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Skeletal Maturity of Children 6-11 Years

United States

Skeletal age (hand-wrist), onset of ossification, and bone-specific skeletal ages by chronological age and sex of boys and girls 6-11 years of age as assessed by the Health Examination Survey Standard based primarily on the Greulich-Pyle Radiographic Atlas.

DHEW Publication No. (HRA) 75-1622

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COOPERATION OF THE BUREAU OF THE CENSUS

In accordance with specifications established by the National Center for Health Statistics, the Bureau of the Census, under a contractual agreement, participated in the design and selection of the sample, and carried out the first stage of the field interviewing and certain parts of the statistical processing.

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SKELETAL MATURITY OF CHILDREN
6-11 YEARS

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INTRODUCTION

This report presents national estimates of the levels of skeletal maturity of the hand-wrist for noninstitutionalized United States children age 6-11 years based on findings from the Health Examination Survey of 1963-65. This is the first time that such estimates for a cross-section of the population have been made for this or any other country.

The Health Examination Survey is one of the major programs of the National Center for Health Statistics, authorized under the National Health Survey Act of 1956 by the 84th Congress as a continuing Public Health Service function to determine the health status of the population.

Three different types of survey programs are used to carry out the intent of the National Health Survey.[1] The Health Interview Survey, which collects health information from samples of people by household interview, is focused primarily on the impact of illness and disability within various population groups. The Health Resources programs obtain health data as well as health resource and utilization information through surveys of hospitals, nursing homes and other resident institutions, and the entire range of personnel in the health occupations. The Health Examination Survey, from which data in this report were obtained, collects health data by direct physical examination, tests, and measurements performed on samples of the population. The latter program provides the best way of obtaining actual diagnostic data on the prevalence of certain medically defined illnesses. It is the only effective way to secure information on unrecognized and undiagnosed conditions and on a variety of physical, physiological, and psychological measures within the population. It also collects demographic and socioeconomic data on the sample population under study to which the examination findings may be related.

The Health Examination Survey is organized as a series of separate programs or cycles, each of which is limited to some specific segment of the U.S. population and to specific aspects of health. From data collected during the first cycle, the prevalence of certain chronic diseases and the distribution of various physical and physiological measures were determined on a cross-section of the defined adult population as previously described.[2,3]

For the second cycle, the program on which this report is based, a probability sample of the noninstitutionalized children 6-11 years of age in the United States was selected and examined. The examination in this cross-sectional study primarily assessed health factors related to growth and development. It included an examination by a pediatrician and by a dentist, tests administered by a psychologist, and a variety of tests and measurements by a technician. The survey plan, sample design, examination content, and operation of the survey have been described in a previous report.[4]

Field collection operations for this cycle, which started in July 1963, were completed in December 1965. Of the 7,417 selected in the sample, 7,119 children, or 96 percent, were examined. This national sample is closely representative of the roughly 24 million noninstitutionalized children 6-11 years of age in the United States with respect to age, sex, race, region, size of place of residence, and rate of change in size of place of residence from 1950 to 1960. Of the children examined, there were an additional 157 who were not radiographed or whose radiograph, taken at the time of the survey, was not suitable for assessment. Thus the skeletal maturity estimates for United States children 6-11 years of age are based on the remaining 6,962 children or 94 percent of the original sample.

During his single visit, each child was given a standardized examination by the examining team in the mobile units specially designed for use in the survey. Prior to this examination, demographic and socioeconomic data on household members as well as medical history, behavioral, and related data on the child to be examined were obtained from his parents. Ancillary data were requested from the school attended by the child; these included his grade placement, teacher's ratings of his behavior and adjustment, and health problems known to his teacher. A birth certificate for each child was obtained for verification of his age and information related to his condition at birth.

Some measure of skeletal age or maturation was considered essential to this study of health factors related to normal growth and development of children. Advice of clinicians and directors of long-term studies of skeletal development was obtained about possible uses of skeletal maturity levels and methods of assessing skeletal age from radiographs. Drs. William Walter Greulich and Harold C. Stuart—the directors of growth studies conducted independently from 1929 to 1962 at the Brush Foundation in Cleveland, Ohio, and the Department of Maternal and Child Health at Harvard University in Boston, Massachusetts—recommended that Dr. S. Idell Pyle assemble a standard for the assessment of skeletal maturity from their film series and studies,[5] specifically for use in the National Health Examination Survey.

At the formal request of the National Center for Health Statistics the 1964 manual—a preliminary edition of the Radiographic Standard of Reference for the Growing Hand and Wrist[6]—was then prepared for this purpose by Dr. Pyle and Dr. Greulich, in collaboration with Dr. Alice Waterhouse, then Medical Advisor to the National Center for Health Statistics. This manual will be referred to in this report as the HES Standard. Bone-specific skeletal age assessments of the hand-wrist radiographs were done by medical students with special training in this method, at Case Western Reserve University under the close supervision of Dr. Pyle.

Statistical notes on the sample design, reliability of the data, and sampling error are in appendix I.

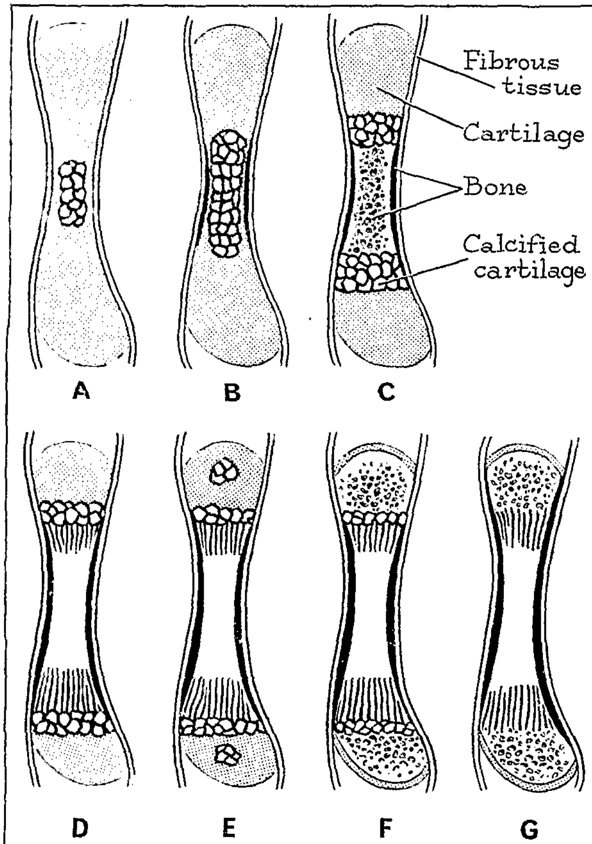
THE NATURE OF SKELETAL MATURATION

It is difficult to describe the nature of skeletal maturation because knowledge of its recognizable criteria is incomplete. A wealth of histological detail has been reported concerning skeletal elongation but there is a surprising lack of corresponding knowledge concerning skeletal maturation. Furthermore, some of the literature indicates a failure to distinguish between elongation and maturation of the skeleton at the histological and radiographic levels. It is customary to consider that the skeleton begins to mature when skeletal rudiments can be recognized first in the embryo and that maturation is complete when comparative stability of skeletal form and function is attained in young adulthood. During maturation, the number of specialized cells increases and biochemical mechanisms become more complex. The skeletal changes after young adulthood, particularly during senescence, include a reduction in the number of specialized cells and therefore can be described reasonably as a negative phase of maturation.

Histological Changes

Maturation of a long bone commences when some embryonic connective tissue in a limb bud condenses to form a model.[7] In the early models of most long bones, the parts that represent the future diaphyses (shafts) are small relative to the epiphyseal parts although the junctions between these parts cannot be identified precisely.[8] The condensed connective tissue of the model is replaced by cartilage; this occurs first in the central part of each model.[9] The connective tissue around this cartilage becomes a well-defined layer called the perichondrium. The outer layer of this perichondrium differentiates to fibrous tissue; the inner layer contains cells that can mature into chondrocytes or osteocytes. The cartilaginous models resemble in shape the adult bones they precede.[10,11] The models for two or more adjacent bones are joined by connective tissue in the regions of future joints; joint cavities form later.[9] The cartilaginous models enlarge by apposition from the perichondrium, from the connective tissue related to their ends, and by the division of chondrocytes within the model.[9]

The chondrocytes in the central parts of the models hypertrophy and vacuolize at about the sixth prenatal week (as shown in figure 1-A).[9,12,13]



NOTE: From Roche, A. F.: The elongation of the mandible, *Am. J. Orthod.* 53:79-94, 1967.

Figure 1. A diagram of the maturation of a long bone in which the length of the bone has been kept constant. The approximate age scale is: A, 6 weeks prenatal; B, 7 weeks prenatal; C, 12 weeks prenatal; D, 16 weeks prenatal to 2 years; E, 2 to 6 years; F, 6 to 16 years; and G, adulthood. The clear area in D-G represents the marrow cavity.

The later calcification of this area[14,15] constitutes a phase of maturation. When this calcified area is sufficiently large, it becomes radio-opaque. This is the first stage of skeletal maturation that can be observed radiographically. The area of hypertrophic chondrocytes and the area of calcified cartilage enlarge more rapidly than the model. This is shown by extension of the hypertrophic and calcified areas along the model (figure 1-B). Ossification begins when a collar of bone forms deep to the perichondrium around the central part of the cartilaginous model (figure 1-B). Soon after this, ossification begins in the central part of the model by replacement of calcified cartilage (figure 1-C). This endochondral ossification begins where cartilage first formed.[9,16-18]

The early stages of endochondral and subperiosteal ossification cannot be distinguished radiographically. Soon these areas unite; later their interrelationships become more complex as a result of remodeling that continues throughout life.[19] The ossified areas extend along the cartilaginous model both centrally (endochondral) and on its surface (subperiosteal). Endochondral ossification occurs in areas where cartilage cells have hypertrophied, the matrix has calcified, and blood vessels, connective tissue cells, and osteoblasts are present.[13] Subperiosteal ossification extends along the cartilaginous model at about the same rate as endochondral ossification. Both endochondral and subperiosteal ossification extend along the model until they reach the future epiphyseal zones[a] (epiphyseo-diaphyseal junctions) at each end of the model (figure 1-D). After this stage of maturation has been reached, it is customary to refer to the ossified area as the diaphysis or shaft of the bone. Before this occurs, a marrow cavity forms by resorption in the central part of the ossified area. This stage of maturation is not suitable for inclusion in a method of assessment based on radiographs. For a considerable period after the diaphysis reaches the ephiphyseal zones,[a] the ossified area does not

[a]The term epiphyseal zone refers to the part of the bone between the epiphysis and diaphysis. It is only applicable after the epiphysis has begun to ossify—between the time when the epiphysis has started to ossify to the time when the epiphysis has fused to the diaphysis. A bone with an epiphysis at each end has two such zones; some other bones have only one.

extend further in relation to the total length of the bone but changes that are visible radiographically occur in the shape of the end of the diaphysis.

From the viewpoint of assessment, a most important stage of maturation occurs when epiphyseal centers of ossification form within the cartilage near the end of the diaphysis (figure 1-E). This occurs near each end of the diaphysis of every long bone and at one end of each short bone, e.g., metacarpals and phalanges. Maturation occurs at the nonepiphyseal ends of short bones also, but, at these sites, it is difficult to divide the process into stages that can be distinguished radiographically.

The histological changes associated with endochondral ossification are the same, whether this occurs in the central part of the model or in the epiphyseal cartilage near the ends of the diaphysis.[9] The ossified area in each epiphyseal cartilage enlarges and, within a few years, the cartilage is replaced completely, except for that in contact with the end of the diaphysis and on the articular surface (figure 1-F). During this phase, the replacement of cartilage by bone is more rapid than the growth of cartilage.

