TRENDS IN SKELETAL MATURATION PATTERNS IN A WESTERN CAPE SAMPLE

BY

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DECLARATION

I A. I. HANSA declare that "Trends in skeletal maturation in a Western Cape Sample" is my own work and that all the sources I have quoted have been indicated and acknowledged by means of references.

Signed: .....

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DEDICATION

This thesis is dedicated to my family and especially my late father whose sacrifice made possible my education.

ABSTRACT

Skeletal age assessment is not only an important aspect in orthodontic treatment planning, but is also widely used in forensic medicine and physical anthropology. Various studies have shown that chronological age may be at variance with an individual's biologic age. Current research would seem to indicate that the hand-wrist radiograph provides the most accurate method of assessing skeletal age for diagnostic purposes.

In recent years the number of patients presenting with malocclusions of a skeletal nature at the University of the Western Cape has increased significantly. If it is accepted that treatment of jaw discrepancies associated with malocclusion is dependent on a large component of dentofacial orthopedics, then by implication it is necessary that a substantial amount of facial growth remains. The need has therefore arisen for the establishment of skeletal maturation trends in the Western Cape.

Skeletal maturity was assessed from hand-wrist radiographs in a sample of 318 Western Cape children aged 6 to 16 years for both sexes, utilising the bone specific Tanner-Whitehouse TW-2 scoring system. Data obtained from the present study showed a marked difference in skeletal maturation trends between females of the Western Cape to that of the British norm, while the males showed less divergence. Further, these findings show that in both sexes the epiphyseal bones matured in advance of the TW-standard. Carpal maturation, however, was delayed in the male when compared to the British standard, while that of the female conformed to that of the British standard.

OPSOMMING

Die vasstelling van skeletouderdom is nie alleen 'n belangrike aspek van die beplanning van ortodontiese behandeling nie maar word ook algemeen gebruik in geregtelike mediese ondersoeke en fisiese antropologie. Verskeie studies het getoon dat chronologiese ouderdom verskillend mag wees van individue se biologiese ouderdom. Volgens onlangse navorsing wil dit blyk dat die radiografie van die polsgewrig die mees akkurate metode is vir die vasstelling van skeletouderdom vir diagnostiese doeleindes.

In die afgelope tyd het die aantal pasiënte waarby wanpassing van skeletale aard voorkom en wat hulle by die Universiteit van Wes-Kaapland se Tandheelkunde Fakulteit aangemeld het noemenswaardig toegeneem. As aanvaar word dat die behandeling van kaakgebreke met gevolglike wanpassing, grootliks steun op ortopedie dan is dit by implikasie nodig dat daar 'n ruime mate van gesigsgroei aanwesig bly. Die behoefte het dus ontstaan om 'n bepaling van die neigings van skeletveroudering in die Wes-Kaap te maak. Skeletveroudering is bepaal deur middel van polsgewrigradiografie in 'n monsterdeursnit van 318 Wes-Kaapse kinders van beide geslagte en deur gebruikmaking van die Tanner-Whitehouse TW-2 tellingsisteem.

Data verskry van die huidige studie toon 'n merkbare verskil in skeletveroudering-neigings tussen vroue van die Wes-Kaap en van die Britse vorm, terwyl mans 'n kleiner verskil aantoon. Verder, hierdie bevindings toon dat beide geslagte die veroudering van epifisêre gebeente vroeër geskied as deur die T.W. standaard aangedui. Polsgewrigveroudering egter, toon 'n vertraging by mans in verhouding met die Britse standaard, terwyl dit by vroue ooreenstem met die Britse standaard.

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INTRODUCTION

Over the years research has increasingly shown that the rate at which bodily growth proceeds, serves as a good indicator of the state of health and nutrition of a given population (Eveleth and Tanner, 1980). Further, it has also been shown that the chronological age of an individual often differs from that of the biologic age (Demirjian et al, 1985; Proffit, 1986; van der Linden, 1986), and hence development may more suitably be evaluated by using indicators assessing physiological maturity (Tanner et al, 1975).

Skeletal development, which is closely related to growth in stature and which provides a useful index of physiological maturity (Marshall, 1977), has long been used as a parameter for assessing somatic maturity (Roche, 1978). During the early nineteenth century, even before the discovery of X-rays, this practice of assessing bone age was used in forensic medicine (Tarranger et al, 1976). Since growth is an important consideration in orthodontic treatment planning, it is prudent to know the extent, amount and direction of growth remaining for each individual (Graber, 1972).

Numerous studies have shown that racial, genetic and environmental factors profoundly influence the rate and pattern of growth for any individual (Acheson, 1966; Tanner et al, 1975). It is apparent, therefore, that research into skeletal maturation patterns for the different race groups is necessary in South Africa.

Graber (1972) observed that the orthodontist works primarily with teeth and bones, and of consequence therefore, both dental and skeletal ages are important considerations for the coordination of treatment procedures. The skeletal age assessment has been found to be especially useful in dentofacial orthopedics, where it becomes necessary to quantitate the amount of growth remaining. This residual growth has been shown to influence the timing, the length of treatment and also the stability of the result (Magnusson, 1979; Joondeph and Riedel, 1985).

A review of the literature shows that little jaw growth occurs after puberty, and hence growth modification (dentofacial orthopedics) should be attempted before or during the adolescent growth spurt (van der Linden, 1986). He further reported that many European and American patients attain their permanent dentitions after the pubertal growth spurt, especially in females. It is obvious therefore, that treatment of those patients should preferably begin in the mixed dentition period for optimum results (Proffit, 1986).

However, it is interesting to note that while certain population groups show an advanced dental maturation pattern in comparison to Caucasoid norms (Chertkow, 1980; Loevy, 1983; Singh, 1985), the reverse may be true for their skeletal maturation patterns (Jones and Dean, 1956; Tobias, 1958). Chertkow (1980) showed that while dental maturation is advanced in South African Blacks, their skeletal maturation is, however, generally delayed. This might imply therefore, that successful growth

modification in the South African Black is possible after the attainment of the permanent dentition.

Singh in 1985, reported that "Coloureds" in the Western Cape similarly had an advanced dental maturation pattern in comparison to Caucasian values. If this Western Cape population, likewise, has a delayed skeletal maturation pattern as is reported for Blacks, then a delay in treatment should not significantly affect the use of dentofacial orthopedics. If, however, skeletal maturation is advanced,then earlier treatment should be recommended.

At the University of the Western Cape there is an ever increasing demand for orthodontic treatment. The socio-political enigma in this country dictates that patients presenting for treatment at this hospital, are mainly of mixed racial descent ("Coloured"). Various workers have considered the "Coloured" to be a definite population entity with its own unique features (Dreyer, 1978; Thomas, 1981) Because of an Orthodontic manpower shortage, treatment has to be given on a priority basis. Whether indeed the skeletal maturation pattern in this Western Cape sample is delayed or advanced, would allow for a generalisation of treatment timing and the setting up of a priority waiting list.

To date, no studies have been undertaken to determine skeletal maturation patterns in the Western Cape "Coloured" population, the need for which is clearly evident. This present cross-sectional study

has been undertaken essentially to establish skeletal maturation trends. Depending on the findings of this project, future longitudinal studies using a larger, randomly selected sample would become necessary to establish norms for this population group.

Having outlined the broader objectives to this study, the specific aims are:-

1) to investigate the pattern of skeletal maturation in a Western Cape sample.
2) to investigate sex differences in skeletal maturation.
3) to compare the skeletal maturation pattern of a select Western Cape sample with the British standards derived by Tanner et al (1975).
4) to provide a set of skeletal maturation trends for use in the Orthodontic Department.

REVIEW OF THE LITERATURE

INTRODUCTION

The general health of a nation, and the nutritional status of it's citizens are reportedly mirrored by the growth rate of its children (Eveleth and Tanner, 1980), and it is in this context therefore, that a well designed growth study could become an important indicator of health for a given population. This data could also help identify those groups whose share in economic and social benefits is less than optimal.

Eveleth and Tanner (1980), further suggested that the infant mortality rate is probably the most sensitive method available for community health assessment. According to these authors, however, once this index reached accepted levels, then growth rate became the parameter of choice in reflecting the socioeconomic development of a population.

Whilst different populations may share the same growth potential, large differences in height and weight and the age at puberty have been shown to exist (Tanner, 1975). The extent to which factors such as the environment or genetics influenced these differences are not fully understood (Eveleth and Tanner, 1980).

Various workers have shown significant differences in the chronological ages at which children reached similar developmental events and it is evident therefore, that the developmental status of a child is best estimated by evaluating specific stages in physiological maturity.

Marshall (1977), reported that the problem inherent in such maturational studies was the lack of an accepted unit of measurement. Units of length (such as inches), or units of time (such as months or years) cannot be used because they lack a common end-point, that is, the process of maturation is not universally completed following a specific amount of linear growth or at a given point in time (Marshall, 1977; Tanner, 1975). Therefore, for a measure of maturity to be valid,it must be based on a method of assessment utilising known maturational events and a common end point (Tanner et al, 1975; Marshall, 1977).

The clinical usefulness of such a index, however, should be based on a standardized method making use of clearly recognizable stages for every individual. Ideally, one would require a method that incorporated many maturity stages, with the attainment of each stage representing an equal step towards the final mature state (Marshall, 1977). At the present time, however, research would seem to indicate that this ideal is as yet unattainable (Tanner, 1975; Marshall, 1977; Roche, 1978; van der Linden, 1986).

Presently, there are many methods of assessing physiological maturity; the four most commonly employed being the sexual, somatic, dental and skeletal maturity indices (Tanner, 1975; Tanner et al, 1975; Marshall, 1977; Demirjian et al, 1985). These indices are used either separately or in combination to assess the degree of physiological maturity for a growing child (Demirjian et al, 1985).

The concept of using the developmental age or physiological age as a maturity indicator was first introduced by Crampton in 1908 in association with Boas, who designated pubescence in boys with the appearance of pubic hair (Tanner, 1975). The physiological age (sexual maturity) was derived at by calculating the number of years for this event to occur. In girls, menarchè can similarly be used to calculate the physiological age at puberty (Tanner, 1962, 1978; Marshall, 1977). The drawbacks inherent in this system, however, relates to its dependence on memory. Also, since these were all secondary sexual characteristics it is only applicable with the onset of puberty (Marshall, 1977; Tanner, 1978). However, because of its simplicity and cost effectiveness, this sexual maturity index is well suited for field studies, especially in 3rd world countries (Tanner, 1962; Eveleth and Tanner, 1980).

The morphological or somatic age index uses body height, weight and size to assess the state of physiological maturity (Marshall, 1977; Tanner, 1978; van der Linden, 1986). These measurements could also be used retrospectively in adults to determine the age at which growth had ceased, by studying annual incremental growth values. Similarly, one could derive the age at which half the adult height was attained (ie. 50% maturity).

The "height developmental age" index which utilizes the age at which a given child's actual height equals the national average, however, is found to have a limited usefulness (Tanner, 1978). For example, a

7-year-old who has the same stature as the average child at age 6, is said to have a height age of a 6 year old. This, however, does not imply that his maturity equals that of the average 6-year-old. It implies merely that his stature falls within the 50th centile for 6-year-olds or at the 10th centile for the 7-year-olds, that is, he is rather small for his age (Marshall, 1977). This "height for age" index further, does not indicate smallness because of late maturation, or whether the individual is destined to end up below this centile (Marshall, 1977; Tanner, 1978). Similarly, a child of above average height for his age, may be an advanced maturer or alternately he may inherently be tall (Tanner, 1978.) The use of weight and "weight age" measurements were also found to be unsuitable indices of maturity (Tanner, 1962; Marshall, 1977).

The dental age index may be employed either by evaluating the eruption or non-eruption of each tooth, or by assessing the state of root development from radiographs for both the primary and secondary dentitions (Demirjian et al, 1985). Marshall (1977), is of the opinion that this method fulfils a basic criterion for maturity indices, namely that it has the same end-point in all normal subjects. He noted that dental maturity is attained when the secondary teeth (with the exception of the 3rd molar) are fully erupted. In the radiographic method, where "scores" are given to the different stages of development of different teeth, adult maturity occurs with closure of the root apices (Demirjian et al, 1985). This method, however, has been shown to be less accurate in determining physiological maturity than either the skeletal age or the sexual

maturity age indices (Tanner, 1962; van der Linden, 1986). However, during the pre-adolescent period, when the skeleton is in a state of relative quiesence, the dental age index may be of some value (Tanner, 1975; Tanner et al, 1975). Notwithstanding, Filipsson and Hall (1975), reported, however, that it was possible to predict a child's adult stature from the age and stature at the time when certain teeth had erupted.

Lastly, the index evaluating skeletal development probably provides the most useful method for maturity assessment, and is shown to be closely related to growth in stature (Marshall, 1977). This practice pre-dates the discovery of X-rays, when bone age was used in forensic medicine during the early nineteenth century (Tarranger et al, 1976). As cartilage of the growing skeleton is gradually converted to bone, the calcified tissue in each centre of ossification undergoes changes in shape and size, which can be observed radiographically. The sequence of changes in each centre is remarkably constant and varies marginally from one child to another (Tanner, 1962; Tanner, et al, 1975; Marshall, 1977). When all these centres are fully calcified, the skeleton is considered mature. It seems evident that skeletal maturation fulfils an essential criteria for a suitable scale or index of maturity, namely that it possesses a number of suitably defined and recognizable skeletal changes that are common for all children and which has a common end point (Acheson, 1966; Tanner, 1975; Marshall, 1977).

SKELETAL MATURATION

Wingate Todd in 1937 wrote that "the progress of maturation is evident in every part of the skeleton, but it is in the transformation of fibrous tissue and cartilage into bone that the most easily identifiable criteria present themselves". This idea of endochondral bone formation as the "ripening or maturing" of cartilage has widely been accepted by many researchers (Tanner, 1962; Acheson, 1966; Tanner et al, 1975; Roche, 1978).

Maturation could be defined as the stage that an individual has reached in the process of development; the degree of maturation is hence a measure of the individual's ontogenic progress to maturity (Persson and Thilander, 1985). Like development, maturation is a very broad term, which usually refers to a specific organ, function or functional system and is usually described in relation to the attainment of specific landmarks. Skeletal development, a commonly used measure of developmental age, is one method of describing physical maturation.

However, this physiologic phenomenon of maturation must not be confused with the concept of growth, which is regarded merely as an increase in size of a tissue or organ (Acheson, 1966). Also these processes, while occurring simultaneously, are often affected differently by factors such as disease and nutrition (Tanner, 1978).

Skeletal maturation is routinely assessed from radiographs by the recognition of certain radiographically detectable features or "maturity indicators" (Greulich and Pyle, 1959; Acheson, 1966; Tanner et al, 1975; Roche, 1978). Roche (1978), noted that for these indicators to be of any clinical relevance, they must occur or be part of the maturation or developmental phase of every child.

In essence, these maturity indicators, a two-dimensional representation, is assessed from the external form of the developing bone, as well as from shape changes that occur therein over time. Further, Roche (1978) reported that bone surfaces appearing as radioopaque lines, could also be used as maturity indicators. Since any change in the direction of the radiographic beam could result in changes in the radiographic image , it is essential therefore that these radiographs be taken under standardized conditions (Tanner et al, 1975).

Maturation events in a growing child are constantly undergoing change and hence serial radiographs could provide data on its duration. Research has shown that a scoring system using indicators of short duration are more informative than those of longer duration (Tanner et al, 1975; Roche, 1978). However, due to the ethical restraints imposed on the number of radiographs that can be taken, and because the taking of these radiographs are time dependent (eg. every 6 months), certain indicators of short duration may be overlooked or are not available for assessment in certain children (Roche, 1978).

HISTORICAL PERSPECTIVE

Before the advent of radiology, ossification or maturation of the skeletal cartilage was studied on cadavers of children, either with the naked eye or by the use of microscopy (Acheson, 1966). It was J.W. Pryor (1907), at the turn of the century who first considered the clinical implications of the "changing shadows" on hand-wrist radiographs of children. His observations that "the bones of the female ossify in advance to those of the male" with the ossification being bilaterally symmetrical and that this "variation in the ossification of bones is a hereditable trait.", is still widely accepted to the present time.

T.M. Rotch (1909), reported that chronological age was a poor indicator of a child's general developmental status, and similarly noted that measurements of stature (height and weight) and dental maturation showed little correlation to general development. In a later study Rotch concluded that the hand-wrist represented a fairly accurate index of general development (Acheson, 1966). The carpal bones were used together with the radius and ulna in assessing skeletal development or age, which he termed the "anatomic age". The Rotch method of measuring maturity, while no longer in use today, was popular before the First World War.

Various methods of skeletal age assessment have subsequently evolved and have become available for clinical use (Bardeen, 1921; Lowell and Woodrow, 1922; Carter, 1926; Flory, 1936; Todd, 1937; Suntag and Lipford, 1943; Greulich and Pyle, 1950, 1959; Acheson, 1954; Tanner et al, 1959, 1962, 1975; Tarranger et al, 1976; Roche, 1978). Although the Greulich-Pyle and Tanner-Whitehouse methods of skeletal assessment are presently the most widely used, the search still continues for an ideal measure of skeletal maturity (Marshall, 1977; Tanner, 1978; Roche, 1978).

THE CLINICAL USE OF SKELETAL MATURATION

Skeletal maturity assessment is primarily used in determining the developmental status of a child (Acheson, 1966; Tanner et al, 1975) However, while a singular assessment using a radiograph permits the clinician to evaluate the child's maturity following the taking of the film, skeletal maturity assessment can also be used to see whether it approximates the median of healthy children of the same race, sex and age (Greulich and Pyle, 1959; Acheson, 1966; Tanner et al, 1975). Further, Acheson (1966) and Tanner (1978) suggested that general developmental or nutritional information may also be obtained from these radiographs.

Eveleth and Tanner (1980), note that in order for an assessment to be meaningful, the level of maturity must be compared to the median derived for the population from which the child comes. Global studies have shown that populations differ in the mean skeletal maturity at any given age and also in their pattern of annual growth increments (Eveleth and Tanner, 1980). Further, it has been suggested that standards of skeletal maturity should be developed separately for each country or state (Tanner et al, 1975; Roche, 1978; Eveleth and Tanner, 1980). In addition Eveleth and Tanner (1980), suggest that because of the changing socio-economic conditions these standards be updated every decade. This seems especially true in countries showing marked fluctuations in living conditions (Rona, 1981).

Acheson in 1966, reported that the diagnosis of certain nutritional metabolic and endocrinological disturbances such as cretinism may be possible from the assessment of skeletal maturity and that treatment progress could similarly be monitored by making use of these radiographs (Greulich and Pyle, 1959; Acheson, 1966).

The method of predicting height at maturity was first developed by Bayley in 1946. Tanner et al (1975), improved on this technique by suggesting that the heights of family members also be considered when undertaking these predictions. Acheson (1966) suggested that height prediction could have an important clinical application in the field of hormonal replacement therapy, while Tanner (1962), was able to make use of such predictions in determining the adult stature of potential professional ballet dancers. Falkner (1964), reported that the onset of ossification as well as epiphyseal union was genetically controlled and suggested that these be used together with blood groups, in determining the genetic relationship of siblings born of a multiple pregnancies.

Further, age estimation from the skeletal remains of children is often important for forensic, scientific or historical reasons. Acheson (1966) noted that careful reconstruction and radiographic study of the available remains and their subsequent comparison to the Greulich and Pyle (1959) or Tanner-Whitehouse (1962) standards is a reliable method of age determination.

These methods of assessing skeletal age from the hand-wrist radiograph is routinely utilised in orthodontic diagnosis and treatment planning; a knowledge of the amount of residual skeletal growth is important in influencing the various treatment modalities available to the orthodontist (Bjork, 1972; Proffit, 1986; van der Linden, 1986).

ANATOMICAL SITES FOR SKELETAL AGE DETERMINATION

Maturation of the human skeleton has been shown to vary from one anatomical site to another and hence the accuracy of estimating maturity for the entire skeleton by using a localised area is somewhat limited (Garn et al, 1964; Roche and French, 1970; Tanner et al, 1975). Roche (1978) felt that the entire skeleton or at least the hemiskeleton should ideally be assessed; however, for practical and ethical reasons this is not possible.

The most frequently used anatomical areas include the hand-wrist, the knee and the foot-ankle, with the hand-wrist presently being more popular. The hand-wrist was the first localized area for which Atlases were prepared (Todd, 1937; Greulich and Pyle, 1950). The clarity of these radiographs (eg. of the Greulich and Pyle atlas) were far superior to those of the knee or, the foot and ankle (Roche, 1978). Additional advantages associated with the use of hand-wrist area have been reported as easy positioning, reduced radiation exposure and the presence of many bones in a relatively confined area.

Rotch (1909), had shown from studies involving some one thousand children from birth to adolescence that the developmental changes occuring in the wrist correlated favourably to those occurring elsewhere in the skeleton. Roche and French (1970) further reported no significant difference whilst comparing the bone ages derived from the hand-wrist or knee areas, and hence Tanner et al (1975) believed that the hand-wrist area could be accepted as a fairly accurate index of general development.

The main drawback in the use of this anatomical site is related to the dormancy in maturation of these bones during puberty. In addition Roche (1978), feels that the hand-wrist area provides little useful information during the first year after birth.

In selecting the appropriate anatomical site, consideration should be given to the type of information required from the assessment; for example in the assessment of aberrant statural growth, the knee would more likely provide a better estimate of skeletal maturation as it is an important site for growth in stature (Roche et al, 1975).

SEX DIFFERENCES IN SKELETAL MATURATION

It is apparent from the literature that intrinsic genetic factors determine the rate and pattern of skeletal maturation (Acheson, 1966; Tanner, 1978). While some are sex-specific and therefore presumably originate from genes on the sex chromosomes, others are common to both sexes and are probably autosomal in origin, while others still are race specific (Falkner, 1958; Masse and Hunt, 1963; Acheson, 1966; Tanner, 1978). From the work of Acheson (1966) it would seem that variations in the chromosome count may also be associated with deviations of skeletal maturation, such as in Down's Syndrome.

The work of Pryor (1907), at the turn of the century had already highlighted sexual dimorphism in skeletal maturation, when he observed that "the bones of a female ossify in advance of those of the male." It is further evident from the work of Tanner (1978) that while the time interval between the stages of maturation differ to the extent of three to four percent, the sequence of maturation in the sexes are similar. It is for this reason that both Greulich and Pyle (1959) and Tanner et al (1975) provide separate skeletal age assessment tables for males and females. While these sex related differences are already apparent in utero, they are not marked and can only be measured in days (Acheson, 1966). This sexual dimorphism is, however, accentuated during postnatal development and reaches a peak around puberty (Hewit and Acheson, 1966). Tanner (1978), further noted that

girls attain fifty percent of their adult height earlier, enter puberty sooner, and cease growth at an earlier age than that for boys.

Studies by Garn and Rohmann (1960) have further re-inforced these findings by their observation that the male skeleton shows greater variability in the onset of ossification than that for the female. Acheson (1966) believes that some of these sex differences, especially those concerned with the overall rate of maturation, may be hormonally related. Pattern differences, however, may originate in the genotype.

Although environmental factors may have different effects on the sexes, the socio-cultural practice of affording better protection to females may also account for these differences (Tanner et al, 1975). Various workers have also shown that physical development, including skeletal maturation, may be innately more stable in females than in males (Greulich and Pyle, 1959; Garn et al, 1964; Acheson, 1966; Tanner, 1978).

SKELETAL AGE ASSESSMENT METHODS

The method of using the onset of ossification in the hand-wrist area as an indication of skeletal age was first introduced by Rotch (1909) and later improved by Bardeen (1921). In his study Rotch placed emphasis on the initiation of calcification in the bony centers of the carpals, radius and ulna, describing a total of 13 stages or categories of maturity. No consideration was given to the changes taking place in an individual carpal center from initial calcification to maturity, while similarly no attention was given to the calcification of the epiphyseal plate (Acheson, 1966). Rotch believed that the appearance of the carpal bones extended over some years, and that the inclusion of the pisiform and the sesamoid bones would adequately allow for differentiation between the developmental stages. Acheson (1966),however, showed that during the prepubertal years the differentiation afforded by this method proved unreliable.

Bardeen (1921), tried to overcome this shortcoming by assigning four stages (A, B, C and D) to each carpal bone. However, he only considered the carpal bones and excluded other useful indicators like the radius and ulna. Further both Rotch and Bardeen failed to take cognisance of the normal variation inherent in the initial ossification sequence. As noted by Acheson (1966), it is not unusual for the lunate to appear before the triquetrum and as suggested by Roche (1978), the carpal bones cannot be taken as representative of the entire skeleton.

In an attempt to correct these shortcomings, later workers began using planimetric measurements directly on radiographs (Lowell and Woodrow, 1922; Carter, 1926; Flory, 1936). Measurements done on the radiograph of the wrist area were later adjusted mathematically by complex ratios to allow for size variations in children (Acheson, 1966).

Santag and Lipford (1943), suggested that several joints be studied and further proposed that "bone age" be assessed from an epiphysis in which ossification has most recently begun. The drawback associated with this method is the extensive exposure to radiation and also the reported variability seen in the initial calcification of bones (Acheson, 1966; Roche, 1978). Dommisse and Leipoldt (1936), in their study on the skeletal maturation of the "Cape Coloured" community made use of this method.

The method of using a reference atlas for skeletal age assessment was first developed by Todd in 1937 and was based on the growth studies of Hellman (1928). Todd had realised the potential of serial radiographic changes occurring in maturing epiphyseal plates and called them "determinators of maturity" which was later named "maturity indicators" by Greulich and Pyle (1950). These indicators are described as those features of individual bones that could be seen on the radiograph and which, because they occur in a regular, definitive and irreversible order, mark their progress toward maturity (Tanner et al, 1975).

The discovery of maturity indicators, while having significant clinical ramifications still had to be related to a so called norm or trend for the growing child (Acheson, 1966), that is, it had to have a time scale. A comprehensive study of the maturation process for the hand-wrist was undertaken by Todd in the 1930's, in a group of healthy and affluent children of all ages in Cleveland, Ohio. Todd, subsequently attempted to select standards from these radiographs for each age and sex, with each bone being at the median stage of development. Each film was assigned a skeletal age, based on the chronological age of a subject whose skeletal development had co-incided with this median stage of development (Todd, 1937).

