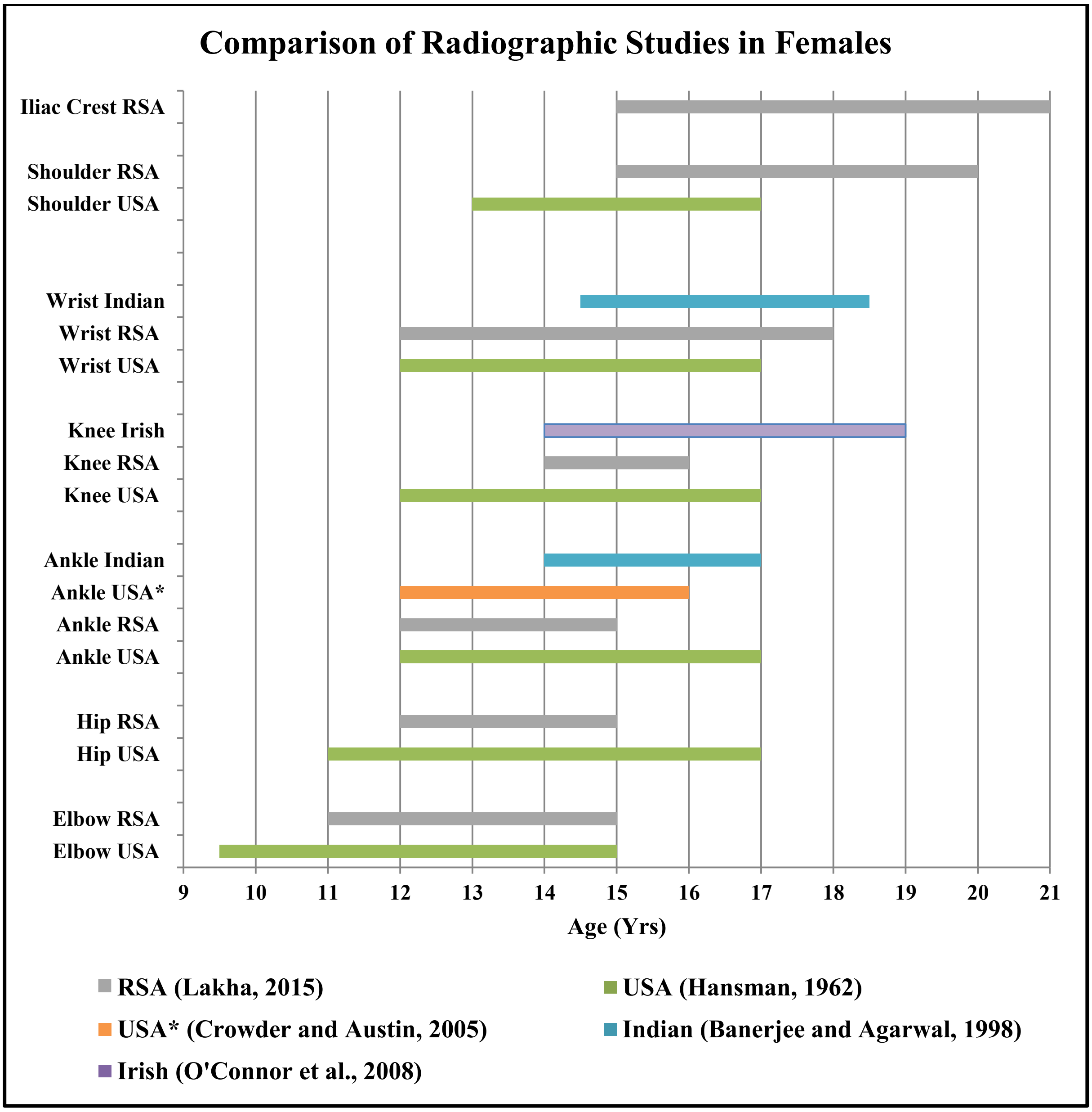


Figure 5.02: *Comparisons of radiographic age range of skeletal maturation in females**.** The left side of each bar represents the first evidence of fusion while the right side is age at complete union.*

Union at the knee in Irish females is initiated two years later than the American (Hansman, 1962) females and complete union two years later as well. Compared to both samples South African females show the shortest duration for maturity at the knee with complete union occurring at 16 years of age compared to 17 years in American females (Hansman, 1962) and 19 years in Irish females.

Union at the wrist and ankle in Indian females begins approximately two years later than American and South African females with the resultant delay of one and a half years in the age at maturity at the wrist (18.5 years) compared to other female comparatives. At the ankle however, Indian females complete union at the same age as those of Hansman (1962) (17 years), one year delayed compared to Crowder and Austin (2005) and two years delayed compared to South African females (15 years compared to 17 years).

South African females show relatively slower durations of maturity at the elbow, hip, ankle and knee compared to the American, Irish and Indian samples. Maturity at the elbow is achieved at the same age in South African and American females (Hansman, 1962) and complete union earlier at the hip, ankle and knee, show similar ages of complete union at the wrist and show delayed union at the shoulder. Compared to Irish females South African females show complete union three years earlier (16 years compared to 19 years) at the knee. They also mature earlier than Indian females at the wrist and ankle. Similar to the observations made in males, females show prolonged periods of maturity at the wrist shoulder and iliac crest and could be an attribute of the genetic makeup of the population.

Compared to the males South African females show rapid union which exhibits less lag, (union is rapid). There are both similarities and differences which appear to be inconsistent suggesting that there is no one population who shows advanced or delayed maturity compared to another and that the amount of human variability which accounts for these differences is so large that population specific standards are better suited to account for this variability. In summary South African males show attributes of prolonged maturation as initially stated by Dembetembe and Morris (2012) whereas females progress rapidly to maturity.

5.5 The Observed Differences between Black and Coloured Males: Biology vs. SES

5.5.1 The Influence of Genetic Background on the Difference in Skeletal Maturity in South African Children.

Since the GP (1959) method is used world-wide, it is able to compare differences between data with standard methodology. GP (1959) skeletal maturity literature consists of numerous studies from the United States (African American, European American, and Hispanic), Europe (Dutch, German, Turkish and Danish), Asia and Africa (Morocco, Malawi and South Africa). This offers the authors of such studies the opportunity compare their data to the GP (1959) method as well as those results published by other authors in order to determine whether differences are related to population background or environment.

Dembetembe (2012) undertook a comparison of all GP (1959) studies completed across the world and showed that GP was only applicable to the Dutch (van Rijn *et al*., 2001), Danish (Lynnerup *et al*., 2008) and German (Schmidt *et al*., 2008b). Schutte (1980) found that biological differences may be more important than SES and social backgrounds since children from low income Black families were seen to mature earlier than middle income White children. While Zhang *et al*., (2009) found differences in the rates of maturity between the GP reference sample Hispanic and Asian individuals were due to biological background. Ontell *et al*., (1996) on the other hand did not find significant differences but acknowledged that GP (1959) should be used with caution on populations from various biological backgrounds. Mora *et al*., (2001) suggested that there is a need to develop population specific standards due to population variability. Dembetembe and Morris (2012) found that GP (1959) underestimated age in South African children while and Speed (2012) found that it both over and underestimated age in her sample of South African children. Dembetembe and Morris suggest that the observed differences are due to biological background.

The South African sample in this study consists of primarily Black and Coloured individuals. The latter have been described to have a complex genetic history with genetic contributions from populations related to the Khoesan, isiXhosa, Europeans, South Asians and Indonesians (Patterson *et al*., 2010). Both South African Coloured (SAC) and Black individuals share significant African genetic heritage, but this may not be enough to homogenise them biologically. According to de Wit *et al*., (2010) the Khoesan are the largest genetic contributors to the SAC gene pool (32% to 43%) followed by the Bantu-speaking Africans (20 – 36%). The complex genetic admixture of the Coloured cohort compared to the less complex genetic make-up of their Black counterparts provides a reasonable explanation for the observed difference in skeletal maturity. This hypothesis suggests that the shared genetic contributions may not be enough to homogenise them and that biological influences of union predominate over SES aspects. Skeletal maturity will therefore be used as a test case for biological and SES differences.

5.5.2 The Influence of SES on the Observed Differences

The data from this study indicate that there are non-significant differences in the attainment of maturity between two groups of different genetic origins (Black and Coloured). Although not statistically significant, it does highlight the existence of a trend toward earlier maturation in Coloured males and females compared to their Black counterparts. This could be a reflection of differing SES.

Literature on effects of SES on children suggests that those from high SES backgrounds are assumed to have access to nutrition of better quality and higher fat content, better living conditions which include improved sanitation conditions and healthcare, formal dwelling structures, access to electricity and running water on site compared to those from lower SES backgrounds; and attain maturity earlier (Hennenberg and Louw, 1995; Goduka, 1992; Fotso 2007 and Hawley *et al*., 2009).

The observed decrease in age at menarche in Coloured South African females from the Western Cape found that "good" SES backgrounds were instrumental in their earlier maturation (Hennenberg and Louw, 1995). They rule out the contribution of genetics to the effects of decreased age at menarche as these are thought to be low. Similarly, the effects of urbanisation (access to resources such as healthcare and employment) have been shown to reduce the age of menarche in Black urban females compared to Black rural females (Cameron, *et al*., 1992 and Cameron, 2003).

Infant mortality rates (IMR) are another indicator of society"s level of socio-economic development where lower levels of IMR are associated with higher levels of socioeconomic development (Anderson *et al*., 2002). Higher rates of IMR have been observed in children from lower SES backgrounds due to the effects of poor sanitation, access to healthcare, and limited access to resources resulting in significant delays in skeletal and cognitive development (Bogin, 1983). Studies from the Western Cape dealing with IMR have found lower rates of IMR in Coloured children compared to Black children as a result of SES and environment (Bachmann *et al*., 1996; Anderson *et al*., 2002 and Heaton and Amoteng, 2007).

5.5.3 The Use of Residential Address as a Proxy for SES

Residential address of suburbs in Southern African may be used as a proxy for SES (Christopher, 2002) due to the effects of apartheid. The group areas act (Act No. 41 of 1950) assigned racial groups to different sections in urban areas. There were separate educational and health systems for each group and the rights and privileges for each group differed significantly (Anderson *et al*., 2002). White institutions had the greatest resources and while

African institutions had the least resources. Influx control into urban areas was practised with a system of pass laws which prohibited Black people from living in urban areas (Bachmann *et al*., 1996 and Anderson *et al*., 2002). The end of influx control in 1990 saw rapid urbanization in the Western Cape with an influx of African people into the greater Cape Town metropolitan area. This resulted in the increase in the number of informal settlements (shacks) to house the urban Black population (Bachmann *et al*., 1996).

The effects of this was heterogeneous metropolitan area that ranges from large affluent areas which are predominantly White followed by poorer areas which are largely Coloured and informal settlements which are largely Black (Bachmann *et al*., 1996). The heterogeneity of the residential suburbs therefore acts as an appropriate proxy for SES classifications.

A large percentage of the sample from the present study (66%) originates from the Cape Flats area of the Western Cape. Historically this is racially segregated area setup by the apartheid Government and consists of predominantly Black and Coloured individuals. The highest number of individuals were from Khayelitsha which is predominantly Black area (99%) followed by the predominantly Coloured area of Mitchells Plain (91%).

A Socio-economic index for each suburb of the Western Cape was derived by the City of Cape Town using the most recent census data on variables such as highest levels of education achieved, percentage of individuals who earn less than minimum wage (R3,200.00 p/m), access to piped water on site as well as electricity for lighting and cooking, sanitation facilities onsite as well as refuse removal. A heat map of the indices maybe viewed in *Figure 5.03* below (City of Cape Town, 2014). This shows that the Black and Coloured individuals from the present sample originate in the major catchment areas described as “needy” and “very needy”. These data suggest that the SES of the sample is therefore homogenous since they were all exposed to poverty.