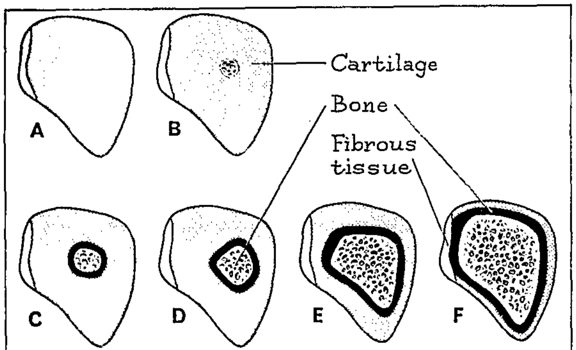
At first, an epiphyseal ossification center enlarges rapidly in all directions; later it enlarges more rapidly in some directions than others.[9,20] Consequently, the shape of the center gradually resembles that of the cartilaginous end of the bone.[21] These shape changes are very important in assessment. The epiphyseal ossification center enlarges by the apposition of bone to each aspect except where the center is in contact with the cartilage of the epiphyseal zone.[22,23]

A transverse layer of cartilage remains between the diaphysis and the ossified epiphysis after bone has replaced most of the epiphyseal cartilage. This transverse layer, together with the end of the diaphysis, is important not only in diaphyseal elongation but in the radiographic assessment of maturity. In this zone, chondrocytes hypertrophy and vacuolize, and the cartilage calcifies preparatory to its replacement by bone. These changes are the same as those that occurred earlier during endochondral ossification in other parts of the cartilage model. These changes are more regular in the epiphyseal layer where there is a columnar arrangement of chondrocytes and a corresponding arrangement of matrix and blood vessels.

The aspect of the epiphyseal ossification center in contact with the epiphyseal layer increases in cross-sectional area more rapidly than either the end of the diaphysis or the epiphyseal zone cartilage. It has been claimed that a collar of periosteal bone, extending from the margin of the diaphysis around the edge of the epiphyseal zone, limits the increase in the cross-sectional area of this zone.[24,25] The opposite view has been stated also: that this collar is necessary for the increase in the area of the zone.[26] The evidence available indicates that this collar is neither a mechanical barrier to the migration of new chondrocytes nor a site of their formation.[27] Rather, the increase in the cross-sectional area of the epiphyseal zone is due to the formation of new chondrocytes in the proliferative layer of the perichondrium and their subsequent migration into the zone.[27-30] The increased cross-sectional area of this zone leads to increases in the cross-sectional areas of the diaphyseal aspect of the epiphysis and of the end of the diaphysis (flaring). These changes are visible radiographically and are very important in assessment.[31]

After an epiphyseal zone is present, the adjacent surfaces of the epiphyseal ossification center and of the diaphysis gradually become reciprocal in contour. The associated radiographic changes are used to assess skeletal maturity. Later, the diaphyseal aspect of the epiphyseal center is covered by a thin densely radio-opaque layer of bone which is used as a maturity indicator. As adult levels of maturity are approached, a thin undulating layer of bone covers the end of the diaphysis and separates it from the calcified cartilage of the epiphyseal zone.[32] This layer of bone and the adjoining calcified cartilage together cause a dense radio-opaque line that is used in assessment.

The changes as the end of the diaphysis (metaphysis) is progressively transformed and relocated to a relatively more central position[33] cannot be graded radiographically. However, the ridges that develop at the limits of some muscular attachments cause radio-opaque lines that are used in assessment, e.g., at the distal portion of the ulnar diaphysis.[5]



NOTE From Roche, A. F.: The elongation of the mandible. *Am J Orthod.* 53:79-94, 1967.

Figure 2. A diagram of the maturation of a carpal bone in which total size has been kept constant. The approximate age scale is: A, prenatal; B, 1-3 years; C, 4-5 years; D, 6 years; E, 10 years; and F, adulthood.

The final phase of the maturation of a long bone is fusion between the epiphysis and the diaphysis. This is preceded by the cessation of skeletal elongation and the formation of a thick layer of calcified cartilage in the epiphyseal zone.[34,35] This calcified cartilage is replaced slowly by bone and, progressively, the remaining epiphyseal zone cartilage is calcified and replaced by bone. There is little doubt that this process is completed first in the central part of the zone, despite some opposite views.[36,37] Ossification of the peripheral part of an epiphyseal zone cartilage may remain incomplete for long periods causing a groove on the surface of a bone that may be visible radiographically. After bony fusion between the epiphysis and diaphysis is complete, the articular cartilage is the sole remnant of the cartilaginous model. The bone has now attained adult maturity (figure 1-G).

Subsequent to epiphyseo-diaphyseal fusion, the layer of bone that joined the adjacent surfaces of the epiphyseal center and the diaphysis is resorbed. This resorption may be delayed for a long time. When this layer persists, it is visible radiographically.[38,39]

Many corresponding stages occur during the maturation of the carpal bones that are in the wrist between the forearm bones and the short bones of the hand. A major difference is that the carpal bones do not develop epiphyseal zones or epiphyseal ossification centers. Each carpal bone first develops as a condensation of embryonic connective tissue. Subsequently, cavitation occurs in this connective tissue in the region of future joints between the carpal and neighboring bones. After this occurs, the cartilaginous model, now resembling the future bone in shape, articulates with its neighbors on adjacent surfaces and is covered by a well-defined perichondrium on other surfaces (figure 2-A). Ossification begins in this cartilaginous model (figure 2-B, 2-C) with the same histological processes as those described for endochondral ossification of long bones.[40] At first, the ossified area expands rapidly in all directions;[9] later growth is more rapid in some directions than others. The changes as the ossified area gradually matures and matches more closely the shape of the adult carpal (figure 2-D, 2-E, 2-F) are used in assessment of skeletal maturity levels of children from their radiographs.

Radiographic Changes

Studies preceding the introduction of radiography drew attention to many macroscopic differences between the skeletons of children and adults. These studies were limited to postmortem material; usually the medical history was unknown and the techniques employed (e.g., dissection, histological section) did not allow serial studies of individuals. Knowledge of skeletal maturation increased rapidly after radiographic techniques became available. Only a few studies selected from a very large body of literature will be mentioned. Rotch[41] described 13 recognizable stages in the development of the hand-wrist. Later, stages of carpal maturation[42] and of epiphyseo-diaphyseal fusion were described.[43,44] These studies led to the elaboration of the Todd method of assessment.[45]

The radiographically visible changes used to assess skeletal maturity are known as "maturity indicators." What can be seen in radiographs are maturity indicators, not skeletal maturity. By definition, these indicators appear in a fixed sequence for each bone[5,46,47] although the sequence is not fixed for an area, e.g., hand-wrist, that includes many bones.[48-50] Each of these indicators must appear during maturation in every child to be useful in the assessment of skeletal maturity.[47]

The radiographic assessment of skeletal maturity depends on the presence and relative radiodensity of areas of calcification or ossification. These differences in radiodensity, although observed in two-dimensional radiographs, reflect three-dimensional shapes of radio-opaque calcified or ossified areas. Parts of the surfaces of these areas (especially the dense cortex of bone) that are approximately parallel to the central axis of the radiographic beam cause dense white zones on a radiograph. If these zones are long and narrow, they are referred to as "lines" and are commonly called "radio-opaque lines" because the structures causing them are relatively radio-opaque.

The changes in contour that occur during maturation, as bones become more adult in shape are important in the radiographic assessment of maturity. These contour changes reflect different rates of bone apposition at various areas. Changes in shape cannot occur without changes in size. Thompson has indicated that form is determined by the rates of growth in different directions.[51] However, all the elements of size used in the assessment of maturity concern relative size (shape) not absolute size. As emphasized by Todd,[45] the use of absolute size would lead to the unacceptable conclusion that adults differ in maturity because they differ in absolute size. This would destroy one major advantage of the present scale of maturity.

Scale of Maturity

The scale used in radiographic assessment is based on the assumption that skeletal maturity is absent at conception and that all individuals reach the same level of complete maturity in young adulthood. By this premise, each individual achieves the same amount of maturation between conception and adulthood, although there are individual differences in rates. In practice, the origin of the scale is the onset of epiphyseal or carpal ossification, as observed radiographically. Bones that develop epiphyseal ossification centers cannot be assessed reliably before this stage.[52,53] Similarly, carpal "bones" cannot be assessed until they are visible radiographically. Some radio-opaque epiphyseal or carpal centers probably consist of calcified cartilage rather than bone when assessors regard them as "ossified." The only convincing radiographic evidence that bone is present is the recognition of trabeculae and these may not be visible for a considerable period after the center becomes radio-opaque. The end point of the skeletal maturity scale is the completion of epiphyseo-diaphyseal fusion in bones that have epiphyses and the attainment of final adult shape in carpal bones.

There are two scales that can be used to make bone-specific skeletal age assessments of the hand-wrist. The Tanner-Whitehouse method[54] is always used in a bone-specific way and the Greulich-Pyle scale can be used to obtain either overall or bone-specific skeletal ages. These scales for individual bones are not divided into intervals known to be equivalent to each other. These ordinal scales do not *measure* skeletal maturity but allow a maturation level to be assigned to a radiograph relative to standards. Like other ordinal scales, they allow rank ordering, in this case, of the degree of maturity. The standards that are used represent the central tendencies of skeletal maturity level in healthy children grouped by age and sex. The levels (assessments) are recorded in years or months of skeletal age. Typically, girls achieve adult levels of skeletal maturity at younger chronological ages than do boys. Consequently, girls mature more than boys during a "skeletal age year." Furthermore, individual bones differ in the average chronological ages at which they reach adult maturity levels. Hence the percentage of adult maturity achieved per skeletal age year must differ among bones.

It is known that a boy with a skeletal age of 2 years is more mature than a boy with a skeletal age of 1 year. However, one cannot conclude that he is twice as mature because of the lack of skeletal maturity units that are equivalent to each other. Nevertheless, because all boys mature until they reach the same adult level of maturity, it follows that all boys at the same skeletal maturity level have achieved the same percentage of adult maturity, although the actual percentage of skeletal maturity is unknown. This is the major advantage of the ordinal scale of skeletal maturity that is used. By contrast, many physical characteristics of children, e.g., stature, are recorded using a cardinal scale. With such scales, ratios between measures can be calculated, e.g., a boy weighing 70 kilograms is twice as heavy as a boy weighing 35 kilograms. This advantage of the cardinal scale is offset to some extent by the fact that adults differ in weight and, therefore, one should not infer that two boys, each weighing 60 kilograms, have each achieved the same percentage of their adult weights. The limitations of some scales have not always been recognized. For example, some dental maturity scales are based on the assumption that incompletely developed roots of teeth can be classified as one-fourth complete, one-third complete, etc.[55,56] These methods imply that root lengths are the same in all adults.

The scale used to assess the Cycle II radiographs is presented in the radiographic standard of reference of Pyle et al.,[6] which is referred to in this report as the HES Standard. This new scale was derived principally from the Greulich-Pyle Atlas,[5] which contains reproductions of ordered sets of radiographs for each sex. Each of these radiographic standards[b] is accompanied by skeletal age equivalents in months or years for each bone.

THE HEALTH EXAMINATION SURVEY STANDARD

As stated in the Introduction, a new radiographic standard for the assessment of skeletal maturity of the hand-wrist was developed by Drs. Greulich and Pyle in collaboration with Dr. Waterhouse at the request of and for specific use in the U.S. National Health Examination Survey. The major difference from the Greulich-Pyle Atlas is that the HES Standard contains a single series of plates by which the two sexes are assessed and compared. The rationale is based on the premises that the process of growth implies maturation, that there are marked individual differences in the timing and velocity of maturation but not the sequence, and that the rate of skeletal maturation in the hand-wrist is an acceptable indicator, for the purposes of this survey, of the rate of overall skeletal maturation of a child. This standard further assumes that selected transitional, ossifying features and articular facets in the cortices of growing bones are maturity indicators identifiable on all children's radiographs, and that they are generally the same for both sexes and all races, and that the chronological intervals between these transitional features of growing bones are not uniform. The process of maturation occurs, on the average, more slowly in males than in females. Consequently, when a single series of standards is used for both sexes, two sets of chronological age equivalents are required.

The HES Standard for the hand-wrist has been based on and in part abstracted from the 1959 Greulich and Pyle Radiographic Atlas.[5] The Atlas was in turn based principally on the research radiographs and other data from the Brush Foundation Study of Human Growth and Development of Cleveland, Ohio, which was organized in 1929 and directed for the first 10 years by Dr. T. Wingate Todd. The Greulich and Pyle Atlas was designed for direct skeletal age readings from 3 months to 18 years with radiographic standards at intervals of 3 to approximately 12 months depending upon the modal rate of maturation in the period. The Atlas contains one series of standards (modal radiographs) and skeletal ages for males and another series of standards and skeletal ages for females.