This original Cleveland hand atlas has subsequently been revised by Greulich and Pyle, (1950; 1959) who continued this project following the demise of Todd. Atlasses of the foot and knee based on the same population were later published (Pyle and Hoerr, 1955; Hoerr, et al, 1962). The Greulich-Pyle atlas for the hand-wrist has a separate series of standards for boys and girls, each with it's own set of corresponding skeletal ages expressed in years and months. In this method the film to be assessed is compared to standards prescribed in the atlas. The standard with the closest resemblance to the film being assessed is selected and a detailed comparison of the individual bones comprising the hand-wrist is then undertaken (Greulich and Pyle, 1959). The mean or median of the bone specific ages are recorded as the area skeletal age for the individual.

In the original system of Todd and that of Greulich and Pyle, the film being assessed was scored according to a standard it most closely resembled. While many researchers still make use of this method, it has been shown to be less accurate than the bone specific method later developed by Greulich and Pyle (Acheson, 1966; Roche, 1978).

Acheson (1954), developed the Oxford method of assessing skeletal maturity, which was independent of the age of the patient and bone size. This method assigned a number to each maturity indicator. An unossified center was scored as 0, earliest indication of calcification was scored as 1, whereas when it acquired a shape it was scored as 2 and so on. The arithmetic sum of the scores of each bone being assessed represented the skeletal maturity for the anatomic area under consideration and hence for the child under examination (Acheson, 1966). The drawback of this method, however, was that similar arithmetic scores could be obtained in various ways, each having a different connotation. For example, well developed epiphyseal centers in the phalanges with little ossification in the carpals, could score similarly to that for precocious ossification of the carpals, with little epiphyseal development (Acheson, 1966). Massē and Hunt (1963), further found this scoring method mathematically unsound.

The subjectivity inherent in the use of the atlas method and the problems associated with the Oxford method prompted Tanner and Whitehouse (1959) and Tanner, Whitehouse and Healy (1962), to develop the Tanner-Whitehouse method of assessment of skeletal maturity using

hand-wrist radiographs. This method, essentially an improvement on the Oxford method of scoring (Acheson, 1966; Roche, 1978), utilised illustrated descriptions of various maturity indicators (Tanner et al, 1962). Further, when using this system, the film can be rated in terms of a skeletal maturity score (which is essentially a percentage value) or by a skeletal age.

The method by which these scores and skeletal ages were derived is as follows: In a small group of healthy British children the appearance of each indicator was analysed in terms of all the other indicators on a proportional scale. It was possible therefore, to state that ossification began in the lunate at 13 percent overall maturity and that fusion of the distal epiphysis of the thumb began at 85 percent maturity and so forth (Tanner et al, 1962). It was anticipated that the percentage values for the indicators in the two sexes would be the similar, however, this proved inaccurate, because of a sex difference of 3 to 4 percent (Tanner et al, 1962; Acheson, 1966). These sex differences nontheless were ignored and a single set of values were obtained by pooling these results when compiling the standards (Tanner et al, 1962).

The Tanner-Whitehouse method was used to rate (score) over 5000 radiographs of normal British children enrolled in the Harpenden Growth Study in Great Britain (Tanner, 1962). Population standards and age equivalents ("skeletal age") were then derived for this population (Tanner et al, 1962). However, Tanner et al (1975), revised their original (TW-1) method because various researchers had reported uncertainty with the differentiation in certain bones of stages H and

I (Tanner et al, 1975). As a consequence thereof, stages H and I were consolidated into stage H for five of the carpal bones. Further, the final stages J and I of the radius and ulna were omitted because of variability in their timing and have been incorporated into I and H respectively (Tanner et al, 1975). Further, in the original system (TW-I method) the use of a single scoring system for both sexes was found to be unacceptable (Tanner et al, 1975). The updated system of skeletal analysis became known as the TW-II method. Notably the standardising sample used in the TW-II system remained the same.

The TW-II method involves the use of either eight or nine maturity indicators (called "stages" and designated by the letters A to I) for each of the 20 hand-wrist bones (see Appendix I and II). The bones of the second and fourth rays or digits (metacarpals and its associated phalanges) were omitted because their skeletal maturity was similar to that of corresponding bones (Roche, 1978). Garn and Rohmann (1959) and Garn et al (1964) did not agree with the dropping of these indicators. It has, however, been suggested that the inclusion of these bones might result in the "swamping" or overlooking of more important information in other bones (Tanner et al, 1975; Roche, 1978).

Each stage in the TW-II method is "unambiguously" described and in addition supported by clearly illustrated line drawings with each stage assigned a numerical score (Tanner et al, 1975). In the TW-1 system males and females were scored equally; however, because of

conclusive evidence that sex definitely affected the rate of maturation of the skeleton (Garn et al, 1966), different sets of scores are computed for males and females in the TW-II method. The numerical scores assigned were worked out mathematically using biologically weighted criteria (Tanner et al, 1975). This system of weighted scores were proposed so as to overcome what Roche (1978) called the "swamping" of the 7 carpal bones and the radius and ulna by the bones of the fingers. Three separate scoring systems were devised. One involved the radius, ulna and finger bones (RUS), another the carpals only, and a third combined both systems (TW-20). By omitting the bones of digit 2 and 4 they were effectively given a zero weighting. Equal weights were given for the radius, ulna and digits (rays) 1, 3 and 5 (with the 3 or 4 bones in each digit being weighted equally) for the RUS score. For the carpal score equal weights were given to each of the seven bones. In the TW-20 score, one half of the RUS and one half of the carpal weights were used (Tanner et al, 1975).

The score for an individual was summed and by referring to the appropriate table (RUS, Carpal or TW-20) the skeletal age was obtained. Separate tables were given for boys and girls and the score value ranged from 0 to 1000, (0 being zero skeletal maturity with no bones visible and 1000 designating adulthood with complete maturity). In the TW-II system, the bones were rated individually in a fixed order (Roche, 1978). The feature of this method is that the score assigned to the bones assessed initially, do not influence the scores assigned to bones assessed later, as is evident in the earlier atlas methods (Roche, 1978). Further, the evidence that the TW2 system is

more reliable than the Greulich-Pyle system is fairly convincing (Acheson et al, 1964, 1966; Roche et al, 1970).

The Mean Appearance Time (MAT) method of bone stages was developed by Tarranger et al (1976). Here the mean appearance time of the various stages of the hand-wrist were calculated using statistical analysis (viz. the probit analysis)*. Each bone stage was assigned a value called a maturity score which corresponded to the mean level of the observation within this stage (Tarranger et al, 1976). The average of the maturity scores of the bone stages gave the maturity level of the child under examination. The average maturity score was "evaluated in standard deviation scores by comparison with the **Gaussian-fitted distribution of averaged maturity scores at the age of the child examined". This method also made use of all the bones of the hand-wrist, with the exception of the epiphyseal bones of digits II

*The Probit analysis is one whereby the prediction of the values of parameters can be maximally estimated from the data observed in a linear model (Armitage, 1971).
**Gaussian-distribution is a normal or bell-shaped distribution (Bahn, 1972).

and IV. Three combinations of these twenty bones were used, namely the MAT -20 (13 Epiphyseal bones and 7 carpal bones), the MAT -RUS* (13 Epiphyseal bones) and the MAT -Carpal (7 Carpal bones).

From preliminary results presented by Tarranger et al (1976) it appeared that the MAT method gave a better estimate of individual skeletal maturity than the TW-II method in the early and late stages of maturation. However, the MAT method was more complex than the TW method and inter- and intraexaminer variability by assessors other than Tarranger et al were lacking. Nonetheless, these authors suggested that this method is better suited in assessing infants from 0-6 years of age.

*Radius, ulna, short finger bones

POPULATION DIFFERENCES IN SKELETAL MATURITY

Many workers have reported that the genotype plays a significant role in determining the rate and pattern of skeletal maturity for an individual (Acheson, 1966; Tanner, 1975). Sex specific differences presumably arise from genes on the sex chromosomes, while other differences may arise from genes on the autosomes; still others are race specific (Falkner, 1958; Massè and Hunt, 1963; Acheson, 1966; Garn and Bailey, 1978; Tanner, 1978). Chromosomal abnormalities, such as in Mongolism, may also be associated with deviations of skeletal maturation (Garn and Bailey, 1978). Global studies have shown that populations differ both in mean skeletal maturity at a given age and in the pattern of increments from age to age (Eveleth and Tanner, 1980; Marshall, 1981).

Skeletal maturity differences between populations have been studied in two ways, namely by comparing the ages at which the ossification centers first become visible, or by comparing mean skeletal ages at given chronological ages (Eveleth and Tanner, 1980). The rate at which the skeleton matures, however, reflects the interaction of both genetic and environmental factors (Tanner et al, 1975; Rona,1981) and the relative contributions of these factors to the population differences observed, are difficult to assess (Acheson, 1966; Tanner, 1978).

Acheson (1966) reported that the sequence of ossification may be under genetic control and this is substantiated in studies of ossification sequences in siblings by Garn and Rohmann (1962). Further, parent-child similarities in unusual or atypical ossification sequences have been reported (Garn and Bailey, 1978). This trend has also been oberseved in twins, with that of monozygotic twins showing the closest correlation (Garn and Bailey, 1978). Falkner (1964), suggests that ossification patterns, along with blood groups could be used in determining the degree of relationship of siblings born of a multiple pregnancy.

Population differences seen in postnatal skeletal maturation would also seem to indicate a genetic basis (Tanner et al, 1975; Garn and Bailey, 1978; Roberts, 1981). However, these findings are confusing and often contradictory as different assessment methods are often used on groups having differing socioeconomic backgrounds (Acheson, 1966; Garn and Bailey, 1978). For example the Greulich and Pyle (1959) norms, based on the Brush Foundation radiographs, were taken from a select upper class Ohio population, while the Tanner-Whitehouse (1975) norms were derived from a random sample of British children.

Roche (1978), reported that up until the sixties, no other population study approached the degree of skeletal advancement seen in the Brush Foundation study. Johnson in 1963, however, reported on a group of

White children in Philadelphia with a more advanced skeletal maturation pattern, while Levine (1972) found that South African White children in Pretoria, closely matched those of the Greulich-Pyle standards. Roche (1967), showed similar results in Melbourne, Australia.

Most European studies, however, showed a slight delay while compared to the Greulich-Pyle standards, but corresponded well to that of Tanner-Whitehouse (Malina, 1970; Garn and Bailey, 1978; Helm, 1976; Eveleth and Tanner, 1980). The delay using the Greulich-Pyle standard were 0,8 "years" for boys and about 0,5 years for girls (Tanner et al, 1975; Magnusson, 1979).

Asian, South American and African studies have all shown varying degrees of differences when compared to the Greulich-Pyle and Tanner-Whitehouse standards (Eveleth and Tanner, 1980). "Black Africans" were found to be skeletally advanced over Whites at birth, but tended to lag behind by age one, two or three years, depending on sample comparisons (Beresowski and Lundie, 1952; Jones and Dean, 1956; Tobias, 1958; Massē and Hunt, 1963; Falkner et al, 1978;).

Beresowski and Lundie (1952), found that South African Black children under the age of 2½ years were skeletally advanced in comparison to Whites. Tobias (1958), however, showed that skeletal development amongst South African Black children older than 5 years, was retarded in comparison to their White peer groups. Chertkow (1980), reported that the mean chronological age on appearance of the ulna sesamoid in

White children were advanced by one year when compared to Black South African children. Marshall et al (1970) found that Jamaicans of African ancestry, living in poor communities, followed a similar pattern.

Studies involving pediatric patients, as well as healthy boys and girls, showed that the American Negro was advanced skeletally, not only during infancy, but also into adolescence (Tanner, 1962; Malina, 1970; Garn et al, 1972; Roche et al, 1974, 1975, 1976). This advancement also evident in utero was even more significant following corrections for income, education level, nutritional status, and smoking (Garn et al, 1972; Garn and Bailey, 1978). Although Negroes in the U.S.A. are considered to have a 20% white gene admixture (Roche, 1976;Garn and Bailey, 1978), it seems likely that the reason for the adolescent skeletal retardation seen in Africans would appear to be environmental rather than genetic (Tanner, 1962; Garn et al, 1972; Tanner et al, 1975; Garn and Bailey, 1978;). This could well be the reason for Africans in Dakar showing a delay in skeletal maturation at age 11, but catching up at puberty (Michaut et al, 1972).

Levine (1972) studied children, 6 to 12 years of age, of four ethnic groups in Pretoria, South Africa and found that "White" children were comparable to the Greulich-Pyle standard. Children of Indian ancestry, however were delayed by 0,4 "years", while "Coloureds" and "Blacks" were delayed by 1.1 and 1.3 "years" respectively. This study done under the auspices of the National Nutrition Research Institute of the Council for Scientific and Industrial Research (CSIR), however, had an age restriction of 6-12 years.

A study by Dommisse and Leipoldt (1936), on children younger than 7 years of age in the "Cape Coloured" population utilising carpal ossification, showed them to be more advanced skeletally than their European counterparts. No recent study has been done on the skeletal maturation trends in the Cape Coloured population.

South African children of Indian ancestry were found to be only slightly delayed when compared to the Greulich-Pyle standards (Levine, 1972). However, infants in Delhi, India were found to be considerably delayed compared to Chicago children (Banik et al, 1970).

Chinese and Japanese children living under good environmental conditions, were shown to be skeletally less mature when compared to Whites at ages 3 to 10 years for girls and 3 to 12 years for boys. Parity was attained at age 12 (for girls) and 14 (for boys) whereafter they remained in advance to the end of growth (Eveleth and Tanner, 1980). It is evident, therefore, that during adolescence the Chinese and Japanese have a greater velocity of bone age than do Europeans and White Americans, advancing about 4 skeletal "years" in 3 chronological years (Eveleth and Tanner, 1980). This increased growth rate which results in rapid closure of the epiphysis and therefore limiting bone growth, could have important clinical implications in orthodontic treatment. This rapid growth rate would require that orthodontists in the Far East endeavouring to harness growth for orthopaedic purposes, need predict the adolescent spurt more accurately than those in Europe and the United States.

The only non-Caucasian race to consistantly show a marked retardation in skeletal development at all ages are the Quecha Americans in the Peruvian Andes. Their growth period is prolonged, lasting to the 20th and 22nd year in males and females respectively (Frisancho and Baker, 1970). The Quechas, however, do not become very tall because of a very much slower growth rate, despite the prolonged growth period (Frisancho and Baker, 1970).

ENVIROMENTAL INFLUENCES ON SKELETAL MATURATION

As stated earlier, the rate at which the skeleton matures, reflects the interaction of genetic and environmental factors (Acheson, 1966; Garn, 1972; Tanner et al, 1975; Rona, 1981). However, there is no universal rule by which a given proportion of growth is determined by either the genotype or the environment (Marshall, 1970; Tanner et al, 1975) and it would appear therefore, that growth is dependent on the interaction of such highly variable factors.

Many environmental factors including social class, number of siblings, nutrition, disease and infection, sanitation, immunisation, standard of maternal care, education, wars, famine and drought amongst others, influence the rate of growth of an individual and hence that of the population (Acheson, 1966; Tanner, 1972; Garn et al, 1972(b); Tanner et al, 1975; Eveleth and Tanner, 1980; Van der Linden, 1986). The effects of these debilitating factors on the individual is largely dependent on the nutritional status, often acting in conjunction with that of infection (Garn and Bailey, 1978; Eveleth and Tanner, 1980; Rona, 1981). While intra-uterine malnutrition may occur in severely malnourished populations, it appears that the critical period is about 6 months after birth when weaning is completed (Eveleth and Tanner, 1980).

Most African studies have shown that Black children are more advanced skeletally than their White counterparts from birth to three years of

age (Eveleth and Tanner, 1980) but thereafter lag behind until adolescence (Garn and Bailey, 1978). However, certain studies on the affluent Negroes of U.S.A. reveal that they are more advanced skeletally than Whites from birth to adolescence (Garn et al, 1972(b); Roche, 1974, 1975, 1976). This would support the view that the environment and more specifically nutrition and disease could be responsible for this pattern of skeletal maturation (Garn and Bailey, 1978).

A study by Shakir and Zaini (1974) on Iraqi children showed the that during the first two years of life, these children were more advanced skeletally than their European counterparts as judged from Tanner-Whitehouse standards. However, from age two onwards children from poorer areas fell behind the TW-standards while children from the affluent areas continued to be in advance upto four years of age. Thereafter, both groups lagged behind the TW-standards, with the less priviledged being more delayed. Social class structure therefore seems as important as the genotype in determining skeletal maturation patterns (Garn and Bailey, 1978).

Heald et al (1969), suggested that at adolescence the child may be more prone to the influence of nutritional factors because of greater calory demands. Eveleth and Tanner (1980), also suggested that insufficient calory intake might result in a smaller growth spurt or a delay in the age of the spurt. These authors further noted that the age of menarchē is earlier in children from more affluent societies.

The effects of these environmental factors on growth,depends on the duration and the severity of the insult and the age at which it occurs (Tanner, 1962). However, it does appear that growth may normalise after a period of increased growth velocity, called catch-up-growth (Tanner, 1978 and 1981). Depending on the intensity of the disturbance, catch-up-growth may or may not completely return growth to normal values (Eveleth and Tanner, 1980). Skeletal maturity assessment is one method of monitoring the above effects (Greulich and Pyle, 1959).

Research has also indicated that the adolescent growth spurt could be retarded due to poor living conditions (Tanner, 1981). This phenomenon was observed in some German towns towards World War II (Howe and Schiller, 1952). If these environmental factors are severe and prolonged, then catch-up growth often cannot reverse the situation. This phenomenon was also documented in the Netherlands during the middle of the previous century (Tanner, 1978; Falkner, 1978; van der Linden, 1986).

Animal experimentation has additionally highlighted the effects of poor living conditions on growth retardation (McCance et al, 1961). Jefferys (1981), showed that shape changes occured in the neurocranium of starving rats, and that the teeth formed during this period had smaller crown sizes.

Available studies would seem to indicate that the climate has no marked or observable effect on growth of humans (Eveleth and Tanner, 1980; van der Linden, 1986). However, the role of genetics and environment are difficult to assess in different climatic conditions. Van der Linden (1986), however, reported that children grew more in spring and summer than during the autumn and winter months. He further speculated that because of the higher levels of growth hormone during the hours of rest at night, a diurnal difference in the amount of growth occurs. Therefore, the need for regular and sufficient sleep is supposedly essential for normal growth to proceed.

From the above the relative importance of the genotype and the environment in determining the growth and maturation of children remains inconclusive. Garn and Bailey (1978), further noted that because of the differing nutritional status of the various population groups,comparitive growth studies are not possible. Therefore, conclusions based on the contribution of the genotype or environment by the comparison of divergent populations may be erroneous (Garn and Bailey, 1978; Eveleth and Tanner, 1980; Marshall, 1981). Tanner (1978), has also shown that girls seem to be more resistant to the effects of such detrimental environmental factors. However, different cultures might afford more protection to girls, which could account for these observations (Shakir and Zaini, 1974).

SECULAR TREND IN SKELETAL MATURITY

Over the past century, children from industrialised countries have increased in size and have also been shown to mature earlier than those of previous generations (Garn and Bailey, 1978; Eveleth and Tanner, 1980). Roede (1979), has shown that these trends have as yet not halted in Europe; however, the expected maximum attainable height has almost been realised. It has been suggested by Eveleth and Tanner (1980), that improved environmental factors such as nutrition, sanitation, immunisation and the associated decrease in infantile diseases, and population mobility (both geographic from rural to urban and improved social class) amongst others, appear to be responsible for this phenomenon. This increased growth velocity, the earlier maturation (probably at an increased height), the earlier cessation of linear growth and a greater adult stature are termed "positive" secular changes (van Wieringen, 1978). The opposite are referred to as "negative" secular trends.

As mentioned earlier under environmental factors, these positive secular trends could be reversed during times of deprivation such as occuring in wars and famines. The critical time for growth to be affected by the environment seems to be during the latter part of the prenatal period and during the first two or three years after birth (van der Linden, 1986). Fluctuation between positive and negative secular changes may occur, depending on the nature of environmental factors affecting a particular population (Eveleth and Tanner, 1980). According to Tanner et al (1975), secular growth trends can therefore be used as an indicator of the health status of a nation.

The effects of the secular trend on maturation, can presently only be studied from available data relating to the age at menarchè (van Wieringen, 1978; Eveleth and Tanner, 1980). Since there is a good correlation between the age at menarchè and skeletal maturation (Tanner, 1978; Proffit, 1986), the trends observed for sexual maturation are expected to be similar to that of skeletal maturation. Eveleth and Tanner (1980), reported that sexual maturation occurs earlier in affluent communities when compared to poorer societies.

Tanner (1962), reported that by the turn of the century European males reach adult height around 26 years of age; presently it occurs around 18 years. However, adult height has also increased by about 10cm in Europe and he suggested that this is due to an increased growth velocity. In 1938 peak height velocity for Swedish boys was reached one year earlier than that in 1883; Norwegian boys in 1825 - 1837 had their peak height velocity at age 17, while in the 1930's this occurred around the age of 14 (Tanner, 1962).

Studies by van Wieringen (1978) reveal that this trend towards earlier menarchè is slowing down in Europe. Children studied in Oslo, though experiencing a secular increase in height from 1950 till 1970 as earlier stated, showed no significant difference in the age of menarchè (Brundtland, 1973). Tanner (1975), also reported that the menarchèal age for London schoolgirls did not change markedly from 1959 till 1966-1967. However, Ljung et al (1974), in a Swedish study between 1965 to 1972, found that menarchèal age was lowered by 0,73 years when compared to an earlier survey.

Whether this positive trend in height increase will continue, and if indeed this will be associated with a cessation of the trend towards earlier maturation (the Oslo experience), or with an ongoing lowering of menarchèal age (as is the Swedish situation), remains to be confirmed in future studies (van Wieringen, 1978). Present studies, however, would seem to indicate that there is a genetic threshold for the minimum age at which menarchè can occur (Tanner, 1978; van Wieringen, 1978).

PUBERTAL GROWTH SPURT

Growth studies have revealed that postnatal growth is fastest during the first year of life and gradually slows down thereafter to an even rate after about three years (van der Linden, 1986). A more pronounced acceleration of growth occurs at about the early teens (Tanner, 1962) and this spurt which is linked to puberty is known as the pubertal or adolescent growth spurt (Marshall, 1977). The growth rate slows down fairly quickly thereafter and adult height is soon achieved (Tanner, 1962; Proffit, 1986).

The age at which the pubertal spurt occurs differs from race to race and between the sexes (Tanner et al, 1975; Eveleth and Tanner, 1980; van der Linden, 1986). Girls generally experienced their growth spurt some two years earlier than boys of the same race. This spurt furthermore is less pronounced and of shorter duration than that for boys (Tanner, 1962). Shuttleworth (1939), reported that the later the pubertal spurt occurred in girls, the less pronounced it was.

Tanner (1962), noted that the different parts of the body experienced a growth spurt in a fairly fixed order or sequence. It generally started with the lengthening of the legs, followed by hip width, then chest breadth, later followed by an increase in the length of the trunk and depth of chest (Tanner, 1962).

According to Nanda (1955), the facial growth spurt occurred some 6 months after peak height velocity was registered. During this period the facial appearance underwent changes resulting in significant morphological differences between the sexes (van der Linden, 1986). Growth of the jaws like that of growth in height, usually correlated well with the physiologic events of puberty (Saltzmann,1974; Proffit, 1986). There is a noticeable adolescent growth spurt in the length of the mandible (though less dramatic than that of body height) and a modest increase in growth at the sutures of the maxilla (van der Linden, 1986). Growth was more pronounced in the lower jaw than in the upper jaw, which follows the normal cephalocaudal gradient of growth experienced throughout the body (Proffit, 1986). This differential jaw growth results in the maturing face thus becoming less convex, as the mandible and chin become more prominent (Proffit, 1986; van der Linden, 1986).

Woodside (1974), has shown that many children, especially girls, exhibit a "juvenile acceleration" of mandibular growth that occurs 1 to 2 years before the pubertal growth spurt and which could be more intensive than that experienced during the pubertal growth spurt. He noted too, that boys almost always had a stronger pubertal growth spurt. Based on the above an accurate assessment of physiologic age is necessary in planning orthodontic treatment. If this were not accounted for clinicians would tend to treat girls too late and boys too soon; especially if treatment were delayed until all the permanent teeth had erupted (Proffit, 1986; van der Linden, 1986).

Steedle and Proffit (1985), have reported that the dentition also experienced an occlusal eruptive spurt during the facial growth spurt at puberty. The exact age of the pubertal eruptive spurt varied but usually began between the ages of 11 and 16. Siersbaek-Nielsen (1971) and Darling and Levers (1976) noted that this spurt lasted for about 2 to 3 years between the ages of 14-18 years, and suggested that the occlusal spurt was probably related to the condylar growth spurt which had resulted in the separation of the jaws. During the occlusal spurt the teeth have been reported to erupt bodily by an amount of 2 to 3 milimeters (Darling and Levers, 1976), together with an associated increase in lower face height (Bjork 1972). The facial tissues especially the facial and masticatory muscles, have also been shown to undergo a period of accelerated pubertal growth, with an associated increase in size (Proffit, 1978; Solow, 1980; Steedle and Proffit, 1985). The eruptive spurt is found to slow down as the face reaches maturity and a relative state of equilibrium is reestablished by the age of 16 to 18 (Darling and Levers, 1976).

PREDICTING THE ADOLESCENT GROWTH SPURT FROM OSSIFICATION EVENTS IN THE HAND-WRIST FILMS

Skeletal age as a parameter of physiological development has been found to be less sensitive at certain stages of growth, being less marked in the 8 to 9 year range for females and the 10 to 12 year age range for males (Tanner, 1962; 1978). In addition, the amount of detectable bony changes observed on the hand-wrist radiograph is less than ideal during this period due to the relative quiescence in the skeletal maturation process (Tanner, 1962).

It has often been suggested that skeletal age could be used to predict the onset of puberty in an individual (Bjork, 1972; Grave and Brown, 1976). While it is true that a child with an advanced skeletal age will be expected to reach puberty earlier than one whose skeletal age is delayed, this has been shown to be true only in the extreme ranges of the normal (Tanner, 1978).

The accuracy of a skeletal age estimation depends on the number of stages appearing per unit time and the duration of each stage (Roche, 1978). The greater the amount of well defined stages of short duration, the greater is the accuracy in the estimation of skeletal age (Roche, 1978). However, during the circumpubertal period, bone maturation is in a period of relative quiescence (Tanner, 1978) as was highlighted by Greulich and Pyle (1959). They reported that the accuracy of skeletal age determination at puberty had a standard

deviation of 1 year compared to one month at 6 months of age, and 4 months at age 2. Tanner (1962), however, suggested that the clinical implication of predicting puberty from skeletal age required that the estimation be accurate to within two months. Houston et al (1979), found that use of the chronological age had an accuracy of 1 year in predicting puberty.