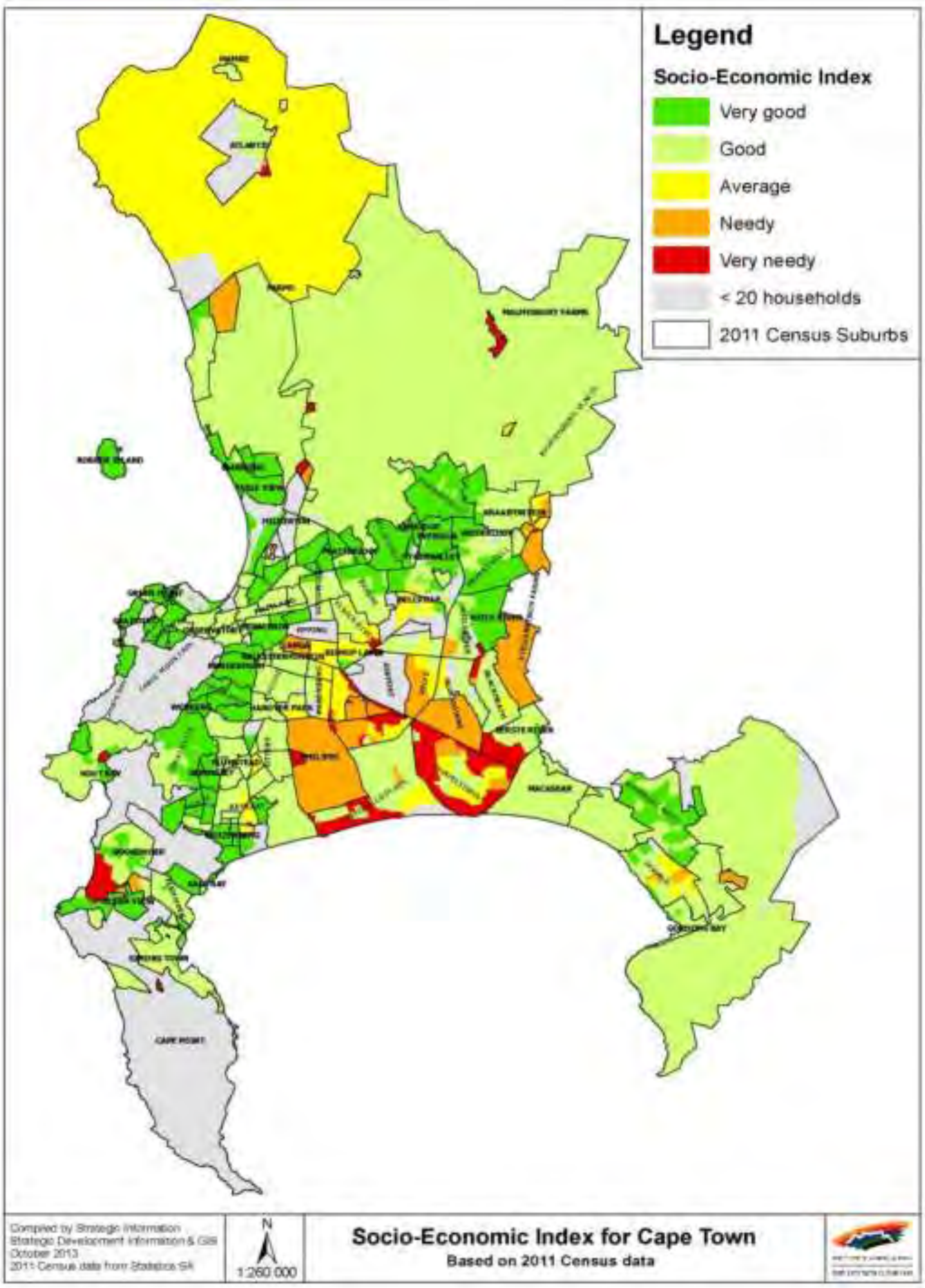


Figure 5.03: *Map of Socio-economic index of the Western Cape showing the grades of index between very good and very needy, courtesy of Development Information and GIS Department (City of Cape Town, 2014)*

This map highlights the fact that neither of the communities in this sample are particularly well-off. Tobias (1985) derived a comparative framework which ranges from “Have-Most”, “Have Ample”, “Have-Little” to the “Have Least” in which the poorest communities are especially badly affect by lack of resources. It is apparent from this figure that the data are concentrated in regions classified by the City of Cape Town SES index as average needy and very needy. This research lacks data from what Tobias (1985) classifies as the “Have-Most” and “Have Ample” groups and may indeed be related to the source of the samples. The samples from the present research visit state owned hospitals for healthcare intervention while those who are from higher SES categories frequent private healthcare facilities. Therefore the lack of affluent individuals in the sample is associated with the observed lack of difference in skeletal maturity between Black and Coloured individuals.

The data therefore suggests that the observed differences in the age at skeletal maturity may indeed be related to the differences in biological/genetic backgrounds due to a lack of significant genetic homogeneity. The data for SES index also suggests that both groups suffered from degrees of poverty and restricted access to resources therefore suggesting that SES does not influence the observed non-significant difference in union times between Black and Coloured males.

5.6 Application of Radiographic Assessment of Union in Dry Bone Forensic Cases

Methodological issues (including the experience of the observer) mean that standards for epiphyseal union developed on radiographs must be used with caution on forensic cases involving skeletonised human remains (Krogman and Iscan, 1986; Ubelaker, 1987; Sorg *et al*., 1989; Lewis and Rutty, 2003; Coqueugniot and Weaver, 2007; Cardoso 2008a and b and Schaefer, 2008). Moreover, skeletal samples from which these bony reference standards are derived are often limited in number (Lewis and Rutty, 2003; Coqueugniot and Weaver, 2007; Cardoso 2008a and b) or have poor representations of infants and young adults (Sorg *et al*., 1989; Johnston and Zimmer, 1989 and Saunders, 2000) and are influenced by secular trends in growth and maturity (Tanner and Whitehouse, 1975; Hennenberg and van Der Berg, 1990; Scheuer and Black, 2007 and Cardoso 2008a and Anholts, *et al*., 2013). Since radiographs of living individuals provide large samples numbers, is it possible to reconcile the problem of comparing data from radiographs and dry bones?

In an aim to develop standards on radiographs of living children which could be applied to forensic cases involving skeletal remains this research involved the gross examination and radiographic assessment of maturity on a sample of skeletal remains from the Raymond Dart Teaching collection situated at the WITS medical school. The initial methodology utilised to assess union on radiographs of living children were amended slightly to facilitate observations of differences related to skeletal material. This involved taking radiographs of the skeletal remains and conducting maturity assessment on these. A gross examination of the stage of maturity was then carried out on the skeletal material. Results of these comparisons showed high levels of agreement (95% -100%) and low standard errors between gross observations and radiographic assessments of same skeletal. Therefore the amended methodology utilised to assess union on skeletal remains in this study may be used on forensic cases involving human skeletal remains.

5.6.1 Comparison of Chronological Age of Union of Gross Observations of Skeletal Material

The data on radiographic assessment of union the South African sample were compared to age estimation studies dealing with epiphyseal closure examined on skeletal remains (*Figure 5.03).* The Portuguese data originate from two cemeteries within Portugal namely Lisbon (Cardoso, 2008a and b) and Coimbra (Coqueugniot and Weaver, 2007). These samples were excavated from local cemeteries to form part of the teaching collections at the respective medical schools and considered to represent individuals from middle to low social class stratifications based on their burial in unmarked graves and employment which is considered to be menial (Cardoso, 2008 a and b). The years of birth for the samples range between 1887 and 1960 for the Lisbon collection (Cardoso, 2008 a and b) and 1826 to 1920 for the Coimbra collection (Coqueugniot and Weaver, 2007). The data utilised by Buikstra and Ubelaker (1994) constitute a number of primary and secondary sources from which their data are derived (McKern and Stewart, 1957; Redfield, 1970; Suchey *et al*., 1984; Krogman and Iscan, 1986; and Ubelaker, 1989a and b) and will thus be referred to as the „generic data set‟. All samples therefore represent historic individuals.

South African males show a one year delay at the elbow compared to the generic American data set (Buikstra and Ubelaker, 1994) but shows advanced union at the hip, ankle, knee, wrist, shoulder and iliac crest ahead of the skeletal samples. The figure illustrates that the termination of epiphyseal union may indeed be observed earlier on radiographs compared to gross examination of skeletal remains (*Figure 5.04*). There appears to be reasonable overlap between the present study and data on skeletal maturation with the exception of Coqueugniot and Weaver (2007) who show extended ranges of complete union in their sample. Their data may not be relied upon and will not be included in the discussion. The difference in union of between one to two years between the present study, the Portuguese and American samples are similar to the difference observed between the present study and the radiographic studies mentioned earlier in the chapter.

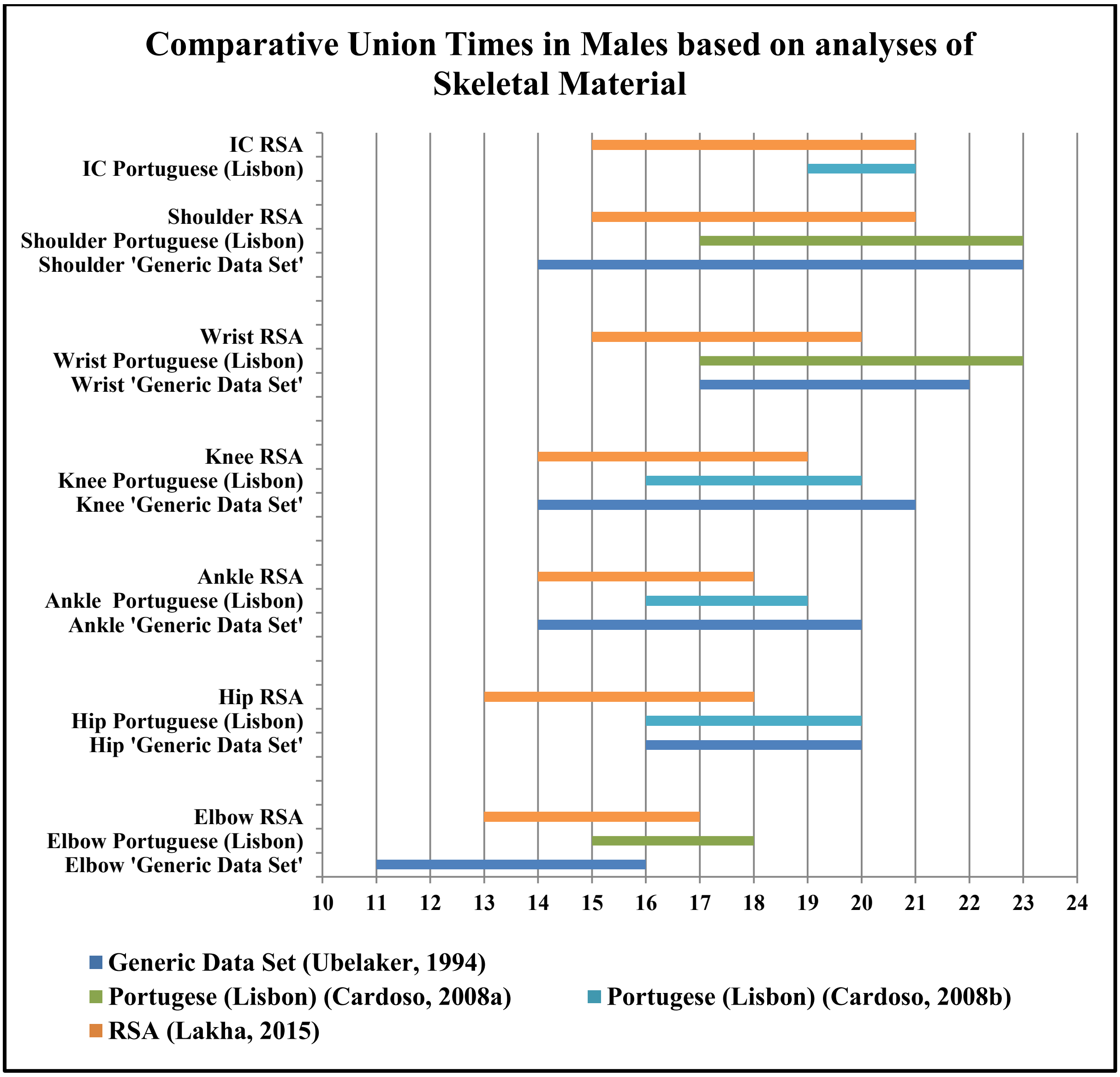


Figure 5.04: *Comparisons of union times between radiographs and gross observation of skeletal material in males. The left side of each bar represents the first evidence of fusion while the right side is age at complete union.*

However, unlike the previous comparisons of radiographic data, the current comparison finds that the South African sample appears to mature earlier than the Portuguese and Generic American sample suggesting that union viewed on radiographs may indeed be viewed earlier compared to gross observations. Before the present study was initiated, this was an expected result due to the difference in samples (skeletal vs. radiographs) and methodology utilised (scoring system). However, the high levels of agreement between radiographic observations and skeletal observations using the amended methodology suggest that these methods are interchangeable.

Skeletal maturity studies were also conducted by McKern and Stewart (1957) as well as Schaefer and Black (2005). The sample utilised by McKern and Stewart represent a sample "war dead" American casualties of the Korean conflict (McKern and Stewart, 1957) while those from the latter study represents Bosnian male causalities of the fall of Srebrenica in 1995 (Schaefer and Black, 2005). The latter study utilises samples whose minimum age is 17 years as they compare their date to that of McKern and Stewart (1957). The South African data may not be directly compared to these skeletal observations since the age of initiation of union is unknown (*Table 5.01*). However, comparisons of data related to age of complete union show that union and hence maturity in the South African sample is observed earlier. These may be attributed to population variability and associated effects which include genetic background; differences in SES, difference related to times of conflict versus none as well as associated influences of nutrition.