Most of the radiographic plates used in preparing the HES Standard were selected from the male hand-wrist series, pages 80-123 in the Greulich-Pyle Atlas.[5] With appropriate modification and supplementation, they provided a series of typically occurring discernible features of developing hand-wrist bones—a series spaced at irregular intervals from 3.8 months to 228 months of skeletal age. These features were related, as accurately as possible, to the chronological age level at which they typically appeared in the modal position for the Cleveland boys and girls who were enrolled in the Brush study. To assign female skeletal age equivalents to these male standards, three sets of hand-wrist radiographs of girls were assessed using the survey standard of reference for the male hand and wrist.

Although each plate in the published HES Standard shows the skeletal age equivalents for both males and females, those who assessed the survey radiographs were not told the sex (or chronological age) of any child whose radiograph was being assessed. The skeletal ages assigned were based on the male equivalents accompanying each standard plate. In this report, the skeletal

[b]The method by which the standard radiographs were selected is described by Greulich and Pyle[5] and Pyle et al.[6]

age data for girls are shown both as directly assessed on the basis of the male standards and after conversion by computer to the corresponding skeletal ages for girls based on equivalents in the manual. It was intended by means of this national survey of children, and the subsequent one of youth (12-17 years), to obtain more precise estimates of the comparative levels of skeletal maturation between the two sexes. In earlier studies of sex-associated differences in skeletal maturity levels, the sex of the children was known by the assessors and this could have influenced the subjective judgments that were made.

METHODS

At each of the 40 selected locations throughout the United States, the children were provided with transportation to and from centrally located mobile centers specially designed for an examination that lasted about 2½ hours. Six children were examined in the morning and six in the afternoon. When each child entered the mobile center, his oral temperature was taken and a screening for acute illness was made; if illness was detected, he was sent home and reexamined later. Each examinee next dressed in shorts, cotton sweat socks, and a light sleeveless shirt and proceeded to a designated but different station for the examination; the sequence of elements in the examination differed for each child so that the six could be examined simultaneously during the half day. The same examiners—physician, dentist, psychologist, and specially trained technicians—conducted their parts of the examination in essentially the same manner for each child. The time of each examination was recorded, but there is no reason to believe that diurnal or sequence effects would be present in the composition or quality of the radiographic data. The number of radiographs assessed is given by year of age in appendix table I.

Field Radiography

Each child was scheduled to have a 10"x 12" radiograph of the right hand and wrist taken at a tube-film distance of 36 inches. However, due to the shortage of radiographic film of this size during part of the survey, 600 radiographs were taken (at the same distance) using either larger or smaller films. The positioning for radiography was otherwise in accordance with the specifications in the Greulich-Pyle Atlas.[5] Because the films were developed immediately in the field, technically inadequate ones could be repeated. Thus each child's record contains a single radiograph showing the dorso-palmar view of his entire hand-wrist with its full complement of ossifying parts, at his examination age. Ninety-eight percent of the radiographs were technically satisfactory for this report (94 percent of the total sample).

The decision to radiograph the right hand-wrist rather than the left, which is the more frequent anthropometric practice, was made on the advice of anthropologist consultants who were interested also in the use of related measurement data for equipment design in which right-side measurements were preferred. The Greulich-Pyle Atlas was designed for the assessment of the left hand-wrist. When the Atlas standards were reproduced in the HES Standard, they were reversed photographically so that they could be used in right-side assessments. Previous reported research on lateral differences in the skeletal maturity of the hand-wrist, either for the area as a whole or bone by bone, has shown that these are too small to be of practical importance.[79]

Training of Assessors

The assessment of skeletal age from the hand-wrist radiographs of children 6-11 years of age in the Health Examination Survey of 1963-65 was made by six medical students at Case Western Reserve University, including one who was an instructor specializing in anatomy. This work was done under contract, with Dr. C. Wesley Dupertius as Project Director, for the National Center for Health Statistics. Prior to the training of these medical students, under the direction and meticulous supervision of Dr. Pyle, each assessor was required to demonstrate his familiarity with the series of maturity indicators of individual bones in the hand-wrist as described on pages 185-228 of the Greulich and Pyle Atlas.[5]

The practice procedures used in training were based on 30 contact-size prints of the hand-wrist radiographs used with the 1959 edition of the Radiographic Atlas and a validating test based on another set of prints of hand-wrist radiographs with which the preliminary version of the HES Standard (showing only the male standard skeletal ages for each plate and each bone) was used.

During the practice, each assessor first arranged 30 prints in ascending skeletal maturity order. The bone-specific skeletal ages for each print were assessed according to the *male standards* in the Greulich and Pyle Atlas[5] and the corresponding skeletal age of the hand-wrist for each print was determined by averaging these skeletal ages. Next, the 30 prints were rearranged according to those hand-wrist skeletal ages and the new array was assessed according to the *female standards* in the Greulich and Pyle Atlas. Then, the first set of bone-specific skeletal ages, based on the *male standards,* were covered and a second set of bone-specific skeletal age assessments was obtained using the male standards for the second time. The first and second sets of assessments were compared, and the assessor decided which he considered the better final rating for each print. These ratings were reviewed to determine whether the assessor needed additional practice and training before proceeding to the next phase. When the project director considered that the assessments were sufficiently reliable, the assessor was given the validating test in which his assessments and the extent of variability in his independent reassessments were compared with those of Dr. Pyle. When the ratings and reliability for the new assessor were in good agreement with those by Dr. Pyle—the majority of differences within 4 months—the new assessor started his assessment of the survey radiographs. Reported evidence[53] suggests that, at the end of this training procedure, the interobserver and intraobserver differences in skeletal maturity ratings should have been similar to those for experienced assessors.

Assessment Procedure

All survey radiographs were assessed by comparison with prints of the series of standards for the male hand-wrist which appear on pages 80 through 123 of the Greulich-Pyle Atlas,[5] as modified for inclusion in the HES Standard but showing the skeletal age equivalents for males only. The readers did not have access to the chronological age, the sex, or any other information about the child. When it appeared appropriate, the assessors interpolated between the standards to monthly intervals.

As a quality control measure and to permit determination of the level of reliability of the assessments throughout this study, independent replicate assessments were obtained on approximately one out of each 11 radiographs. One randomly selected radiograph from each 23 was rated independently by another assessor for a measure of interobserver variability and one randomly selected radiograph among each 20 was rated independently a second time by the same reader to give a measure of intraobserver variability. At the second assessment, there was no indication to the assessor that it was a reassessment and there was sufficient time lapse between the two assessments that there was little likelihood of recall. Information on the degree of reliability of these assessments is contained in appendix II.

In skeletal age assessments using reference standards, there are limits to the range of skeletal ages that can be applied to each bone. For example, as shown in table A, the trapezoid is not visible until plate 12 of the HES Standard,[6] where the skeletal age (hand-wrist) is the equivalent of 72 months and the trapezoid shadow measures about 4.5 x 4.0 mm.; the trapezoid would be smaller than this when first radio-opaque. Thus it is reasonable to assign an age slightly less than 72 months to some radiographs. However, the assigned skeletal age must exceed 60 months because at that level (plate 11) the trapezoid is not radio-opaque. Lower limits for these assessments were arbitrarily set for each bone that was midway in skeletal age between the last standard in which the particular bone was not radio-opaque and the first in which it was radio-opaque. Three exceptions were made: for the pisiform and the adductor and flexor sesamoids, minimum ages for 2 months above the last non-radio-opaque plate were allowed. These exceptions were made because the limits were set *after* the assessments had been made and, for many radiographs, the assigned ages for

Table A. Minimum and maximum acceptable skeletal ages in months using the HES male standards: Health Examination Survey, 1963-65

Hand-wrist bone	Minimum[a]	Maximum[b]
	Skeletal age in months	
Radius	15	228
Ulna	70	215
Capitate	---	197
Hamate	---	197
Triquetral	17	197
Lunate	35	197
Scaphoid	68	197
Trapezium	51	197
Trapezoid	68	197
Metacarpal I	25	191
Metacarpal II	17	215
Metacarpal III	16	209
Metacarpal IV	17	209
Metacarpal V	24	215
Proximal phalanx I	33	215
Proximal phalanx II-V	15	209
Middle phlanx II-IV	23	209
Middle phalanx V	39	209
Distal phalanx I	15	191
Distal phalanx II, V	39	191
Distal phalanx III	22	191
Distal phalanx IV	32	191
Pisiform	110	197
Adductor sesamoid	146	197
Flexor sesamoid	158	197

[a]Minimum age (according to standard) of radio-opacity of epiphysis or carpal.
[b]One month below "adult" age.

these three bones were slightly lower than the "midway" limits.

There are limits also at the upper end of the range, when bones become adult. Only the designation "adult," and not a skeletal age in months, can be assigned to a bone in which maturation is complete. The median ages from the HES Standard, at which this occurs in boys, were used to calculate skeletal ages in months for each bone beyond which only the designation "adult" can be applied. The maximum values were assigned 1 month below the "adult" skeletal age as shown in table A. In the assessments of the survey radiographs, bone-specific male skeletal ages were assigned to both boys and girls; the assessor did not know the sex of the child.

As expected, within chronological age groups, the skeletal ages assigned to the girls were more advanced than those assigned to the boys. This occurs because, although boys and girls pass through the same skeletal maturity stages, girls tend to mature more rapidly than boys. The female equivalent skeletal ages, bone by bone, corresponding to the male skeletal ages were determined during the preparation of the HES Standard but were not used in assessment of the survey radiographs. The method by which these female equivalent skeletal ages were obtained is described in detail in Pyle et al.[6] These ages were estimated using three sets of serial radiographs of normal United States girls. The modal radiograph (in maturity) for each chronological age group in each set was assessed against the female standards in the Greulich–Pyle Atlas[5] and against the HES Standard (male). These sequential female equivalent skeletal ages were then smoothed.

The skeletal age data for girls in this report are given both in terms of the male standards as originally assessed and in terms of the female equivalent skeletal ages. The later conversion was done, bone by bone, using the equivalency data in the HES Standard with interpolation between the published values to monthly intervals. The skeletal age (hand-wrist) values for boys and girls in this report were determined by computer from the original bone-specific assessments by averaging the ages assigned each hand-wrist bone for the child.

FINDINGS

Skeletal Age (Hand-Wrist)

The mean skeletal age (hand-wrist) of boys in the United States increases consistently with chronological age from 6.3 years (75.5 months) for those 6 years of age at their last birthday (mean chronological age, 6.5 years or 78 months) to 10.4 years (124.2 months) at chronological age 11 years (mean, 11.5 years or 138 months) (table 1).

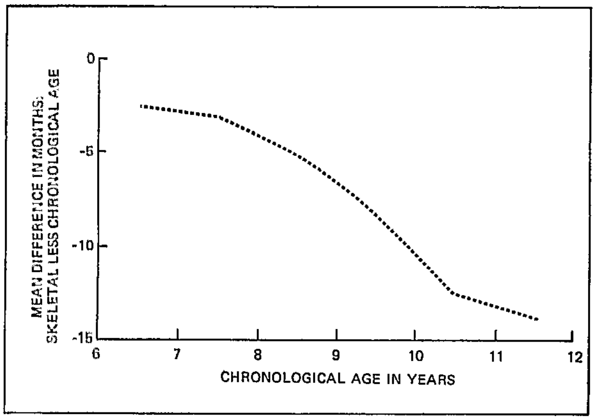


Figure 3. Mean difference in months between skeletal age (hand-wrist) and chronological age of boys, by chronological age in years: United States, 1963-65.

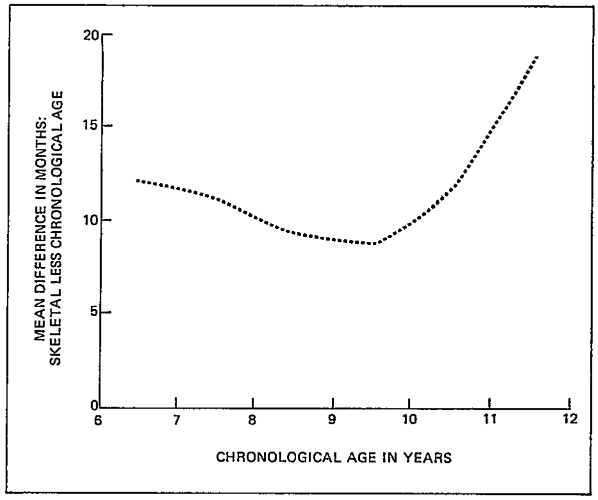


Figure 4. Mean difference in months between skeletal age (hand-wrist) on the male standard and chronological age of girls, by chronological age in years: United States, 1963-65.