Marshall (1974), found that when girls reached breast stage 2 (B2) their skeletal age varied between 8 and 14 "years", while at B5 they varied between 12 and 16 "years". Thus the variation in skeletal age is similar to that of chronological age for breast development (Tanner, 1978). Menarchè, however, was shown to be better correlated to skeletal age with 85% of girls having bone ages of between 13 and 14 "years" at their first menses (Marshall, 1974). He also found that at this stage (skeletal age 13 "years") the girls had reached 95% of their mature height. However, at the peak of the adolescent growth spurt (peak height velocity) bone ages varied between 10 and 15 "years". This implies therefore, that peak height velocity does not correlate with any given or fixed amount of skeletal maturation, as is the case for menarchè (Marshall, 1974). Marshall (1974) found similar results in boys. Their skeletal ages were significantly less variable than their chronological ages when they reached 95% of their final stature. However, at peak height velocity the variation of skeletal age and chronological age were very similar, both showing no significant correlation to peak height velocity.

In order to improve the accuracy of skeletal age estimation during the relatively quiescent prepubertal period, additional bone stages were utilized by Hagg and Tarranger (1982). However, despite these additional stages they failed to significantly improve on the accuracy of predicting the onset of the growth spurt, even though peak height velocity and end of the spurt estimation, were more accurately predicted. To complicate matters further, it was found that the prediction in onset of the growth spurt was difficult, despite the use of direct measurements of standing height (Shuttleworth, 1939; Tanner, 1962; and Hagg and Tarranger, 1980).

Hagg and Tarranger (1980), found that only half the girls and one fifth of the boys studied, showed a marked and continuous increase in growth rate at puberty. They also found that a quarter of the female sample and one third of the male sample showed minor prepubertal growth spurts. It seems evident, therefore, that any indirect prediction of the onset of the growth spurt utilising hand-wrist radiographs or any other method, is bound to have some measure of inaccuracy (Tanner, 1962; Houston et al, 1979; Smith, 1980).

Houston et al (1979), are of the opinion that the use of ossification events (ie. when one maturation stage changes to another) represents an improvement of growth spurt prediction, with the bone more commonly evaluated being the ulna sesamoid (Flory, 1936; Garn and Rohmann, 1962; Bjork and Helm, 1967; Bowden, 1971; Pileski et al, 1973; Grave and Brown, 1976). Bjork amd Helm (1967), found that initial ossification of the ulna sesamoid always preceded or coincided with

peak height velocity. However, other researchers have reported that ossification of the ulna sesamoid often occurred after peak height velocity (Bowden, 1971; Garn et al, 1972; and Pileski et al, 1973). Pileski et al (1973), found that in 25,3% of males and in 19.5% of females the ulna sesamoid bone appeared after maximum velocity of mandibular growth was completed.

In order to make the estimates more reliable, various workers used the ulna sesamoid bone together with other ossification events occurring at puberty (Bowden 1971; Grave and Brown 1976; Helm 1979). Radiographs in these studies were taken annually and therefore estimates of the onset of puberty could only be made to the nearest 6 months. However, the increased accuracy, if any, of this method over chronological age was not discussed. Houston et al (1979), made use of 3 monthly radiographs at puberty and 6 monthly radiographs before puberty and showed that any improvement in the estimates of peak height velocity were of a limited clinical value. In an orthodontic context, therefore, the use of a single hand-wrist radiograph to estimate the timing of the growth spurt still remains questionable (Houston et al, 1979; Houston, 1980; Smith, 1980). It would appear that the clinical application of a single hand-wrist radiograph could be to ascertain whether the growth spurt had occurred or not (Houston, 1980).

Some researchers have attempted to predict the pubertal growth spurt from dental maturation. However, most authors have noted a lack of correlation between dental development and peak height velocity

(Demirjian, 1978). Meredith (1959), however, found a slight correlation between peak height velocity and the eruption of the mandibular canine and first and second molars. Chertkow (1980), similarly noted a close correlation between calcification stage G* of the mandibular canine and the initial ossification of the ulna sesamoid bone. Hagg and Tarranger (1984), in their study had noted that the relationship between puberty and the initial ossification of the ulna sesamoid was clinically insignificant and reported that the comparison by Chertkow (1980), of a skeletal stage of a short duration (initial ossification of the ulna sesamoid bone) with that of a tooth formation stage, of long duration (stage G which lasts about 2.7 years) is scientifically unsound and therefore not appropriate.

Demirjian (1978), in reviewing the development of the dentition, concluded that dental development occurred independently of the skeletal maturation, peak height velocity, height and the onset of puberty. Further, Hagg and Tarranger (1984) also noted that a low correlation existed between dental and somatic development in both sexes.

*Stage G. The walls of the root canals are parallel (distal roots in molars). The apical ends of the root canal is completely closed (distal root and apex).

Notwithstanding the problems associated with the prediction of puberty, skeletal maturation has an important role in assessing the growth status of orthodontic patients (Houston, 1980; Proffit, 1986). Further, although chronological age may be used to predict the onset of peak height velocity, wide discrepencies have been shown to exist amongst the races. For example a typical affluent caucasian girl begins her adolescent growth spurt at about 10,5 years and attains peak height velocity at about 12 years (Tanner, 1978), while Nigerian girls attain puberty at about 15 years (Dadia and Oguranti, 1986). Further, limited information is available on the age of puberty in the South African population. Therefore, in the treatment of jaw-discrepancy associated malocclusions the use of caucasian norms may not be applicable, and the use of maturation measures other than chronological age may be more appropriate.

MATERIALS AND METHODS

This project investigated skeletal maturation trends in a Western Cape sample, using hand-wrist radiographs. The materials and methods used in this study will be discussed under the following headings:

1) The Population Sample
2) Radiographic Materials
3) Evaluation of Skeletal Maturity
4) Statistical Analysis

(1) THE POPULATION SAMPLE

The South African population comprises several ethnic groups, the four larger groups being the Bantu-speaking Africans, Caucasians of European ancestory, Asians (predominantly from the Indian subcontinent), and "Coloureds" of mixed origin.

In terms of the Population Registration Amendment Act 106 of 1969, the South African government classified the "Coloured" people as a distinct race-group. An earlier edict (Act 30 of 1950) defined a "Coloured" as somebody who is neither white nor black. However, subdivisions were later introduced to legally differentiate between the Cape Coloured, Malay and Griqua on the one hand, and Chinese, Indians and "other Asiatics" on the other hand (W.H. Thomas, 1982). Based on government policy, the four major racial groups are forced to live separately in well defined residential areas (1950 Group Areas Act).

The population sample used in this study was drawn entirely from the so-called "Coloured" population group. This being that the majority of patients attending the Orthodontic Clinic, at the University of the Western Cape, are classified as "Coloured".

The "Coloured" population in the Cape Peninsula live in well defined areas under the following Municipalities (Louw, 1982).

1) Cape Town
2) Bellville
3) Parow
4) Goodwood
5) Milnerton
6) Pinelands
7) Cape Divisional Council
8) Simonstown
9) Durbanville

Patients seen in the Department of Orthodontics were drawn from all the above mentioned areas. This was especially so, as no orthodontic service was provided at any of the community-based dental clinics. The patient sample was therefore representative of the varying socio-economic levels within this "race" group (Louw, 1982).

2) RADIOGRAPHIC MATERIAL

The hand-wrist radiographs used in this study were obtained from patient files in the Department of Orthodontics. A total of five hundred and thirty two (532) radiographs, representing patients of suitable age distribution, were so obtained. Of these, fifty three (53) radiographs were rejected either for lack of radiographic clarity or because they were not from so called "Coloured" patients.

The radiographic material finally investigated were obtained from 130 males and 188 females (Table 1).

Table 1 Age Distribution of Sample Evaluated.

Age (years)	Boys	Girls	Total
6:00 - 6:99	8	8	16
7:00 - 7:99	3	7	10
8:00 - 8:99	9	12	21
9:00 - 9:99	11	23	34
10:00 - 10:99	15	19	34
11:00 - 11:99	10	21	31
12:00 - 12:99	21	28	49
13:00 - 13:99	15	23	38
14:00 - 14:99	16	15	31
15:00 - 15:99	13	17	30
16:00 - 16:99	9	15	24
Total	130	188	318

(3) EVALUATION OF SKELETAL MATURITY

The data recorded from the three hundred and eighteen (318) files included the name, date of birth, date of the hand-wrist radiograph and the address for each patient. The chronological age of the patient was calculated and recorded in years, as prescribed by Eveleth and Tanner (1980).

Each radiograph was assessed using the revised *Tanner-Whitehouse method (Tanner et al 1975), whereby the twenty prescribed hand-wrist bones were investigated in a fixed order, namely, radius, ulna, metacarpals 1,3,5; proximal phalanges 1,3,5; middle phalanges 3,5; distal phalanges 1,3,5; capitate, hamate, triquetral, lunate, scaphoid, trapezium and trapezoid (Figure 1). These radiographs were studied on a standard radiographic viewing box**.

The maturation level for each bone was assessed by comparing it to the diagrams and descriptions given by Tanner et al (1975). Figure 2 represents an example of the method outlined. The maturation stage so allocated was based on shape criteria and labelled, using the letters A to I (Appendix I). Nine stages were used for each bone except the ulna, capitate, triquetral, lunate, scaphoid and trapezium which have 8 stages. Tanner et al (1975) suggested that where the specific bone under investigation did not match the prescribed radiographic illustration, then the written description should be followed.

* The TW-II Method of Tanner-Whitehouse (1975) is a revised version of their 1962 TW1 method.
**Dentaurum Type L1 Viewing Box.

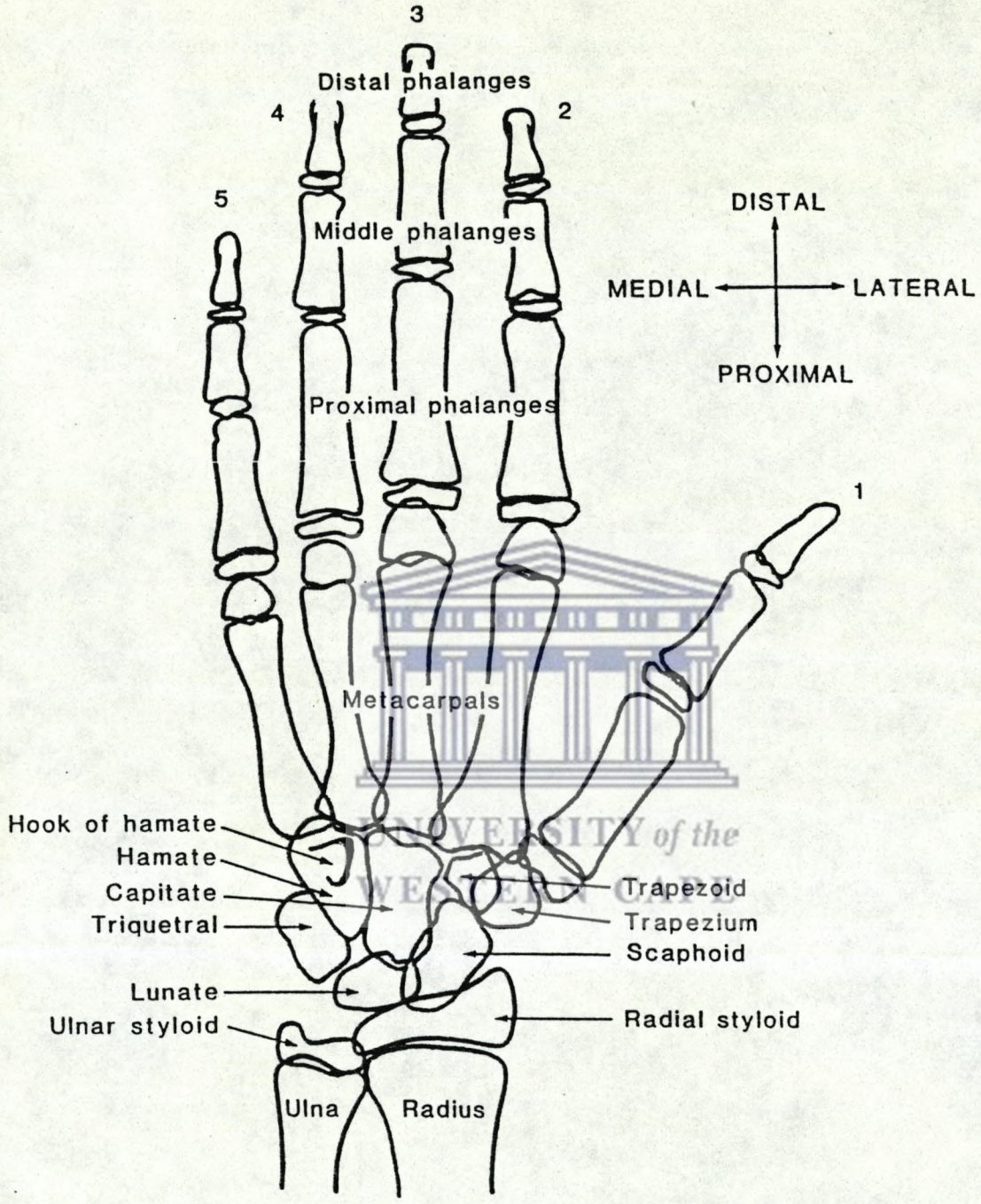


Figure 1 An illustration of the hand-wrist bones used in this study.

Figure 2 An illustration for the staging and scoring method used in the TW-11 method. This illustration is of the radius at maturation stage G. The TW2 score of 77 for boys in the TW2 method indicates the level of maturity of this particular bone at stage G.

BOYS SCORE		Stage G	GIRLS SCORE	
TW2	RUS		TW2	RUS
77	87	(i) The dorsal surface now has distinct lunate and scaphoid articular edges joined at a small hump. Lateral to the scaphoid surface the styloid process carries the border distally in a distinct convexity.	85	114
		(ii) 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.		

The scoring method used in this study was similarly based on a method prescribed by Tanner et al (1962, 1975), who divided the twenty bones into RUS, Carpal and TW-20 scores. The RUS* score incorporated the radius; ulna; metacarpals 1,3 and 5; proximal phalanges 1,3 and 5; middle phalanges 3 and 5; and distal phalanges 1,3 and 5. The remaining 7 carpal bones constituted the Carpal score, while the TW-20 score comprised all 20 bones (Figure 3).

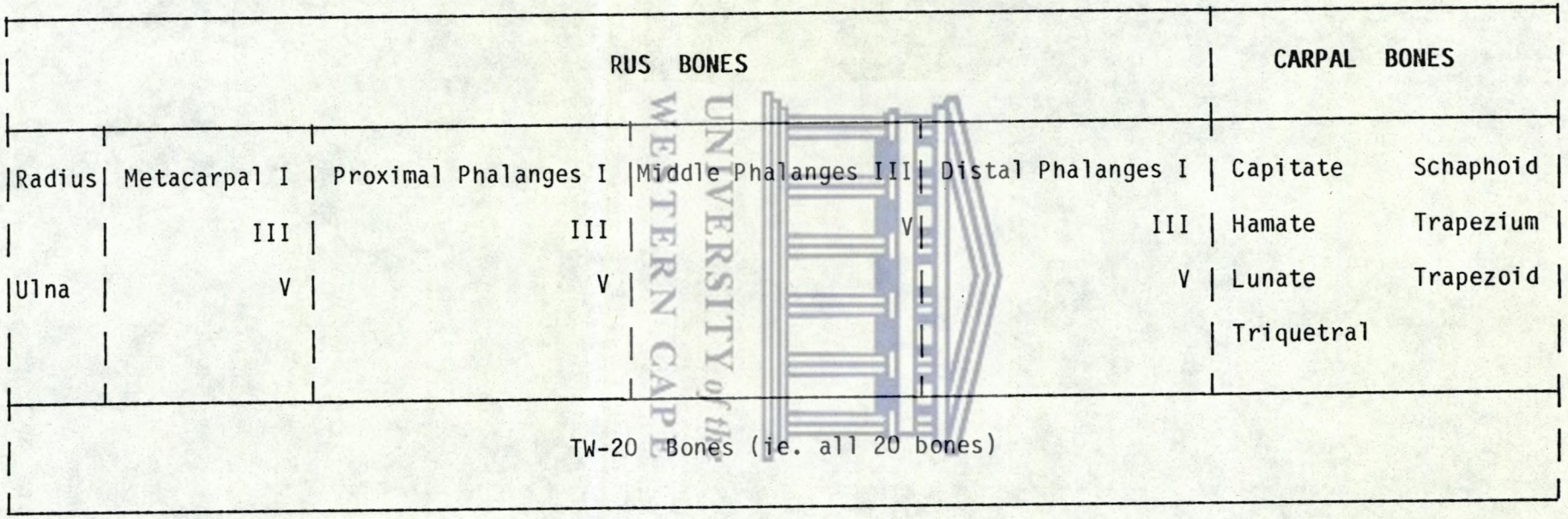
The individual bone, therefore, for each stage had two biologically weigthted numerical scores allocated, namely the TW-20 and either the RUS or Carpal maturity score. Further, because of differences in skeletal maturation between the sexes, Tanner et al (1975) assigned different scores for boys and girls at each maturity stage (Appendix I).

The summation of the respective numerical scores provided either the RUS, Carpal or TW-20 maturity score for each hand-wrist radiograph as required (Appendix IV). The total for each of the three numerical scores ranged from 0 through to 1000, where 1000 designated adulthood. In other words when the bones under investigation reach their adult form, the score allocated would be a 1000 (complete maturity). For the RUS bones this stage is reached when all the epiphyses have totally fused with their respective diaphyses. For the carpal bones, however, complete maturity is attained with the attainment of a specified form or feature of the bone in question (Appendix I).

* Radius, ulna and short finger bones.

Fig. 3 Schematic representation of bone groupings

There are 13 RUS and 7 Carpal bones and the two combined make up the twenty TW-20 bones.



Tanner et al (1975) provided separate tables for the conversion of the RUS, Carpal and TW-20 maturity scores into the appropriate "skeletal" or "bone age" (Appendix II). The "bone age" represented the chronological age of the average British child having the said maturity score. Separate conversion tables were provided for males and females (Appendix II).

In the present study, the three maturity scores were converted into the appropriate "bone ages" for each individual and, the mean "bone age" was then compared to the mean chronological age of the sample. This mean "bone age" was also compared to the British Standard.

Tanner et al (1975) also provided male and female centile standard curves for the RUS, Carpal and TW-20 scores. These percentile levels were used to compare the maturity scores of the Western Cape sample to the British standards. (See appendix III).

Intra- and Inter-examiner Variability

To assess the validity of the results obtained, 35 randomly selected radiographs were re-examined by the author 3 weeks later. These radiographs were also subjected to an independent investigation by a member from the Department of Radiology at the Dental Faculty. The Intra- and Inter-examiner variability was then computed using the Spearmans correlation coefficient.

(4) STATISTICAL ANALYSIS

The data obtained was placed in data tables and the following statistical analyses were computed, namely:

(i) the median chronological age

(ii) the range, median, first and 3rd quartile values of skeletal age for each of the maturity scores (RUS, Carpal and TW-20).

(iii) the number of subjects that fell into the 8 percentile levels for each maturity score.

(iv) the mean skeletal age and mean chronological age.

This study compared the findings in a Western Cape sample to that of the British standard and, hence, the results obtained were evaluated at the percentile levels prescribed by Tanner et al (1975) (See Appendix III). Further, because of the small sample size, these findings were also evaluated at the 50th percentile level.

Differences between the two samples, was evaluated by using the Chi-squared test. Sexual dimorphism in the Western Cape Sample was similarly compared using the Chi-squared test.

The mean skeletal age was compared to the mean chronological age of the sample for each of the three maturity scores obtained. A matched-paired t-test was used to detect any differences in this sample.

RESULTS

1) THE SKELETAL AGE OF THE WESTERN CAPE SAMPLE

The range, first quartile, median and third quartile values for the RUS, Carpal and TW-20 skeletal ages are tabulated in tables 2 to 4. As stated in the materials and methods, the skeletal ages were derived from the appropriate numerical maturity scores via the use of conversion tables provided by Tanner et al (1975) (Appendix II). These results are further, graphically illustrated by means of box plots in figures 4 to 9.

a) Table 2 (Figures 4 and 5)

From table 2 it can be seen that 25% of the female sample attained RUS skeletal maturity at 14 years, 75% at 15 years and 100% at 16 years (4th quartile inclusive). For the male sample, 25% attained RUS skeletal maturity at 15 years and 50% at 16 years.

b) Table 3 (Figures 6 and 7)

Table 3 indicates that for the carpal bones 25% of the female sample attained skeletal maturity at 11 years, 50% at 12 years, 75% at 13 and 14 years and 100% from 15 years onward. In the male sample, 25% attained carpal skeletal maturity at 14 years and 75% at 15 years. However, in the 16 year age group only 50% had attained skeletal maturity.

c) Table 4 (Figures 8 and 9)

The results in Table 4 indicate that for the TW-20 bones, 25% of the female sample attained skeletal maturity at 14 years, 75% at 15 years and 100% at 16 years. For the male sample, 25% attained skeletal maturity at 15 years and 50% at 16 years. Thus, the results in table 1 and 3 are similar for both sexes.

Table 2. Range, Median and Quartiles of Skeletal Age (RUS) for males and females

Age Groups	FEMALES					MALES				
	N	Range	First Quartile	Median	Third Quartile	N	Range	First Quartile	Median	Third Quartile
6 - 7	15	4,9 - 9,4	6,65	7,2	7,3	11	5,8 - 8,8	7,25	7,8	8,1
8	12	7,8 - 11,7	8,4	9,4	9,9	9	7,1 - 10,9	8,1	8,8	8,8
9	23	7,9 - 11,7	9,7	10,9	11,15	11	8,2 - 11,4	8,85	10	10,25
10	19	9,8 - 13,1	10,75	11,5	12,1	15	7,1 - 12,8	9,55	11,3	12,1
11	21	10,2 - 16	12	12,7	13,3	10	9,3 - 15,4	11,3	12,3	14,1
12	28	11,3 - 16	13,05	13,35	14	21	10 - 15,3	12,4	13,4	14,5
13	23	11,9 - 16	13,85	14,1	14,9	15	10,5 - 15,5	11,95	13,5	14,65
14	15	13,2 - 16	13,75	14,9	16	16	11,5 - 18,2	13,95	15,1	15,55
15	17	13,3 - 16	16	16	16	13	13,5 - 18,2	15,1	15,4	18,2
16	15	16 - 16	16	16	16	9	13,5 - 18,2	15,6	18,2	18,2

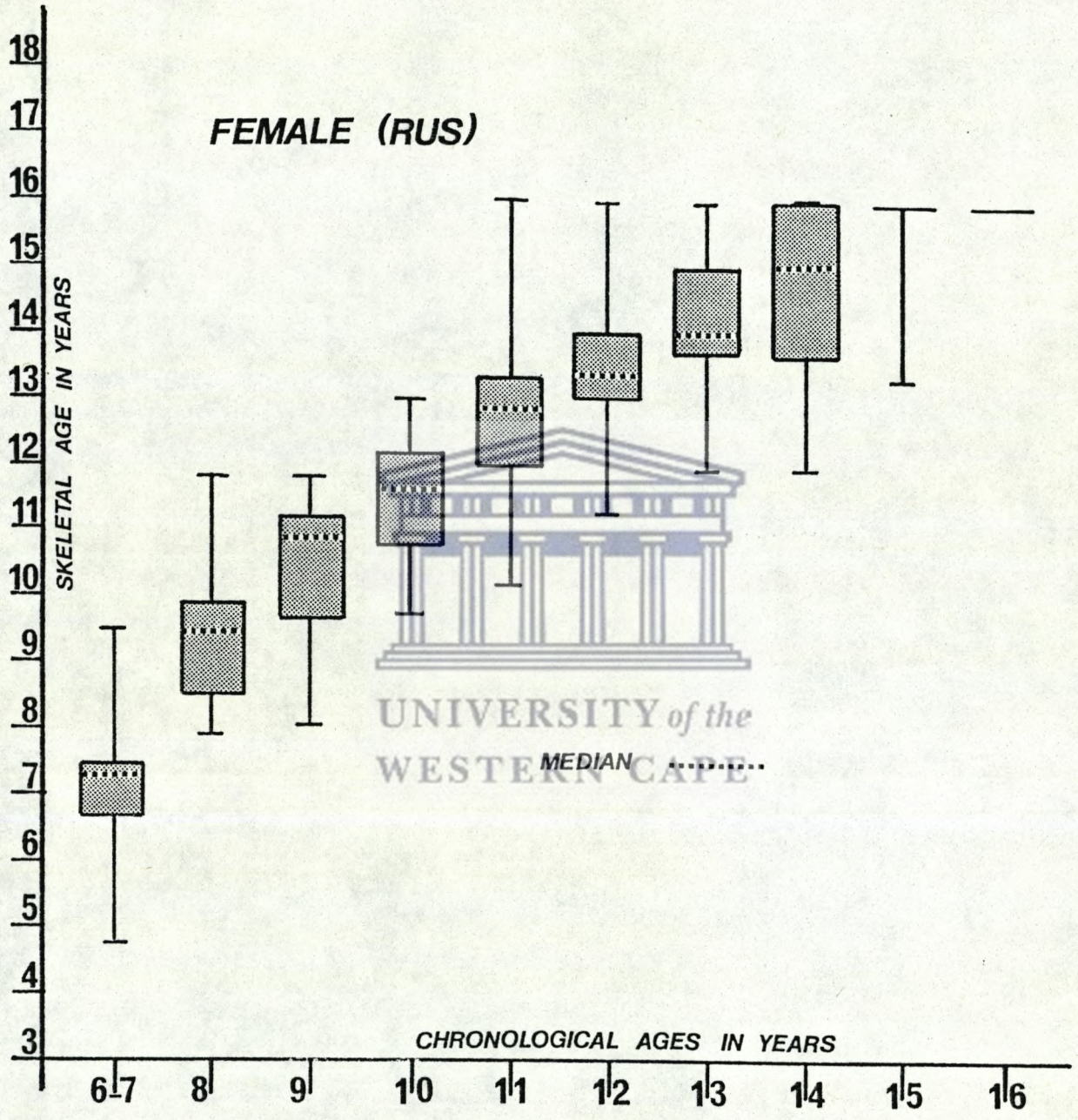


Fig. 4 Range, Median and Quartiles of Skeletal age (RUS) in Females (N = 188)