Table 5.01: Age of 100% Union from Gross Observations of Skeletal Material

Bone	McKern and Stewart (1957)	Schaefer and Black(2005)	Lakha (2015)
Proximal Humerus	24 years	22 years	21 years
Distal Radius	23 years	21 years	20 years
Distal Ulna	23 years	21 years	20 year
Distal Femur	22 years	21 years	19 years
Proximal Tibia	23 years	21 years	19 years
Proximal Fibula	22 years	19 years	19 years
Iliac Crest	23 years	22 years	21 years

Similar trends are observed in females (*Figure 5.05*). The initiation of union is observed earlier at the hip and ankle of South African females compared to the Lisbon collection, however the initiation of union at the elbow, knee, wrist and iliac crest appears around the same age. Similar to observations of union made in males; complete union in the radiographs is observed earlier than those on skeletal remains in females.

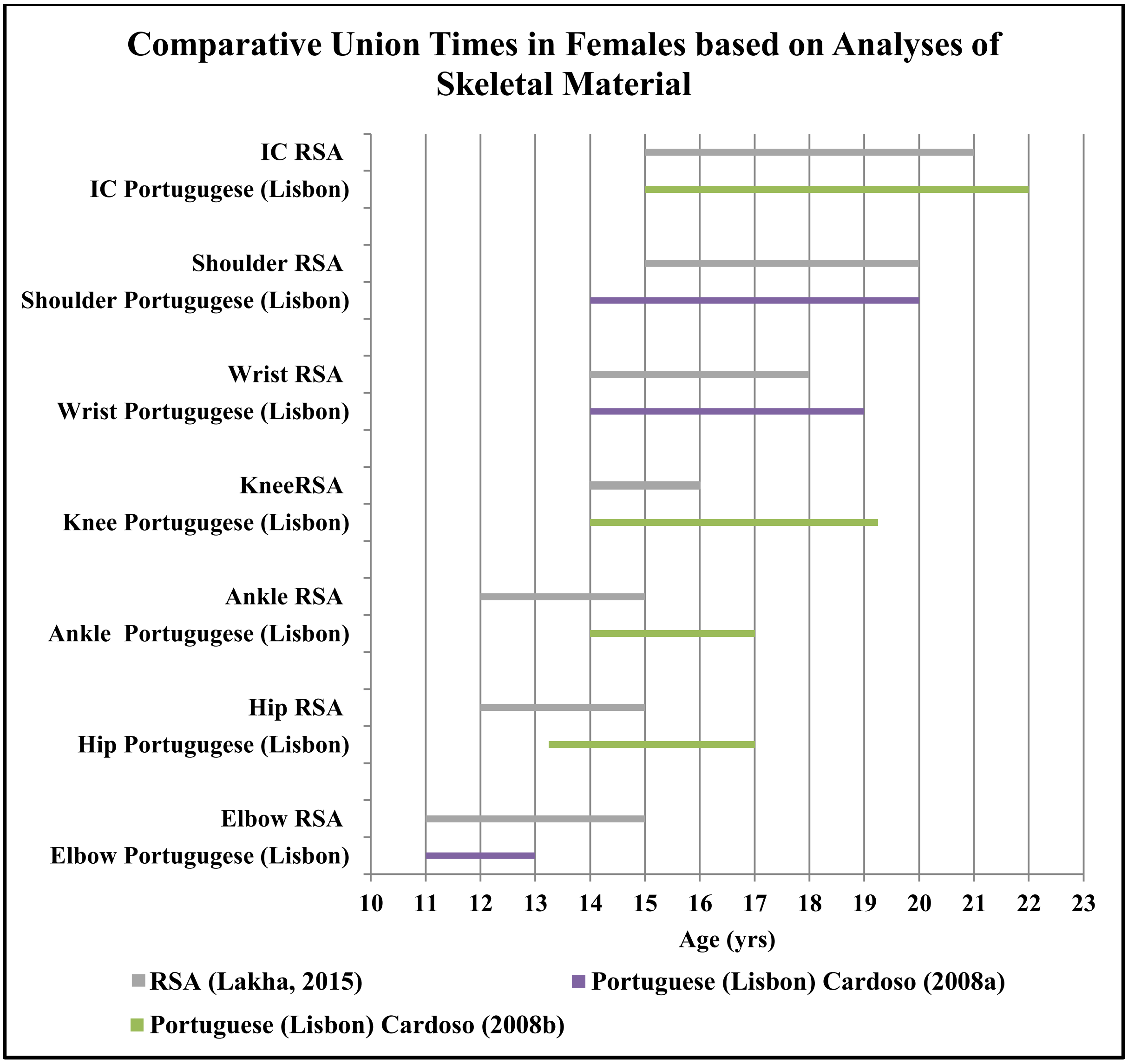


Figure 5.05: *Comparisons of union times between radiographs and gross observation of skeletal material in females. The left side of each bar represents the first evidence of fusion while the right side is age at complete union.*

5.6.2 Union Scores and Predicted Age Ranges

In 1957 McKern and Stewart carried out analysis on American war dead in which they suggest that that all sites do not mature at the same rate and separated the joints into early and late uniting epiphyses. In 1970 McKern created a mathematical score for combined maturation in a small number of critical growth areas to account for the variability in maturity among skeletal growth areas. He suggests that final age assessments should be based on the combined growth status of as many areas as possible (McKern, 1970). The age of an individual could be calculated from the sum of scores for epiphyseal activity in these critical areas namely medial clavicle, iliac crest, distal femur, head of the humerus, medial epicondyle of the humerus, distal end of the radius, lateral sacral joints and finally the 3-4 joint of the sacrum. Epiphyseal activity is scored between a numerical score of 1 to 5 where 1 = non-union, 2 = one quarter union, 3 = half union, 4 = three quarters united and 5 = complete union.

Table 5.02 below is a table extracted from McKern (1970) which shows the total score, age range and predicted age for a particular score.

Table 5.02: Total Maturation Score Showing Age Range and Predicted Age (McKern, 1970)

Total Score	Observed age range	Predicted Age
18	17 - 18	17.98
20	17 - 20	18.13
22	17 - 20	18.28
24	17 - 21	18.43
26	17 - 20	18.59
28	17 - 20	18.74
30	17 - 21	18.89
32	17 - 22	19.04
34	17 - 22	19.19
36	17 - 22	19.34
38	18 - 23	19.15
40	18 - 24	20.27
42	18 - 25	21.39
44	19 - 25	22.52
46	19 - 25	23.64

This system is limited since the lowest age range is 17.98 years. It also assumes that a score will be obtained for each of the nine sites which is itself a limitation as its application to forensic cases in which incomplete remains are obtained is of limited use. Attempts were made to determine the applicability of this scoring system on the South African sample, however; this could not be completed as some of the critical points could not be observed on the radiographs. Therefore, this system would yield lower scores and incorrect estimates if less than the nine critical points are assessed. McKern"s (1970) the observed age ranges for scores also show a substantial amount of overlap and are vague in their definition. The current system derived herein however makes concession for using individual epiphysis which is advantageous for use in forensic cases and more accurate age estimates are obtained.

5.7 Setting up an Age Assessment Table for Forensic Use

Results of the radiographic assessment of skeletal remains and gross examination of the same skeletal remains in this research showed high levels of agreement (95% -100%) and low standard errors. Therefore data from the present research in the form of union scores for particular joint associated with an age and standard deviation can be utilised in cases involving human skeletal remains. If the amended methodology is utilised in forensic cases involving human remains there is no need to use correction factors due to the high agreement between the two methods. Therefore when assessing skeletal remains stage 1 is usually characterised by the difference in size between the epiphysis and diaphysis and lack of association between the two surfaces. Stage 2 on the other hand maybe differentiated as the epiphysis is usually the same size as the adjacent diaphyses and less than 50% union is taking place and will therefore the epiphysis will appear as a separate entity. Stage three may be recognised when the epiphysis is attached to the diaphysis but a small margin of unfused areas may be seen. Finally complete union is when this groove disappears.

Since there is high agreement between the two methods data for reference standards derived in part one serve as reference standards for epiphyseal union South African Children and may therefore be used on cases involving unidentified skeletal remains.

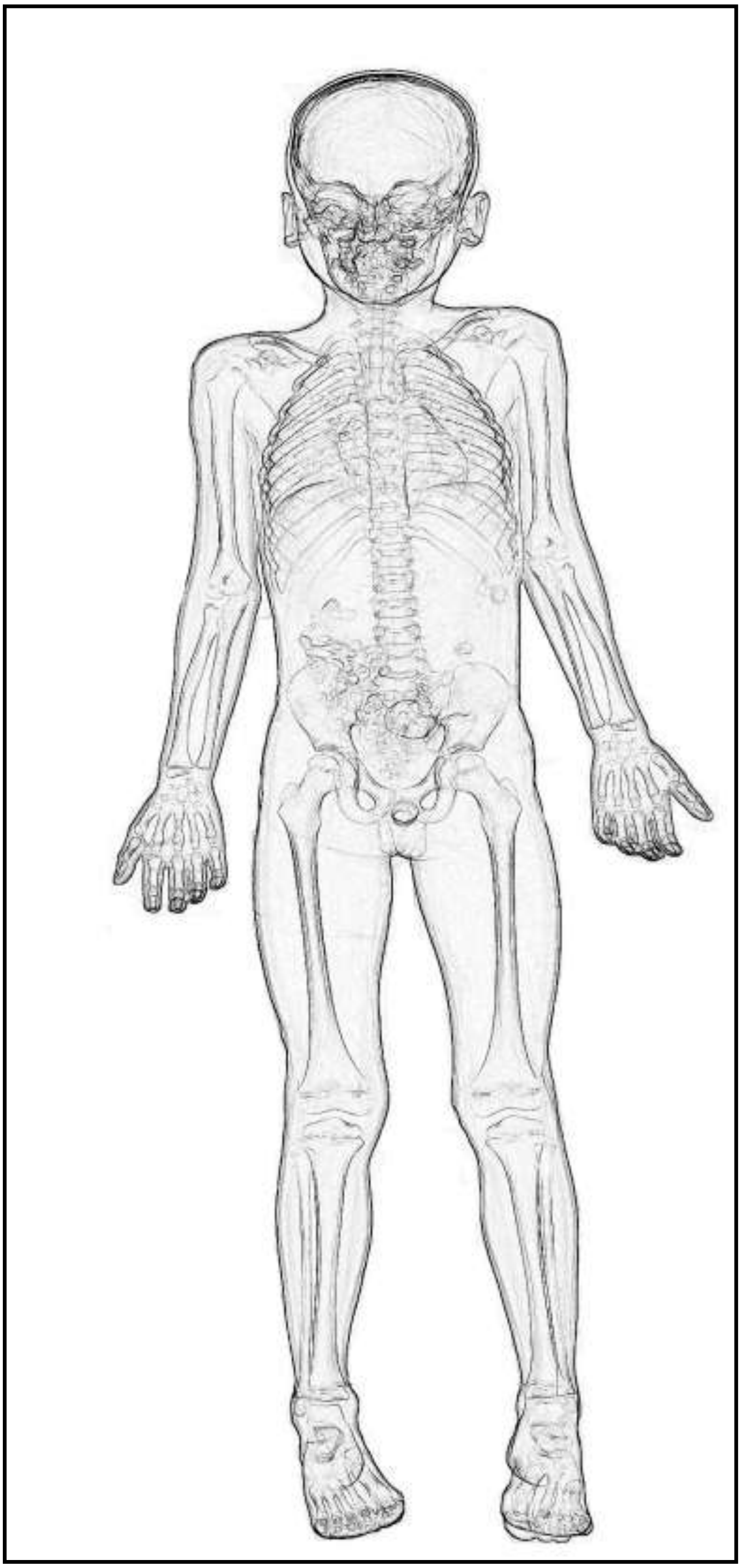
Similar to the scores derived by McKern (1970), scores were developed from the South African data also based on the stage of epiphyseal union. The ideal situation is the availability of all epiphyses during assessment for a more accurate age estimate. However this is often not the case in forensic settings and necessitates the use of individual epiphyses. Age estimations yielded from assessment of joints appear to have the second highest accuracy followed finally by individual epiphyses. First the sex of the individual needs to be determined, however if this is ambiguous estimates should be generated for both sexes. Should the age estimate be based on skeletal elements which constitute a joint the equations in *Table 5.03* may be utilised. Each epiphysis is allocated a scored ranging from one to four and the average of the joint will depend on the number of epiphyses in the joint. For purposes of the wrist for example which consists of two epiphyses, the sum of the scores should be divided by the number of epiphyses.