The reader is reminded that the findings shown in this report are national estimates derived from data of the Health Examination Survey collected in 1963-65. The hand-wrist radiograph assessments of skeletal age were made using the HES Standard,[6] which is based on the Greulich-Pyle Radiographic Atlas,[5] as previously described. On the basis of these assessments, the skeletal age (hand-wrist) of boys does not progress as fast as their chronological age does, from a mean difference of 2.5 months at chronological age 6 years to nearly 14 months at chronological age 11 years (figure 3). The mean differences between chronological and skeletal ages of boys are statistically significant at the 5-percent probability level (i.e., exceed the 95-percent confidence limits for these estimates) or less throughout the age range in the study.

Among girls, when assessment is made against the HES Standard for males by readers not knowing the sex of the child, the mean skeletal age (hand-wrist) increases consistently from 7.5 years (90.0 months) at 6 years of chronological age (mean, 6.5 years or 78 months) to 13.1 years (156.5 months) at chronological age 11 years (mean, 11.5 years or 138 months). The skeletal age ratings against the male standard consistently exceeded the chronological age of American girls by differences ranging on the average from 12 months at age 6 years to 18.5 months at age 11 years (figure 4). Although they show no consistent linear trend with chronological age, the differences tend to be smaller at chronological ages 8 and 9 years than earlier or later.

In terms of the female equivalent skeletal ages corresponding to and derived from the male skeletal ages, as described in the "Methods" section, the mean skeletal age (hand-wrist) of American girls also increases consistently with chronological age from 6.4 years (77.0 months) among those 6 years of age at their last birthday to 10.7 years (128.2 months) at chronological age 11 years. As in the case of boys, the skeletal age of girls on the average lags consistently behind their chronological age (figure 5). The differences

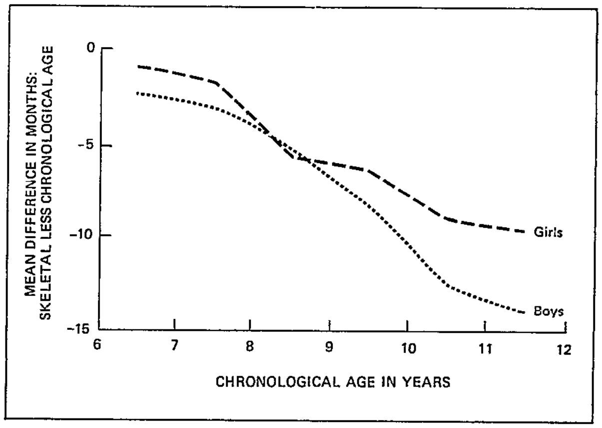


Figure 5. Mean difference in months between skeletal age (hand-wrist) and chronological age of boys and girls (female equivalent values of skeletal age used for girls), by chronological age in years: United States, 1963-65.

across chronological age are at a minimum of 1-2 months among 6- and 7-year-old girls, increase to about 6 months at ages 8 and 9 years, and reach a maximum between 9 and 10 months at ages 10 and 11 years.

Among both boys and girls, the marked tendency for skeletal age to be increasingly lower than chronological age as chronological age increases is clearly demonstrated in figures 3 and 5, where the findings are expressed as the difference between the respective means for skeletal age (female equivalent values for girls) and chronological age.

Comparison of skeletal ages for boys with those for girls (using the female equivalent values for the latter) shows close agreement among those 8 years of age (at their last birthday), where the mean skeletal age of boys exceeds that for girls by less than 1 month (figure 5). Among other younger children—at 6, 7, and 9 years—the mean skeletal ages for girls are 1-2 months in advance of those for boys, while among the oldest children—10 and 11 years—girls are substantially more advanced than boys by mean values of 3-4 months. These latter differences are statistically significant at the 5-percent probability level.

The mean skeletal age (hand-wrist) at 6-month intervals of chronological age shows a consistent pattern of increase with chronological age for both boys and girls similar to that at annual chronological age intervals (table 1). However, the actual rate of increase in skeletal age over successive 6-month periods of chronological age varies among both boys and girls but generally tends to be somewhat slower among boys. Among boys the mean increase in skeletal age between the first and the last half of chronological age 11 years is slightly greater than for younger boys and girls, while for girls of chronological age 11 years the mean increase in skeletal age between the first and last half of the year is less than for younger girls. Only among the oldest children in this study (chronological age 11) is the difference in the mean increase in skeletal age between boys and girls large enough to be statistically significant at the 5-percent probability level.

At single-month intervals of chronological age, the mean skeletal ages show a similar but less consistent pattern (table 2), primarily because the sample is too small to provide reliable mean estimates within these brief intervals. However, the high level of association between skeletal age (hand-wrist) and chronological age is readily apparent. The rectilinear product-moment correlation coefficient between the two measures of age is slightly but not significantly (statistically) greater among girls than boys—+.85 and +.82, respectively.

The extent of variation in skeletal ages among boys and girls, as measured by the standard deviations, does not increase consistently with the mean values. Among boys, the standard deviations in skeletal age ranged from a low of 9.9 months for those of chronological age 10 years (at their last birthday) to 12.5 months at chronological age 11 years; among girls these values range from 10.1 months of skeletal age (female equivalent values) at chronological age 7 years to 13.8 months at chronological age 10 years (table 1). The variability in skeletal age among girls, but not boys, was slightly greater among older (9-11 years of chronological age) than younger children (6-8 years). The relative variability in relation to the mean, as measured by the coefficient of variation $(100\ s_x / \bar{x})$ is greatest among the youngest boys and girls (14.8 and 13.6, respectively, at chronological age 6 years as shown in figure 6). Among boys, but not girls, the coefficient decreases consistently with chronological age from 14.8 at age 6 years to 8.7 at chronological age 10 years. Boys tended to show slightly greater relative variability in

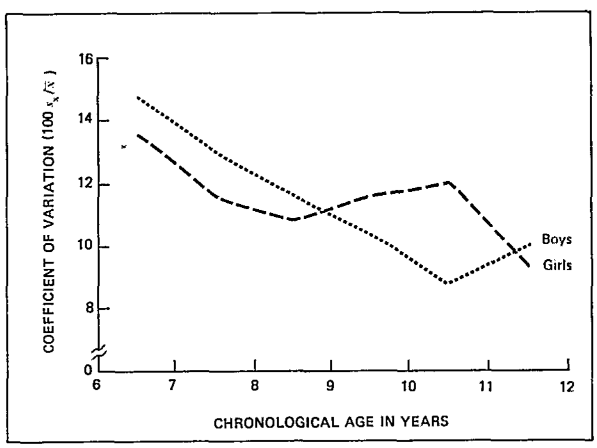


Figure 6. Relative variability in skeletal age (hand-wrist) for boys and girls, by chronological age in years: United States, 1963-65.

skeletal age than girls at four of the six chronological years of age, the two exceptions being at ages 9 and 10 years.

The distribution of skeletal age (hand-wrist) for boys and girls in the United States is similar and essentially normal at each chronological year of age (tables 1 and 3). The approximate chi-square test of goodness of fit to the normal curve indicates only chance differences that are not significant at the 5-percent probability level (χ^2_{24} =0.21-3.58, for the individual years of age and for each $p > 99$). Consequently, the mean and median skeletal age values are generally in close agreement. Only in four of the 12 age-sex groups of boys and girls do the mean and median skeletal ages differ by as much as 2-3 months. At chronological age 11 years for boys and 9 for girls (female equivalent values) the median skeletal ages are both lower than the mean by 2.6 months; while at chronological age 7 years for girls and 9 years for boys the median values are greater than the means by 2.0 and 1.8 months, respectively.

The percentage distributions of skeletal age (hand-wrist) among children within each chronological yearly and 6-month age interval are shown in tables 3 and 4. The interquartile range (P_{75} - P_{25}) or the central half of the distribution of the differences between chronological and skeletal ages, as shown in figure 7, for boys is lowest at age 10 years (range of 12 months), while differences at the other ages vary between 15 and 18 months. Among girls (female equivalent values) this measure of variability ranges from a minimum of 11 months at chronological ages 8 and 11 years to a high of 19 months at age 6 years. The 90-percent range (P_{95} - P_5) in the distribution of differences between chronological and skeletal age shows less variability with respect to chronological age. For boys this 90-percent range is at a minimum (35 months) at chronological ages 9 and 10 years and for girls (female equivalent values of skeletal age) at chronological ages 8 and 11 years, while it reaches a maximum of 42 months for boys at chronological age 11 and of 40 months for girls at chronological age 6 years.

Comparison with previous findings in the United States.—Comparison with findings from previous studies has been restricted to those including at least 25 boys or 25 girls at each age interval. In most of these investigations, radiographs were taken of the left hand-wrist, but the possible small lateral differences in skeletal

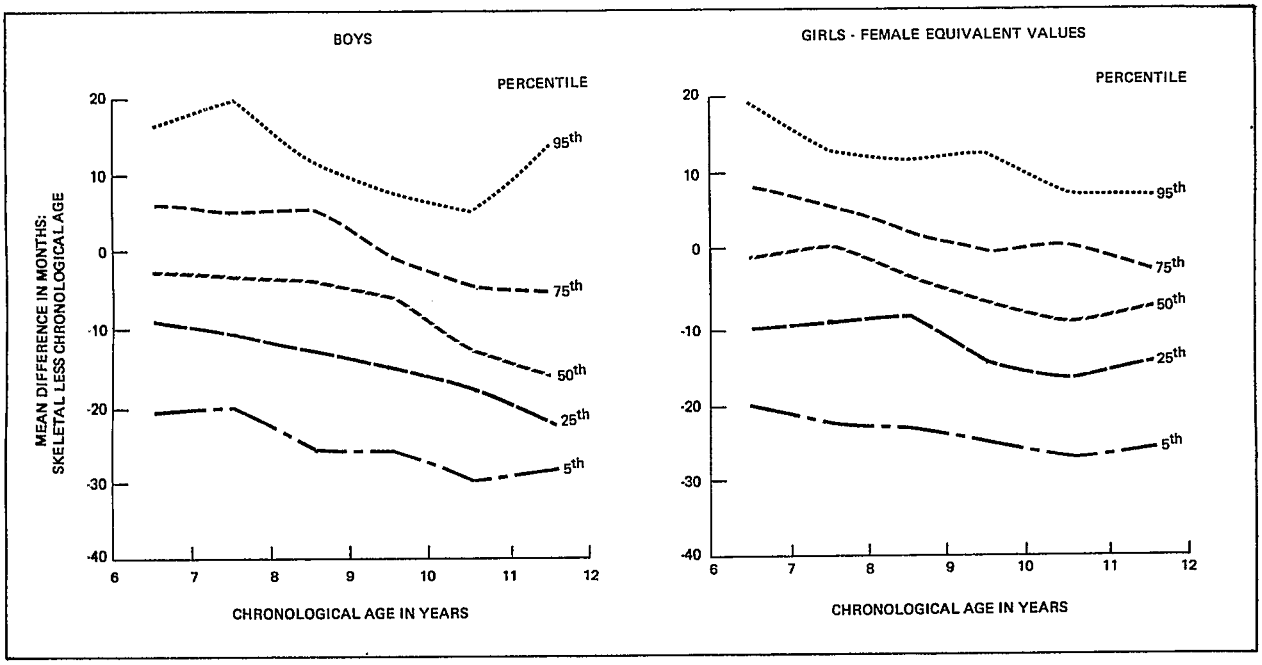


Figure 7. Selected percentiles in the distribution of the differences between skeletal (hand-wrist) and chronological ages for boys and girls (female equivalent values of skeletal age used for girls), by chronological age in years: United States, 1963-65.

maturity have been disregarded in this review. Means and standard deviations for skeletal age have been reported within chronological age groups by Simmons,[57] Greulich and Pyle,[5] Johnston,[58] and Fry;[59] Maresh[60] reported medians. To facilitate comparisons, the data reported by various investigators have been adjusted to a common Greulich-Pyle baseline. To achieve this adjustment for those reports, the standard modal plates of Flory[61] and Todd[45] have been assessed using the Greulich–Pyle Atlas[5] to assign bone-specific ages, interpolating when this appeared desirable. The maturity levels assigned to the Flory and Todd plates resemble medians rather than means.