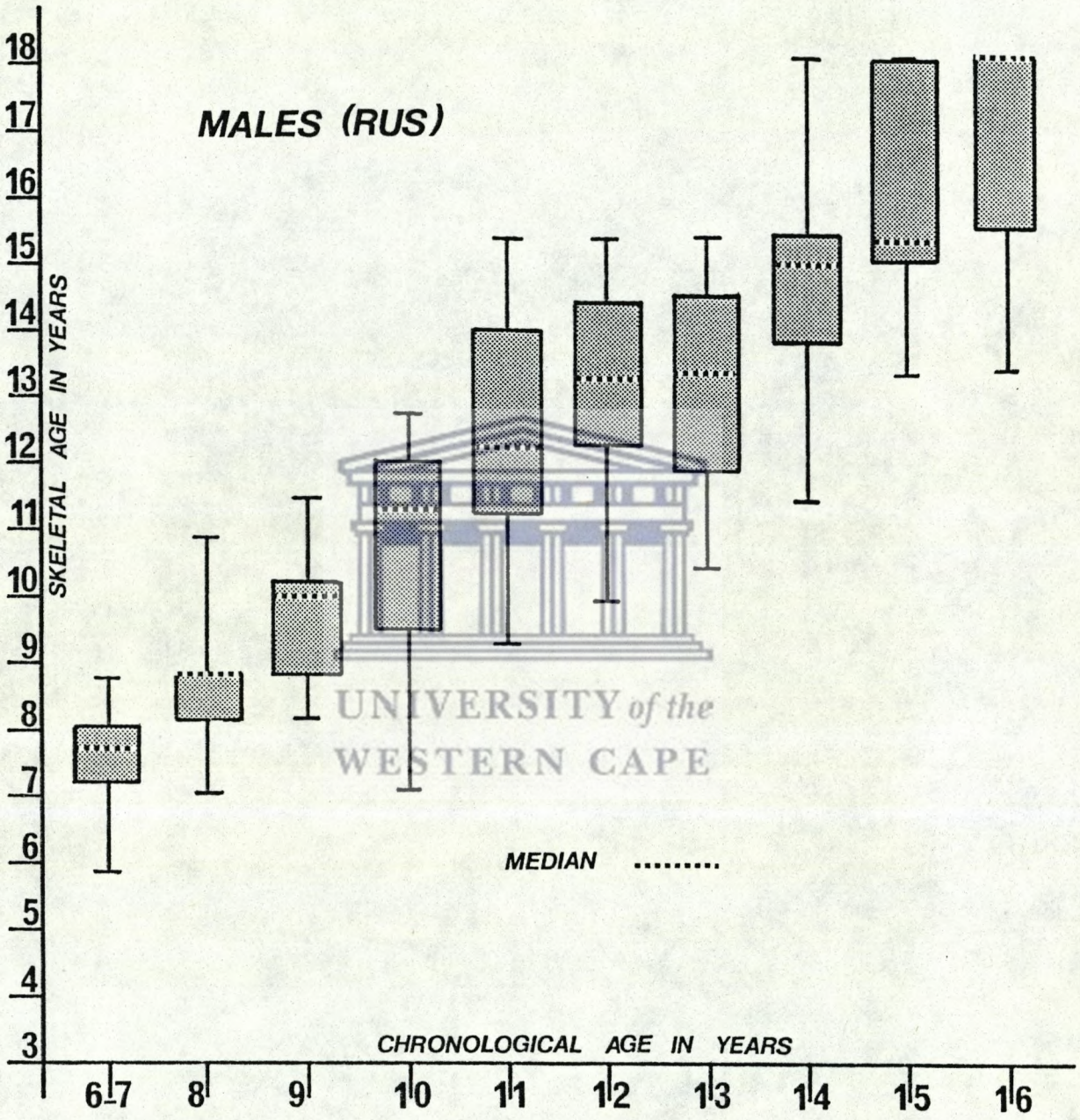


Fig. 5 Range, Median and Quartiles of Skeletal age (RUS) in Males (N = 130)

Table 3. **Range, Median and Quartiles of Skeletal Age (CARPAL) for males and females**

Age Groups	FEMALES					MALES				
	N	Range	First Quartile	Median	Third Quartile	N	Range	First Quartile	Median	Third Quartile
6 - 7	15	3,8 - 8,9	6,1	6,7	7,65	11	5,3 - 8,2	5,75	7,1	7,4
8	12	7,5 - 9,7	7,8	8,5	8,95	9	6,8 - 9,8	8,2	8,3	9,1
9	23	8 - 11,2	8,75	9,1	9,95	11	7,5 - 10,2	7,95	8,8	9,5
10	19	9,1 - 13	9,5	10,2	10,8	15	8,2 - 11,4	9,45	10	10,4
11	21	9,3 - 13	10,4	11,6	13	10	8,8 - 15	10	10,6	12,6
12	28	9,9 - 13	11,85	13	13	21	9,5 - 15	11,1	12	13,5
13	23	11,9 - 13	13	13	13	15	9,9 - 15	11,2	12,1	13,7
14	15	10,9 - 13	13	13	13	16	11 - 15	12,65	14,5	15
15	17	13 - 13	13	13	13	13	13,1 - 15	15	15	15
16	15	13 - 13	13	13	13	9	12,1 - 15	14,2	15	15

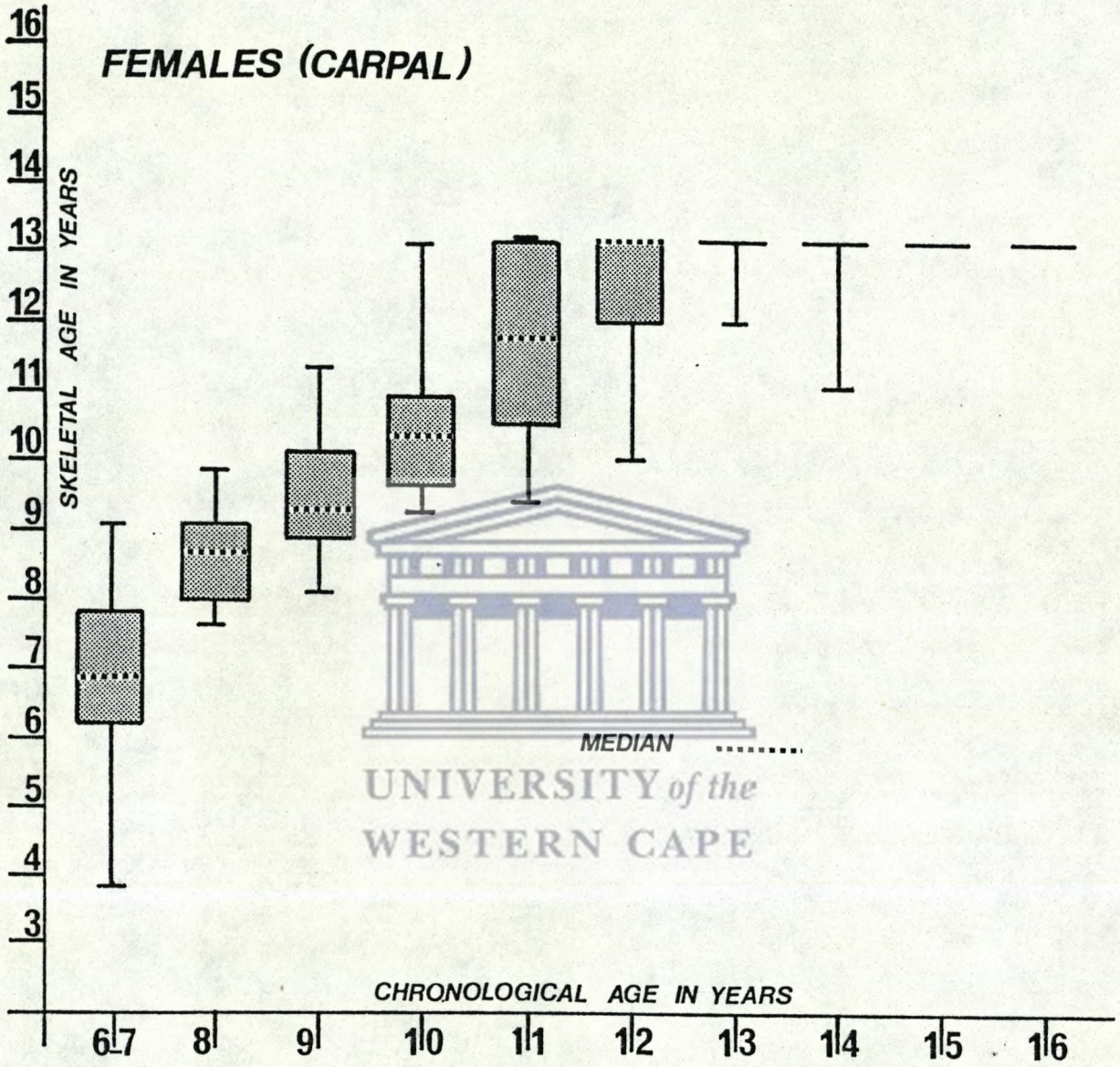


Fig. 6 Range, Median and Quartiles of Skeletal age (Carpal) in Females (N = 188)

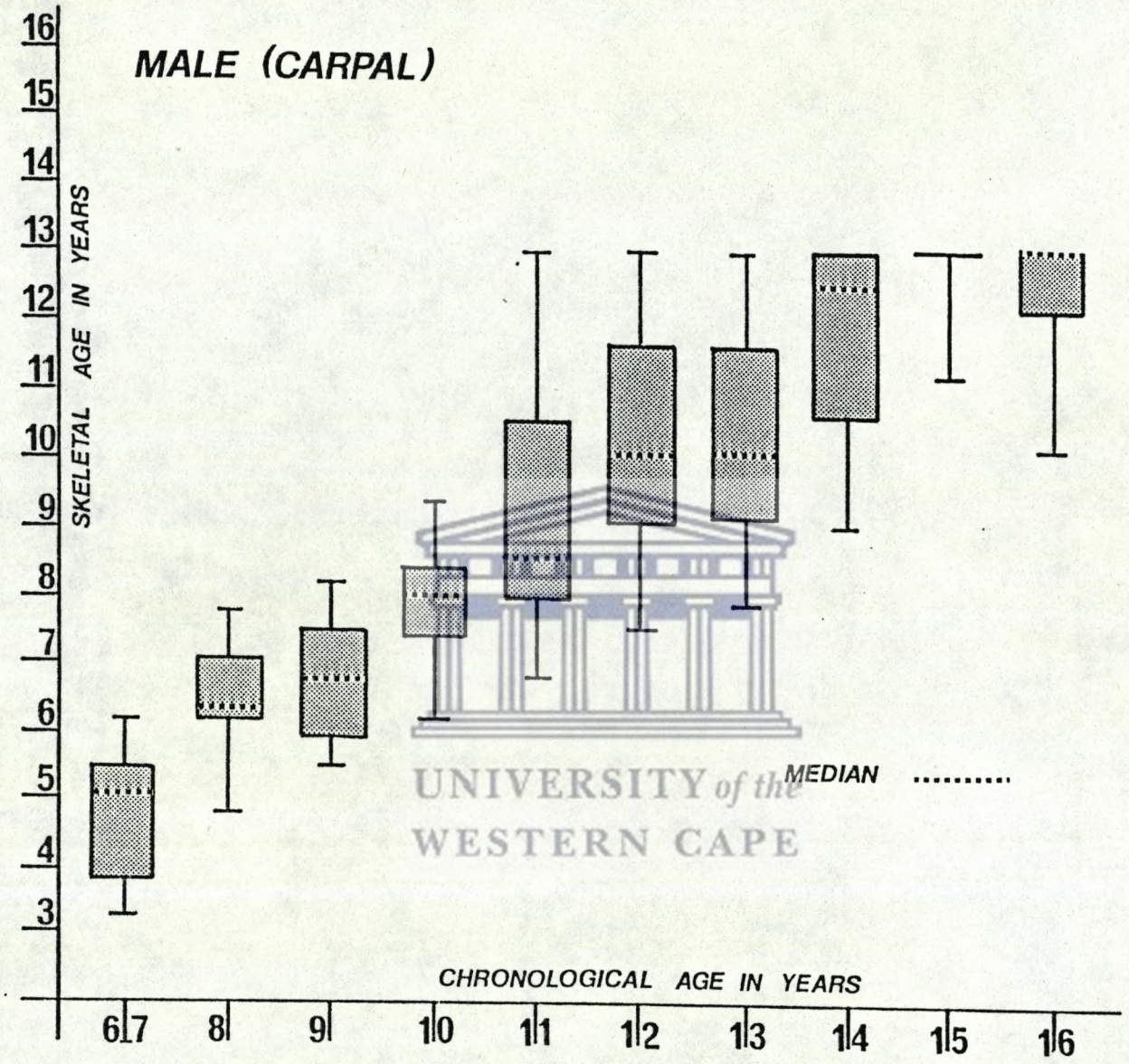


Fig. 7 Range, Median and Quartiles of Skeletal age (Carpal) in Males (N = 130)

Table 4. **Range, Median and Quartiles of Skeletal Age (TW-20) for males and females**

Age Groups	FEMALES					MALES				
	N	Range	First Quartile	Median	Third Quartile	N	Range	First Quartile	Median	Third Quartile
6 - 7	15	4,5 - 8,4	6,45	6,8	7,65	11	5,7 - 8,3	6,15	7,3	7,7
8	12	7,5 - 11,5	8,1	8,8	9,2	9	7 - 10,2	8,2	8,6	9
9	23	7,8 - 11,4	9,45	9,7	10,25	11	7,9 - 10,3	8,65	9,1	10
10	19	9,4 - 13,1	10,15	10,8	11,2	15	7,8 - 11,9	9,6	10,5	11,1
11	21	9,7 - 16,0	11,3	12,2	12,8	10	8,6 - 15	10,6	11,15	13,1
12	28	11 - 16	12,3	13,2	13,5	21	9,7 - 15,4	11,5	12,3	14,4
13	23	11,4 - 16	13,2	13,7	14,25	15	10,2 - 15,3	11,45	13,5	14,65
14	15	11,7 - 16	13,35	13,9	16	16	11,2 - 18	13,2	14,95	15,45
15	17	12,6 - 16	16	16	16	13	13,6 - 18	15,2	15,5	18
16	15	16 - 16	16	16	16	9	12,7 - 18	15,3	18	18

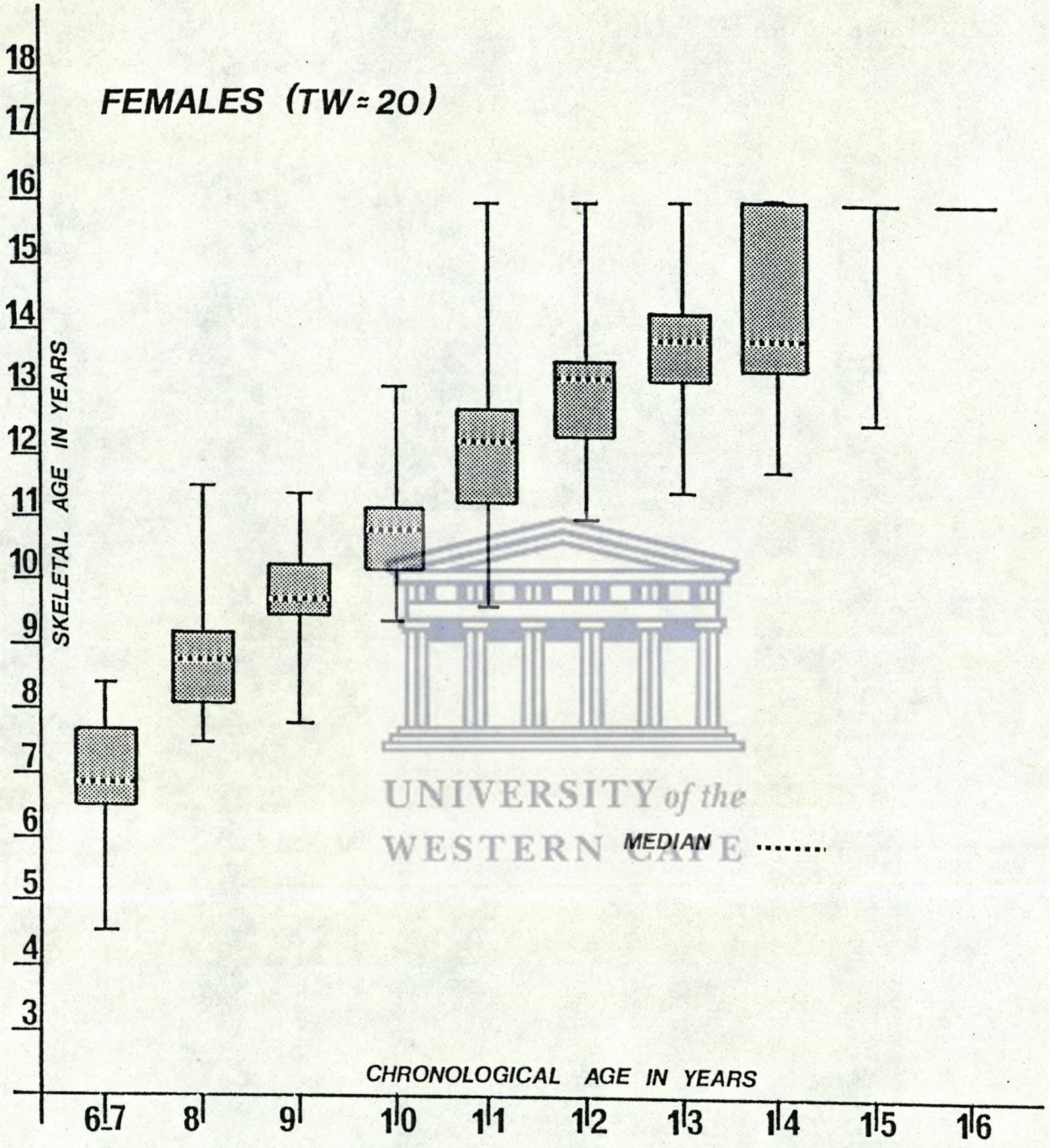


Fig. 8 Range, Median and Quartiles of Skeletal age (TW-20) in Females (N = 188)

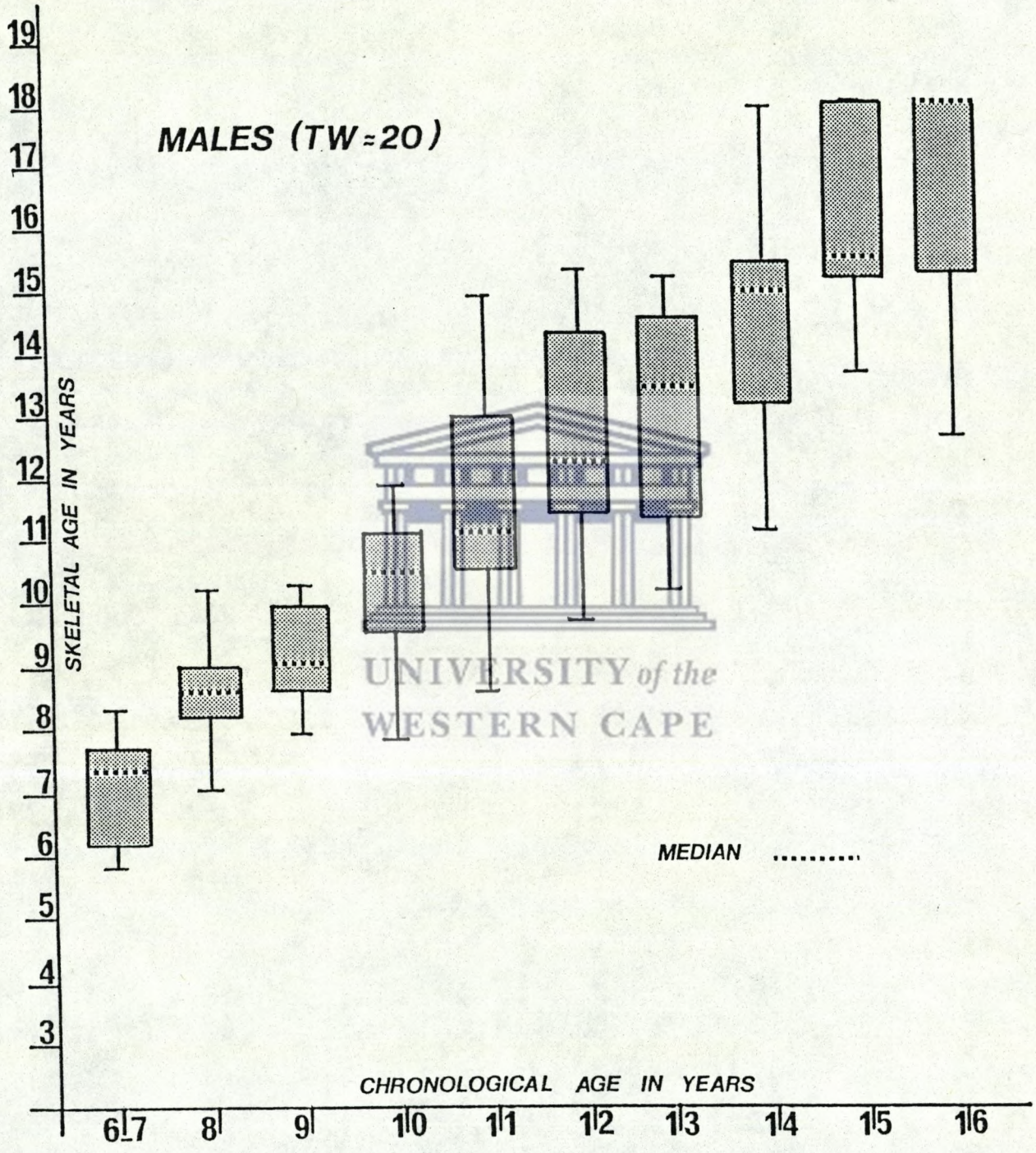


Fig. 9 Range, Median and Quartiles of Skeletal age (TW-20) in Males (N= 130)

2) COMPARISON OF SKELETAL AGE BETWEEN THE WESTERN CAPE SAMPLE AND THE T.W. STANDARD.

In the comparison of the Western Cape sample to Tanner-Whitehouse standard certain age groups were not included. This was done because comparisons made after the age at which 50% of the Tanner-Whitehouse standard reach skeletal maturity are meaningless (Roche, 1974). For example, a 16 year old female with a carpal maturity score of 1000 (ie. adult maturity) will be seen to lie under the 3rd percentile level if one plots her score on the Tanner-Whitehouse percentile charts (Appendix III). This is because the average British child reaches carpal maturity at 13 years. Thus, for females the following age groups were not included:

(1) RUS - 16 year age group.

(2) Carpal - 13, 14, 15 and 16 year age groups.

(3) TW-20 - 16 year age group.

As for the males, the carpal 15 and 16 year age groups were not included, whereas all the age groups were included for the RUS and TW-20 scores.

The number of subjects lying above and below the 50th percentile level are compared to the Tanner-Whitehouse standard in table 5 and 6. Chi-square tests were then performed to detect any differences between the Tanner-Whitehouse standard and the Western Cape Sample.

Table 5 Comparison of Males of the Western Cape and the Tanner Whitehouse Standard above and below the 50th percentile level.
(df = 1)

		< 50%	> 50%	x^2	Significance
RUS	Observed	40	90		
N = 130	Expected	65	65	19,231	*p<0,01
CARPAL	Observed	61	47	1,815	0,1>p<0,2
N = 108	Expected	54	54		
TW-20	Observed	61	69	0,492	p>0,5
N = 130	Expected	65	65		

The results in Table 5 show that males of the Western Cape are significantly more advanced in comparison to the Tanner-Whitehouse standard in so far as the RUS bones are concerned (p<0,01). However, the carpal bones are only slightly delayed, although not significantly (0,1>p<0,2).

In so far as the TW-20 bones are concerned, there is no difference between the Tanner-Whitehouse standard and the Western Cape sample (p>0,5).

Table 6 Comparison of Females of the Western Cape and the Tanner-Whitehouse standards above and below the 50th percentile level. (df = 1)

		< 50%	>50%	x^2	Significance
RUS	Observed	36	137	58,96	*p<0,01
N = 130	Expected	86.5	86.5		
CARPAL	Observed	57	61	0,136	p>0,5
N = 108	Expected	59	59		
TW = 20	Observed	58	115	18,78	*p<0,01
N = 173	Expected	86.5	86		

Table 6 indicates that the females of the Western Cape are significantly more advanced in comparison to the Tanner-Whitehouse standard for both the RUS and TW-20 bones ($p < 0,01$). However, no difference is apparent between the carpal bones of the Western Cape females in comparison to the Tanner-Whitehouse standard ($p>0,5$).

3) COMPARISON AT EACH AGE GROUP OF THE WESTERN CAPE SAMPLE WITH THE T.W. STANDARD

Table 5 and 6 showed some significant differences between the Western Cape sample and the Tanner-Whitehouse standard. It was therefore decided to investigate whether significant differences also exist within each age group in comparison to the Tanner-Whitehouse standard by using the Chi-squared test. The results are tabulated in table 7 and 8.

Table 7 Comparison of Females of the Western Cape at each age group with the Tanner Whitehouse Standard above and below the 50th percentile level. (df =1).

7(1) RUS

Age	< 50	> 50	x^2	Significance
6-7	6	9	0,6	$0.2 > p < 0.5$
8	4	8	1,33	$0.2 > p < 0.5$
9	4	19	9,78	$*p < 0.01$
10	4	15	6,37	$0.01 > p < 0.02$
11	4	17	8,05	$*p < 0.01$
12	3	25	17,29	$*p < 0.01$
13	3	20	12,57	$*p < 0.01$
14	6	9	0,6	$0.2 > p < 0.5$
15	2	15	9,94	$*p < 0.01$

The results in Table 7(1) indicates that females of the Western Cape are in advance over the Tanner-Whitehouse standard for RUS scores. This is more apparent from 9 years through to 15 years though at 10 and 14 years the difference is less explicit.

7(2) Carpal

Age	< 50	>50	x^2	Significance
6-7	7	8	0,067	$p > 0.5$
8	8	4	1,33	$0.2 > p < 0.5$
9	13	10	0,39	$p > 0.5$
10	12	7	1,32	$0.2 > p < 0.5$
11	9	12	0,43	$p > 0.5$
12	8	20	5,14	$0.02 > p < 0.05$

Table 7(2) shows no significant differences between females of the Western Cape and Tanner-Whitehouse standard for carpal bones.