Table 5.03: Formulae for Age Estimation from Respective Joints

Joint	Formula for Mean Score
Shoulder	Greater Tubercle (Score) + Head of Humerus (Score) / 2
Elbow	ME (Score) + Trochlea (Score) + Capitulum (Score) + LE (Score) + Proximal Radius (Score) /5
Wrist	Distal Ulna (Score) + Distal Radius (Score) / 2
Hip	HoF (Score) + GT (Score) + LT (Score) / 3
Knee	Dist. Fem + Prox Tib. + Prox Fib /3
Ankle	Dist. Tib. + Dist. Fib /2

This score associated with an age for the joint analyses as well as standard deviation can be found in *Appendix 3* (*Tables 3.01 to 3.07*) for males and *Appendix 4 for* females *(Tables 4.01 to 4.07)*. Data on genetic background have thus far yielded non-significant differences; however, the sample is made up of predominantly Black and Coloured South African individuals and suggested that these reference standards be limited to use in South Africans.

The present study also accommodates estimates based on individual epiphyses which may not be associated into a joint. *Appendix 5 (Tables 5.01 to 5.17*) presents the mean scores, associated stand deviation (SD) and ages for males and females (*Appendix 6, Tables 6.01 to 6.17*. The epiphysis in questions is assessed for stage of union an estimates would generated for males and females should sex be undetermined. Similar to the assessment of joint the mean scores are consulted for an age estimate (Refer to *Figure 5.06* for a worked example).



Mean Score for the Elbow in a male =

ME (Score) + Trochlea (Score) + Capitulum (Score) + LE (Score) + Proximal Radius (Score) /5

= (1) + (2) + (1) + (1) + (1)
= 6/5
= 1.2
Associated age estimate = 6 years (*Appendix A3*)

<u>Or Score for Proximal Radius</u>

= 1

Associated age estimate = 6 or 7 years *(Appendix A5)*

Figure 5.06: *Example of the application of the scoring system to epiphyses.*

CHAPTER 6: CONCLUSION

6.1 Conclusion

Due to a lack of radiographic reference standards for age at skeletal maturity in South African children and adolescents, a study of this nature was undertaken on radiographic images of contemporary children and adolescents and adults. The result of this exercise is the formulation of radiographic reference standards for this contemporary sample. The methodology used to ascertain stage of union from radiographs in contemporary samples can be utilised to assess age in forensic cases involving human skeletal remains. Additionally the individual data derived in the present study on union times for separate epiphyses may also serve as a reference for forensic cases where only incomplete skeletal remains are present.

Data were extracted from full body radiographic images and categorised by personal patient information in the form of residential address, language spoken, biological background and chronological age. All data came from hospitals and mortuaries around the Western Cape and hospitals around Gauteng. Determination of socio-economic status was conducted using census information based on the individual‟s suburb of origin. However, data for White South Africans is lacking.

Data for union times in South African children show that maturity in females at the elbow, hip and ankle are achieved at approximately 15 years of age followed by the knee at 16 years, wrist at 18 years, and shoulder at 20 years. The radiographically visible epiphyses of the iliac crest are the last epiphyses to complete union at 21 years. Males progress through union in the same sequence with the exception that there is a two year delay in the age at maturity. The elbow in males completes union at approximately 17 years followed by the hip and ankle at 18 years, knee at 19 years, wrist at 20 years, and shoulder at 21 years and finally the iliac crest at 22 years. The South African data concur with previous research which suggests that females attain skeletal maturity on average two years earlier compared to males. South African males tend to show prolonged periods of union before reaching maturity which appears to be a feature of African maturity (Dembetembe and Morris, 2012) compared to the rapid progression of union in females. Contrary to the prolonged union in males in general, females progress rapidly through the process. This is related to the hormonal differences between males and females and due to the effect of estrogen in females which promote maturity and union in females compared to males. The present study also agrees with the sequence of union first described by Stevenson (1924) and later Krogman (1955), McKern and Stewart (1957) and Johnston (1961) which states that union begins at the elbow and progresses to the hip followed by the ankle, knee, wrist shoulder and finally the iliac crest.

Data related to the biological differences in union times showed advanced but non-significant advanced union in the Coloured cohort compared to their Black peers. Age at maturity is thought to be influenced by the socio economic status (SES) as well as biological background of individuals. Data on skeletal maturity were used to determine whether the observed differences were due to SES or biological background. Residential suburbs were used as a proxy for SES owing to the apartheid system which was practised in South Africa. Apartheid was a policy or system of segregation or discrimination on grounds of genetic background which favoured Whites and whose effects still shape modern South African population distribution. Residential areas in Cape Town and Johannesburg still maintain their racial character to large degree. Coloured communities (also known as South African Coloured or SAC) in the Cape Town area are both culturally and genetically distinctive. Their biological identity is unique to South Africa and is characterised by a wide range of genetic complexity (Tishkoff *et al.,* 2009, Patterson *et al.,* 2010). The genetic admixture of the SAC suggests that the SAC and Black individuals share significant African genetic heritage, but this may not be enough to homogenise them biologically. Data collected by the City of Cape of Town municipality in the most recent population census (2011) reveal that areas from which nearly all of the samples for the present study are derived originate from less well-off catchment area. This suggests that both Coloured and Black individuals were exposed to severe economic hardships and SES differentiation between them is not possible. Previous research on age at menarche (Hennenberg and Louw, 1995; Cameron, *et al*., 1993 and Cameron, 2003) has found a lower mean age of menarche in South African Coloured females compared to Black females and has interpreted this as due to difference in SES conditions. Given the lack of strong SES differences between the two communities in this study, the observed advanced union in SAC appears more likely to be an effect of the biological differences between the groups. Therefore observed differences have been attributed to biological origin opposed to SES differences.

The extensive review of available literature suggests that differences in union time due to population origins are common on a world-wide scale. The difference in union times have been explained by the effect of the environment on growth, differences in social, genetic background, economic situations and methodology. However; in general it appears as if the South African sample shows delayed union at most sites compared to the rest of the populations observed. It is impossible from the data gathered here to be precise as to whether the delay in the timing of epiphyseal union in SA is caused by biological differences or because South Africans are still behind in their secular transition to the optimum growth rate.

Skeletal material from the Dart collection in Johannesburg was radiographed in order to enable comparison between the x-ray images and the state of fusion seen in gross skeletal remains. The results of this test showed high levels of agreement between the two comparisons and concluded that the amended methodology could be applied to forensic cases involving human skeletal remains. The data on union times and the progression of stages of union derived in this study may be used as a reference standard for direct observation on dry bones in South African cases of skeletonised remains. However, in forensic cases there is seldom a complete skeleton and only some epiphyses may be presented for assessment. The reference standards therefore may also be used for individual joints.

Stages of union for each epiphysis and joint are compared to the relevant sex based reference standards for joints presented in *Appendices 3 - 6*. Where only limited bones are presented, sex must be determined and if this is not possible then estimates for both sexes should be obtained. The skeletal elements present should be assessed for stage of union and tables related to individual epiphyses should be consulted for age estimates. The data from the present study is representative of Black and Coloured individuals of South Africa. The sample lacked substantial individuals from the European genetic background. Therefore, the reference standards should be used with caution on individuals of unknown genetic origin.

6.2 Future Research

Future research should concentrate on collecting more data to fill the gaps such as data for South African White children as well as to add onto data for females.

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Appendix 1: ETHICS APPROVAL

UNIVERSITY OF CAPE TOWN

Health Sciences Faculty
Research Ethics Committee
Room E52-24 Groote Schuur Hospital Old Main Building
Observatory 7925
Telephone [021] 406 6338 • **Facsimile** [021] 406 6411
e-mail: lamees.emjedi@uct.ac.za

17 June 2009

REC REF: 274/2009

Prof A Morris
Human Biology

Dear Prof Morris

PROJECT TITLE: SEQUENTIAL CHANGES IN EPIPHYSEAL UNION IN SOUTH AFRICAN CHILDREN BETWEEN THE AGES THIRTEEN UP TO TWENTY ONE YEARS USING FULLY BODY LODOX SCANS

Thank you for submitting your study to the Research Ethics Committee for review.

It is a pleasure to inform you that the Ethics Committee has **formally approved** the above-mentioned study.

Approval is granted for one year till the 30th June 2010.

Student involved in this research: Kavita Chibba

Please send us an annual progress report if your research continues beyond the approval period. Alternatively, please send us a brief summary of your findings so that we can close the research file.

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Please quote the REC. REF in all your correspondence.

Chris Hani Baragwanath Hospital
Department of Radiology
P O Bertsham
2013

Tel: +27 11 933-8411
Fax: +27 11 933.8424
Email: nagdeeia@gmail.com

14/01/10

Re: KABITA CHIBBA

THIS IS TO GRANT PERMISSION TO KABITA CHIBBA TO USE THE RADIOLOGICAL INFORMATION (RETROSPECTIVE) FROM THE LODOX FOR HER PHD STUDY (VIA UCT).
THIS STUDY HAS TO BE DONE IN CONJUNCTION WITH A CONSULTANT IN THE DEPT OF RADIOLOGY.

REGARDS

PROF MALA MODI
CHIEF SPECIALIST
HEAD OF DEPT: RADIOLOGY

School of Anatomical Sciences

University of the Witwatersrand, Johannesburg

7 York Rd, Parktown, 2193, South Africa • Tel: +27 11 717 2713 • Fax: +27 11 717 2422 • www.wits.ac.za

Date: 4th April 2011

To Whom It May Concern:

This letter aims to confirm permission granted to Kavita Chiba (PhD candidate), for the radiological assessment of specimens housed within the Raymond Dart skeletal repository, Medical School, University of the Witwatersrand. Radiological assessment was proposed to be carried out at the Charlotte Maxeke Hopsital, Trauma unit, Johannesburg.

Conditions

The Collections policy clearly stipulates that the skeletal material may only be removed from the repository under the strict supervision and accompaniment of the curator.

Specimens may not be used for no longer than 24 hours outside of the actual repository.

Specimens may not be stored overnight outside of the actual repository and should be returned daily.

Permission for use has been granted for a period of 3 months only (4 April 2011- 4 June 2011).

The School will take no liability for any damage caused to specimens during the radiological assessment and analysis.

Yours sincerely

Thomas J. Daly

(Head of School)

Anatomical Sciences

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG
Division of the Deputy Registrar (Research)

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)
R14/49 Ms Kavita Chibba

CLEARANCE CERTIFICATE	**M10456**
PROJECT	The Sequential Changes in Epiphyseal Union in South African Children Using Low Dose X-Rays
INVESTIGATORS	Ms Kavita Chibba.
DEPARTMENT	School of Anatomy
DATE CONSIDERED	30/04/2010
DECISION OF THE COMMITTEE*	Approved unconditionally

Unless otherwise specified this ethical clearance is valid for 5 years and may be renewed upon application.

DATE 03/05/2010 **CHAIRPERSON** ....
(Professor PE Cleaton-Jones)

*Guidelines for written 'informed consent' attached where applicable
cc: Supervisor : Prof A Morris

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10004, 10th Floor, Senate House, University.
I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to a completion of a yearly progress report.**

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES...

Kavita Chibba

From:	Peter Cleaton-Jones [Peter.Cleaton-Jones@wits.ac.za]
Sent:	17 March 2011 07:43 AM
To:	Kavita Chibba
Cc:	joseph.daly@wits.ac.za
Subject:	RE: Epiphyseal union in South African Children

Dear Mr Chibba,

I confirm that to study anatomical material in the Dart collection you do not require ethics approval only the approval of the Head of the School of Anatomical Sciences Professor Joseph Daly. Such anatomical material is covered in a section of the National Health Act - Professor Daly has a formal waiver from the ethics committee confirming this.

Good Luck,

Peter Cleaton-Jones
Chair, Wits HREC(Medical)

From: Kavita Chibba [mailto:KChibba@npa.gov.za]
Sent: Wed 2011/03/16 04:26 PM
To: Peter Cleaton-Jones
Cc: kavitachibba@yahoo.com
Subject: Epiphyseal union in South African Children

Dear Professor Jones

I am writing to you after our brief yet very insightful discussion this morning.
Let me recap to remind you. I thought I needed to amend my ethics application as I now need to take radiographic images of anatomical material from the Dart collection at medical school. You explained to me that I all I needed was a letter from department of Anatomy. However you did suggest you would write a letter for me stating that.