The Greulich-Pyle standards were selected from radiographs of white children of upper socioeconomic status living in Cleveland. These children were born between 1917 and 1942 and were radiographed close to their birthdays and half birthdays. The method by which these standard plates were selected from the 100 radiographs available for each sex at each age is described in detail in the Atlas of Greulich and Pyle.[5]

Mean level.—Howard[62] published standards selected from radiographs of Atlanta public school children born between 1917 and 1922. These standards were selected from samples of 50 radiographs for each annual interval in each sex. Their maturity levels are about 2 years below those of the Greulich-Pyle standards. The data have not been included in figures 8a and 8b because neither ethnic origin nor socioeconomic status of the sample was reported. Furthermore, the sample was too small for a reliable selection of standards, considering that these radiographs were taken at random chronological ages.

A mixed longitudinal study of white Chicago children of above average socioeconomic status born between 1911 and 1923 was reported by Flory.[61] Radiographs taken within 2 weeks of a birthday were available for 100 children of each sex at each age except 6 and 7 years, when at least 80 radiographs were available. The plates selected by Flory as best representing the central tendencies in his groups are about 1 skeletal age year below the corresponding Greulich-Pyle standards for each sex. This difference tends to increase with age for the boys and to decrease for the girls (figures 8a and 8b).

Simmons[57] reported mixed longitudinal data from Cleveland children of above average socioeconomic status who were born between 1917 and 1942 and examined at or near their birthdays. The number of radiographs assessed for each

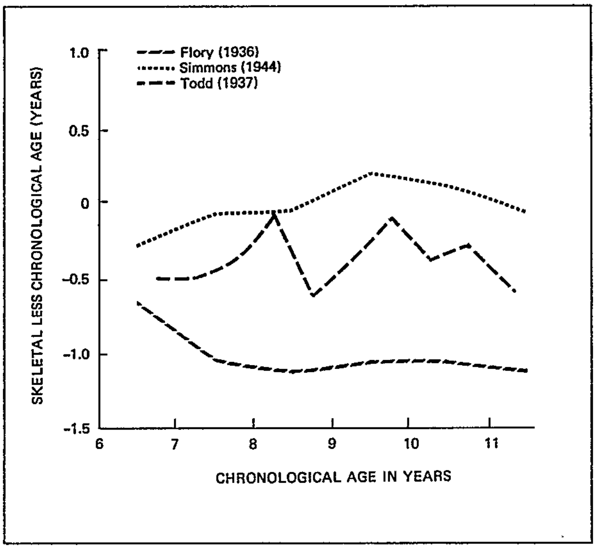


Figure 8a. Differences between skeletal and chronological ages of boys by chronological age in years in studies of Flory (1936), Simmons (1944), and Todd (1937).

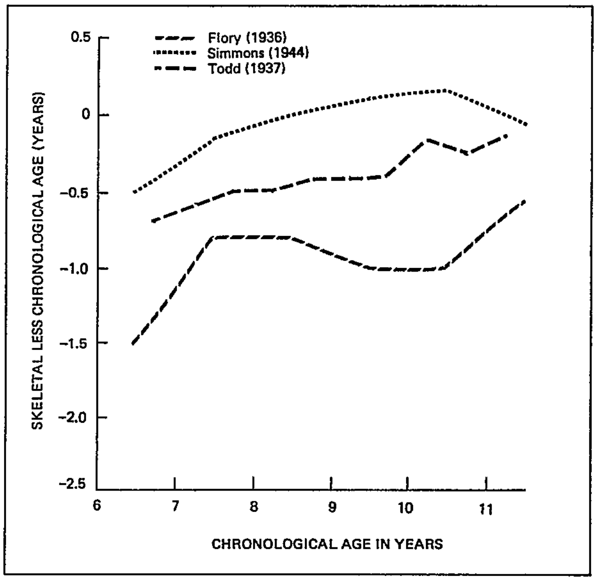


Figure 8b. Differences between skeletal and chronological ages of girls (female equivalent values for former) by chronological age in years in studies of Flory (1936), Simmons (1944), and Todd (1937).

year of age varied from 154 to 206 in each sex. After adjustment to compensate for the use of the Todd Atlas, all the mean skeletal ages reported by Simmons are within 0.5 year (skeletal age) of the Greulich-Pyle standards. This close correspondence is not surprising because the radiographs used by Simmons formed part of the sample used by Greulich and Pyle. In each sex, there is a tendency for the means of Simmons to be slightly higher than those of Greulich and Pyle at 7-10 years for boys and 8-10 years for girls but not at 6 and 11 years for either sex.

Todd's Atlas [45] was based on radiographs of Cleveland children of all socioeconomic levels who were born between 1920 and 1930 and examined serially near each birthday or half birthday. The standard plates were selected from samples of 35-94 children of each sex for each 6 months of age. The median levels of the Todd Atlas are about 0.5 year (skeletal age) lower than the Greulich-Pyle standards at most ages in both boys and girls (figures 8a and 8b). Expectedly, the maturity levels of Todd [45] are lower than those of Simmons.[57] Although there was some overlap between the samples of radiographs used by these two investigators, Simmons used only those of children who were of high socioeconomic status; Todd used radiographs of children from all socioeconomic levels.

Mixed longitudinal data from the Harvard Growth Study were reported by Greulich and Pyle.[5] These radiographs were of white middle class Boston children who were born between 1930 and 1939 and examined near each birthday. The sample size varied from 63 to 67 at each age in each sex. All the mean skeletal ages are within 0.3 year of the corresponding Greulich-Pyle standards.

Johnston [58] reported mixed longitudinal data from middle and upper middle class Philadelphia white children who were born between 1937 and 1955. The sample size varied from 23 to 51 for each annual interval in each sex. The examinations were made at random chronological ages. Consequently, the data relating to, for example, "9 years chronological age" were derived from children ranging in age from 8.5 to 9.49 years. The mean skeletal ages for the boys gradually advanced, with chronological age, relative to the Greulich-Pyle standards, until the mean was advanced 0.65 year at the age of 11 years. The means for the girls were within 0.3 year of the Greulich-Pyle standards at all ages.

Skeletal age data from middle class white children (including many twins) in Nebraska born between 1950 and 1960 and examined cross-sectionally at random ages have been reported by Fry.[59] The sample for each annual interval included 25 boys and 25 girls. The mean skeletal ages for the boys were below the Greulich-Pyle standards by amounts that exceeded 1 year (skeletal age) at 6 and 7 years. These differences for the boys decreased with increasing chronological age. The mean skeletal ages for the girls also were below the Greulich-Pyle standards at most ages by about 0.5 year (figures 9a and 9b).

Mixed longitudinal data from middle class white children living in Denver were obtained from radiographs taken close to birthdays and half birthdays. These children were born between 1915 and 1964, but most of the radiographs were taken after 1947. The sample size varied from 39 to 57 for each 6-month age interval in each sex.[60] The median skeletal ages for boys and girls were about 0.6 year below the Greulich-Pyle standards during the age range 6-11 years.

In general the data reported by those who have applied the Greulich-Pyle Atlas [5,58-60] indicate a trend to lesser retardation of skeletal age with increasing chronological age in boys (figure 9a). There are similar trends for girls in the data of Johnston [58] and Maresh [60] (figure 9b). However, the data from the present national survey show a definite tendency to increasing retardation in both boys and girls.

It is of interest to consider these reported means in relation to possible secular changes in skeletal maturity levels. As far as can be determined, all the samples considered in this review were similar in ethnic origin, but only those of Flory [61] and Simmons [57] were of upper class children. The median birth dates for the Flory sample are 13 years in advance of those for the sample of Simmons. The skeletal maturity levels reported by Flory are lower than those reported by Simmons, indicating a possible secular trend. The approximate median birth dates for the samples of middle class children are: Greulich and Pyle (Harvard data), 1935;[5] Johnston,

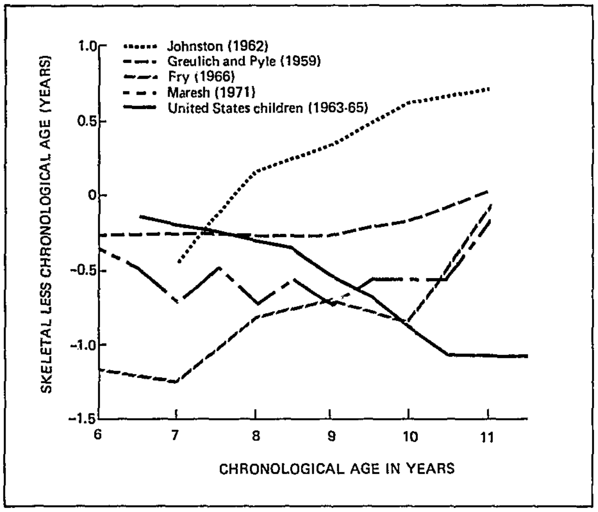


Figure 9a. Differences between skeletal and chronological ages of boys by chronological age in years, in studies of Fry (1966), Maresh (1971), Johnston (1952), and Greulich and Pyle (1959) and for United States children (1963-65).

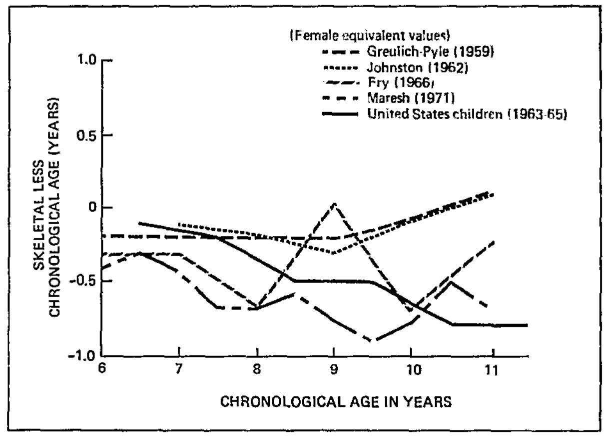


Figure 9b. Differences between skeletal and chronological ages of girls, female equivalent values for the former, by chronological age in years in studies of Fry (1966), Maresh (1971), Johnston (1952), and Greulich and Pyle (1959) and for United States children (1963-65).

1944;[58] Maresh, 1955;[63] and Fry, 1955.[59] Generalizing across age and sex, the mean levels reported by Greulich and Pyle and by Johnston tend to be higher, while those reported by Maresh and Fry tend to be lower. This suggestion of a reverse secular trend could be due to the effects of altitude (unlikely), imperfect comparability between assessors, and variations in what is considered "middle class." It is not in agreement with the present national survey findings, which are based on a much larger and differently selected probability sample representative of United States children born between 1953 and 1958 who were still alive at the time of the survey. In the national survey sample, the earlier born (and thus the older at the time of the survey) tend to have skeletal ages that are further behind their chronological ages.

Variability.—Means and standard deviations of skeletal ages, within chronological age groups, have been reported for most of the investigations considered here. Hence it is possible to compare the relative variability in skeletal age in relation to the size of the mean values for children in these studies. Greater variability might be expected for children in the present national study since radiographs were taken throughout the year rather than close to birthdays or half birthdays as was done in most of the previous available studies. This factor could be responsible for the relatively greater variability at some of the chronological ages among boys and girls studied by Fry.[59]

The relative variability in skeletal ages reported by Simmons[57] among boys 6-10 years of age and by Greulich and Pyle[5] among girls 6-9 years tend to be smaller than that for the corresponding age-sex group reported by others and is smaller than that for the children in the present national survey, when the latter are grouped into annual age intervals. After consideration of these reports, no clear picture emerges with regard to possible sex-associated differences in the variability of skeletal age. The relative variability in findings reported by Simmons[57] and Johnston[58] tended to be slightly larger for girls than for boys; an opposite and more marked tendency is present in the data of Flory[61] except at 8 years, Greulich and Pyle[5] through 10 years, and Fry[59] at 8-11 years. The corresponding sex differences in variability were small and inconsistent in direction in the national estimates provided by the HES data (table B).

The size of the probability sample in the national survey was larger than in the other reported studies; furthermore, only such a national survey can provide reliable estimates for the United States population.

Table B. Relative variability[a] in skeletal ages among boys and girls within chronological age groups from selected studies

Sex and age	Flory, 1936[61]	Simmons, 1944[57]	Greulich and Pyle, 1959[5]	Johnston, 1962[58]	Fry, 1966[59]	United States, 1963-65
Boys	Coefficient of variation					
6 years	20.6	13.3	13.7	---	15.4	14.8
7 years	21.0	10.7	12.5	10.4	14.0	12.9
8 years	15.9	9.6	11.7	10.0	14.7	11.6
9 years	13.5	8.2	10.6	11.4	15.9	10.3
10 years	11.1	8.1	9.7	8.9	15.9	8.7
11 years	10.4	7.7	8.0	6.8	11.1	10.0
Girls						
6 years	19.8	15.5	12.7	---	16.0	13.6
7 years	13.4	11.8	10.1	10.7	18.1	11.5
8 years	15.3	10.6	9.4	10.8	14.0	10.8
9 years	10.9	9.8	8.9	11.5	10.0	11.6
10 years	9.1	9.6	9.1	11.3	13.3	11.9
11 years	9.0	9.1	9.2	10.2	8.1	9.3

[a]Coefficient of variation = 100 standard deviation/mean.