7(3) TW-20

Age	< 50	>50	x^2	Significance
6-7	6	9	0,6	$0.2 > p < 0.5$
8	4	8	1,33	$0.2 > p < 0.5$
9	4	19	9,78	$*p < 0.01$
10	4	15	6,37	$0.01 > p < 0.02$
11	4	17	8,05	$*p < 0.01$
12	3	25	17,29	$*p < 0.01$
13	3	20	12,57	$*p < 0.01$
14	6	9	0,6	$0.2 > p < 0.5$
15	2	15	9,94	$*p < 0.01$

Table 7,(3) shows that females of the Western Cape are in advance over the Tanner-Whitehouse standard from 9 years through to 15 for the TW-20 scores. At 14 years the advancement is less significant (0,2>p<0,5).

Table 8 Comparison of Males of the Western Cape at each age group with the Tanner Whitehouse Standard above and below the 50th percentile level.
(df =1).

8(1) RUS

Age	< 50	>50	x^2	Significance
6-7	1	10	7,36	*p < 0.01
8	2	7	2,78	0.05>p < 0.1
9	5	6	0,091	p > 0.5
10	5	10	1,67	0.1 > p < 0.2
11	2	8	3,6	0.05>p < 0.1
12	6	15	3,68	0.02>p < 0.05
13	5	10	1,67	0.1 > p < 0.2
14	5	11	2,25	0.1 > p < 0.2
15	5	8	0,69	0.2 > p < 0.5
16	4	5	0,11	p < 0.5

From Table 8(1) it can be seen that only in the 6 to 7 year age group is an advancement apparent for the RUS scores in Western Cape males in comparison to the Tanner Whitehouse standard. From 8 years through to 16 years little significant difference exists. This in contrast to Table 4 where the males were shown to be significantly different to the Tanner-Whitehouse standard. This could be due to the small Western Cape sample being spread out over 10 groups in Table 8(1) which masks the general advancement of the Western Cape males.

8(2) Carpal

Age	< 50	> 50	x^2	Significance
6-7	4	7	0,818	$0.2 > p < 0.5$
8	4	5	0,11	$p > 0.5$
9	7	4	0,82	$0.2 > p < 0.5$
10	9	6	0,6	$0.2 > p < 0.5$
11	6	4	0,4	$p > 0.5$
12	14	7	2,33	$0.1 > p < 0.2$
13	9	6	0,6	$0.2 > p < 0.5$
14	8	8	0	$p > 0.5$

The results in Table 8 (2) and 8 (3) show that no significant difference exists for the Carpal bones and TW-20 scores in males of the Western Cape in comparison to the Tanner-Whitehouse standard.

8(3) TW-20

Age	< 50	> 50	x^2	Significance
6-7	4	7	0,82	$0.2 > p < 0.5$
8	4	5	0,11	$p > 0.5$
9	5	6	0,091	$p > 0.5$
10	8	7	0,067	$p > 0.5$
11	5	5	0	$p > 0.5$
12	12	9	0,43	$p > 0.5$
13	7	8	0,067	$p > 0.5$
14	6	10	1,0	$0.2 > p < 0.5$
15	6	7	0,07	$p > 0.5$
16	4	5	0,11	$p > 0.5$

4) COMPARISON AT 8 PERCENTILE LEVELS OF THE WESTERN CAPE SAMPLE AND THE T.W. STANDARD

Since significant differences were found between the Tanner-Whitehouse Standard and the Western Cape Sample above and below the 50th percentile level it was decided to investigate whether significant differences also exist at 8 percentile levels for the sample as a whole. These findings are tabulated in tables 9 and 10.

However, because of the small sample size, comparisons at 8 percentile levels for each age group was not possible.

Table 9 Comparison of the Western Cape Female to the Tanner Whitehouse Standard at 8 Percentile Levels. (df = 7).

Maturity Index	< 3	3-10	10-25	25-50	50-75	75-90	90-97	> 97		x^2 test	Significance
RUS	1	5	11	19	43	39	26	29	Observed		
N = 130	5,19	12,11	25,95	43,25	43,25	25,95	12,11	5,19	Expected	161,495	*p < 0,01
CARPAL	6	9	13	29	35	19	3	4	Observed		
N = 108	3,54	8,26	17,7	29,5	29,5	17,7	8,26	3,54	Expected	7,563	p > 0,5
TW.20	6	9	19	24	53	32	15	15	Observed		
N = 173	5,19	12,11	25,95	43,25	43,25	25,95	12,11	5,19	Expected	34,732	*p < 0,01

Table 9 collaborates the findings of table 6. The RUS and TW-20 bone scores in the Western Cape female are significantly more advanced in comparison to the Tanner-Whitehouse standards (p 0,01). Carpal bones are, however, similar to the Tanner-Whitehouse Standard.

Table 10 Comparison of the Western Cape Male to the Tanner Whitehouse Standard at 8 Percentile Levels. (df = 7).

Maturity Index	< 3	3-10	10-25	25-50	50-75	75-90	90-97	>97		x^2 test	Significance
RUS	10	6	8	16	23	35	15	17	Observed		
N = 130	3,9	9,1	19,5	32,5	32,5	19,5	9,1	3,9	Expected	88,6813	$*p < 0,01$
CARPAL	8	11	20	22	26	10	5	6	Observed		
N = 108	3,24	7,56	10,2	27	27	16,2	7,56	3,24	Expected	16,0035	$0,02 > p < 0,05$
TW.20	14	10	10	27	28	18	7	16	Observed		
M = 130	3,9	9,1	19,5	32,5	32,5	19,5	9,1	3,9	Expected	70,568	$*p < 0,01$

Table 10 indicates that the RUS scores for males of the Western Cape are in advance of the Tanner-Whitehouse standards which conforms to table 5. Carpal scores are similar to the Tanner-Whitehouse standard which also collaborates the findings of Table 5. However, in so far as the TW-20 bone scores go, a significant difference ($p < 0,01$) is found between the Western Cape males and the Tanner-Whitehouse standard. This is surprising because no difference was detected in table 5. The reason for this apparent contradiction will be discussed later.

5) MALE/FEMALE COMPARISON OF THE WESTERN CAPE SAMPLE

A comparison between the sexes, above and below the 50th percentile, was obtained using the chi-square test. Further, the chi-square test was also used to compare the sexes at 8 percentile levels.

Table 11 Comparison of the Western Cape Male and Female above and below the 50th percentile. (df = 1)

Maturity Index	Male		Female		x^2-test	Significance
	<50	>50	<50	>50		
RUS	40	90	36	137	3,915	$0,02 > p < 0,05$
CARPAL	61	47	57	61	2,926	$0,05 > p < 0,1$
TW = 20	61	69	58	115	5,58	$0,01 > p < 0,02$

Table 11 shows that the percentile distribution of both RUS and Carpal bones for both sexes is similar ie. there is no real difference between the sexes for RUS and Carpal bones at the 1% level of significance.

The TW-20 bones however, shows a difference between the sexes at the 1-2% level of significance ie. the females are more advanced than the Tanner-Whitehouse-standard while the males have a similar pattern of distribution to the Tanner-Whitehouse standard.

Table 12 Comparison of the Western Cape Male and Female at 8 Percentile Levels. (df = 7).

Maturity Index	< 3	3-10	10-25	25-50	50-75	75-90	90-97	> 97		x^2 test	Significance
RUS	10	6	8	16	23	35	15	17	Male		
	1	5	11	19	43	39	26	29	Female	14,73	0,02 > p < 0,05
CARPAL	8	11	20	22	26	10	5	6	Male		
	6	9	13	29	35	19	3	4	Female	9,38	0,2 > p < 0,5
TW.20	14	10	10	27	28	18	7	16	Male		
	6	9	19	24	53	32	15	15	Female	15,00	0,02 > p < 0,05

Table 12 indicates that both the RUS and TW-20 scores are slightly different between the sexes at 2-5% level of significance. No difference is found in the carpal bones between the sexes. However, table 11 is less informative than table 6 because of the small sample size ie. the spreading of the values over 8 percentile levels masks any differences in a small sample.

6) COMPARISON OF THE MEAN SKELETAL AGE AND THE MEAN CHRONOLOGICAL AGE IN THE WESTERN CAPE SAMPLE

Table 13 through to 18 compares the mean skeletal age to the mean chronological age of the Western Cape Sample. A matched-paired T-test was done for each comparison (RUS, Carpal and TW-20) to detect whether any significant differences exist.

The mean skeletal ages at various chronological ages for each bone score (RUS, Carpal and TW-20) are further illustrated in figures 10 to 15. The straight line in these figures is the expected mean of the British children (Tanner-Whitehouse) used as the Standard; their skeletal age is by definition equal to their chronological age.

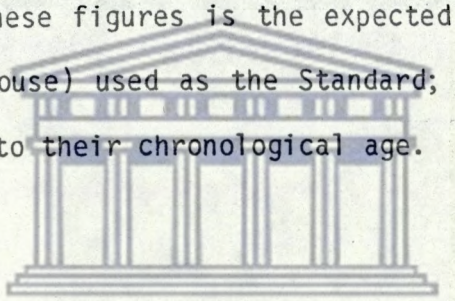


Table 13 Difference between the mean chronological age and mean skeletal age in Western Cape Males (TW-20).

Age	Mean Chron. Age	Mean Skeletal Age	S.D.	Chron. Age - Skeletal Age	T-test
6-7	6.68	7.05	0,947	-0,37	
8	8.46	8.6	0,9433	-0,14	
9	9.5	9.2	0,8473	0,3	t_9=-0,522
10	10.43	10.27	1,2175	0,16	
11	11.52	11.65	1,879	-0,13	
12	12.52	12.65	1,709	-0,13	p > 0,5
13	13.3	13.05	1,727	0,25	
14	14.48	14.53	1,869	-0,05	
15	15.62	16.05	1,456	-0,43	
16	16.53	16.4	2,075	0,13	
				$\bar{x}$ = -0,04	

The results in Table 13 reveal no significant differences between chronological age and skeletal age in males of the Western Cape for the TW-20 scores ie. the males are similar to the Tanner-Whitehouse standard.

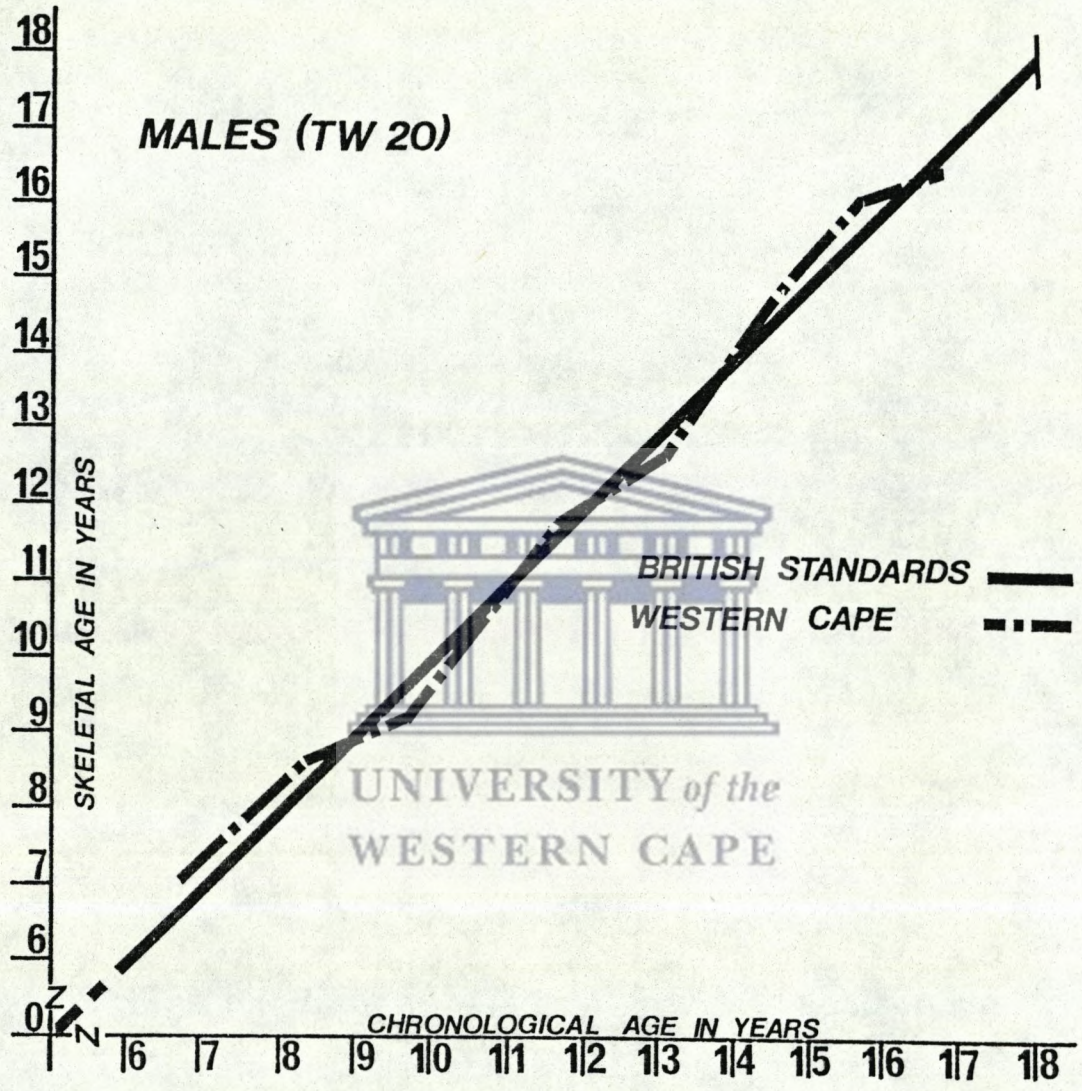


Fig. 10 Comparison of the Mean Skeletal Age with the mean chronological age in Males (TW-20).

Table 14 Difference between the mean chronological age and mean skeletal age in Western Cape Females (TW-20).

Age	Mean Chron. Age	Mean Skeletal Age	S.D.	Chron. Age - Skeletal Age	T-test
6-7	6.9	6.83	1,077	0,07	
8	8.6	8.82	1,1530	-0,22	
9	9.43	9.68	0,8785	-0,25	
10	10.55	10.85	1,0335	-0,3	t_8=-2,866
11	11.52	12.05	1,439	-0,53	0,02 > p < 0,05
12	12.36	13.05	1,190	-0,7	
13	13.47	13.86	1,253	-0,39	
14	14.41	14.38	1,496	0,03	
15	15.51	15.49	1,151	-0,02	
				$\bar{x}$ = -0,26	

Table 14 shows that females start advancing over the Tanner-Whitehouse standards from 8 years (where the difference is 0,22 years) progressively upto 12 years (where the difference is 0,7 years). Thereafter, the advancement decreases such that little difference exist between them at ages of 14 and 15 years.

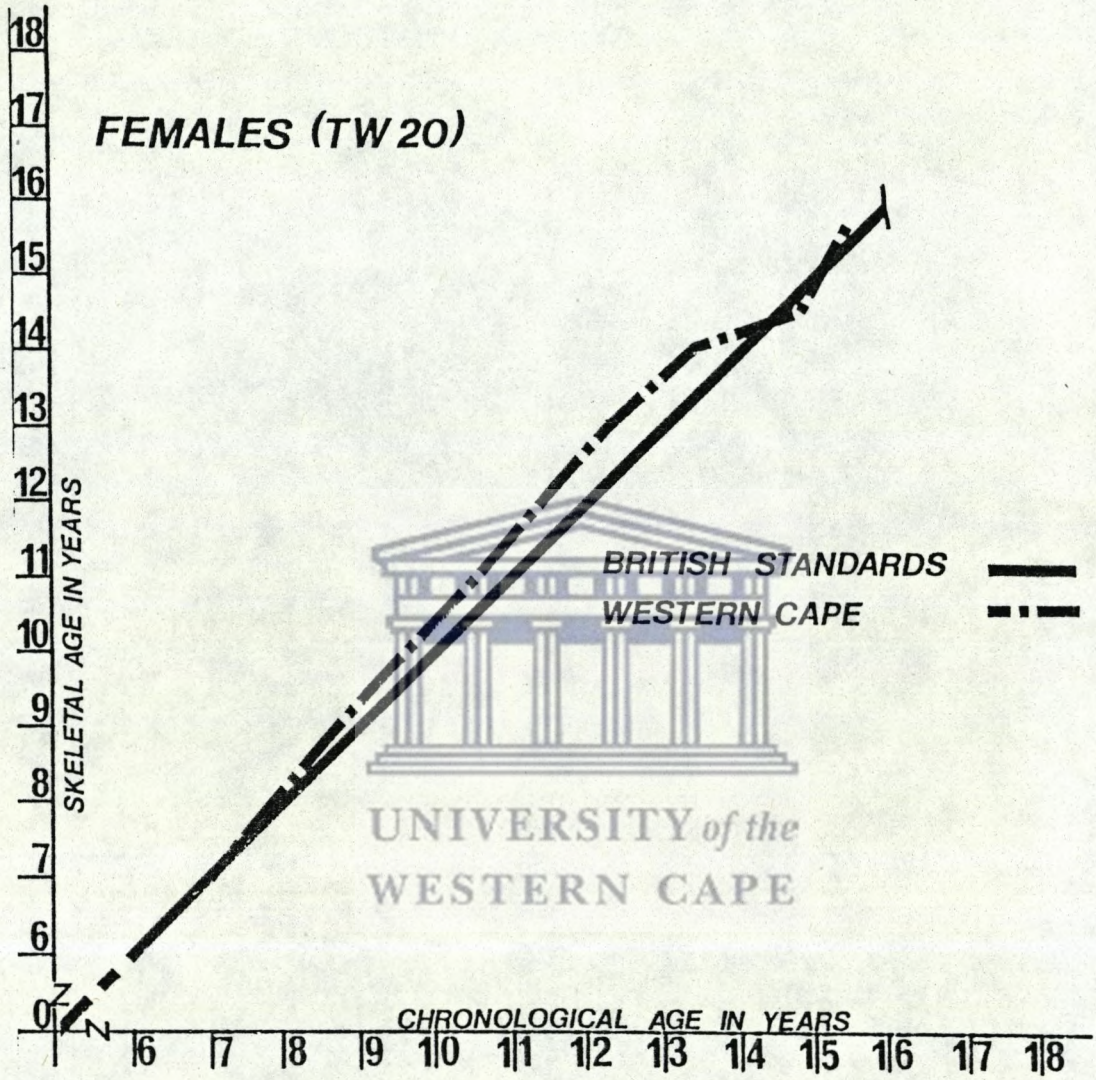


Fig. 11 Comparison of the Mean Skeletal Age with the mean chronological age in Females (TW-20).

Table 15 Difference between the mean chronological age and mean skeletal age in Western Cape Males (Carpal).

Age	Mean Chron. Age	Mean Skeletal Age	S.D.	Chron. Age - Skeletal Age	T-test
6-7	6.68	6.7	1,037	-0,07	
8	8.46	8.38	0,8828	0,08	
9	9.5	9.78	0,9897	0,72	$t_7=3,767$
10	10.43	9.79	0,9114	0,64	$p < 0,01$
11	11.52	11.12	1,849	0,4	
12	12.52	12.295	1,788	0,23	
13	13.3	12.5	1,615	0,8	
14	14.48	13.78	1,544	0,7	
				$\bar{x} = 0,44$	

Table 15 indicates that the males of the Western Cape are delayed in comparison to Tanner-Whitehouse standard for carpal bone scores from 8 years onward. The delay is somewhat reduced at 11 and 12 years. The period of maximum delay occurs at 9 and 10 years and again at 13 and 14 years.

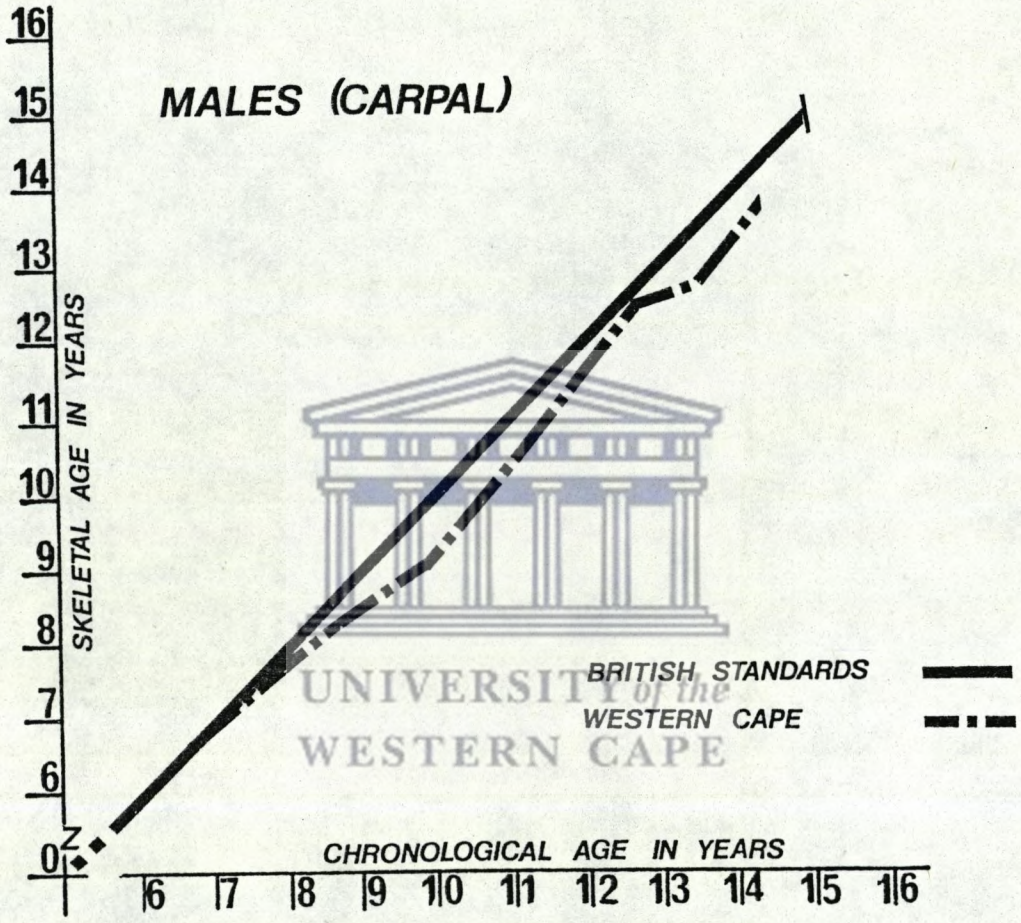


Fig. 12 Comparison of the Mean Skeletal Age with the mean chronological age in Males (Carpal).

Table 16 Difference between the mean chronological age and mean skeletal age in Western Cape Females (Carpal).

Age	Mean Chron. Age	Mean Skeletal Age	S.D.	Chron. Age - Skeletal Age	T-test
6-7	6.9	6.92	1,361	-0,02	
8	8.6	8.51	0,7647	-0,09	$t_5=1,031$
9	9.43	9.29	0,7898	0,14	$0,2 > p < 0,5$
10	10.55	10.52	1,245	0,03	
11	11.52	11.55	1,364	-0,03	
12	12.36	12.39	1,055	-0,03	
				$\bar{x}$ = 0,00	

Table 16 indicates that females of the Western Cape are similar to the Tanner-Whitehouse standard in so far as the carpal scores are concerned.

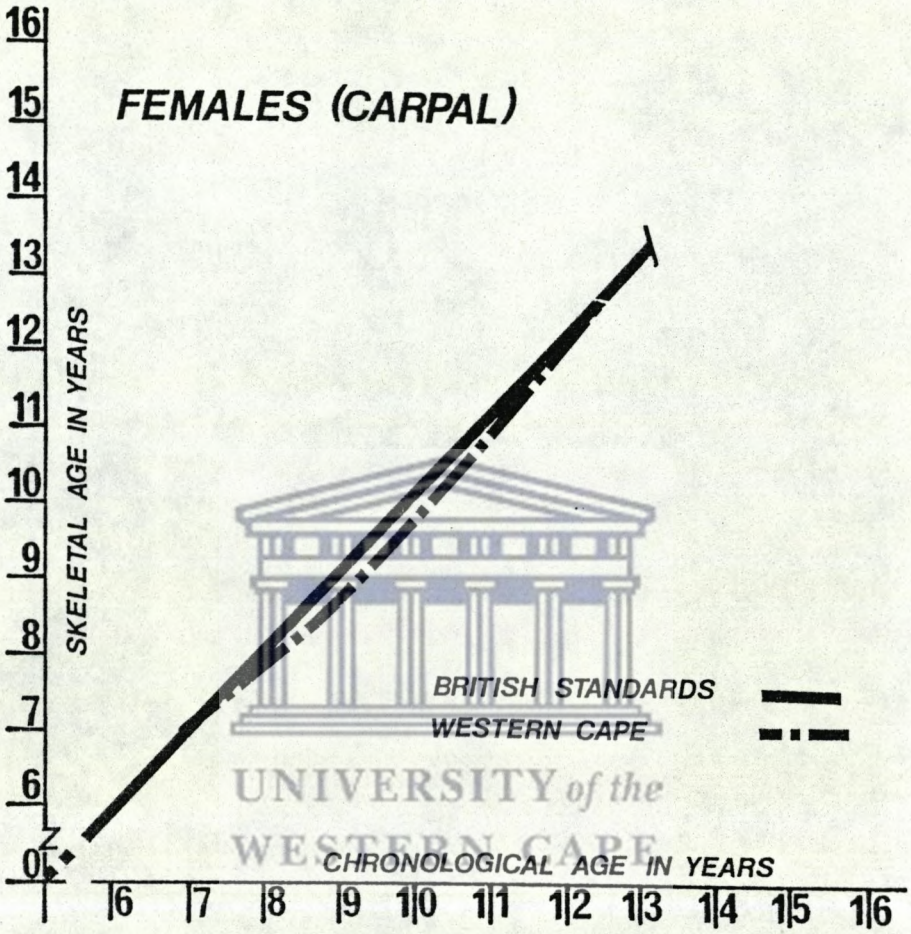


Fig. 13 Comparison of the Mean Skeletal Age with the mean chronological age in Females (Carpal).