Thank you kindly for your assistance
Kavita Chibba
Missing Persons Task Team
National Prosecuting Authority
Tel: 012 845 6353
Cell: 0832682357
Email: kchibba@npa.gov.za

Netcare Milpark Hospital

Tel: +27 (0) 11 480 5600
Fax: +27 (0) 11 482 3317
9 Guild Road, Parktown West, Johannesburg, South Africa
PO Box 91155, Auckland Park, 2006, South Africa
www.netcare.co.za

29 July 2010

Fax and Mail to:
Professor K Boffard
Milpark Hospital

Dear Professor Boffard

RE: Kavita Chibba-LODOX The Sequential changes in Epiphyseal Union in South African Children using low dose X-Rays

The Netcare Milpark Hospital Ethics Committee has reviewed the above mentioned research Project

Approval has been granted to conduct the research at Netcare Milpark Hospital.

We wish you every success in your recruitment. The Netcare Milpark Hospital Ethics committee requires a Progress report and your Documented Findings on completion of the research

Yours sincerely

Dr Pro Obe I- Chairperson Netcare Milpark Hospital Ethics Committee

Appendix 2: CATERGORISATION OF RESIDENTIAL SUBURBS INTO SES CLASSES

Table 2.1: Classification of SES by Residential Suburb

Suburb	Black	White	Coloured	Education	Employment	Wage less than R3,200 p/m	Dwelling	Access to water	Toilet	Refuse Removal	Electricity for lighting	SES Category
Masiphumelele	91			35	69	82	27	73	91	99	95	MWC
Phillippi	94			32	62	78	44	67	77	84	86	MWC
Mfuleni	96			32	60	77	51	78	87	88	84	MWC
Khayelitsha	99			36	62	74	45	62	72	81	81	MWC
Nyanga	99			31	55	74	67	79	81	92	95	MWC
Langa	99			40	60	72	58	67	72	94	98	MWC
Guguletu	99			37	60	71	52	58	63	89	97	MWC
Delft	46		52	27	59	69	83	90	91	98	96	IMC
Manenberg			85	26	64	61	90	98	94	99.7	99	IMC
Hanover Park			94	24	64	58	91	96	91	99	99	IMC
Strand	54	17	27	42	74	58	77	92	95	98	95	IMC
Steenberg			94	36	81	53	96	99	97	99.7	99.7	IMC
Bonteheuwel			94	23	73	52	87	96	91	99	99	IMC
Atantis			85	32	73	50	85	88	82	96	85	IMC
Elsies River			89	28	76	50	84	95	89	95	95	IMC
Bishop Lavis			92	28	74	47	81	98	92	99	99	IMC
Retreat			87	38	82	39	93	97	94	99	99	IMC
Mitchells Plain			91	35	76	38	95	99	96	99.5	99	IMC
Salt River	40	45		65	81	38	98	99.8	99	96	99	IMC
Belhar			90	38	79	35	93	99	95	99.5	99	IMC
Maitland	42		50	59	86	34	93	96	96	99	99	IMC
Grassy Park			88	50	86	32	98	99.7	98	99.9	99	IMC

Athlone			62	59	88	31	95	96	96	97	97	IMC
Observatory	40	34		85	91	31	99	99	98	99	99	IMC
Eereste Rivier			79	43	79	30	93	98	88	99	98	IMC
Woodstock	25	14	50	62	86	28	98	99	98	99	98	IMC
Kuils River	19	20	58	61	87	27	92	99	97	99	99	IMC
Parow		28	57	56	87	27	97	99.5	98	98	99	IMC
Wyneberg	21	24	46	70	91	26	99	99.5	99	99	99.5	IMC

Suburb	**Black**	**White**	**Coloured**	**Education**	**Employment**	**Wage less than R3,200 p/m**	**Dwelling**	**Access to water**	**Toilet**	**Refuse Removal**	**Electricity for lighting**	**SES Category**
Lansdowne			66	65	90	24	98	99	99	99	99	IMC
Rondebosch	24	56		92	95	24	99	99	99	99	99.5	IMC
Fishhoek		81		81	95	22	99	99.6	99.7	99.6	99.8	IMC
Hout Bay		56	33	68	88	22	94	98	94	99	99	IMC
Kraaifontein		46	42	64	94	22	98	99	97	99	99	IMC
Goodwood		44	32	67	93	21	99	99.5	99	96	99.5	UC
Ottery			72	66	91	20	96	96	99	99	99	UC
Bellville		61		77	93	19	99	99.7	99.5	99	99.6	UC
Someset West		73		81	94	19	98	99	98	99	99	UC
Plumstead		55	29	75	94	18	99	99	99	99	99	UC
Cape Town CBD	47	31		89	95	18	99	99.5	99.5	97	99.6	UC
Muizenberg	23	50	18	81	93	18	99	99.8	99	99	100	UC
Table View		76		82	94	15	99.5	99.6	99	99	99.6	UC
Claremont		64		89	95	15	99.5	99.8	99.6	99	99.9	UC
Milnerton		72		84	95	12	99	99.5	99	99.5	99	UC
Pinelands		62		88	96	10	99.5	99.8	99.9	99.7	99.6	UC

Appendix 3: MEAN SCORES FOR JOINTS IN MALES (TABLES 3.01 – 3.07)

Table A3.01: Mean Scores and Associated age for the Shoulder Males

Age	N	Min	Max	Mean	SD
6	3	2	2	1.50	0.000
7	44	2	2	1.51	0.075
8	90	1	2	1.52	0.128
9	57	2	2	1.52	0.093
10	68	2	3	1.60	0.216
11	58	2	2	1.65	0.230
12	58	2	3	1.82	0.334
13	36	2	4	1.97	0.534
14	19	2	3	2.63	0.496
15	25	2	4	3.04	0.539
16	24	3	4	3.08	0.282
17	59	3	4	3.42	0.490
18	61	3	4	3.70	0.459
19	89	3	4	3.79	0.405
20	85	2	4	3.94	0.283
21	94	3	4	3.96	0.203
22	101	3	4	3.98	0.148
23	82	3	4	3.96	0.189
24	94	4	4	4.00	0.000

Table A3.02: Mean Scores and Associated age for the Elbow in Males

Age	N	Min	Max	Mean	SD
6	4	1	1	1.20	0.000
7	44	2	2	1.51	0.075
8	95	1	2	1.18	0.148
9	59	1	2	1.25	0.181
10	68	2	3	1.60	0.216
11	58	1	3	1.63	0.342
12	63	1	4	2.09	0.525
13	39	1	4	2.45	0.858
14	19	2	4	3.35	0.727
15	25	3	4	3.86	0.314
16	23	3	4	3.95	0.183
17	59	4	4	4.00	0.000
18	61	4	4	3.99	0.051
19	89	4	4	4.00	0.000
20	86	4	4	4.00	0.000
21	94	4	4	4.00	0.000
22	102	4	4	4.00	0.000
23	82	4	4	4.00	0.000
24	94	4	4	4.00	0.000

Table A3.03: Mean Scores and Associated age for the Wrist in Males

Age	N	Min	Max	Mean	SD
6	3	1	1	1.00	0.000
7	44	1	2	1.03	0.127
8	81	1	2	1.06	0.158
9	53	1	2	1.17	0.293
10	62	1	2	1.27	0.347
11	42	1	2	1.45	0.410
12	45	1	2	1.62	0.401
13	30	1	4	1.88	0.751
14	15	2	3	2.43	0.495
15	23	2	4	3.04	0.638
16	20	2	4	3.20	0.616
17	59	3	4	3.75	0.429
18	61	3	4	3.90	0.300
19	89	3	4	3.93	0.252
20	86	3	4	3.97	0.185
21	94	4	4	4.00	0.000
22	102	3	4	3.99	0.099
23	82	3	4	3.99	0.110
24	94	3	4	3.99	0.103

Table A3.04: Mean Scores and Associated age for the Hip in Males

Age	N	Min	Max	Mean	SD
6	4	1	2	1.42	0.167
7	55	1	2	1.39	0.182
8	112	1	2	1.43	0.211
9	75	1	2	1.52	0.275
10	89	1	2	1.68	0.348
11	72	1	2	1.92	0.305
12	84	1	3	2.02	0.342
13	52	1	4	2.22	0.571
14	24	2	4	2.65	0.618
15	30	2	4	3.33	0.637
16	24	2	4	3.69	0.564
17	59	3	4	3.96	0.153
18	61	3	4	3.99	0.085
19	89	4	4	3.99	0.050
20	86	3	4	3.99	0.072
21	94	4	4	4.00	0.000
22	102	4	4	4.00	0.000
23	82	4	4	4.00	0.000
24	94	4	4	4.00	0.000

Appendix 3: MEAN SCORES FOR JOINTS IN MALES CONT…

Table A3.05: Mean Scores and Associated age for the Ankle Males

Age	N	Min	Max	Mean	SD
6	4	1	2	1.25	0.319
7	54	1	2	1.24	0.300
8	112	1	2	1.29	0.287
9	74	1	2	1.49	0.354
10	88	1	2	1.69	0.383
11	69	1	3	1.97	0.367
12	82	1	3	2.10	0.303
13	52	1	4	2.25	0.502
14	24	2	4	2.57	0.496
15	30	2	4	3.11	0.583
16	23	2	4	3.36	0.521
17	59	3	4	3.82	0.368
18	61	3	4	3.93	0.250
19	89	3	4	3.98	0.149
20	86	3	4	3.99	0.072
21	94	4	4	4.00	0.000
22	102	3	4	3.99	0.099
23	82	4	4	4.00	0.000
24	94	4	4	4.00	0.000

Table A3.06: Mean Scores and Associated age for the Iliac Crest Males

Age	N	Min	Max	Mean	SD
6	4	1	1	1.00	0.000
7	55	1	1	1.00	0.000
8	112	1	1	1.00	0.000
9	75	1	1	1.00	0.000
10	91	1	1	1.00	0.000
11	72	1	1	1.00	0.000
12	84	1	1	1.00	0.000
13	52	1	4	1.15	0.607
14	24	1	3	1.33	0.637
15	30	1	4	2.00	0.910
16	24	1	4	2.63	0.711
17	59	1	4	3.29	0.767
18	61	1	4	3.59	0.616
19	89	2	4	3.66	0.499
20	86	2	4	3.88	0.357
21	94	3	4	3.96	0.203
22	102	3	4	3.98	0.139
23	82	3	4	3.99	0.110
24	94	4	4	4.00	0.000

Table A3.07: Mean Scores and Associated age for the Knee in Males

Age	N	Min	Max	Mean	SD
6	4	1	2	1.25	0.319
7	54	1	2	1.24	0.300
8	112	1	2	1.29	0.287
9	74	1	2	1.49	0.354
10	88	1	2	1.69	0.383
11	69	1	3	1.97	0.367
12	82	1	3	2.10	0.303
13	52	1	4	2.25	0.502
14	24	2	4	2.57	0.496
15	30	2	4	3.11	0.583
16	23	2	4	3.36	0.521
17	59	3	4	3.82	0.368
18	61	3	4	3.93	0.250
19	89	3	4	3.98	0.149
20	86	3	4	3.99	0.072
21	94	4	4	4.00	0.000
22	102	3	4	3.99	0.099
23	82	3	4	3.99	0.110
24	94	4	4	4.00	0.000

Appendix 4: MEAN SCORES FOR JOINTS IN FEMALES (TABLES 4.01- 4.07)

Table A4.01: Mean Scores and Associated age for the Shoulder in Females

Age	N	Min	Max	Mean	SD
6	4	2	2	1.50	0.000
7	28	1	2	1.48	0.094
8	55	2	3	1.64	0.263
9	57	2	3	1.71	0.266
10	31	2	3	1.87	0.387
11	40	2	3	2.08	0.538
12	40	2	3	2.60	0.533
13	16	2	3	2.50	0.516
14	9	2	3	2.89	0.333
15	8	3	4	3.25	0.463
16	3	3	4	3.17	0.289
17	5	4	4	3.80	0.274
18	9	4	4	3.94	0.167
19	10	3	4	3.90	0.316
20	9	4	4	4.00	0.000
21	21	4	4	4.00	0.000
22	16	3	4	3.94	0.250
23	18	3	4	3.94	0.236
24	9	4	4	4.00	0.000

Table A4.02: Mean Scores and Associated age for the Elbow in Females

Age	N	Min	Max	Mean	SD
6	4	1	2	1.35	0.191
7	30	1	2	1.31	0.227
8	56	1	4	1.44	0.404
9	57	1	3	1.66	0.517
10	32	1	3	1.98	0.509
11	39	1	4	2.71	0.792
12	41	1	4	3.23	0.750
13	17	3	4	3.59	0.487
14	9	1	4	3.60	0.889
15	8	4	4	3.98	0.071
16	3	4	4	4.00	0.000
17	5	4	4	4.00	0.000
18	9	4	4	4.00	0.000
19	10	4	4	4.00	0.000
20	9	4	4	4.00	0.000
21	21	4	4	4.00	0.000
22	16	4	4	4.00	0.000
23	18	4	4	4.00	0.000
24	9	4	4	4.00	0.000