Onset on Ossification

In the Health Examination Survey radiographs, the median age of onset of ossification or the first observable stage in skeletal maturation for each of the 31 hand-wrist bones was assumed to be midway between the last plate in the HES Standard in which the bone was not radio-opaque and the first in which it was radio-opaque. As shown in table A, slightly lower limits were allowed for the pisiform and the adductor and flexor sesamoids.

The median number of radio-opaque hand-wrist bones among boys increased from just under 26 at chronological age 6 years to 29 at chronological age 11 years. The girls were about two bones advanced in this respect throughout the age range in the national survey (table 5). As previously discussed the term radio-opaque for the short bones, the radius, and the ulna refers to the epiphysis rather than the shaft of the bones. The proportion of boys with fewer than 24 radio-opaque bones decreased rapidly from 9 percent among those of chronological age 6 years to 3 percent at chronological age 7 years and to 1 percent or less among those of chronological ages 8-11 years. For girls, less than 1 percent had fewer than 24 radio-opaque bones at chronological age 6 years. This again indicates that girls are more advanced in skeletal maturity than boys.

None of the 31 hand-wrist bones had reached "adult" skeletal age among boys in the national study, while among girls the proportion with at least one or more assessed as "adult" increased from 1 percent at chronological age 9 to 12 percent at chronological age 11 years.

Information concerning the modal ages of onset of ossification for some of the later-forming bones available from previous smaller studies is shown in table C. These previous studies included three types of modal ages: median ages at onset of ossification, mean ages at onset of ossification, and the percentage incidence of ossified centers within age intervals. The latter data allow the calculation of modal ages. Estimates of modal age of onset of ossification from the national survey are based on the chronological age at which 50 percent of the children were found to have the bone radio-opaque. To facilitate comparison, it has been assumed that any systematic differences that are due to the method of analysis between corresponding mean and median ages and ages when the center is present in 50 percent of children can be disregarded.

Table C. Modal ages in years for onset of ossification in selected bones from various studies

Bone	MODAL AGES from previous studies						United States, 1963-65
Boys							
Distal ulna	6.7,[61]	7.1,[68]	7.1,[69]	7.2,[64]	7.4,[5]	7.4 [66]	7.1
Trapezium	5.9,[69]	5.9,[61]	6.1,[5]	6.2,[64,68]	6.3 [66]		6.2
Trapezoid	6.0,[68]	6.1,[64,61]	6.2,[5,69]	6.8 [66]			6.4
Pisiform	10.5,[5]	11.0,[64]	11.2,[68]	11.7 [66]			11.3
Girls							
Pisiform	8.4,[5]	8.4,[64]	8.6,[66]	9.0,[61]	9.7 [68]		8.8
Adductor sesamoid	10.5,[64]	10.7,[69]	10.8,[5]	11.0,[20]	11.2 [66]		10.7

NOTE: Modal ages for studies of Greulich and Pyle[5] and Pyle et al.[20] have been increased by 0.5 to be more nearly comparable with assessment methods used in the other studies (see pages 18 and 19).

The report of Flory[61] concerning onset of ossification was based on the sample described earlier in relation to skeletal age. Essentially the same sample of Boston children was studied by Harding[64] and by Pyle et al.,[20] and it has been described in reference to the skeletal age data of Bayley.[65] The sample of Denver children studied by Hansman[66] has been described in relation to the report of Maresh.[60] Skeletal age has been studied in the Brush Foundation sample by Simmons;[57] ages at onset of ossification in these children have been reported by Greulich and Pyle.[5] Greulich and Pyle reported data using both the whole Brush sample (more than 200 children of each sex) and also the subset of 100 boys and 100 girls whose radiographs had been used to construct the Greulich and Pyle Atlas. Because there are only slight differences between corresponding mean ages for the two Greulich-Pyle samples, table C contains single references to both.

Lurie et al.[67] reported cross-sectional data on 1,129 white children from Cinninnati born between 1920 and 1940, approximately. These children were examined at the Child Guidance Home of the Jewish Hospital. While not necessarily Jewish, they were referred because of emotional disturbances. Although data from children with endocrine disturbances or marked nutritional deficiencies were excluded, the normality of the remainder of the sample is questionable. Consequently, these data have been excluded from the present review. Baldwin et al.[68] reported mixed longitudinal data from upper middle class white children in Iowa City, born between 1901 and 1928. The sample size varied from 29 to 49 in each annual interval for each sex. The mixed longitudinal data of Garn et al.[69] were derived from middle socioeconomic class white children in southwestern Ohio who were born between 1929 and 1966. The sample size was about 180 for each sex in each 6-month interval.

Considerable variation would be expected between the findings from these reports because the studies differ in many respects including sampling and the methodology of radiography and data analysis. Furthermore, most have reported data relating to the age at which a center was seen to be ossified; others[5,20] have recorded an age for onset of ossification in each child that was interpolated between the last radiograph in which the center was not ossified and the first radiograph in which it was ossified. For this reason, the means reported by Greulich and Pyle [5] and by Pyle et al. [20] are about 0.5 year in advance of those that would have been reported had the more common procedure been followed.

The modal ages based on reported data in table C should be interpreted with care because of these methodological differences. The ages in the table relating to the studies by Greulich and Pyle [5] and Pyle et al. [20] have been increased by 0.5 year to compensate for some of these differences. The reported modal ages at which the distal epiphysis of the ulna ossifies in boys differ comparatively little between these studies. This age is earliest for the Flory sample [61] and latest for the Hansman sample [66] with a difference of 0.7 year between these extremes. The modal ages for the onset of ossification in the trapezium in boys differ by 0.4 year from the earliest [69] to the latest. [66] The modal ages for the trapezoid in boys differ by 0.8 year from the early age reported by Baldwin et al.[68] to that reported by Hansman.[66]

All these reports indicate that the pisiform tends to ossify later in boys than in girls. The reported modal ages range from 10.5 to 11.7 years for the boys and from 8.4 to 9.7 years for the girls with Greulich and Pyle [5] reporting relatively early ages for each sex and relatively late ages being reported for boys by Hansman[66] and for girls by Baldwin et al.[68]

It is of interest to compare modal ages across studies (range 5.9 to 7.4 years) for the onset of ossification in the distal ulnar epiphysis, the trapezium, and trapezoid in boys.[5,61,64,66,68,69] The methodological differences between these studies would not be expected to cause systematic differences between these modal ages. The ages reported by Hansman [66] are the latest ones for each bone. The associations between the modal ages across bones are similar for the five studies except that the age reported by Hansman [66] for the trapezoid is later than one would expect from the ages she reported for other bones.

The modal ages reported for the adductor sesamoid and the pisiform in boys differed by 1.7 years in the data of Greulich and Pyle [5] and 2.0 years in the data of Hansman, [66] indicating satisfactory replicability. However, the differences between the modal ages for the onset of ossification of the pisiform in boys and girls range from 1.5 years in the sample of Baldwin et al. [68] to 3.1 years in the Denver children studied by Hansman.[66] The unusually large difference in the data on Denver children would lead one to expect that the boys would be skeletally retarded compared with the girls; there is no such tendency in the data for hand-wrist skeletal ages from essentially the same sample.[60]

The corresponding modal ages of onset of ossification in the U.S. children from the present survey tended to be within the range of the findings from other studies of more limited groups of children in this country. A review of some of the survey radiographs indicated that they were of unusually good quality and that even very small areas of ossification in the cartilaginous model of the pisiform had been recognized by the assessors.

Bone-Specific Skeletal Ages

In the Greulich-Pyle method of assessment as used in the national survey, bone-specific skeletal ages are assigned each radio-opaque hand-wrist bone. The skeletal age (hand-wrist) is determined from these bone-specific ages. Commonly within children the hand-wrist bones differ in their levels of skeletal maturity. The means and standard deviations of the bone-specific skeletal ages for each of the 31 hand-wrist bones of boys and girls 6-11 years of age in the United States, as determined from the survey male standard and for the girls also in terms of the female equivalent values, are shown in table 6 at 1-year chronological age intervals and in table 7 at 6-month chronological age intervals. Selected percentiles in the distributions of these bone-specific skeletal ages within single years of chronological age are shown in table 8.

As may be seen in figure 10 and table 6, there is a consistent increase in mean skeletal age with chronological age for each of the 28 bones for which the modal age of onset of ossification was below the age range of the study. For the remaining three—the pisiform and the adductor and flexor sesamoids—where this age is near or above the upper chronological age limit for the children in the study, the number of children in whom these centers had ossified is too few to

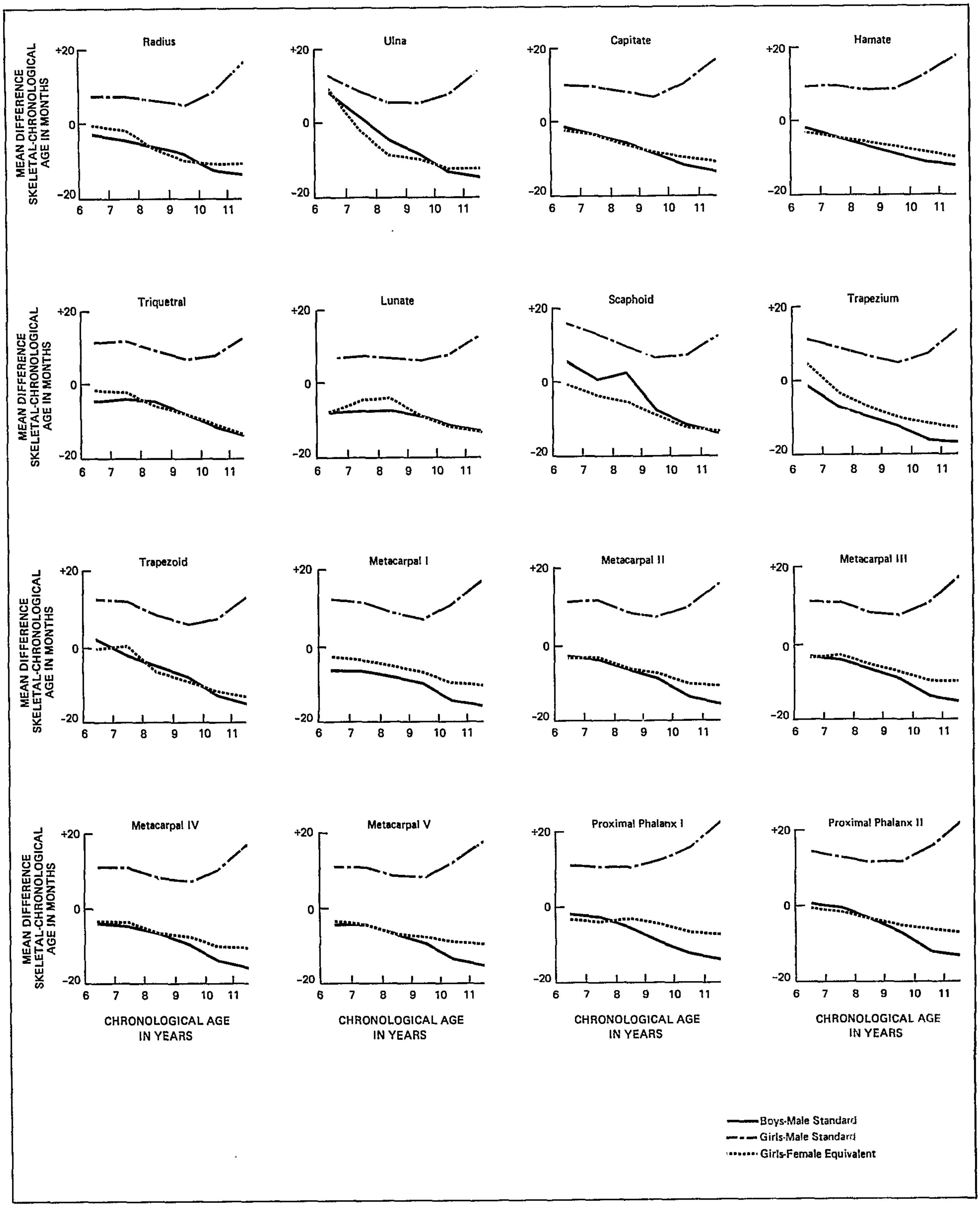


Figure 10. Mean difference in months between bone-specific skeletal and chronological ages for the 31 hand-wrist bones for boys and girls on the male standard and female equivalent means for girls, by chronological age in years: United States, 1963-65.