Table 17 Difference between the mean chronological age and mean skeletal age in Western Cape Males (RUS)

Age	Mean Chron. Age	Mean Skeletal Age	S.D.	Chron. Age - Skeletal Age	T-test
6-7	6.68	7.35	0,903	-0,85	
8	8.46	8.79	1,1072	-0,33	
9	9.5	9.65	0,9771	-0,15	$t_9=-4,264$
10	10.43	10.75	1,7455	-0,32	
11	11.52	12.49	1,884	-0,97	$p<0,01$
12	12.52	13.19	1,540	-0,67	
13	13.3	13.37	1,640	-0,07	
14	14.48	14.83	1,681	-0,35	
15	15.62	16.03	1,658	-0,41	
16	16.53	16.62	2,014	-0,09	
				$\bar{x}$ = -0,42	

The results in Table 17 indicate that males of the Western Cape are consistently, albeit slightly, advanced over the Tanner-Whitehouse standard in so far as the RUS scores go. The amount of advancement decreases from 6 through to 9 years from 0,85 to 0,15 years. Thereafter, the advancement increases at 10 years to reach a peak of 0,97 years at 11. The advancement decreases to its lowest level at the age of 13 (0,07 years). At 14 and 15 years there is once again a slight increase in the advancement (0,4 years). At 16 years the advancement decreases once again.

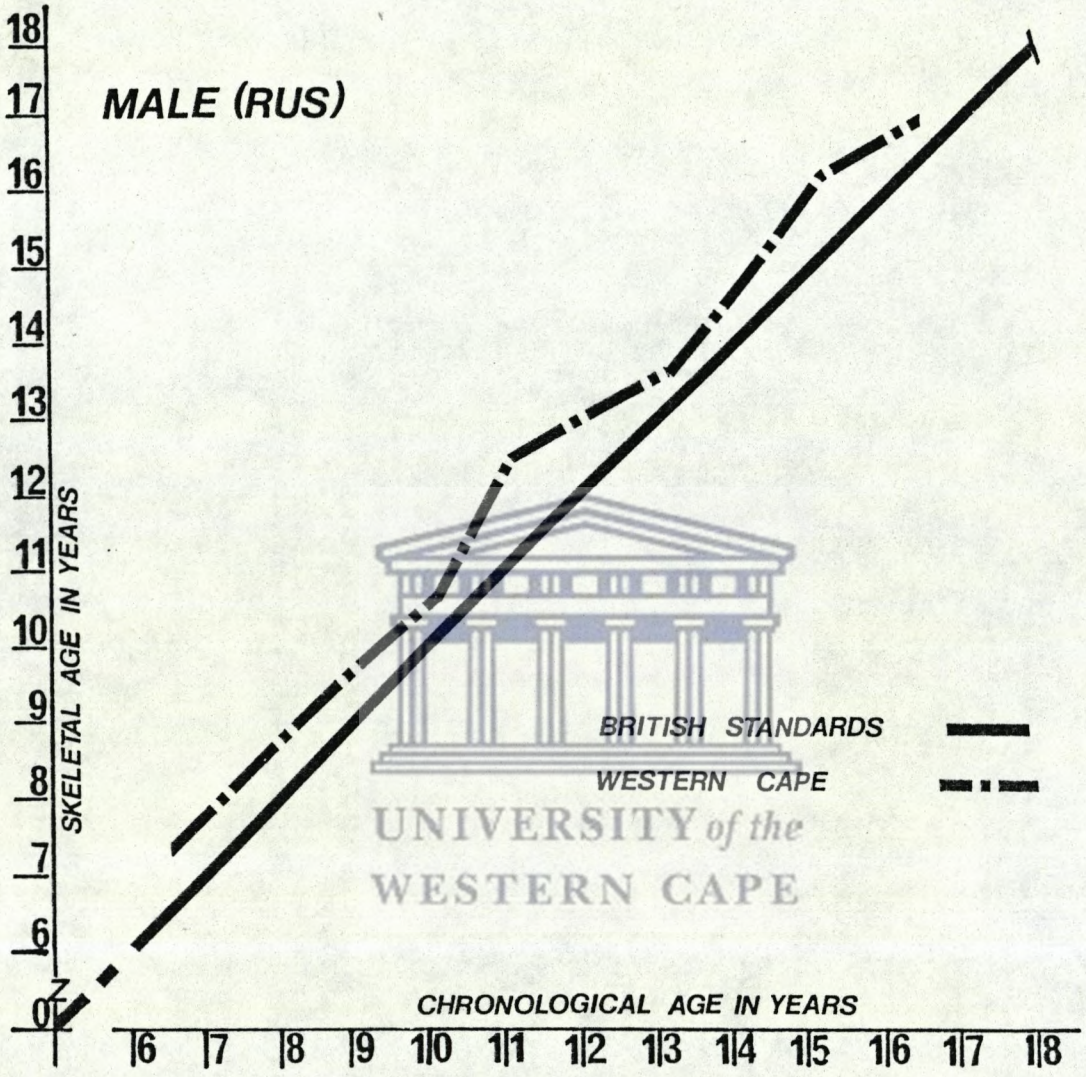


Fig. 14 Comparison of the Mean Skeletal Age with the mean chronological age in Males (RUS).

Table 18 Difference between the mean chronological age and mean skeletal age in Western Cape Females (RUS)

Age	Mean Chron. Age	Mean Skeletal Age	S.D.	Chron. Age - Skeletal Age	T-test
6-7	6.9	7.03	1,277	-0,13	
8	8.6	9.27	1,1858	-0,67	
9	9.43	10.36	1,1073	-0,93	t_9=-5,558
10	10.55	11.45	0,9714	-0,9	
11	11.52	12.56	1,348	-1,04	p<0,01
12	12.36	13.56	1,017	-1,2	
13	13.47	14.29	1,085	-0,82	
14	14.41	14.84	1,152	-0,43	
15	15.51	15.69	0,801	-0,18	
				$\bar{x}$ = -0,7	

Table 18 indicates that females of the Western Cape are consistently advanced over the Tanner-Whitehouse standard in so far as the RUS scores are concerned. The advancement increases progressively from 0,13 years at the 6-7 year age group upto a peak of 1,2 years at 12. Thereafter, it falls progressively through to 15 years although they still remain ahead of the Tanner-Whitehouse standard.

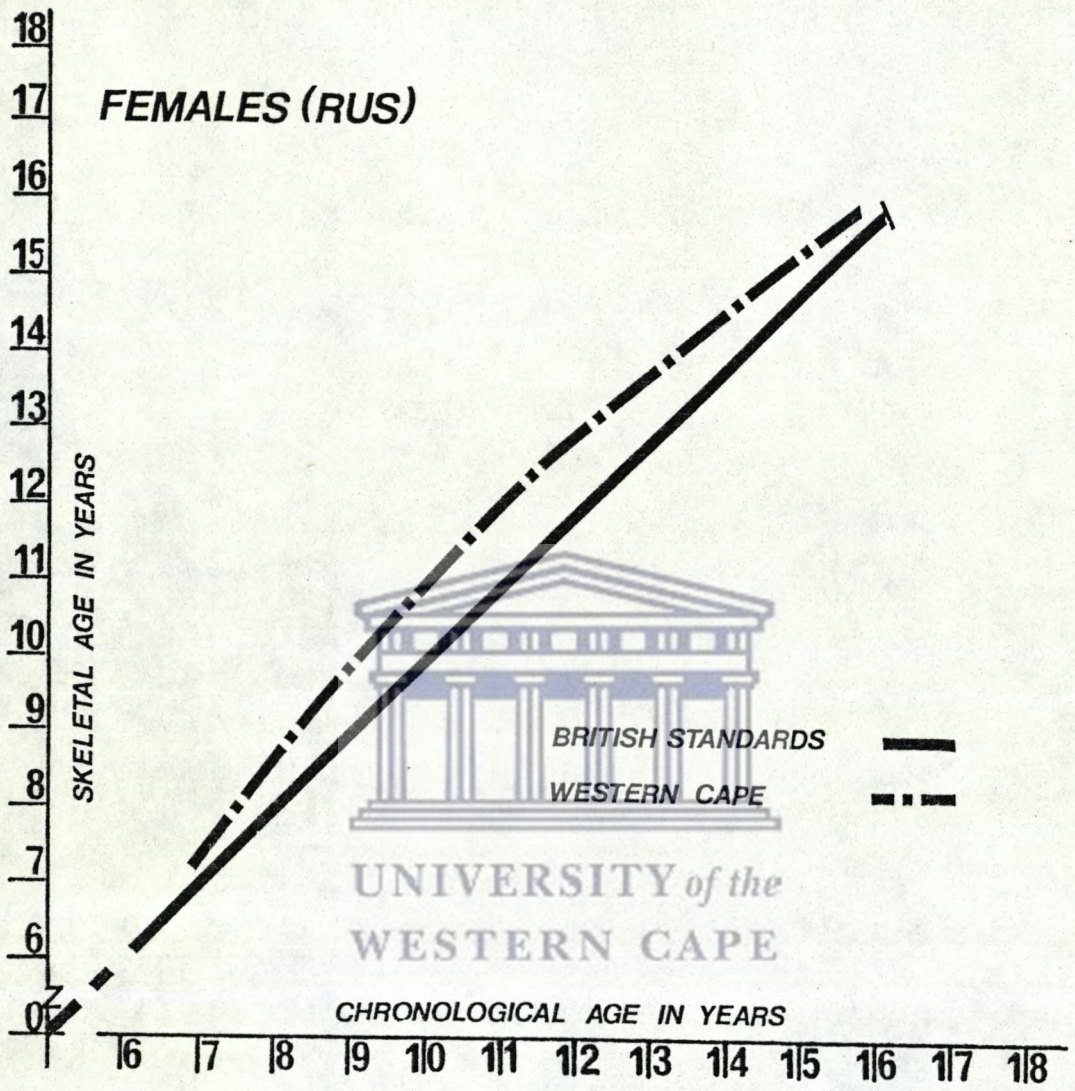


Fig. 15 Comparison of the Mean Skeletal Age with the mean chronological age in Females (RUS).

DISCUSSION

One of the main objectives of this study was to determine whether any significant differences existed between skeletal maturation patterns in the so called "Coloured" population group of the Western Cape and universally accepted British and American norms (Greulich and Pyle, 1959; Tanner et al, 1975; Roche, 1975).

In orthodontic treatment planning, skeletal age assessment using a hand-wrist radiograph, is necessary to quantitate the growth status of an individual (Bjork, 1972; Proffit, 1986). This is especially so, since research has shown that the biologic age of an individual varies from that of the chronological age (Greulich and Pyle, 1959; Acheson, 1966; Tanner, 1978).

In most European and American patients the attainment of the permanent dentition occurs before the pubertal growth spurt, especially in females (Van der Linden, 1986). Numerous studies have also shown that little jaw growth occurs after puberty and therefore, treatment should begin in the mixed dentition period for successful growth modification (Proffit, 1986; Van der Linden, 1986; McNamara, 1986).

However, it is interesting to note that some population groups show an advanced dental maturation pattern in comparison to Caucasoid norms (Chertkow, 1980; Loevy, 1983; Singh, 1985), while their skeletal maturation is delayed (Jones and Dean, 1956; Tobias, 1958). In the South African Black, Chertkow (1980) found that the dental maturation is advanced, while their skeletal maturation is delayed. This implies therefore, that successful growth modification may be undertaken in South African Blacks after the attainment of their permanent dentition.

Singh (1985) similarly, reported that the "Coloureds" in the Western Cape had an advanced dental maturation pattern in comparison to Caucasian values. The skeletal maturation pattern for the "Coloureds" of the Western Cape is largely unknown, and it is therefore necessary to determine these trends, as this could be of use in orthodontic treatment planning.

Notwithstanding the great diversity in the genetic makeup and living conditions within the "Coloured" population group, a major problem encountered in this study was the actual definition or delineation of the population sample. This is especially significant in view of the political genesis of this "race group". To avoid confusion, it became necessary to apply a fairly loose descriptive definition of the population sample under study. Hence, in the context of this study, the term "Coloured" implies any person of mixed racial origin.

The sample used in this study was drawn from the patient list of the Department of Orthodontics at the University of the Western Cape. Since most of these patients belong to the so called "Coloured" group it was decided to confine the study to this population group. The information available from the patient files allowed for this to be done entirely on a "group area" basis as "Coloureds" live in well defined residential areas. It is possible that utilization of this sampling technique is representative of a broader socio-economic strata within the "Coloured" population group.

The selection of the most appropriate method of skeletal age assessment, from the many available, did not prove easy. The decision to use the method advocated by Tanner et al (1975) was taken because of the reliability, ease of application, accuracy and versatility of this method (Acheson et al, 1963; 1966; Roche et al, 1970; Taranger et al, 1976).

Both the intra- and inter-examiner correlation in this study was high (r = 0,978 and 0,964 respectively). Disagreements between the two examiners never exceeded one stage of the Tanner-Whitehouse method of evaluation. This, despite their obvious lack of experience with the application thereof, which therefore corroborated its easy usage,and further vindicated the decision to use this method.

The data from the present study showed a marked difference in skeletal maturation between females of the Western Cape to that of the British norms (Tanner et al, 1975), while the Western Cape males showed less divergence. As is evidenced from table 2 and 4, 50% of the male sample attained skeletal maturity by 16 years, which closely followed the British norm. Notably, the RUS and Carpal bone ages showed some difference (Table 13, 15 and 17); the latter being delayed while the former being advanced. Since the Carpal and RUS bones together constituted the TW-20 score, these differences are cancelled out for the overall score (TW-20). Levine (1972) and Roche (1978) indeed, have noted that the carpal bones cannot alone be taken as representative of the entire skeleton. Also, it has been shown to be more subject to environmental influences (Garn et al, 1964; Acheson et al, 1974; Marshall, 1978).

The total female sample in this study reached skeletal maturity by about the age of 16 years (Table 2 to 4), which is generally more advanced for both the RUS and TW-20 bone ages than the British norm. The maturation of the carpal bones, however, tend to be similar to British standards.

It appears from the data obtained, therefore, that the carpal bones in both males and females are delayed in relation to the RUS bones, with males being delayed to a greater degree. This phenomenon could be attributed to, amongst others, developmental, environmental, cultural and genetic factors (Garn et al, 1964; Acheson, 1966; Malina, 1970; Tanner et al, 1975).

Levine (1972), found that skeletal maturation amongst "Coloured" male children in Pretoria, between the ages of 6 and 12 years were on average 0,9 "years" (11,2 months) delayed when correlated to the Greulich-Pyle atlas. However, since the Tanner-Whitehouse standards have, on average been shown to be 0,8 "years" delayed when compared to this standard (Eveleth and Tanner 1980), it becomes evident that Levine's coloured male sample is about 0,1 "years" advanced, relative to the Tanner-Whitehouse standards. Similarly, the females in Levine's study were found to be 1,3 years (15 months) delayed in comparison to the Greulich-Pyle standard, which when adjusted to the Tanner-Whitehouse standard as earlier stated, becomes delayed by about 0,5 "years".

The present study, therefore indicated that the data for males closely approximated that of the British TW-20 standards (Table 5). Therefore, when correlated to Levine's study, "Coloured" males in Pretoria and the Western Cape region have similar skeletal maturation patterns. This study has also shown that females are, on average 0,3 "years" more advanced than the British standard. Again, when compared to Levine's study, "Coloured" females of the Western Cape are more advanced than "Coloured" females in Pretoria by about 0,8 "years".

Although the divergence for these findings are not readily apparent, it appears from the literature, that the influences affecting skeletal maturation are more of a genetic and environmental nature (Eveleth and Tanner, 1980). It is probable that the "Coloureds" in Pretoria and of the Western Cape enjoy different living conditions, which when coupled with their multigenetic constitution are likely to affect the present study.

Reporting on similar male-female differences in the Negro population of the United States, Malina (1970) suggested that their gene pool could be implicated as a causative factor. He suggested that the flow of genes into the American Negro has been undirectional with respect to the sex chromosomes (European males - Negro females). It becomes evident therefore, that a greater proportion of the Y-chromosomes in the American Negro gene pool are from European sources. This disproportionate contribution of Y-chromosomes, according to Malina, could result in the similarity of skeletal maturation patterns in Negro

and White males of the U.S.A. In the so called "Coloured" population of the Western Cape there is reason to believe, given the sociopolitical conditions, that a similar unidirectional gene flow could be implicated. However, the gene flow here is made more complex with European, Middle Eastern, Indian and Far Eastern Populations all contributing to the gene pool (van der Ross, 1986), which complicates the use of Malina's hypothesis in the South African context.

Dommisse and Leipoldt (1936) compared the skeletal maturation pattern of 0-7 year old "Coloured" children to their European counterparts in the Cape Town area. The carpal bones, together with the epiphyses of the radius and ulna were assessed using hand-wrist radiographs. They showed the skeletal age of these children to be several months ahead of Whites, this despite the poorer general nutritional status of these "Coloureds". Dommisse and Leipoldt (1936) notably, do not report on any male-female differences.

It should be noted, however, that the Dommisse and Leipoldt study was undertaken in 1936 using an outdated system of skeletal maturation assessment. Also, it is probable that living conditions of the "Coloured" may have changed appreciably since then. Nonetheless, the present study suggests that the general skeletal advancement seen in "Coloured" infants (Dommisse and Leipoldt, 1936) continues through to maturity, although the carpal bones per se are delayed in the male.

Levine (1972) showed in his study that the carpal bones did not collate well with the other skeletal maturation indicators used in the

Greulich-Pyle method. The carpal bone maturation in the "Coloured" male generally lagged behind that of the epiphyses, which is in agreement with the findings of the present study. However, the females in Levine's study were found to have carpal development ahead of that of the epiphyses. The present study indicates that carpal maturation is delayed in relation to the epiphysis. The reasons for these differences between females of the respective samples, still remains unanswered.

There is evidence indicating that the carpal and epiphyseal bones constitute two distinct groups which mature, to an extent, independently of each other (Robinow, 1942; Garn et al, 1972; Levine, 1972). If, as has been suggested (Levine, 1972), carpal maturation is more susceptible to adverse environmental factors, the delay of carpal bone maturation in the "Coloured" could be due to environmental influences. It would seem therefore, that as the living conditions of the "Coloured" improve the difference between the two bone groups may diminish. Thus, although the carpal bones may be of less value in skeletal age assessment (Johnston and Jahina, 1965; Garn et al, 1972), its omission may result in significant loss of information regarding the health status of a child (Levine, 1972). However, it remains to be shown whether indeed skeletal age assessed from both the carpals and epiphyses combined correlates less well with parameters such as stature, menache, puberty and dental development than skeletal age assessed from the epiphyses alone (Levine, 1972).

The present study merely indicates trends in the skeletal maturation pattern of this select Western Cape sample. It is clear, however, that significant differences exist when compared to the British standard. This, therefore, necessitates further investigation utilising a larger, random sample, which should also be updated every decade because of the secular trend phenomenon (Eveleth & Tanner, 1980).

Further, Singh (1985) in an earlier study, found an advanced dental maturation trend in a Western Cape "Coloured" sample when compared to accepted Caucasian norms, and also suggested that a detailed study be undertaken to establish norms for the "Coloured" population. It is suggested therefore, that future research on skeletal and dental maturation be combined. This may be of value to the orthodontic department in it's selection of patients at the optimum time for growth modification treatment, and could also be of importance for the monitoring of our nations health as living conditions change (Eveleth and Tanner, 1980).

CONCLUSION

The following conclusions were drawn from this study:-

1) The pattern of skeletal maturity of the Western Cape "Coloured" female was shown to be 0,26 "years" advanced when compared to the British (TW-2) standard; the males, however, follow a similar pattern to the British standard.

2) The epiphyseal bones (RUS) of the hand-wrist, however, generally matured earlier to that of the TW-2 standard for both the sexes; that for the males and females being 0,42 and 0,7 "years" respectively.

3) The carpal bones in relation to the epiphyseal bones showed a delay in maturation especially for boys. This resulted in a lower value for the combined 20 bone (TW-20) score.

4) It is implicit in the findings of this study that further longitudinal studies on a larger, random sample is necessary to establish norms for skeletal maturation patterns in the Western Cape.

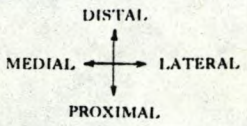
APPENDIX I

Maturation Stages of the hand-wrist bones (Tanner et al 1975)

The Maturation Stages of the Radius and Hamate bones are provided in figures A1 and A2, and serve as examples of an epiphyseal and carpal bone respectively.

The reader is referred to Tanner et al (1975), for the staging of the other 18 bones used in the TW-2 system.

Fig. A1(A)



Radius



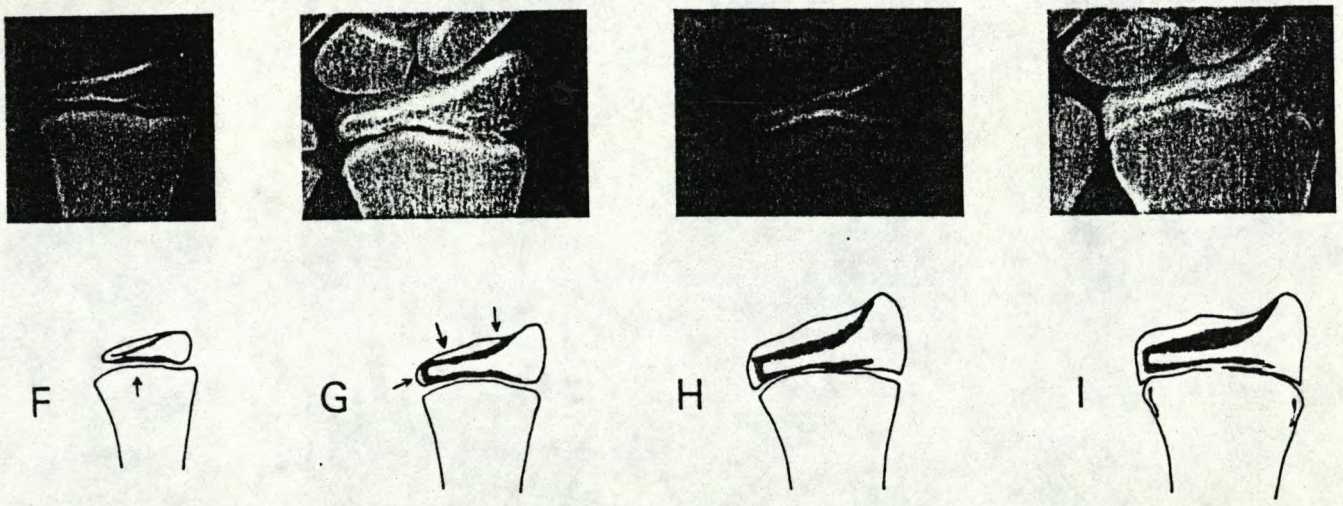

B 
C 
D 
E 



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

Fig. A1(B)

Radius



Boys' Scores			Girls' Scores	
		Stage F		
TW2	RUS	(i) The proximal border of the epiphysis is now differentiated into palmar and dorsal surfaces; the palmar surface is visible as a broad irregularly thickened white line at the proximal edge of the epiphysis.	*TW2*	*RUS*
48	59	(ii) Both ends of the epiphysis, but particularly the medial one, have grown outward 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		
TW2	RUS	(i) The dorsal surface now has distinct lunate and scaphoid articular edges joined at a small hump. Lateral to the scaphoid surface the styloid process carries the border distally in a distinct convexity.	*TW2*	*RUS*
77	87	(ii) 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.	*85*	*114*
		(iii) The proximal border of the epiphysis is now slightly concave.		
		Stage H		
TW2	RUS	(i) The epiphysis now caps the metaphysis on one (usually the medial) or both sides.	*TW2*	*RUS*
96	138	(The styloid process is much further developed than in the last stage.)	*99*	*160*
		Stage I		
TW2	RUS	(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.	*TW2*	*RUS*
106	213		*106*	*218*

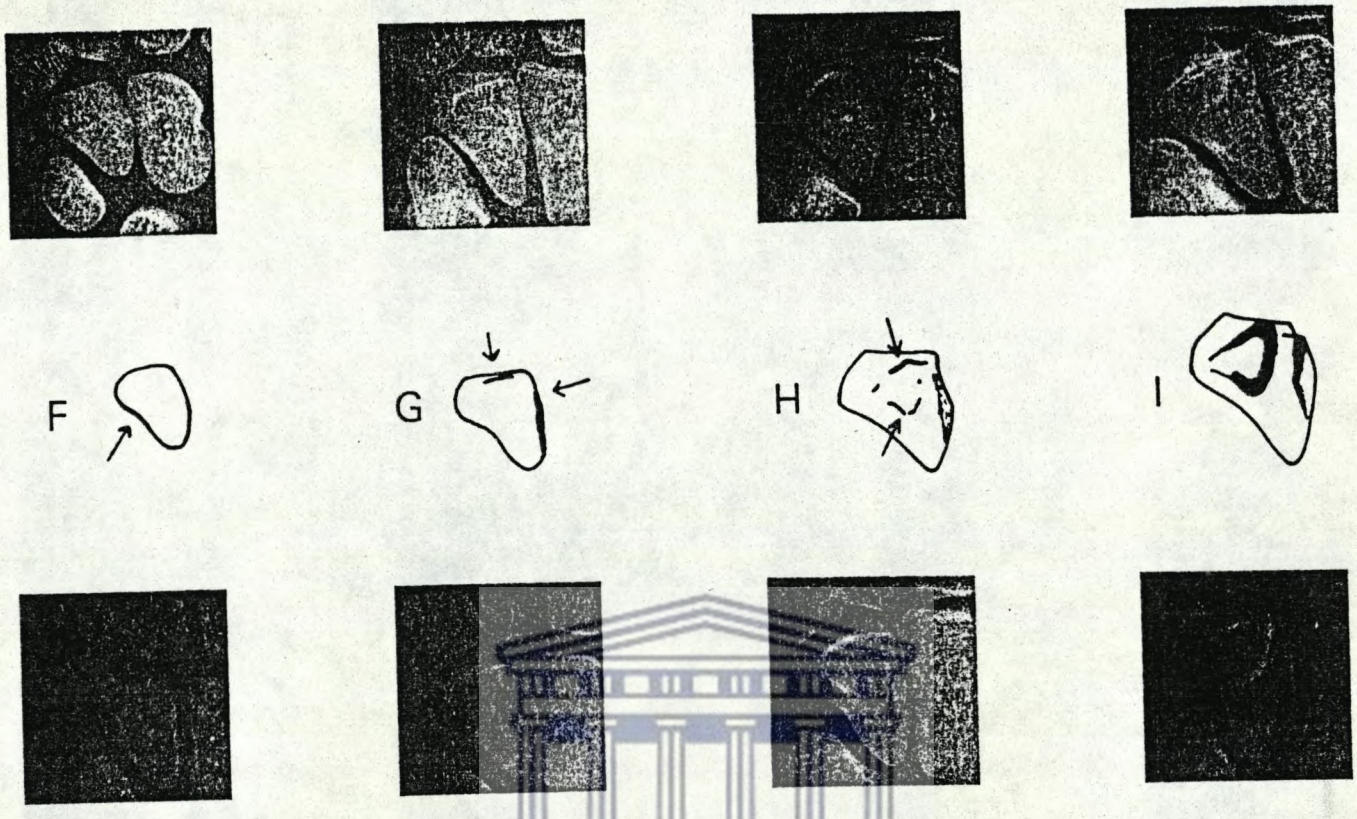
Fig. A2(A)

DISTAL
MEDIAL LATERAL
PROXIMAL

Hamate

Boys' Scores			Girls' Scores	
TW2	Carp		TW2	Carp
42	73	**Stage B** (i) The centre is just visible as a single deposit of calcium, or more rarely as multiple deposits. The border is frequently ill-defined.	44	72
TW2	Carp	**Stage C** (i) The centre is distinct in appearance and round in shape, with a smooth continuous border. (The maximum diameter is less than half the width of the radial metaphysis.)	TW2	Carp
44	75		47	74
TW2	Carp	**Stage D** (i) The maximum diameter is half or more the width of the radial metaphysis. (ii) The surface that later articulates with the triquetral has flattened so that the appearance of the hamate (like that of the capitate at the same stage) is D-shaped, with the straight side running diagonally to the long axis of the hand.	TW2	Carp
49	79		53	78
TW2	Carp	**Stage E** (i) The capitate border has now begun to shape to the hamate indentation of the capitate. This shaping usually takes the form of a slight bulge appearing about half to two-thirds of the way down the border, with somewhat flattened edges proximal and distal to it. (ii) The metacarpal and capitate borders have become differentiated so that the shape has changed from a D to a three-sided figure.	TW2	Carp
59	100		64	102

Fig. A2(B) Hamate



Boys' Scores

Girls' Scores

Stage F

(i) A concavity is now present in the triquetral border (because of considerable growth upwards towards the base of the fifth metacarpal since the last stage).