Table A4.03: Mean Scores and Associated age for the Wrist in Females

Age	N	Min	Max	Mean	SD
6	4	1	2	1.38	0.250
7	28	1	2	1.13	0.259
8	46	1	2	1.21	0.343
9	49	1	2	1.38	0.402
10	26	1	2	1.62	0.408
11	32	1	3	1.83	0.414
12	34	1	4	2.21	0.579
13	13	2	3	2.46	0.519
14	28	1	2	1.13	0.259
15	8	2	4	2.94	0.678
16	8	3	4	3.63	0.518
17	3	3	4	3.67	0.577
18	5	4	4	4.00	0.000
19	9	4	4	4.00	0.000
20	10	4	4	4.00	0.000
21	9	4	4	4.00	0.000
22	16	4	4	4.00	0.000
23	18	4	4	4.00	0.000
24	9	4	4	4.00	0.000

Table A4.04: Mean Scores and Associated age for the Hip in Females

Age	N	Min	Max	Mean	SD
6	4	1	2	1.50	0.192
7	35	1	2	1.50	0.260
8	67	1	3	1.70	0.361
9	68	1	3	1.88	0.304
10	44	2	3	2.11	0.225
11	46	2	3	2.20	0.277
12	45	2	4	2.53	0.597
13	18	2	4	2.65	0.542
14	8	4	4	4.00	0.000
15	9	2	4	3.26	0.741
16	3	4	4	4.00	0.000
17	5	4	4	4.00	0.000
18	9	4	4	4.00	0.000
19	10	4	4	4.00	0.000
20	10	2	4	3.80	0.632
21	21	4	4	4.00	0.000
22	16	4	4	4.00	0.000
23	18	4	4	4.00	0.000
24	9	4	4	4.00	0.000

Appendix 4: MEAN SCORES FOR JOINTS IN FEMALES CONT…

Table A4.05: Mean Scores and Associated age for the Knee in Females

Age	N	Min	Max	Mean	SD
6	4	1	2	1.58	0.319
7	35	1	2	1.30	0.273
8	67	1	3	1.65	0.371
9	68	1	2	1.90	0.351
10	44	2	2	2.09	0.253
11	46	2	3	2.30	0.283
12	45	2	3	2.49	0.345
13	18	2	3	2.57	0.223
14	9	2	4	3.15	0.626
15	8	3	4	3.83	0.309
16	5	4	4	4.00	0.000
17	9	4	4	4.00	0.000
18	10	4	4	4.00	0.000
19	10	2	4	3.83	0.527
20	21	4	4	4.00	0.000
21	16	3	4	3.94	0.250
22	18	4	4	4.00	0.000
23	9	4	4	4.00	0.000
24	94	4	4	4.00	0.000

Table A4.06: Mean Scores and Associated age for the Ankle in Females

Age	N	Min	Max	Mean	SD
6	4	2	2	2.00	0.000
7	35	2	2	2.00	0.000
8	65	2	2	2.00	0.000
9	67	2	2	2.00	0.000
10	44	2	3	2.01	0.075
11	46	2	3	2.03	0.163
12	44	2	4	2.45	0.618
13	18	2	4	2.47	0.606
14	9	2	4	3.11	0.782
15	8	4	4	4.00	0.000
16	3	4	4	4.00	0.000
17	5	4	4	4.00	0.000
18	9	4	4	4.00	0.000
19	10	4	4	4.00	0.000
20	10	2	4	3.80	0.632
21	15	4	4	4.00	0.000
22	18	4	4	4.00	0.000
23	9	4	4	4.00	0.000
24	82	4	4	4.00	0.000

Table A4.07: Mean Scores and Associated age for the Iliac Crest in Females

Age	N	Min	Max	Mean	SD
6	4	1	1	1.00	0.000
7	35	1	1	1.00	0.000
8	67	1	1	1.00	0.000
9	68	1	1	1.00	0.000
10	44	1	1	1.00	0.000
11	46	1	2	1.02	0.147
12	45	1	3	1.22	0.471
13	18	1	2	1.17	0.383
14	9	1	3	1.67	0.707
15	8	1	4	2.75	0.886
16	3	3	3	3.00	0.000
17	5	3	4	3.20	0.447
18	9	3	4	3.78	0.441
19	10	3	4	3.70	0.483
20	10	1	4	3.60	0.966
21	21	4	4	4.00	0.000
22	16	4	4	4.00	0.000
23	18	4	4	4.00	0.000
24	9	4	4	4.00	0.000

Appendix 5: MEAN SCORES FOR EPIPHYSES IN MALES (TABLES 5.01 TO 5.18)

Table A5.01: Mean Scores and Associated ages for Head of Humerus in Males

Age (yrs.)	N	Min	Max	Mean	SD
6	3	2	2	2.00	0.000
7	44	2	2	2.00	0.000
8	90	1	2	1.99	0.105
9	57	2	2	2.00	0.000
10	68	2	3	2.01	0.121
11	58	2	2	2.00	0.000
12	58	2	3	2.03	0.184
13	36	2	4	2.14	0.424
14	19	2	3	2.63	0.496
15	25	2	4	3.04	0.539
16	24	3	4	3.08	0.282
17	59	3	4	3.44	0.501
18	61	3	4	3.70	0.460
19	89	3	4	3.80	0.404
20	85	2	4	3.94	0.283
21	94	3	4	3.96	0.203
22	101	3	4	3.98	0.140
23	82	3	4	3.96	0.189
24	94	4	4	4.00	0.000

Table A5.02: Mean Scores and Associated ages for Greater Tubercle in Males

Age (yrs.)	N	Min	Max	Mean	SD
6	3	1	1	1.00	0.000
7	44	1	2	1.02	0.151
8	90	1	2	1.06	0.230
9	57	1	2	1.04	0.186
10	68	1	2	1.18	0.384
11	58	1	2	1.29	0.459
12	58	1	3	1.60	0.560
13	36	1	4	1.81	0.710
14	19	2	3	2.63	0.496
15	25	2	4	3.04	0.539
16	24	3	4	3.08	0.282
17	59	3	4	3.41	0.495
18	61	3	4	3.69	0.467
19	89	3	4	3.78	0.420
20	85	2	4	3.94	0.283
21	94	3	4	3.96	0.203
22	101	3	4	3.97	0.171
23	82	3	4	3.96	0.189
24	94	4	4	4.00	0.000

Table A5.03: Mean Scores and Associated ages for Medial Epicondyle in Males

Age (yrs.)	N	Min	Max	Mean	SD
6	4	1	1	1.00	0.000
7	47	1	2	1.06	0.247
8	95	1	2	1.07	0.263
9	59	1	2	1.20	0.406
10	75	1	2	1.39	0.490
11	58	1	3	1.72	0.555
12	63	1	3	1.97	0.567
13	39	1	4	2.36	0.873
14	19	2	4	3.21	0.713
15	25	2	4	3.68	0.627
16	23	3	4	3.91	0.288
17	59	4	4	4.00	0.000
18	61	3	4	3.98	0.128
19	89	4	4	4.00	0.000
20	86	4	4	4.00	0.000
21	94	4	4	4.00	0.000
22	102	4	4	4.00	0.000
23	82	4	4	4.00	0.000
24	94	4	4	4.00	0.000

Appendix 5: MEAN SCORES FOR EPIPHYSES IN MALES CONT…

Table A5.04: Mean Scores and Associated ages for Trochlea in Males

Age (yrs.)	N	Min	Max	Mean	SD
6	4	1	2	1.25	0.500
7	47	1	1	1.00	0.000
8	95	1	2	1.04	0.202
9	59	1	2	1.03	0.183
10	75	1	3	1.11	0.352
11	58	1	3	1.41	0.593
12	63	1	4	2.13	0.871
13	39	1	4	2.38	1.115
14	19	1	4	3.42	0.961
15	25	3	4	3.96	0.200
16	23	4	4	4.00	0.000
17	59	4	4	4.00	0.000
18	61	4	4	4.00	0.000
19	89	4	4	4.00	0.000
20	86	4	4	4.00	0.000
21	94	4	4	4.00	0.000
22	102	4	4	4.00	0.000
23	82	4	4	4.00	0.000
24	94	4	4	4.00	0.000

Table A5.05: Mean Scores and Associated ages for Capitulum in Males

Age (yrs.)	N	Min	Max	Mean	SD
6	4	1	2	1.75	0.500
7	47	1	3	1.55	0.544
8	95	1	3	1.71	0.481
9	59	1	3	1.85	0.407
10	75	1	3	1.97	0.519
11	58	1	3	2.17	0.534
12	63	2	4	2.67	0.539
13	39	2	4	3.00	0.688
14	19	3	4	3.63	0.496
15	25	3	4	3.96	0.200
16	23	3	4	3.96	0.209
17	59	4	4	4.00	0.000
18	61	4	4	4.00	0.000
19	89	4	4	4.00	0.000
20	86	4	4	4.00	0.000
21	94	4	4	4.00	0.000
22	102	4	4	4.00	0.000
23	82	4	4	4.00	0.000
24	94	4	4	4.00	0.000

Table A5.06: Mean Scores and Associated ages for Lateral Epicondyle in Males

Age (yrs.)	N	Min	Max	Mean	SD
6	4	1	1	1.00	0.000
7	47	1	1	1.00	0.000
8	95	1	1	1.00	0.000
9	59	1	1	1.00	0.000
10	75	1	3	1.03	0.231
11	58	1	3	1.10	0.360
12	63	1	4	1.54	0.820
13	39	1	4	2.10	1.209
14	19	1	4	3.21	1.134
15	25	3	4	3.88	0.332
16	23	3	4	3.96	0.209
17	59	4	4	4.00	0.000
18	61	3	4	3.98	0.128
19	89	4	4	4.00	0.000
20	86	4	4	4.00	0.000
21	94	4	4	4.00	0.000
22	102	4	4	4.00	0.000
23	82	4	4	4.00	0.000
24	94	4	4	4.00	0.000

Appendix 5: MEAN SCORES FOR EPIPHYSES IN MALES CONT…

Table 5.07: Mean Scores and Associated ages for Proximal Radius in Males

Age (yrs.)	N	Min	Max	Mean	SD
6	4	1	1	1.00	0.000
7	47	1	1	1.00	0.000
8	95	1	2	1.06	0.245
9	59	1	2	1.19	0.393
10	75	1	2	1.36	0.483
11	58	1	2	1.72	0.451
12	63	1	3	2.14	0.503
13	39	1	4	2.38	0.907
14	19	2	4	3.26	0.872
15	25	2	4	3.80	0.500
16	23	3	4	3.91	0.288
17	59	4	4	4.00	0.000
18	61	4	4	4.00	0.000
19	89	4	4	4.00	0.000
20	86	4	4	4.00	0.000
21	94	4	4	4.00	0.000
22	102	4	4	4.00	0.000
23	82	4	4	4.00	0.000
24	94	4	4	4.00	0.000

Table A5.08: Mean Scores and Associated ages for Distal Ulna in Males

Age (yrs.)	N	Min	Max	Mean	SD
6	3	1	1	1.00	0.000
7	44	1	1	1.00	0.000
8	82	1	2	1.01	0.110
9	53	1	2	1.08	0.267
10	62	1	2	1.11	0.319
11	42	1	2	1.31	0.468
12	45	1	2	1.47	0.505
13	30	1	4	1.83	0.791
14	15	2	4	2.47	0.640
15	23	2	4	3.04	0.638
16	20	2	4	3.20	0.616
17	59	3	4	3.76	0.429
18	61	3	4	3.90	0.300
19	89	3	4	3.93	0.252
20	86	3	4	3.97	0.185
21	94	4	4	4.00	0.000
22	102	3	4	3.99	0.099
23	82	3	4	3.99	0.110
24	94	3	4	3.99	0.103

Table 5.09: Mean Scores and Associated ages for Distal Radius in Males

Age (yrs.)	N	Min	Max	Mean	SD
6	3	1	1	1.00	0.000
7	44	1	2	1.07	0.255
8	81	1	2	1.10	0.300
9	53	1	2	1.26	0.445
10	62	1	2	1.42	0.497
11	42	1	2	1.60	0.497
12	46	1	2	1.78	0.417
13	30	1	4	1.93	0.740
14	15	2	3	2.40	0.507
15	23	2	4	3.04	0.638
16	20	2	4	3.20	0.616
17	59	3	4	3.75	0.439
18	61	3	4	3.90	0.300
19	89	3	4	3.93	0.252
20	86	3	4	3.97	0.185
21	94	4	4	4.00	0.000
22	102	3	4	3.99	0.099
23	82	3	4	3.99	0.110
24	94	3	4	3.99	0.103