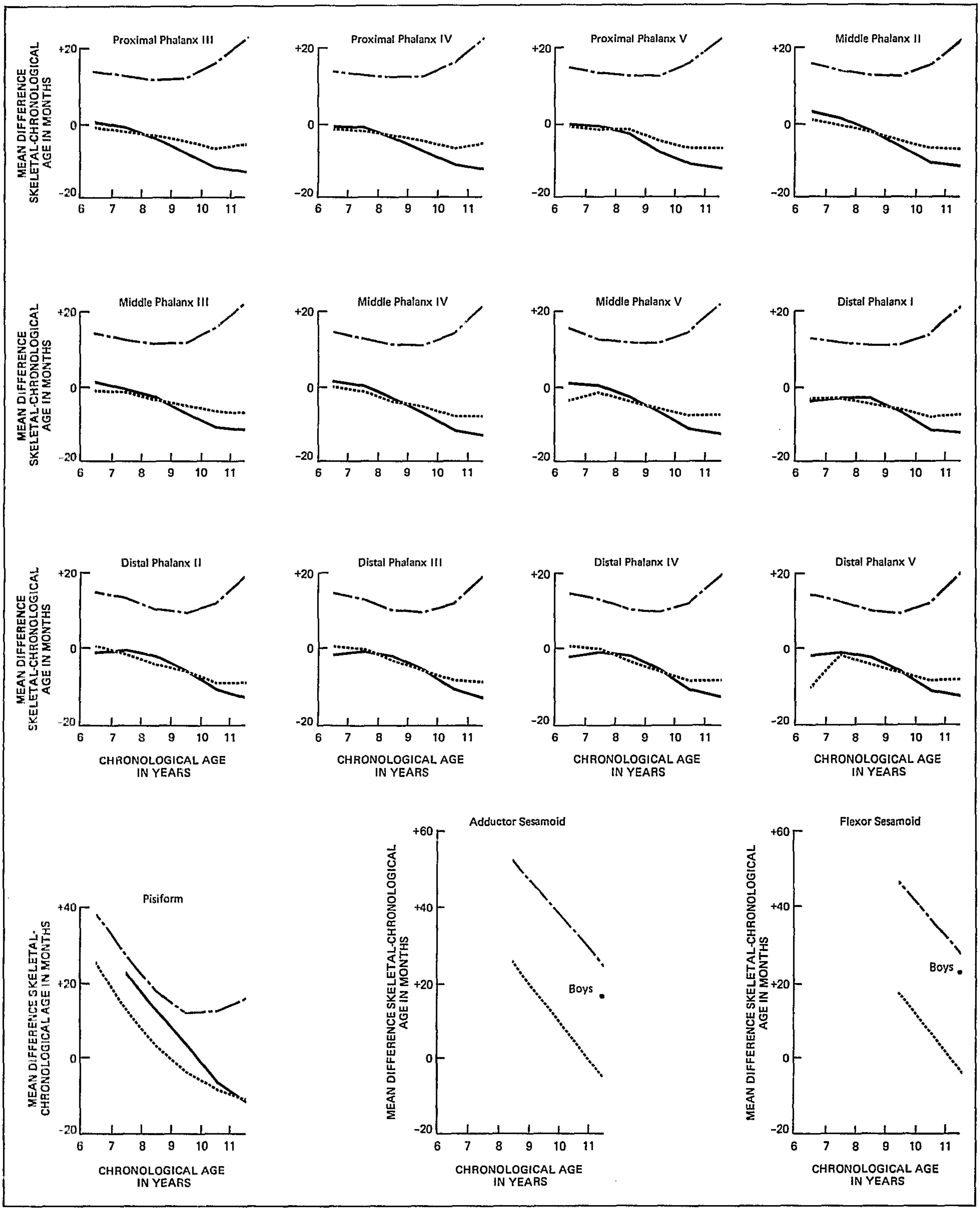


Figure 10. Mean difference in months between bone-specific skeletal and chronological ages for the 31 hand-wrist bones for boys and girls on the male standard and female equivalent means for girls, by chronological ages in years: United States, 1963-65–Con.

provide reliable estimates of their skeletal maturity. Particular attention is directed to the findings shown in figure 10; these findings are similar for each bone, with a few exceptions to which reference will be made later. The differences between the mean values for boys and girls (female equivalent values) are small at all ages. However, the differences between the mean skeletal ages for the boys and the mean skeletal ages for the girls (when assessed as boys) increase fairly regularly from about 15 months at the chronological age of 6 years to about 32 months at chronological age 11 years. The exceptions to the above pattern are bones that ossify relatively late. For the latter, age ranges occur during which the comparisons are between most of the girls but only a few of the boys. The boys included in these comparisons are those who are skeletally advanced relative to chronological age. Consequently the sex differences between the means are small, particularly at younger chronological ages. This effect is present for the ulna (6-7 years), the pisiform, and the adductor and the flexor sesamoids.

Mean bone-specific skeletal ages for girls (female equivalent values) are generally higher than the corresponding bone-specific skeletal ages for boys, particularly among older children—of chronological ages 9-11 years (at their last birthday). Among these older children, about one-half of the 89 mean differences in bone-specific skeletal age between boys and girls (for whom reliable national estimates are available from this survey) exceed the 95-percent confidence limits for such estimates—are statistically significant at the 5-percent probability level. For three-fourths of these differences which are statistically significant, the mean bone-specific skeletal ages for the girls exceed those for boys of corresponding chronological ages. By chronological ages 10 and 11 bone-specific skeletal age means for girls are significantly (statistically) more advanced than those for boys, with few exceptions. Of the 28 bones in which the onset of ossification is relatively early the mean differences in bone-specific skeletal age between the sexes only for the radius, ulna, trapezoid, triquetral, lunate, and scaphoid are negligible at chronological age 10 years; while at chronological age 11 years there are three which are negligible—the triquetral, lunate, and scaphoid.

Among younger children (chronological ages 6-8 years), there is no consistent pattern. About one-third of the 86 mean differences in bone-specific skeletal ages between boys and girls (for which reliable national estimates are available from the survey) are large enough to be statistically significant at the 5-percent probability level, and of these, the means for girls are as likely to exceed as be less than those for boys. After the age of 9 years girls are more likely to exceed boys in (bone-specific) skeletal age.

The variability of these bone-specific skeletal ages, as indicated by the standard deviations and the interquartile range ($P_{75} - P_{25}$) tends to increase irregularly with age (tables 6-8). The skeletal maturity levels of the lunate for boys and the proximal phalanx I for girls are more variable than those of the other bones. A similar tendency is not present for the triquetral despite earlier reports that the levels of maturity of this bone are very variable.[45,70]

When using the Greulich and Pyle Atlas, many workers follow the instructions of the authors in assigning bone-specific skeletal ages before combining these to obtain a single skeletal age for each hand-wrist area. This combination is necessary because, in almost every child, hand-wrist bones differ in skeletal age. These differences are partly genetically determined [48,71-73] and are not entirely due to the effects of illness and other environmental factors which were emphasized by Todd.[45] Various combinations of the same bone-specific skeletal ages yield different area skeletal ages but it is not known which method of combination is the best.[74]

Bone-specific skeletal ages are needed to calibrate the Greulich-Pyle Atlas and to assist recognition of clinical conditions in which maturation is dysharmonic.[75-77] In these conditions, particular bones differ markedly in maturity from the other bones of the same hand-wrist. Despite this need, the only reported bone-specific data for United States children are those of Peritz and Sproul.[78] Their sample included Oakland children of slightly above average socioeconomic status who were within 2.5 percentile points of age-specific and sex-specific medians for stature. Adjusted mean bone-specific skeletal ages at the chronological age of 6.5 years were obtained from cross-sectional data between 5 and 9 years. Means were reported for four selected bones in white children (80 boys and 84 girls) and black children (33 boys and 36 girls). Neither the basis for selection of these particular bones (triquetral, lunate, proximal phalanx III, and distal phalanx III) nor the mean skeletal ages for the hand-wrist areas were reported. These data indicate a tendency for the triquetral to be advanced in girls and for the lunate to be retarded in all groups in relation to the other bones selected. These findings for the lunate among girls, but not those for the triquetral, have been confirmed in the present study. Means and standard errors of differences between bone-specific skeletal ages and the mean skeletal ages for the same hand-wrists have been reported for normal Australian children of British ancestry.[79] These children were similar to U.S. white children in many parameters of growth, maturation, and illness experience[80] but they were 4 years old; consequently, these data are not directly comparable with those of Cycle II.

Normative data have not been reported concerning the spread of bone-specific skeletal ages within the hand-wrist areas of individual children. Possibly, the range from the least mature to the most mature bone varies with the difference between hand-wrist skeletal age and chronological age.[77] Pyle et al.[81] have suggested graphing the most mature and the least mature bone-specific skeletal ages in addition to the mean skeletal age, and that the most mature age indicates the child's potential rate of skeletal maturation. This attitude agrees with Todd's[45] statement that the principle of assessment is the utilization of the most advanced centers, not the average of all. Few have followed the suggestion of Pyle et al.[81] because normative data are lacking and because the usefulness of these graphs has not been demonstrated.

The survey findings are presented in table 9 as percentiles in the distributions of the ranges of the bone-specific skeletal ages for boys and girls at each year of chronological age for the total group and also within approximate years of skeletal age (hand-wrist). It should be noted that these are the ranges of skeletal ages that could be assigned. In some children a few individual bones were already adult while in other children some had not ossified. Consequently these are not the complete ranges of skeletal maturity but are the ranges of ages that could be assigned. The interquartile ranges (P_{75}-P_{25}) for boys and girls at chronological ages 6-8 years differ by less than 1 month and are approximately the same at chronological age 9 years, but among older children of chronological ages 10 and 11 years, they are smaller by 2 to 3 months for boys.

Within chronological age groups, the median ranges tend to decrease with chronological age in boys but there is no apparent trend for girls. In each sex, there is some skewness to the right. These data are shown graphically in figure 7. The data in table 9 show that the ranges are independent of skeletal age within chronological age groups.

The present national study is the first in which the data allow a good estimate of the extent to which bone-specific skeletal ages vary within individual hand-wrists. If the 95th percentile level may be accepted as the upper limit of normal, then the normal range is greater in boys than in girls. In boys, the range of variation decreases with chronological age from 51 months at age 6 years to 39 months at age 11 years. In girls, there is no evidence of a trend with age—the 95th percentiles are between 41 and 47 months for each age from 6 through 11 years.

DISCUSSION

Two subjects that will be emphasized in this discussion are the nature of the sample and how skeletal ages were obtained for each participant. The 7,119 children who were examined during the period July 1963 through December 1965 were 96 percent of the national probability sample of 7,417 noninstitutionalized children selected for this survey. However, 157 of these examined children were not radiographed or had unsatisfactory radiographs. It was assumed that the distribution of skeletal ages for these 157 children would be similar to that of the children whose radiographs were assessed. After inflation of the sample findings to the population from which the sample was drawn by differential weighting which compensated for the 298 nonrespondents (appendix I), the data provided close estimates of skeletal maturity for the total noninstitutionalized United States population aged 6-11 years in 1963-65. The national sample was known to be representative and the examined group was closely representative of that group in the population with respect to age, sex, race, geographic region, size of place of residence, and mobility of place of residence.

Skeletal ages of the individual bones in the right hand-wrist area were assessed by medical students who had been trained and were carefully supervised by Dr. S.I. Pyle. Their reliability is shown to be acceptable in comparison with reported data (appendix II). Assessments were made by comparison with the standards of Pyle et al.[6] This set of standards was derived primarily from the Greulich and Pyle Atlas[5] and was compiled for this national survey. The assessors knew neither the sex nor the chronological age of the child; consequently, a possible source of bias was removed. All the children were assessed using male standards, thus providing reliable estimates of sex differences in maturity status. Later, the data for the girls were adjusted, bone by bone, for the reported sex differences in skeletal maturity.[6]

The Need for a Survey

Skeletal age is commonly assessed because of the need for a measure of biological age when appraising the progress of children in stature, weight, or specialized dimensions such as those of interest to orthodontists. Furthermore, a biological age measure is important in screening for endocrinopathies, for example, hypothyroidism, and in selecting ages for surgical induction of epiphyseal fusion in children whose legs are unequal in length. Others use these assessments to monitor intervention programs or the effects of hormones or drugs, for example, in the management of children with hypothyroidism or excessive stature. Skeletal age assessments are used also to predict the mature statures of individuals from childhood parameters.