TW2	Carp
70	128

TW2	Carp
74	131

Stage G

(i) The articular facet for the fourth metacarpal has now begun to form and differentiation into palmar and dorsal surfaces can be seen as a thickening running along or inside the distal border of the bone.

(Palmar and dorsal surfaces of the articulation with the capitate are visible.)

TW2	Carp
81	159

TW2	Carp
85	161

Stage H

(i) The hook of the hamate has begun to appear as a white line (to be distinguished from the articular surfaces adjacent to metacarpals four and five, described below.)

(ii) The articulations with the fourth and fifth metacarpals have now progressed so that there are two distinct surfaces at the distal edge of the bone, one running transversely and the other, on the medial side, running diagonally to the axis of the hand.

(The triquetral articulation has also advanced so that the proximal part of the hamate is now triangular in shape with a pointed apex proximally.)

TW2	Carp
92	181

TW2	Carp
97	183

Stage I

(i) The hook of the hamate is now visible throughout its entire outline.

(ii) The spaces between the hamate and the capitate and between the hamate and the triquetral are now reduced to a thin black line or entirely obliterated by overlapping.

TW2	Carp
106	194

TW2	Carp
109	194

APPENDIX II

Self Weighted Scores and Conversion tables for Maturity Ratings/Scores (Tanner et al 1975)

Table A1

TW2 20-Bone Maturity Scores

BOYS

RATINGS	A	B	C	D	E	F	G	H	I
BONES									
Radius	0	15	17	21	27	48	77	96	106
Ulna	0	22	26	30	39	56	73	84	
Metacarpal I	0	4	5	11	19	24	28	30	32
III	0	3	4	6	10	16	22	23	25
V	0	3	3	6	12	17	21	23	25
Proximal Phalanges I	0	4	5	8	15	23	28	30	32
III	0	3	4	6	13	20	23	24	26
V	0	3	3	6	13	19	22	23	25
Middle Phalanges III	0	3	4	7	13	19	22	23	25
V	0	4	4	8	14	19	21	22	23
Distal Phalanges I	0	4	4	7	14	23	30	31	33
III	0	3	4	6	10	16	21	22	24
V	0	3	4	7	11	16	20	21	23
Capitate	0	60	62	65	71	79	89	116	
Hamate	0	42	44	49	59	70	81	92	106
Triquetral	0	7	10	17	28	38	45	62	
Lunate	0	10	13	20	27	36	44	60	
Scaphoid	0	14	18	23	30	35	42	58	
Trapezium	0	12	15	21	28	34	39	47	59
Trapezoid	0	14	16	20	23	32	39	56	

Table A2

TW2 20-Bone Maturity Scores

GIRLS

RATINGS	*A*	*B*	*C*	*D*	*C*	*F*	*G*	*H*	*I*
BONES									
Radius	*0*	*17*	*19*	*25*	*33*	*54*	*85*	*99*	*106*
Ulna	*0*	*22*	*26*	*30*	*39*	*60*	*73*	*80*	
Metacarpal I	*0*	*5*	*6*	*11*	*18*	*24*	*29*	*31*	*33*
III	*0*	*3*	*5*	*7*	*11*	*17*	*23*	*24*	*26*
V	*0*	*3*	*4*	*7*	*12*	*18*	*22*	*24*	*25*
Proximal Phalanges I	*0*	*5*	*5*	*8*	*14*	*24*	*29*	*30*	*32*
III	*0*	*4*	*4*	*7*	*13*	*20*	*24*	*25*	*26*
V	*0*	*4*	*4*	*7*	*13*	*19*	*23*	*24*	*25*
Middle Phalanges III	*0*	*4*	*4*	*7*	*13*	*20*	*23*	*24*	*25*
V	*0*	*4*	*5*	*8*	*14*	*20*	*22*	*22*	*23*
Distal Phalanges I	*0*	*5*	*5*	*8*	*15*	*24*	*31*	*32*	*34*
III	*0*	*3*	*4*	*6*	*10*	*17*	*22*	*23*	*24*
V	*0*	*3*	*4*	*7*	*11*	*17*	*21*	*22*	*23*
Capitate	*0*	*53*	*56*	*61*	*67*	*76*	*85*	*113*	
Hamate	*0*	*44*	*47*	*53*	*64*	*74*	*85*	*97*	*109*
Triquetral	*0*	*8*	*12*	*19*	*28*	*36*	*46*	*63*	
Lunate	*0*	*10*	*14*	*20*	*27*	*35*	*46*	*60*	
Scaphoid	*0*	*13*	*17*	*23*	*29*	*36*	*44*	*57*	
Trapezium	*0*	*12*	*14*	*20*	*25*	*32*	*39*	*49*	*59*
Trapezoid	*0*	*13*	*16*	*20*	*24*	*31*	*40*	*57*	

Table A3
RUS (Radius, Ulna, Short Bones) Maturity Scores
BOYS

RATINGS	A	B	C	D	E	F	G	H	I
BONES									
Radius	0	16	21	30	39	59	87	138	213
Ulna	0	27	30	32	40	58	107	181	
Metacarpal I	0	6	9	14	21	26	36	49	67
III	0	4	5	9	12	19	31	43	52
V	0	4	6	9	14	18	29	43	52
Proximal Phalanges I	0	7	8	11	17	26	38	52	67
III	0	4	4	9	15	23	31	40	53
V	0	4	5	9	15	21	30	39	51
Middle Phalanges III	0	4	6	9	15	22	32	43	52
V	0	6	7	9	15	23	32	42	49
Distal Phalanges I	0	5	6	11	17	26	38	46	66
III	0	4	6	8	13	18	28	34	49
V	0	5	6	9	13	18	27	34	48

Table A4
RUS (Radius, Ulna, Short Bones) Maturity Scores
GIRLS

RATINGS	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*
BONES									
Radius	*0*	*23*	*30*	*44*	*56*	*78*	*114*	*160*	*218*
Ulna	*0*	*30*	*33*	*37*	*45*	*74*	*118*	*173*	
Metacarpal I	*0*	*8*	*12*	*18*	*24*	*31*	*43*	*53*	*67*
III	*0*	*5*	*8*	*12*	*16*	*23*	*37*	*47*	*53*
V	*0*	*6*	*9*	*12*	*17*	*23*	*35*	*48*	*52*
Proximal Phalanges I	*0*	*9*	*11*	*14*	*20*	*31*	*44*	*56*	*67*
III	*0*	*5*	*7*	*12*	*19*	*27*	*37*	*44*	*54*
V	*0*	*6*	*7*	*12*	*18*	*26*	*35*	*42*	*51*
Middle Phalanges III	*0*	*6*	*8*	*12*	*18*	*27*	*36*	*45*	*52*
V	*0*	*7*	*8*	*12*	*18*	*28*	*35*	*43*	*49*
Distal Phalanges I	*0*	*7*	*9*	*13*	*22*	*33*	*48*	*51*	*68*
III	*0*	*7*	*8*	*11*	*15*	*22*	*33*	*37*	*49*
V	*0*	*7*	*8*	*11*	*15*	*22*	*32*	*36*	*47*

Table A5
Carpal Bones Maturity Scores
BOYS

RATINGS	A	B	C	D	E	F	G	H	I
Capitate	0	100	104	106	113	133	160	214	
Hamate	0	73	75	79	100	128	159	181	194
Triquetral	0	10	13	28	57	84	102	124	
Lunate	0	14	22	39	58	84	101	120	
Scaphoid	0	26	36	52	71	85	100	116	
Trapezium	0	23	31	46	66	83	95	108	117
Trapezoid	0	27	32	42	51	77	93	115	

Table A6
Carpal Bones Maturity Scores
GIRLS

RATINGS	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*
Capitate	*0*	*84*	*88*	*91*	*99*	*121*	*149*	*203*	
Hamate	*0*	*72*	*74*	*78*	*102*	*131*	*161*	*183*	*194*
Triquetral	*0*	*11*	*16*	*31*	*56*	*80*	*104*	*126*	
Lunate	*0*	*16*	*24*	*40*	*59*	*84*	*106*	*122*	
Scaphoid	*0*	*24*	*35*	*51*	*71*	*88*	*104*	*118*	
Trapezium	*0*	*20*	*27*	*42*	*60*	*80*	*95*	*111*	*119*
Trapezoid	*0*	*21*	*30*	*43*	*53*	*77*	*97*	*118*	

Table A7

RUS (TW2) Bone Age for Given Maturity Score

BOYS

Maturity score	Bone "age"	Maturity score	Bone "age"	Maturity score	Bone "age"	Maturity score	Bone "age"
—	1·0	189	6·0	330	11·0	744	16·0
—	·1	192	·1	334	·1	762	·1
—	·2	194	·2	337	·2	780	·2
—	·3	197	·3	340	·3	798	·3
—	·4	199	·4	342	·4	816	·4
—	·5	202	·5	346	·5	833	·5
26	·6	204	·6	349	·6	850	·6
32	·7	207	·7	352	·7	867	·7
38	·8	209	·8	354	·8	883	·8
43	·9	212	·9	358	·9	899	·9
49	2·0	215	7·0	361	12·0	915	17·0
55	·1	218	·1	365	·1	928	·1
61	·2	222	·2	369	·2	940	·2
65	·3	224	·3	373	·3	951	·3
70	·4	227	·4	378	·4	962	·4
75	·5	230	·5	382	·5	971	·5
80	·6	233	·6	386	·6	980	·6
84	·7	235	·7	391	·7	986	·7
89	·8	238	·8	395	·8	992	·8
93	·9	240	·9	400	·9	995	·9
98	3·0	243	8·0	405	13·0	997	18·0
101	·1	245	·1	410	·1	999	·1
105	·2	248	·2	416	·2	1000	ADULT
108	·3	251	·3	422	·3		
112	·4	253	·4	427	·4		
115	·5	257	·5	434	·5		
118	·6	260	·6	440	·6		
122	·7	263	·7	447	·7		
125	·8	266	·8	454	·8		
128	·9	269	·9	463	·9		
132	4·0	272	9·0	472	14·0		
135	·1	275	·1	481	·1		
138	·2	278	·2	490	·2		
141	·3	281	·3	501	·3		
144	·4	283	·4	512	·4		
147	·5	286	·5	524	·5		
150	·6	289	·6	536	·6		
153	·7	292	·7	548	·7		
156	·8	295	·8	560	·8		
159	·9	297	·9	574	·9		
162	5·0	300	10·0	588	15·0		
165	·1	303	·1	602	·1		
168	·2	306	·2	616	·2		
171	·3	309	·3	630	·3		
173	·4	312	·4	645	·4		
177	·5	316	·5	660	·5		
180	·6	319	·6	675	·6		
182	·7	321	·7	692	·7		
185	·8	325	·8	708	·8		
187	·9	328	·9	726	·9		

Table A8

Carpal (TW2) Bone Age for Given Maturity Score

BOYS

Maturity score	Bone "age"	Maturity score	Bone "age"	Maturity score	Bone "age"	Maturity score	Bone "age"
—	1·0	281	5·0	632	9·0	944	13·0
—	·1	287	·1	641	·1	950	·1
—	·2	294	·2	650	·2	955	·2
—	·3	300	·3	659	·3	960	·3
—	·4	307	·4	668	·4	964	·4
—	·5	314	·5	677	·5	968	·5
—	·6	322	·6	686	·6	972	·6
—	·7	330	·7	695	·7	976	·7
—	·8	338	·8	705	·8	980	·8
—	·9	346	·9	715	·9	983	·9
—	2·0	354	6·0	724	10·0	986	14·0
—	·1	362	·1	733	·1	989	·1
—	·2	371	·2	742	·2	991	·2
—	·3	380	·3	751	·3	992	·3
190	·4	389	·4	760	·4	994	·4
190	·5	398	·5	769	·5	995	·5
191	·6	407	·6	777	·6	996	·6
192	·7	417	·7	786	·7	997	·7
194	·8	426	·8	794	·8	998	·8
195	·9	436	·9	802	·9	999	·9
197	3·0	445	7·0	810	11·0	1000	ADULT
198	·1	454	·1	818	·1		
200	·2	463	·2	825	·2		
202	·3	472	·3	833	·3		
203	·4	481	·4	840	·4		
206	·5	491	·5	848	·5		
209	·6	500	·6	856	·6		
213	·7	509	·7	863	·7		
217	·8	518	·8	870	·8		
221	·9	526	·9	877	·9		
225	4·0	535	8·0	884	12·0		
229	·1	544	·1	890	·1		
234	·2	552	·2	897	·2		
239	·3	562	·3	903	·3		
244	·4	571	·4	910	·4		
250	·5	581	·5	915	·5		
256	·6	591	·6	921	·6		
262	·7	601	·7	927	·7		
268	·8	611	·8	933	·8		
274	·9	621	·9	939	·9		

Table A9

20-Bone (TW2) Bone Age for Given Maturity Score

BOYS

Maturity score	Bone "age"	Maturity score	Bone "age"	Maturity score	Bone "age"	Maturity score	Bone "age"
114	1·0	355	6·0	678	11·0	970	16·0
116	·1	360	·1	684	·1	973	·1
119	·2	366	·2	690	·2	976	·2
123	·3	372	·3	697	·3	979	·3
126	·4	378	·4	703	·4	981	·4
129	·5	384	·5	711	·5	983	·5
133	·6	390	·6	718	·6	985	·6
136	·7	396	·7	725	·7	987	·7
139	·8	402	·8	732	·8	989	·8
142	·9	409	·9	740	·9	991	·9
146	2·0	415	7·0	747	12·0	992	17·0
150	·1	422	·1	754	·1	994	·1
154	·2	428	·2	761	·2	995	·2
159	·3	435	·3	768	·3	996	·3
163	·4	441	·4	774	·4	996	·4
168	·5	447	·5	781	·5	997	·5
172	·6	454	·6	788	·6	998	·6
176	·7	460	·7	795	·7	999	·7
181	·8	466	·8	802	·8	999	·8
185	·9	472	·9	809	·9	999	·9
190	3·0	477	8·0	817	13·0	1000	ADULT
195	·1	483	·1	823	·1		
200	·2	489	·2	830	·2		
205	·3	495	·3	836	·3		
210	·4	501	·4	842	·4		
215	·5	507	·5	849	·5		
220	·6	513	·6	855	·6		
226	·7	520	·7	861	·7		
231	·8	526	·8	867	·8		
236	·9	533	·9	873	·9		
242	4·0	540	9·0	879	14·0		
247	·1	546	·1	884	·1		
252	·2	553	·2	889	·2		
258	·3	560	·3	895	·3		
264	·4	566	·4	900	·4		
270	·5	573	·5	906	·5		
276	·6	580	·6	911	·6		
282	·7	587	·7	916	·7		
287	·8	594	·8	921	·8		
292	·9	601	·9	926	·9		
298	5·0	608	10·0	931	15·0		
303	·1	615	·1	936	·1		
308	·2	622	·2	940	·2		
314	·3	629	·3	944	·3		
319	·4	636	·4	948	·4		
325	·5	643	·5	952	·5		
331	·6	650	·6	956	·6		
337	·7	657	·7	959	·7		
343	·8	664	·8	963	·8		
349	·9	671	·9	967	·9		

Table A10
RUS (TW2) Bone Age for Given Maturity Score

GIRLS

Maturity score	*Bone "age"*	*Maturity score*	*Bone "age"*	*Maturity score*	*Bone "age"*	*Maturity score*	*Bone "age"*
32	*1·0*	*248*	*5·0*	*375*	*9·0*	*674*	*13·0*
42	*·1*	*251*	*·1*	*380*	*·1*	*684*	*·1*
53	*·2*	*253*	*·2*	*386*	*·2*	*695*	*·2*
63	*·3*	*256*	*·3*	*392*	*·3*	*705*	*·3*
74	*·4*	*259*	*·4*	*397*	*·4*	*715*	*·4*
83	*·5*	*261*	*·5*	*402*	*·5*	*726*	*·5*
92	*·6*	*264*	*·6*	*407*	*·6*	*737*	*·6*
101	*·7*	*267*	*·7*	*413*	*·7*	*747*	*·7*
110	*·8*	*270*	*·8*	*419*	*·8*	*758*	*·8*
117	*·9*	*272*	*·9*	*425*	*·9*	*769*	*·9*
125	*2·0*	*275*	*6·0*	*431*	*10·0*	*779*	*14·0*
133	*·1*	*277*	*·1*	*437*	*·1*	*790*	*·1*
140	*·2*	*280*	*·2*	*444*	*·2*	*801*	*·2*
147	*·3*	*283*	*·3*	*450*	*·3*	*812*	*·3*
153	*·4*	*286*	*·4*	*457*	*·4*	*822*	*·4*
159	*·5*	*289*	*·5*	*464*	*·5*	*834*	*·5*
164	*·6*	*292*	*·6*	*471*	*·6*	*847*	*·6*
169	*·7*	*295*	*·7*	*478*	*·7*	*859*	*·7*
175	*·8*	*298*	*·8*	*485*	*·8*	*873*	*·8*
180	*·9*	*301*	*·9*	*493*	*·9*	*886*	*·9*
185	*3·0*	*303*	*7·0*	*500*	*11·0*	*900*	*15·0*
189	*·1*	*307*	*·1*	*507*	*·1*	*915*	*·1*
192	*·2*	*310*	*·2*	*515*	*·2*	*929*	*·2*
196	*·3*	*314*	*·3*	*523*	*·3*	*942*	*·3*
200	*·4*	*318*	*·4*	*530*	*·4*	*954*	*·4*
203	*·5*	*321*	*·5*	*538*	*·5*	*966*	*·5*
207	*·6*	*324*	*·6*	*545*	*·6*	*977*	*·6*
210	*·7*	*327*	*·7*	*553*	*·7*	*986*	*·7*
214	*·8*	*330*	*·8*	*560*	*·8*	*993*	*·8*
217	*·9*	*334*	*·9*	*569*	*·9*	*997*	*·9*
221	*4·0*	*337*	*8·0*	*578*	*12·0*	*1000*	ADULT
224	*·1*	*341*	*·1*	*587*	*·1*		
227	*·2*	*344*	*·2*	*596*	*·2*		
230	*·3*	*348*	*·3*	*605*	*·3*		
232	*·4*	*351*	*·4*	*614*	*·4*		
235	*·5*	*355*	*·5*	*624*	*·5*		
238	*·6*	*358*	*·6*	*633*	*·6*		
240	*·7*	*362*	*·7*	*643*	*·7*		
243	*·8*	*366*	*·8*	*653*	*·8*		
246	*·9*	*371*	*·9*	*664*	*·9*		

Table A11
Carpal (TW2) Bone Age for Given Maturity Score
GIRLS

Maturity score	*Bone "Age"*	*Maturity score*	*Bone "age"*	*Maturity score*	*Bone "age"*	*Maturity score*	*Bone "age"*
—	*1·0*	*296*	*4·0*	*555*	*7·0*	*872*	*10·0*
—	*·1*	*304*	*·1*	*564*	*·1*	*881*	*·1*
—	*·2*	*312*	*·2*	*573*	*·2*	*890*	*·2*
—	*·3*	*320*	*·3*	*582*	*·3*	*899*	*·3*
—	*·4*	*329*	*·4*	*591*	*·4*	*908*	*·4*
—	*·5*	*337*	*·5*	*600*	*·5*	*916*	*·5*
172	*·6*	*346*	*·6*	*610*	*·6*	*924*	*·6*
175	*·7*	*354*	*·7*	*620*	*·7*	*931*	*·7*
177	*·8*	*362*	*·8*	*630*	*·8*	*938*	*·8*
179	*·9*	*371*	*·9*	*639*	*·9*	*944*	*·9*
182	*2·0*	*379*	*5·0*	*648*	*8·0*	*950*	*11·0*
184	*·1*	*387*	*·1*	*657*	*·1*	*956*	*·1*
187	*·2*	*396*	*·2*	*666*	*·2*	*961*	*·2*
190	*·3*	*405*	*·3*	*677*	*·3*	*966*	*·3*
194	*·4*	*413*	*·4*	*688*	*·4*	*970*	*·4*
198	*·5*	*422*	*·5*	*699*	*·5*	*974*	*·5*
202	*·6*	*431*	*·6*	*711*	*·6*	*978*	*·6*
207	*·7*	*440*	*·7*	*724*	*·7*	*981*	*·7*
212	*·8*	*449*	*·8*	*736*	*·8*	*984*	*·8*
217	*·9*	*459*	*·9*	*748*	*·9*	*986*	*·9*
223	*3·0*	*468*	*6·0*	*761*	*9·0*	*988*	*12·0*
229	*·1*	*477*	*·1*	*773*	*·1*	*990*	*·1*
235	*·2*	*485*	*·2*	*785*	*·2*	*992*	*·2*
241	*·3*	*494*	*·3*	*798*	*·3*	*993*	*·3*
248	*·4*	*502*	*·4*	*810*	*·4*	*994*	*·4*
256	*·5*	*511*	*·5*	*821*	*·5*	*995*	*·5*
264	*·6*	*520*	*·6*	*831*	*·6*	*996*	*·6*
272	*·7*	*529*	*·7*	*841*	*·7*	*997*	*·7*
280	*·8*	*537*	*·8*	*851*	*·8*	*998*	*·8*
288	*·9*	*546*	*·9*	*862*	*·9*	*999*	*·9*
						1000	ADULT

Table A12

20-Bone (TW2) Bone Age for Given Maturity Score

GIRLS

Maturity score	*Bone "age"*	*Maturity score*	*Bone "age"*	*Maturity score*	*Bone "age"*	*Maturity score*	*Bone "age"*
131	1·0	389	5·0	653	9·0	953	13·0
136	·1	395	·1	662	·1	956	·1
140	·2	402	·2	670	·2	960	·2
146	·3	408	·3	680	·3	963	·3
152	·4	414	·4	690	·4	966	·4
159	·5	420	·5	700	·5	969	·5
165	·6	426	·6	710	·6	972	·6
172	·7	432	·7	721	·7	974	·7
179	·8	438	·8	731	·8	976	·8
186	·9	444	·9	742	·9	979	·9
192	2·0	450	6·0	752	10·0	981	14·0
199	·1	456	·1	762	·1	982	·1
206	·2	462	·2	772	·2	984	·2
213	·3	468	·3	783	·3	986	·3
220	·4	474	·4	794	·4	987	·4
226	·5	480	·5	803	·5	989	·5
233	·6	485	·6	812	·6	990	·6
240	·7	491	·7	821	·7	991	·7
247	·8	497	·8	830	·8	993	·8
253	·9	503	·9	838	·9	994	·9
260	3·0	510	7·0	845	11·0	995	15·0
267	·1	516	·1	852	·1	995	·1
274	·2	522	·2	859	·2	996	·2
281	·3	529	·3	866	·3	996	·3
287	·4	535	·4	872	·4	997	·4
293	·5	541	·5	879	·5	997	·5
299	·6	547	·6	885	·6	998	·6
305	·7	553	·7	891	·7	998	·7
311	·8	559	·8	898	·8	999	·8
317	·9	565	·9	903	·9	999	·9
324	4·0	571	8·0	908	12·0	1000	ADULT
331	·1	578	·1	913	·1		
338	·2	585	·2	918	·2		
345	·3	592	·3	923	·3		
351	·4	600	·4	928	·4		
357	·5	608	·5	932	·5		
363	·6	617	·6	937	·6		
370	·7	625	·7	940	·7		
376	·8	634	·8	944	·8		
382	·9	643	·9	948	·9		

APPENDIX III

Percentile Curves of British (Tanner-Whitehouse) standard

(Tanner et al 1975)