Appendix 5: MEAN SCORES FOR EPIPHYSES IN MALES CONT…

Table A5.10: Mean Scores and Associated ages for Iliac Crest in Males

Age (yrs.)	N	Min	Max	Mean	SD
6	4	1	1	1.00	0.000
7	55	1	1	1.00	0.000
8	112	1	1	1.00	0.000
9	75	1	1	1.00	0.000
10	91	1	1	1.00	0.000
11	72	1	1	1.00	0.000
12	84	1	1	1.00	0.000
13	52	1	4	1.15	0.607
14	24	1	3	1.33	0.637
15	30	1	4	2.00	0.910
16	24	1	4	2.63	0.711
17	59	1	4	3.29	0.767
18	61	1	4	3.59	0.616
19	89	2	4	3.66	0.499
20	86	2	4	3.88	0.357
21	94	3	4	3.96	0.203
22	102	3	4	3.98	0.139
23	82	3	4	3.99	0.110
24	94	4	4	4.00	0.000

Table A5.11: Mean Scores and Associated ages for Head of Femur in Males

Age (yrs.)	N	Min	Max	Mean	SD
6	4	2	2	2.00	0.000
7	55	2	3	2.07	0.262
8	112	1	3	2.11	0.364
9	75	2	3	2.24	0.430
10	89	2	3	2.43	0.497
11	72	2	3	2.72	0.451
12	84	2	3	2.80	0.404
13	52	2	4	2.90	0.495
14	24	3	4	3.25	0.442
15	30	3	4	3.57	0.504
16	24	3	4	3.83	0.381
17	59	4	4	4.00	0.000
18	61	4	4	4.00	0.000
19	89	3	4	3.99	0.106
20	86	4	4	4.00	0.000
21	94	4	4	4.00	0.000
22	102	4	4	4.00	0.000
23	82	4	4	4.00	0.000
24	94	4	4	4.00	0.000

Table A5.12: Mean Scores and Associated ages for Greater Trochanter in Males

Age (yrs.)	N	Min	Max	Mean	SD
6	4	1	2	1.25	0.500
7	55	1	2	1.11	0.315
8	112	1	2	1.15	0.360
9	75	1	2	1.28	0.452
10	89	1	2	1.55	0.500
11	72	1	2	1.85	0.362
12	84	1	3	1.89	0.411
13	52	1	4	2.17	0.585
14	24	2	4	2.58	0.717
15	30	2	4	3.30	0.651
16	24	1	4	3.63	0.711
17	59	3	4	3.95	0.222
18	61	3	4	3.98	0.128
19	89	3	4	3.99	0.106
20	86	2	4	3.98	0.216
21	94	4	4	4.00	0.000
22	102	4	4	4.00	0.000
23	82	4	4	4.00	0.000
24	94	4	4	4.00	0.000

Appendix 5: MEAN SCORES FOR EPIPHYSES IN MALES CONT…

Table A5.13: Mean Scores and Associated ages for Lesser Trochanter in Males

Age (yrs.)	N	Min	Max	Mean	SD
6	4	1	1	1.00	0.000
7	55	1	1	1.00	0.000
8	112	1	2	1.02	0.133
9	75	1	2	1.04	0.197
10	89	1	2	1.07	0.252
11	72	1	2	1.18	0.387
12	84	1	3	1.38	0.558
13	52	1	4	1.60	0.823
14	24	1	4	2.13	0.900
15	30	1	4	3.13	0.900
16	24	1	4	3.63	0.711
17	59	3	4	3.93	0.254
18	61	3	4	3.98	0.128
19	89	4	4	4.00	0.000
20	86	4	4	4.00	0.000
21	94	4	4	4.00	0.000
22	102	4	4	4.00	0.000
23	82	4	4	4.00	0.000
24	94	4	4	4.00	0.000

Table A5.14: Mean Scores and Associated ages for Distal Femur in Males

Age (yrs.)	N	Min	Max	Mean	SD
6	4	1	2	1.50	0.577
7	55	1	3	1.51	0.540
8	112	1	3	1.63	0.520
9	74	1	3	1.96	0.560
10	89	1	3	2.12	0.540
11	71	1	3	2.39	0.547
12	83	1	3	2.61	0.514
13	52	1	4	2.73	0.598
14	24	2	4	2.96	0.464
15	30	3	4	3.37	0.490
16	23	3	4	3.52	0.511
17	59	3	4	3.86	0.345
18	61	3	4	3.93	0.250
19	89	3	4	3.98	0.149
20	86	4	4	4.00	0.000
21	94	4	4	4.00	0.000
22	102	3	4	3.99	0.099
23	82	3	4	3.99	0.110
24	94	4	4	4.00	0.000

Table A5.15: Mean Scores and Associated ages for Proximal Tibia in Males

Age (yrs.)	N	Min	Max	Mean	SD
6	4	1	2	1.25	0.500
7	55	1	2	1.20	0.404
8	112	1	2	1.20	0.399
9	74	1	2	1.43	0.499
10	89	1	2	1.69	0.467
11	71	1	3	1.93	0.308
12	83	1	3	1.96	0.290
13	52	1	4	2.13	0.486
14	24	2	4	2.46	0.588
15	30	2	4	3.07	0.640
16	23	2	4	3.30	0.559
17	59	3	4	3.80	0.406
18	61	3	4	3.93	0.250
19	89	3	4	3.98	0.149
20	86	3	4	3.99	0.108
21	94	4	4	4.00	0.000
22	102	3	4	3.99	0.099
23	82	3	4	3.99	0.110
24	94	4	4	4.00	0.000

Appendix 5: MEAN SCORES FOR EPIPHYSES IN MALES CONT…

Table A5.16: Mean Scores and Associated ages for Proximal Fibula in Males

Age (yrs.)	N	Min	Max	Mean	SD
6	4	1	1	1.00	0.000
7	54	1	2	1.02	0.136
8	112	1	2	1.04	0.207
9	74	1	2	1.08	0.275
10	88	1	2	1.25	0.435
11	69	1	3	1.57	0.528
12	82	1	2	1.71	0.458
13	52	1	4	1.88	0.646
14	24	1	4	2.29	0.624
15	30	2	4	2.90	0.759
16	23	2	4	3.26	0.619
17	59	3	4	3.80	0.406
18	61	3	4	3.93	0.250
19	89	3	4	3.98	0.149
20	86	3	4	3.99	0.108
21	94	4	4	4.00	0.000
22	102	3	4	3.99	0.099
23	82	3	4	3.99	0.110
24	94	4	4	4.00	0.000

Table A5.17: Mean Scores and Associated ages for Distal Tibia in Males

Age (yrs.)	N	Min	Max	Mean	SD
6	4	1	2	1.50	0.577
7	54	1	2	1.98	0.136
8	111	1	2	1.97	0.163
9	74	2	2	2.00	0.000
10	89	2	2	2.00	0.000
11	72	2	2	2.00	0.000
12	83	2	3	2.02	0.154
13	51	2	4	2.22	0.541
14	24	2	4	2.67	0.702
15	29	2	4	3.24	0.636
16	23	2	4	3.65	0.573
17	58	3	4	3.91	0.283
18	60	3	4	3.98	0.129
19	89	3	4	3.99	0.106
20	86	4	4	4.00	0.000
21	94	4	4	4.00	0.000
22	102	4	4	4.00	0.000
23	82	4	4	4.00	0.000
24	94	4	4	4.00	0.000

Table A5.18: Mean Scores and Associated ages for Distal Fibula in Males

Age (yrs.)	N	Min	Max	Mean	SD
6	4	1	2	1.50	0.577
7	52	1	2	1.98	0.139
8	111	1	2	1.98	0.134
9	73	2	2	2.00	0.000
10	88	1	2	1.99	0.107
11	71	2	2	2.00	0.000
12	83	2	3	2.01	0.110
13	51	2	4	2.18	0.518
14	24	2	4	2.54	0.588
15	29	2	4	3.24	0.636
16	23	2	4	3.70	0.559
17	58	3	4	3.91	0.283
18	60	3	4	3.98	0.129
19	89	3	4	3.99	0.106
20	86	4	4	4.00	0.000
21	94	4	4	4.00	0.000
22	102	4	4	4.00	0.000
23	82	4	4	4.00	0.000
24	94	4	4	4.00	0.000

Appendix 6: MEAN SCORES FOR EPIPHYSES IN FEMALES (TABLES 6.1 TO 6.18)

Table A6.01: Mean Scores and Associated ages for HOH in Females

Age (yrs.)	N	Min	Max	Mean	SD
6	4	2	2	2.00	0.000
7	28	1	2	1.96	0.189
8	55	2	3	2.04	0.189
9	57	2	3	2.02	0.132
10	31	2	3	2.16	0.374
11	40	2	3	2.25	0.439
12	40	2	3	2.68	0.474
13	16	2	3	2.50	0.516
14	9	2	3	2.89	0.333
15	8	3	4	3.25	0.463
16	3	3	4	3.33	0.577
17	5	4	4	4.00	0.000
18	9	4	4	4.00	0.000
19	10	3	4	3.90	0.316
20	9	4	4	4.00	0.000
21	21	4	4	4.00	0.000
22	16	3	4	3.94	0.250
23	18	3	4	3.94	0.236
24	9	4	4	4.00	0.000

Table A6.02: Mean Scores and Associated ages for Greater Tubercle in Females

Age (yrs.)	N	Min	Max	Mean	SD
6	4	1	1	1.00	0.00
7	28	1	1	1.00	0.00
8	55	1	2	1.24	0.43
9	57	1	2	1.40	0.49
10	31	1	3	1.58	0.62
11	40	1	3	1.90	0.71
12	40	1	3	2.53	0.64
13	16	2	3	2.50	0.52
14	9	2	3	2.89	0.33
15	8	3	4	3.25	0.46
16	3	3	3	3.00	0.00
17	5	3	4	3.60	0.55
18	9	3	4	3.89	0.33
19	10	3	4	3.90	0.32
20	9	4	4	4.00	0.00
21	21	4	4	4.00	0.00
22	16	3	4	3.94	0.25
23	18	3	4	3.94	0.24
24	9	4	4	4.00	0.00

Table A6.03: Mean Scores and Associated ages for Medial Epicondyle in Females

Age (yrs.)	N	Min	Max	Mean	SD
6	4	1	2	1.50	0.577
7	30	1	2	1.37	0.490
8	56	1	3	1.54	0.571
9	57	1	3	1.70	0.626
10	32	1	3	1.97	0.595
11	39	1	4	2.41	0.751
12	41	1	4	2.90	0.800
13	17	2	4	3.18	0.809
14	9	1	4	3.44	1.130
15	8	4	4	4.00	0.000
16	3	4	4	4.00	0.000
17	5	4	4	4.00	0.000
18	9	4	4	4.00	0.000
19	10	4	4	4.00	0.000
20	9	4	4	4.00	0.000
21	21	4	4	4.00	0.000
22	16	4	4	4.00	0.000
23	18	4	4	4.00	0.000
24	9	4	4	4.00	0.000

Appendix 6: MEAN SCORES FOR EPIPHYSES IN FEMALES CONT…

Table A6.04: Mean Scores and Associated ages for Trochlea in Females

Age (yrs.)	N	Min	Max	Mean	SD
6	4	1	1	1.00	0.000
7	30	1	2	1.03	0.183
8	56	1	4	1.20	0.585
9	57	1	4	1.40	0.678
10	32	1	3	1.78	0.832
11	39	1	4	2.69	1.127
12	41	1	4	3.37	0.994
13	17	3	4	3.76	0.437
14	9	1	4	3.56	1.014
15	8	4	4	4.00	0.000
16	3	4	4	4.00	0.000
17	5	4	4	4.00	0.000
18	9	4	4	4.00	0.000
19	10	4	4	4.00	0.000
20	9	4	4	4.00	0.000
21	21	4	4	4.00	0.000
22	16	4	4	4.00	0.000
23	18	4	4	4.00	0.000
24	9	4	4	4.00	0.000

Table A6.05: Mean Scores and Associated ages for Capitulum in Females

Age (yrs.)	N	Min	Max	Mean	SD
6	4	2	2	2.00	0.000
7	30	1	3	2.00	0.455
8	56	1	4	2.11	0.562
9	57	1	4	2.28	0.590
10	32	2	3	2.69	0.471
11	39	2	4	3.26	0.637
12	41	2	4	3.61	0.586
13	17	3	4	3.76	0.437
14	9	2	4	3.78	0.667
15	8	4	4	4.00	0.000
16	3	4	4	4.00	0.000
17	5	4	4	4.00	0.000
18	9	4	4	4.00	0.000
19	10	4	4	4.00	0.000
20	9	4	4	4.00	0.000
21	21	4	4	4.00	0.000
22	16	4	4	4.00	0.000
23	18	4	4	4.00	0.000
24	9	4	4	4.00	0.000

Table A6.06: Mean Scores and Associated ages for Lateral Epicondyle in Females

Age (yrs.)	N	Min	Max	Mean	SD
6	4	1	1	1.00	0.000
7	30	1	1	1.00	0.000
8	56	1	4	1.07	0.420
9	57	1	3	1.23	0.567
10	32	1	3	1.41	0.712
11	39	1	4	2.51	1.144
12	41	1	4	3.12	0.980
13	17	3	4	3.71	0.470
14	9	1	4	3.56	1.014
15	8	4	4	4.00	0.000
16	3	4	4	4.00	0.000
17	5	4	4	4.00	0.000
18	9	4	4	4.00	0.000
19	10	4	4	4.00	0.000
20	9	4	4	4.00	0.000
21	21	4	4	4.00	0.000
22	16	4	4	4.00	0.000
23	18	4	4	4.00	0.000
24	9	4	4	4.00	0.000

Appendix 6: MEAN SCORES FOR EPIPHYSES IN FEMALES CONT…

Table A6.07: Mean Scores and Associated ages for Proximal Radius in Females

Age (yrs.)	N	Min	Max	Mean	SD
6	4	1	2	1.25	0.500
7	30	1	2	1.13	0.346
8	56	1	3	1.29	0.494
9	57	1	3	1.70	0.680
10	32	1	3	2.06	0.669
11	39	1	4	2.67	0.838
12	41	1	4	3.17	0.834
13	17	2	4	3.53	0.624
14	9	2	4	3.67	0.707
15	8	3	4	3.88	0.354
16	3	4	4	4.00	0.000
17	5	4	4	4.00	0.000
18	9	4	4	4.00	0.000
19	10	4	4	4.00	0.000
20	9	4	4	4.00	0.000
21	21	4	4	4.00	0.000
22	16	4	4	4.00	0.000
23	18	4	4	4.00	0.000
24	9	4	4	4.00	0.000

Table A6.08: Mean Scores and Associated ages for Distal Ulna in Females

Age (yrs.)	N	Min	Max	Mean	SD
6	4	1	1	1.00	0.000
7	28	1	2	1.04	0.189
8	47	1	2	1.11	0.312
9	49	1	2	1.22	0.422
10	26	1	2	1.46	0.508
11	32	1	3	1.78	0.491
12	34	1	4	2.18	0.626
13	13	2	3	2.46	0.519
14	8	1	4	2.88	0.835
15	8	3	4	3.63	0.518
16	3	3	4	3.67	0.577
17	5	4	4	4.00	0.000
18	9	4	4	4.00	0.000
19	10	4	4	4.00	0.000
20	9	4	4	4.00	0.000
21	21	4	4	4.00	0.000
22	16	4	4	4.00	0.000
23	18	4	4	4.00	0.000
24	9	4	4	4.00	0.000

Table A6.09: Mean Scores and Associated ages for Distal Radius in Females

Age (yrs.)	N	Min	Max	Mean	SD
6	4	1	2	1.75	0.500
7	28	1	2	1.21	0.418
8	46	1	2	1.30	0.465
9	49	1	2	1.53	0.504
10	26	1	2	1.77	0.430
11	32	1	3	1.88	0.421
12	34	1	4	2.24	0.554
13	13	2	3	2.46	0.519
14	8	2	4	3.00	0.535
15	8	3	4	3.63	0.518
16	3	3	4	3.67	0.577
17	5	4	4	4.00	0.000
18	9	4	4	4.00	0.000
19	10	4	4	4.00	0.000
20	9	4	4	4.00	0.000
21	21	4	4	4.00	0.000
22	16	4	4	4.00	0.000
23	18	4	4	4.00	0.000
24	9	4	4	4.00	0.000

Appendix 6: MEAN SCORES FOR EPIPHYSES IN FEMALES CONT…

Table A6.10: Mean Scores and Associated ages for Iliac Crest in Females

Age (yrs.)	N	Min	Max	Mean	SD
6	4	1	1	1.00	0.000
7	35	1	1	1.00	0.000
8	67	1	1	1.00	0.000
9	68	1	1	1.00	0.000
10	44	1	1	1.00	0.000
11	46	1	2	1.02	0.147
12	45	1	3	1.22	0.471
13	18	1	2	1.17	0.383
14	9	1	3	1.67	0.707
15	8	1	4	2.75	0.886
16	3	3	3	3.00	0.000
17	5	3	4	3.20	0.447
18	9	3	4	3.78	0.441
19	10	3	4	3.70	0.483
20	10	1	4	3.60	0.966
21	21	4	4	4.00	0.000
22	16	4	4	4.00	0.000
23	18	4	4	4.00	0.000
24	9	4	4	4.00	0.000

Table A6.11: Mean Scores and Associated ages for Head of Femur in Females

Age (yrs.)	N	Min	Max	Mean	SD
6	4	2	3	2.25	0.500
7	35	2	3	2.20	0.406
8	67	2	3	2.46	0.502
9	68	2	3	2.72	0.452
10	44	2	3	2.98	0.151
11	46	2	3	2.98	0.147
12	45	2	4	3.09	0.358
13	18	2	4	3.17	0.514
14	9	3	4	3.44	0.527
15	8	4	4	4.00	0.000
16	3	4	4	4.00	0.000
17	5	4	4	4.00	0.000
18	9	4	4	4.00	0.000
19	10	4	4	4.00	0.000
20	10	3	4	3.90	0.316
21	21	4	4	4.00	0.000
22	16	4	4	4.00	0.000
23	18	4	4	4.00	0.000
24	9	4	4	4.00	0.000

Table A6.12: Mean Scores and Associated ages for Greater Trochanter in Females

Age (yrs.)	N	Min	Max	Mean	SD
6	4	1	2	1.25	0.500
7	35	1	2	1.31	0.471
8	67	1	3	1.57	0.529
9	68	1	3	1.79	0.475
10	44	1	3	2.00	0.305
11	46	2	3	2.15	0.363
12	45	2	4	2.64	0.645
13	18	2	4	2.72	0.575
14	9	2	4	3.33	0.707
15	8	4	4	4.00	0.000
16	3	4	4	4.00	0.000
17	5	4	4	4.00	0.000
18	9	4	4	4.00	0.000
19	10	4	4	4.00	0.000
20	10	2	4	3.80	0.632
21	21	4	4	4.00	0.000
22	16	4	4	4.00	0.000
23	18	4	4	4.00	0.000
24	9	4	4	4.00	0.000

Appendix 6: MEAN SCORES FOR EPIPHYSES IN FEMALES CONT…

Table A6.13: Mean Scores and Associated ages for Lesser Trochanter in Females

Age (yrs.)	N	Min	Max	Mean	SD
6	4	1	1	1.00	0.000
7	35	1	1	1.00	0.000
8	67	1	2	1.06	0.239
9	68	1	2	1.12	0.325
10	44	1	2	1.34	0.479
11	46	1	3	1.46	0.622
12	45	1	4	1.84	0.976
13	18	1	4	2.06	0.938
14	9	1	4	3.00	1.118
15	8	4	4	4.00	0.000
16	3	4	4	4.00	0.000
17	5	4	4	4.00	0.000
18	9	4	4	4.00	0.000
19	10	4	4	4.00	0.000
20	10	1	4	3.70	0.949
21	21	4	4	4.00	0.000
22	16	4	4	4.00	0.000
23	18	4	4	4.00	0.000
24	9	4	4	4.00	0.000

Table A6.14: Mean Scores and Associated ages for Distal Femur in Females

Age (yrs.)	N	Min	Max	Mean	SD
6	4	2	2	2.00	0.000
7	35	1	2	1.66	0.482
8	67	1	3	2.12	0.537
9	68	1	3	2.40	0.522
10	44	2	3	2.73	0.451
11	46	2	3	2.83	0.383
12	45	2	4	2.89	0.383
13	18	3	3	3.00	0.000
14	9	2	4	3.33	0.707
15	8	4	4	4.00	0.000
16	3	4	4	4.00	0.000
17	5	4	4	4.00	0.000
18	9	4	4	4.00	0.000
19	10	4	4	4.00	0.000
20	10	3	4	3.90	0.316
21	21	4	4	4.00	0.000
22	16	3	4	3.94	0.250
23	18	4	4	4.00	0.000
24	9	4	4	4.00	0.000

Table A6.15: Mean Scores and Associated ages for Proximal Tibia in Females

Age (yrs.)	N	Min	Max	Mean	SD
6	4	1	2	1.50	0.577
7	35	1	2	1.23	0.426
8	67	1	3	1.66	0.509
9	68	1	2	1.85	0.357
10	44	2	2	2.00	0.000
11	46	2	3	2.20	0.401
12	45	2	3	2.44	0.503
13	18	2	3	2.61	0.502
14	9	2	4	3.11	0.601
15	8	3	4	3.75	0.463
16	3	4	4	4.00	0.000
17	5	4	4	4.00	0.000
18	9	4	4	4.00	0.000
19	10	4	4	4.00	0.000
20	10	2	4	3.80	0.632
21	21	4	4	4.00	0.000
22	16	3	4	3.94	0.250
23	18	4	4	4.00	0.000
24	9	4	4	4.00	0.000

Appendix 6: MEAN SCORES FOR EPIPHYSES IN FEMALES CONT…

Table A6.16: Mean Scores and Associated ages for Proximal Fibula in Females

Age (yrs.)	N	Min	Max	Mean	SD
6	4	1	2	1.25	0.500
7	35	1	2	1.03	0.169
8	67	1	2	1.16	0.373
9	68	1	2	1.46	0.502
10	44	1	2	1.55	0.504
11	46	1	3	1.87	0.400
12	45	1	3	2.13	0.457
13	18	2	3	2.11	0.323
14	9	2	4	3.00	0.707
15	8	3	4	3.75	0.463
16	3	4	4	4.00	0.000
17	5	4	4	4.00	0.000
18	9	4	4	4.00	0.000
19	10	4	4	4.00	0.000
20	10	2	4	3.80	0.632
21	21	4	4	4.00	0.000
22	16	3	4	3.94	0.250
23	18	4	4	4.00	0.000
24	9	4	4	4.00	0.000

Table A6.17: Mean Scores and Associated ages for Distal Tibia in Females

Age (yrs.)	N	Min	Max	Mean	SD
6	4	2	2	2.00	0.000
7	35	2	2	2.00	0.000
8	67	2	2	2.00	0.000
9	68	2	2	2.00	0.000
10	44	2	3	2.02	0.151
11	46	2	3	2.04	0.206
12	44	2	4	2.48	0.628
13	18	2	4	2.50	0.618
14	9	2	4	3.11	0.782
15	8	4	4	4.00	0.000
16	3	4	4	4.00	0.000
17	5	4	4	4.00	0.000
18	9	4	4	4.00	0.000
19	10	4	4	4.00	0.000
20	10	2	4	3.80	0.632
21	21	4	4	4.00	0.000
22	15	4	4	4.00	0.000
23	18	4	4	4.00	0.000
24	9	4	4	4.00	0.000

Table A6.18: Mean Scores and Associated ages for Distal Fibula in Females

Age (yrs.)	N	Min	Max	Mean	SD
6	4	2	2	2.00	0.000
7	35	2	2	2.00	0.000
8	65	2	2	2.00	0.000
9	67	2	2	2.00	0.000
10	44	2	2	2.00	0.000
11	46	2	3	2.02	0.147
12	44	2	4	2.43	0.625
13	18	2	4	2.44	0.616
14	9	2	4	3.11	0.782
15	8	4	4	4.00	0.000
16	3	4	4	4.00	0.000
17	5	4	4	4.00	0.000
18	9	4	4	4.00	0.000
19	10	4	4	4.00	0.000
20	10	2	4	3.80	0.632
21	21	4	4	4.00	0.000
22	16	4	4	4.00	0.000
23	18	4	4	4.00	0.000
24	9	4	4	4.00	0.000

Appendix 7: LIST OF ABBREVIATIONS

Abbreviation	Meaning
GT	Greater Trochanter
LT	Lesser Trochanter
HoF	Head of Femur
GP (1959)	Greulich and Pyle
ME	Medial Epicondyle
LE	Lateral Epicondyle
Prox Rad	Proximal radius
Dist. Rad	Distal Radius
Dist. Ulna	Distal Ulna
Dist. Tib	Distal Tibia
HoHum	Head of Humerus
SES	Socio-economic Status
IC	Iliac Crest
RUS	Radius, Ulna and Short bones (TW)
BT 20	Birth to 20
MWC	Marginal Working Class
IWC	Intermediate Working Class
UC	Upper Class
TW	Tanner and Whitehouse
SD	Standard Deviation
Min	Minimum
Max	Maximum
SE	Standard Error
Df	Degrees of Freedom
Sig	Significance
N	Number
CA	Chronological age
SA	Skeletal Age
SAC	South African Coloured
UNHCR	United Nations High Commission for Refugees
AP	Anterior-Posterior

Appendix 8: PROCESS FLOW DIAGRAM