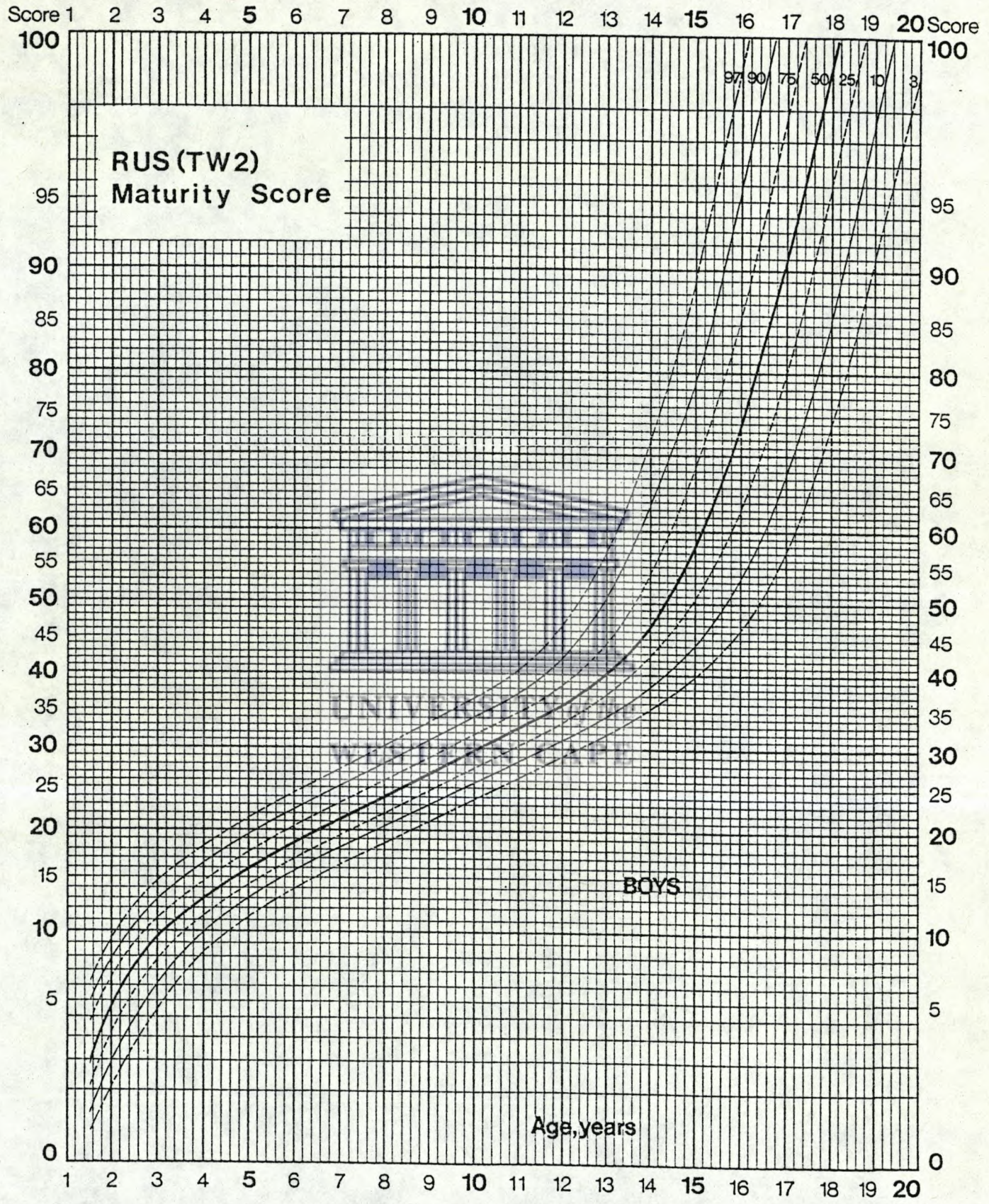


Figure A3 Standards for RUS Skeletal Maturity Score: Boys

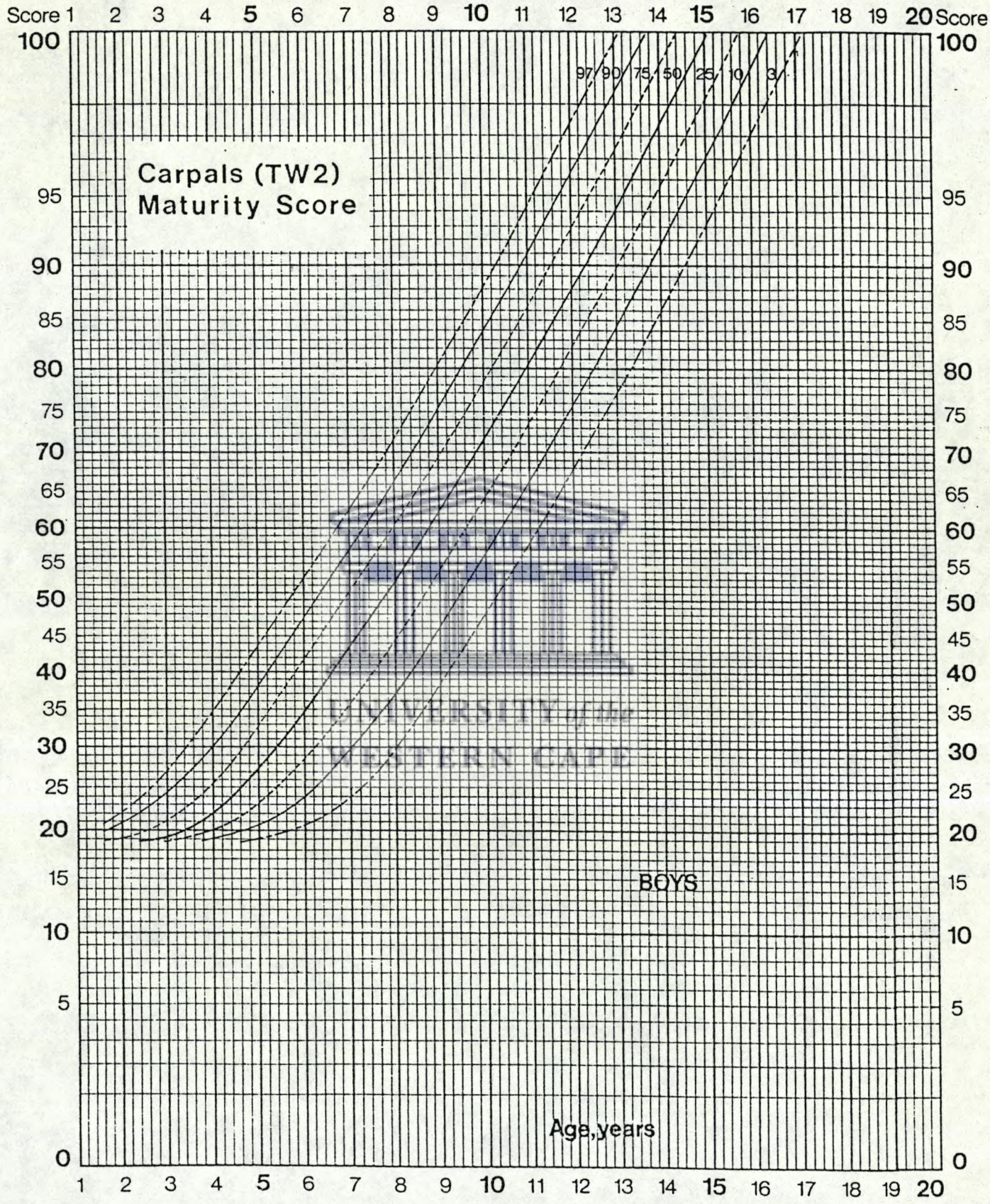


Figure A4 Standards for Carpal Skeletal Maturity Score. Boys

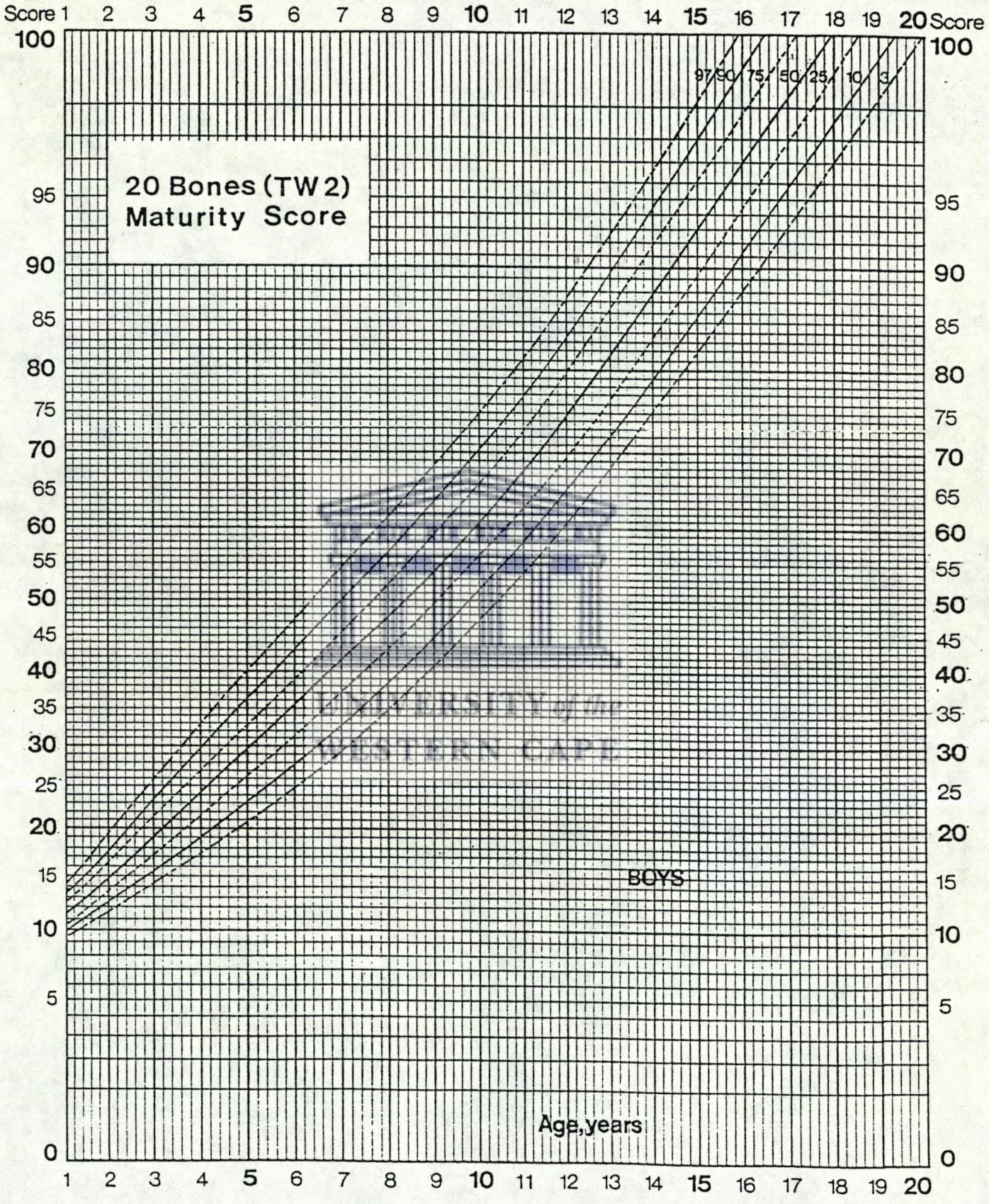


Figure A5 Standards for 20-Bone Skeletal Maturity Score: Boys

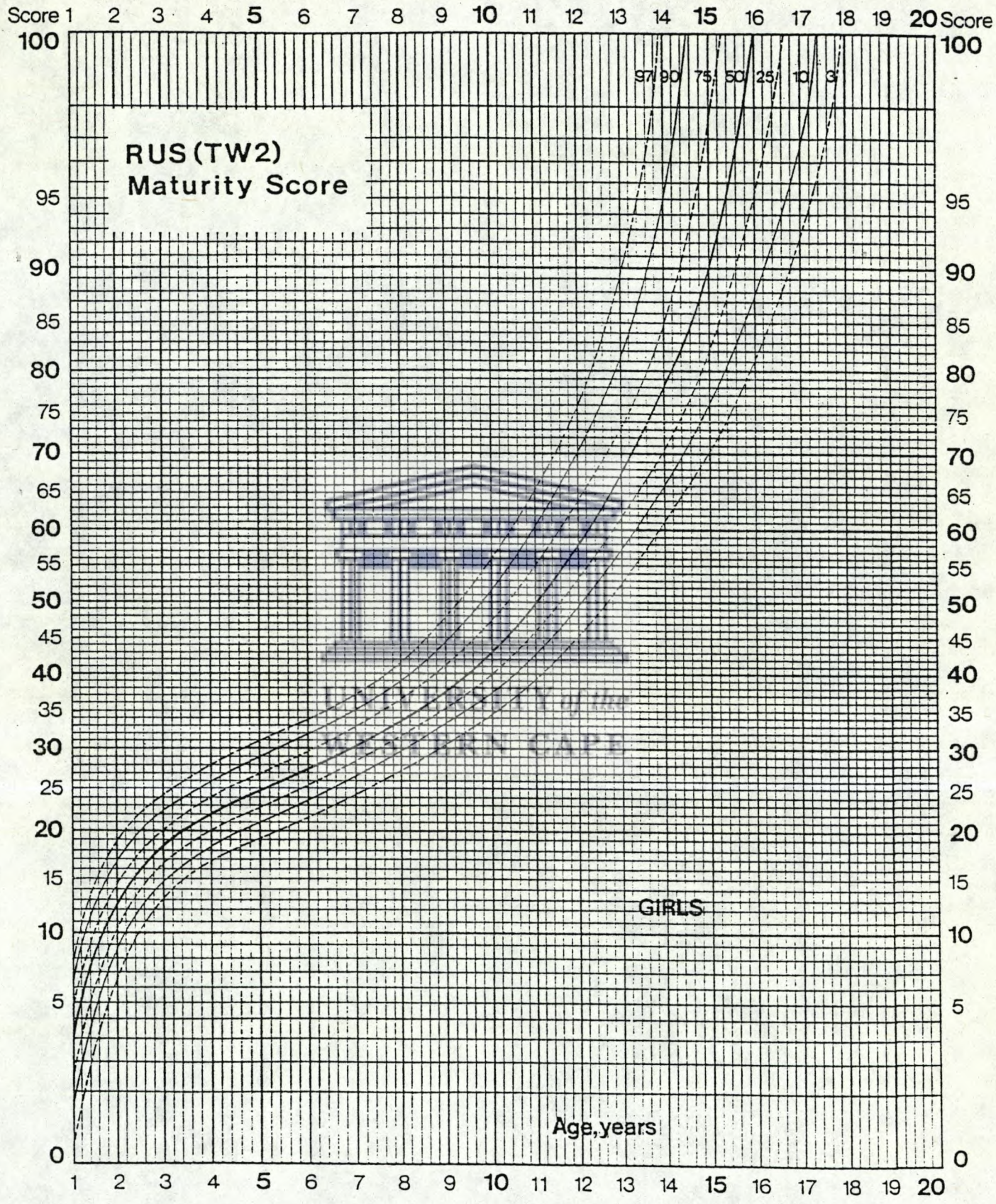


Figure A6 Standards for RUS Skeletal Maturity Score: Girls

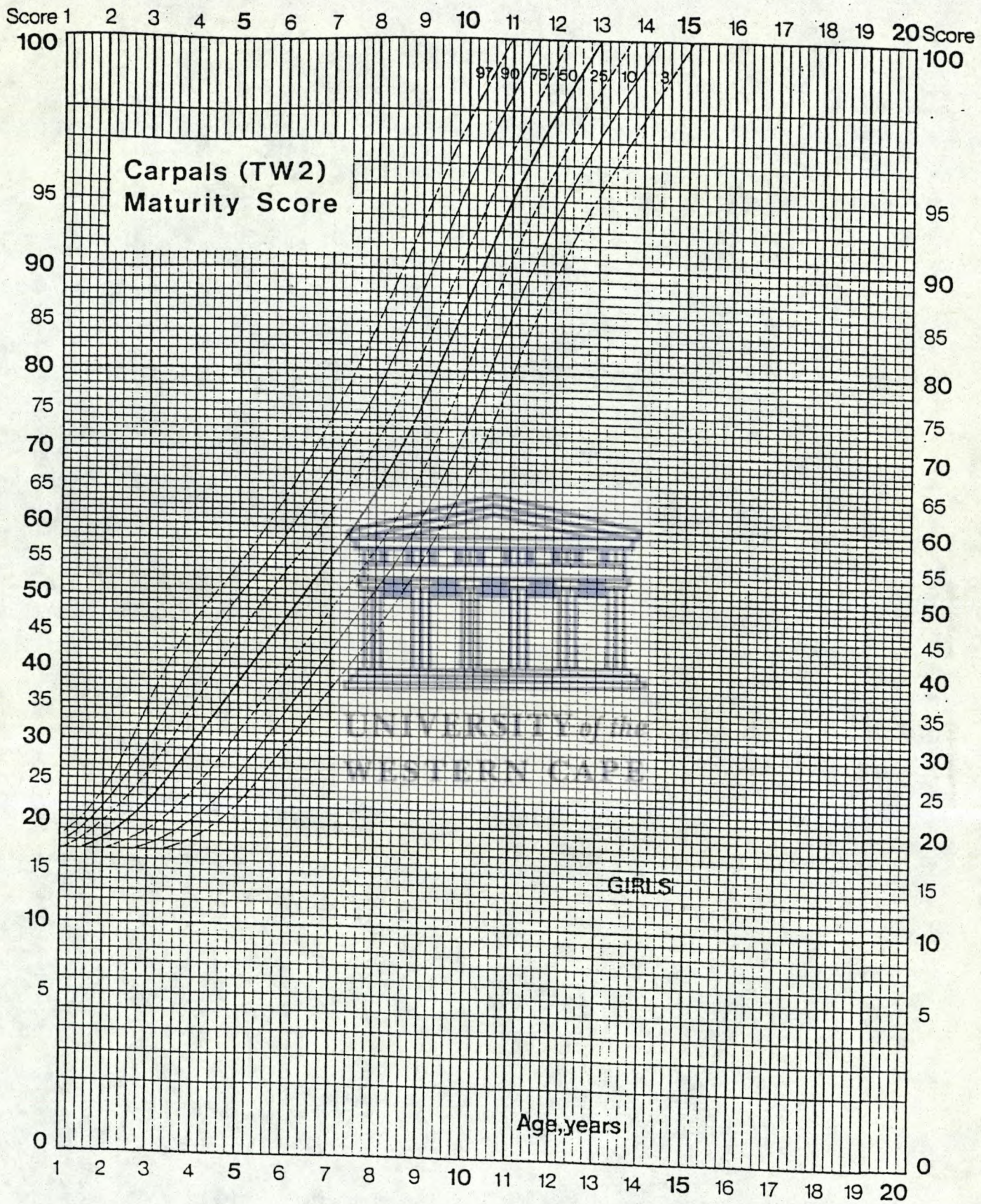


Figure A7 Standards for Carpal Skeletal Maturity Score: Girls

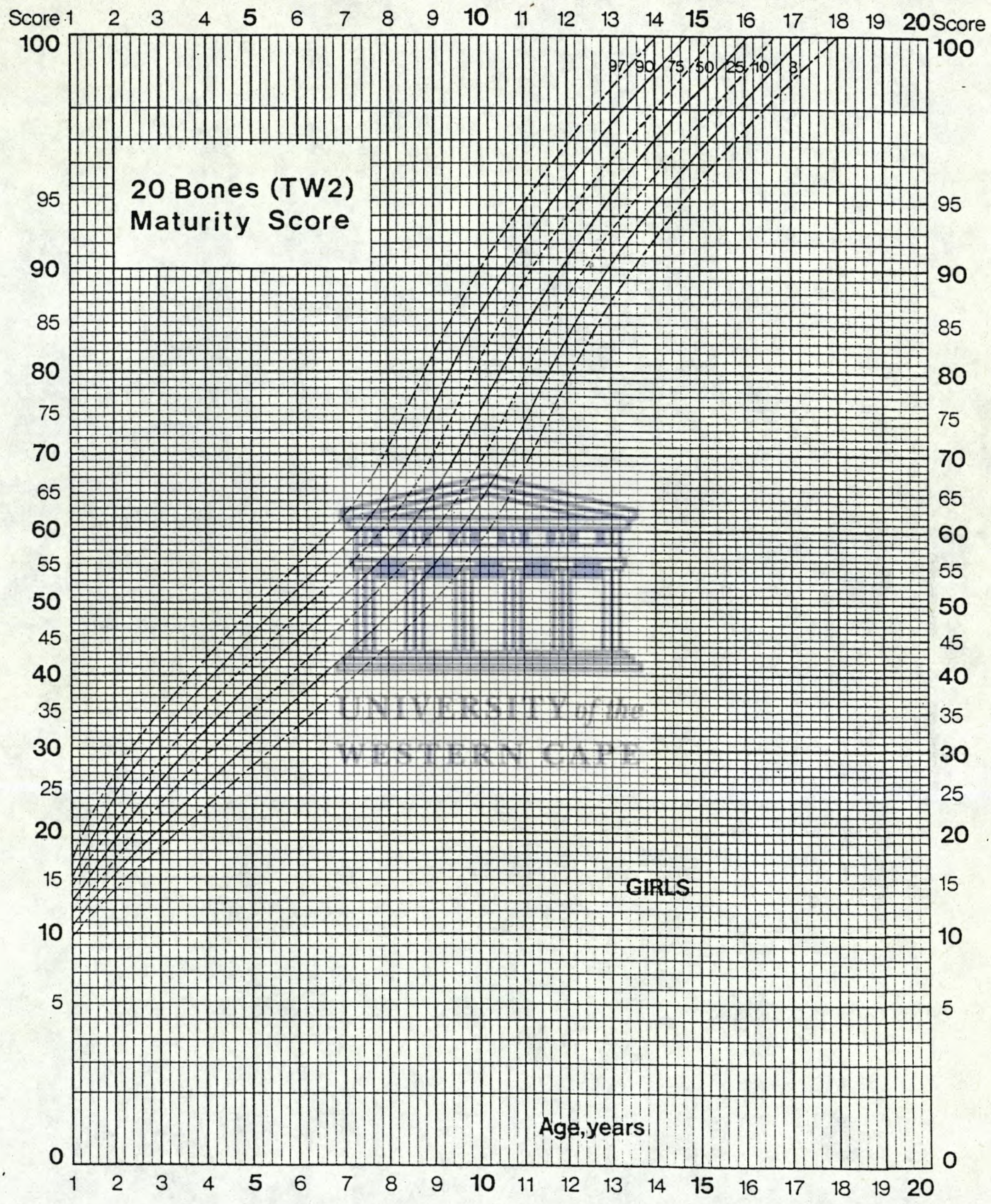


Figure A8 Standards for 20-Bone Skeletal Maturity Score: Girls

APPENDIX IV

An example of the Score Card Used

Table A13 A worked example of assigning the maturity scores and skeletal ages for a boy aged 9.0 years.

Males 9 to 9,99 years

No.	Name	File No	Chronological Age	Index	Maturity Score	Skeletal Age	Percentile Level
1	F Daniels	8303-31	9.0	RUS	287	9,5	75-90
				Carpal	773	10,6	90-97
				TW-20	622	10,2	75-90

APPENDIX V

Statistics

The following statistics were utilised in this study:

1) The Chi-Squared (x^2) test.

This test was used to compare the Western Cape Sample and the British standard. Male/Female differences in the Western Cape Sample were also compared with this test

The data was listed as observed and expected values and the following formula was used

$$x^2 = \sum_i \frac{(O_i - E_i)^2}{E_i}$$

where O_i = observed values

E_i = expected values

2) The "t"-test

To test for difference of means between the mean chronological age and mean skeletal age of the Western Cape sample, the following test was utilised.

$$t = \frac{x_i - x_2}{\sqrt{\left(\frac{1}{n_1} + \frac{1}{n_2}\right) \times \frac{(n_1-1)\, s_1^2 + (n_2-1)\, s_2^2}{n_1 + n_2 - 2}}}$$

3) Spearmans Coefficient of Rank Correlation

This formula was used to test the correlation between the two examiners:

$$r = 1 - \frac{6 \quad (A - B)^2}{n^3 - n}$$

Intra-Examiner Variability

	A	B	d	d^2
1	13,4	13,4	0	0
2	12,4	11,6	0,8	0,64
3	14,8	14,8	0	0
4	13,9	13,9	0	0
5	16	16	0	0
6	16	16	0	0
7	12,6	15,6	-3	9
8	16	16	0	0
9	16	16	0	0
10	16	16	0	0
11	9,6	9,5	0,1	0,01
12	9,4	9,4	0	0
13	10,1	9,9	0	0
14	4,3	4,3	0	0
15	7,3	7,3	0	0
16	13,9	13,8	0,1	0,01
17	11,1	11,6	-0,5	0,25
18	11,3	11,3	0	0
19	11,7	12,1	-0,4	0,16
20	8,6	9,1	-0,5	0,25
21	12,5	12,9	-0,4	0,16
22	10,5	10,4	0,1	0,01
23	9	9	0	0
24	9,6	9,6	0	0
25	10,7	10,8	-0,1	0,01
26	16	16	0	0
27	13,2	13,8	-0,6	0,36
28	15,1	15,1	0	0
29	12,9	12,9	0	0
30	11,8	12,6	-0,8	0,64
31	12,4	12,7	-0,3	0,09
32	13,2	13,4	-0,2	0,04
33	12,0	12,4	-0,4	0,16
34	9,7	9,9	-0,2	0,04
				$\leq 11,87$

Inter-Examiner Variability

	A	B	d	d^2
1	13,4	13,8	-0,4	0,16
2	12,4	13,2	-0,8	0,64
3	14,8	13,2	1,6	2,56
4	13,9	14,4	-0,5	0,25
5	16	16	0	0
6	16	16	0	0
7	12,6	11,9	0,7	0,49
8	16	16	0	0
9	16	16	0	0
10	16	16	0	0
11	9,6	11,0	-1,4	1,96
12	9,4	10,1	-0,7	0,49
13	10,1	10,0	0,1	0,01
14	4,3	4,9	-0,6	0,36
15	7,3	6,9	0,4	0,16
16	13,9	15,2	-1,3	1,69
17	11,1	12,6	-1,5	2,25
18	11,3	11,9	-0,6	0,36
19	11,7	10,3	1,4	1,96
20	8,6	8,5	0,1	0,01
21	12,5	11,9	0,6	0,36
22	10,5	10,5	0	0
23	9	8,2	0,8	0,64
24	9,6	9,3	0,3	0,09
25	10,7	10,9	-0,2	0,04
26	16	16	0	0
27	13,2	13,4	-0,2	0,04
28	15,1	15,6	-0,5	0,25
29	12,9	13,2	-0,3	0,09
30	11,8	12,1	-0,3	0,09
31	12,4	11,9	0,5	0,25
32	13,2	13,1	0,1	0,01
33	12,0	11,8	0,2	0,04
34	9,7	9,5	0,2	0,04
				≤15,3

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