These data from the national survey were needed because the distribution of hand-wrist skeletal ages was unknown for United States children. The Greulich-Pyle Atlas[5] is satisfactory for many purposes, but it is based on radiographs of highly selected upper class white children who lived in Cleveland and were born between 1917 and 1942. Clearly, this sample was not representative of the total United States population. In addition, possible differences in maturity status reflecting racial and socioeconomic factors are poorly documented; a subsequent report on the present data will address these subjects.

It could be suggested that a single fixed scale is adequate for all countries and for all time. The difficulties that could arise from this can be illustrated using age at menarche as an analogy. In Norway, the mean age of menarche decreased from 17.1 years in 1844 to 13.3 years in 1952.[82] If a scale developed a century ago for determining whether age at menarche was "normal" were still in use today, almost all Norwegian girls would be considered precocious. It would be necessary for clinicians and others to adjust the scale for the secular changes that had occurred. This would involve knowing the extent of the changes in the means and the distributions. A national survey would be indicated to obtain the necessary data. Apart from possible secular changes, particular racial and socioeconomic groups in the United States may have levels of skeletal maturity different from those of the Greulich-Pyle standards; such differences should be documented and their causes sought.

Skeletal Age (Hand-Wrist)

The skeletal ages of the boys in the national survey tended to lag *behind* their chronological ages when assessed against the HES Standard. The mean difference increased from 2.5 months at age 6 years to 13.8 months at 11 years. When the girls were assessed against the same male standards, their mean skeletal ages were consistently *ahead* of the chronological ages by differences ranging from 12 months at 6 years to 18.5 months at 11 years. When skeletal ages for the girls were adjusted to become approximately equivalent to what they would have been if assessed against female standards, the mean skeletal ages lagged behind the chronological ages. The difference was only 1.0 month at 6 years but increased to 9.8 months at 11 years.

The distributions of skeletal age were essentially normal for each annual interval. The standard deviations ranged from 9.9 to 13.8 months and tended to increase with chronological age for girls but not for boys. Variability, measured by the range from the 25th to the 75th percentile, was lower at 10 years for boys and 8 and 11 years for girls than at other ages. Modal radiographs for boys and girls of these ages have similar maturity characteristics. The 90-percent ranges (5th to 95th percentiles) varied between 35 and 42 months for boys and 33 and 40 months for girls. The lack of a clear-cut tendency for skeletal age to become more variable with increasing chronological age is probably due to the nature of the scale used to assess skeletal maturity. This scale was derived from modal radiographs for chronological age groups which would tend to obscure the effects of variation between individuals in the timing of puberty.

The present data can be compared with previously reported data for various groups of United States children. The standards of Flory[61] for upper class white Chicago children are about one year below the Greulich-Pyle standards in each sex. These differences tended to increase with age for the boys and to decrease for the girls. The close correspondence between the data of Simmons[57] and the Greulich-Pyle standards helps substantiate that the Greulich-Pyle standards were modal because many radiographs were used in both these studies. In addition, the mean levels for the children in the Harvard Growth Study closely matched the Greulich-Pyle standards.[5] The accuracy of selection by Greulich and Pyle is attested to by the fact that the Todd standards[45] are about 0.5 year below the Greulich-Pyle standards. This would be expected because Todd used radiographs of children from all socioeconomic levels.

The mean skeletal ages of upper and middle class white boys in Philadelphia exceeded the mean chronological ages by small amounts that increased with age to 0.65 year at 11 years.[58] The mean skeletal ages for the girls in this study were closer to Greulich-Pyle standards. For middle class white boys in Nebraska, the mean skeletal ages were below the mean chronological ages by more than one year at 6 and 7 years; subsequently the differences decreased with age.[59] The mean skeletal ages for the girls in this Nebraska study were below the Greulich and Pyle standards by about 0.5 year at most ages.

In other middle class white children, the median skeletal ages were about 0.6 year below the Greulich-Pyle standards from 6 through 11 years.[60] In general, the previous data show a tendency for the skeletal ages of boys to be below Greulich-Pyle standards which is in agreement with the national survey findings. Nevertheless, the national survey data show an increasing lag of skeletal age with advancing chronological age that is the opposite of the trends reported from smaller and less representative samples.

Comparisons between these studies of generally middle class children could indicate a possible reverse secular trend, but this conclusion is very tenuous because sampling methods varied between studies and comparability between assessors was rarely established. This possible trend is also inconsistent with the findings in the present national survey data which show greater retardation in skeletal maturity in the older, and consequently, earlier born children.

The relative variability of the distributions of skeletal age from the present national survey is greater than that found in the groups studied by Simmons[57] and Greulich and Pyle.[5] This would be expected because of differences in sampling and in schedules for examination. The children included in the earlier studies were relatively homogeneous socioeconomically. Furthermore in those previous studies there was a narrow spread of chronological ages within each age group because children were examined within 2 weeks of their birthdays. In contrast for children in the present national study, chronological age was essentially uniformly distributed throughout the entire year. The effects of such differences in schedules for examinations on recorded data have been discussed by Healy[83] and Goldstein and Carter.[84]

Onset of Ossification

National estimates of the median number of bones ossified is slightly higher in girls than in boys at corresponding ages. Advancement of girls is apparent also in the percentages within chronological age groups, with fewer than 24 bones ossified. Furthermore, in the girls 1 percent of bones were "adult" at 9 years and this increased to 12 percent at 11 years, while not a single bone of any boy was judged adult. While these data are cited to confirm the maturational advancement of girls demonstrated by skeletal age, observations of onset of ossification alone (by combining the number of centers ossified) can be an effective assessment technique in preschool children only.[85]

The national study estimates modal ages of onset of ossification among children in the United States for the distal ulnar epiphysis, trapezium, and trapezoid in boys, for the adductor sesamoid in girls, and for the pisiform in each sex. Earlier studies among selected groups of children in this country were based on smaller, less representative samples, yet the mean ages from the national survey are within the range of those previously reported "modal" ages. The national survey values were within 0.3 year of those reported by Greulich and Pyle[5] with the exception of the pisiform. The modal ages for this bone in the national survey children were later by 0.8 year in boys and 0.4 year in girls. The national survey radiographs were of excellent quality and an independent check showed that very small areas of ossification in the pisiform were being recognized. These comparisons with the onset of ossification data of Greulich and Pyle are of particular interest because the latter used many of the same radiographs both in the construction of the Greulich and Pyle Atlas and for their onset of ossification data.

Bone-Specific Skeletal Ages

The Health Examination Survey provides national estimates of means and standard deviations for each of the 31 hand-wrist bones when both sexes were assessed against male standards and also after the values for the girls had been changed to female equivalent values. The sex differences between the means were small when the latter values were used but there was a tendency for the skeletal ages to be somewhat greater in the girls than in the boys at later chronological ages.

The differences between means for the boys and girls, when both were assessed as male, increased fairly regularly with age from age 8 years except for bones that were relatively late to ossify (ulna, pisiform, and adductor and flexor sesamoids). The increase in the mean differences between the sexes was more rapid in the national findings, both for skeletal age (hand-wrist) and for the individual bones, than that reported by Greulich and Pyle[5] (figures 11 and 12). These comparisons between the two studies are based on most of the girls but only the rapidly maturing boys (only the ones in whom the bones had ossified and therefore could be assessed). There are no substantial data for bone-specific skeletal ages in United States children with which the present findings can be compared. They are important, however, for several reasons: they provide for a better description of clinical syndromes in which skeletal maturation is dysharmonic,[77] they provide a better basis for comparison with other methods of rating skeletal maturation, they can be used as a basis for the development of scoring systems of skeletal maturity, they allow the identification of bones particularly sensitive in maturation to environmental effects, and they can identify possible racial or other genetic patterns of maturation within hand-wrist areas.

Ranges of Bone-Specific Skeletal Ages

Use of the range of skeletal ages from the most mature to the least mature bone has been suggested for monitoring the effects of illness and malnutrition.[81] The usefulness of this approach has not been satisfactorily demonstrated and normative data were lacking. These national survey data fulfill a real need in supplying reliable estimates of percentiles for the ranges of bone-specific skeletal ages at each year of chronological age for the United States child population. It should be noted that these are the ranges of skeletal ages that could be assigned. In some children a few individual bones were already adult while in others some had not ossified. Consequently these are not the complete ranges of skeletal maturity but are the ranges of ages that could be assigned.

The sex differences in these ranges were small, and these ranges were independent of skeletal age within chronological age groups despite a contrary suggestion based on data relating to onset of ossification from the Ten-State Nutrition Survey.

Sex-Associated Differences in Skeletal Maturity

One major contribution to knowledge from this national survey concerns sex differences. This possibility resulted from the nature of the sampling and from the fact that both sexes were assessed against a single set of standards without the assessors knowing the sex of the children. In figure 11, sex differences in skeletal age in months (male less female) are graphed against chronological age. These graphs compare the findings from the national survey with those reported by Pyle et al.[6] The two reports are in essential agreement until 8 years in the whole hand-wrist; later the differences from the national survey exceed those reported by Pyle et al. by increasing amounts.

These comparative findings for the whole

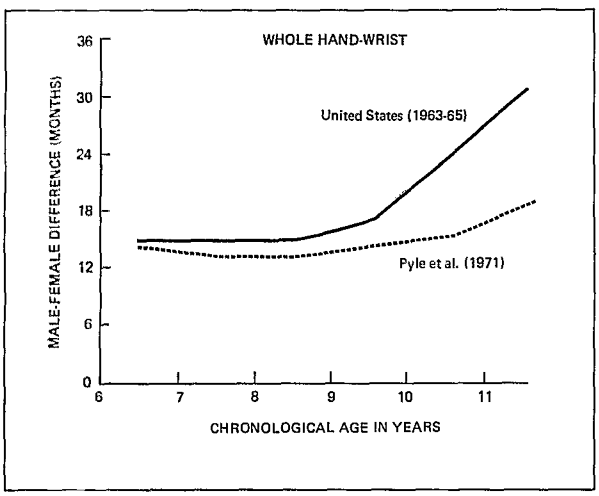


Figure 11. Mean differences between boys and girls in skeletal age (hand-wrist) on the male HES standard for United States children from the national study (1963-65) and from the data of Pyle et al.[6] by chronological age.

hand-wrist are reflected in those for the bone-specific skeletal ages. Only selected graphs of the latter have been reproduced because of the close similarity between the differences for some bones (figure 12). The patterns for the radius closely resembled those for the ulna; both sources (national survey and Pyle et al.) are in general agreement up to 9 years, after which the differences from the national survey become markedly larger. The data for the capitate, hamate, and triquetral are similar; the differences between the present data and those of Pyle et al. are small until 10 and 11 years, when those from the present survey markedly exceed those of Pyle et al. In the data of Pyle et al.,[6] the differences for the lunate and trapezium were irregular across age; this same irregularity is not present in the national survey data. In the scaphoid and trapezoid, there were marked differences in trends rather than in levels between the two studies. The differences reported by Pyle et al. were nearly constant across age; those from the national survey increased gradually.

The patterns were similar for all the metacarpals both in the national survey data and in those of Pyle et al. Data for metacarpal II have been graphed as an example (figure 12). The two reports agree until 9 years, after which the differences between the sexes from the national survey markedly exceeded those reported by Pyle et al. The proximal phalanges all followed similar patterns, and the data for proximal phalanx III are shown. For this, the two studies were in agreement until age 8 years; after that the sex differences from the national survey exceeded those reported by Pyle et al. by amounts that increased with age.

The patterns of sex differences across age for each middle phalanx and distal phalanx were similar. The differences from the national survey resembled those reported by Pyle et al. until age 9 years; later sex differences from the national survey became markedly larger. The findings for middle phalanx IV are shown as an example (figure 12). The data for the pisiform showed slightly greater sex differences in the national survey children, but the samples available for study were unrepresentative because only early maturing boys have the pisiform ossified during the age range considered.

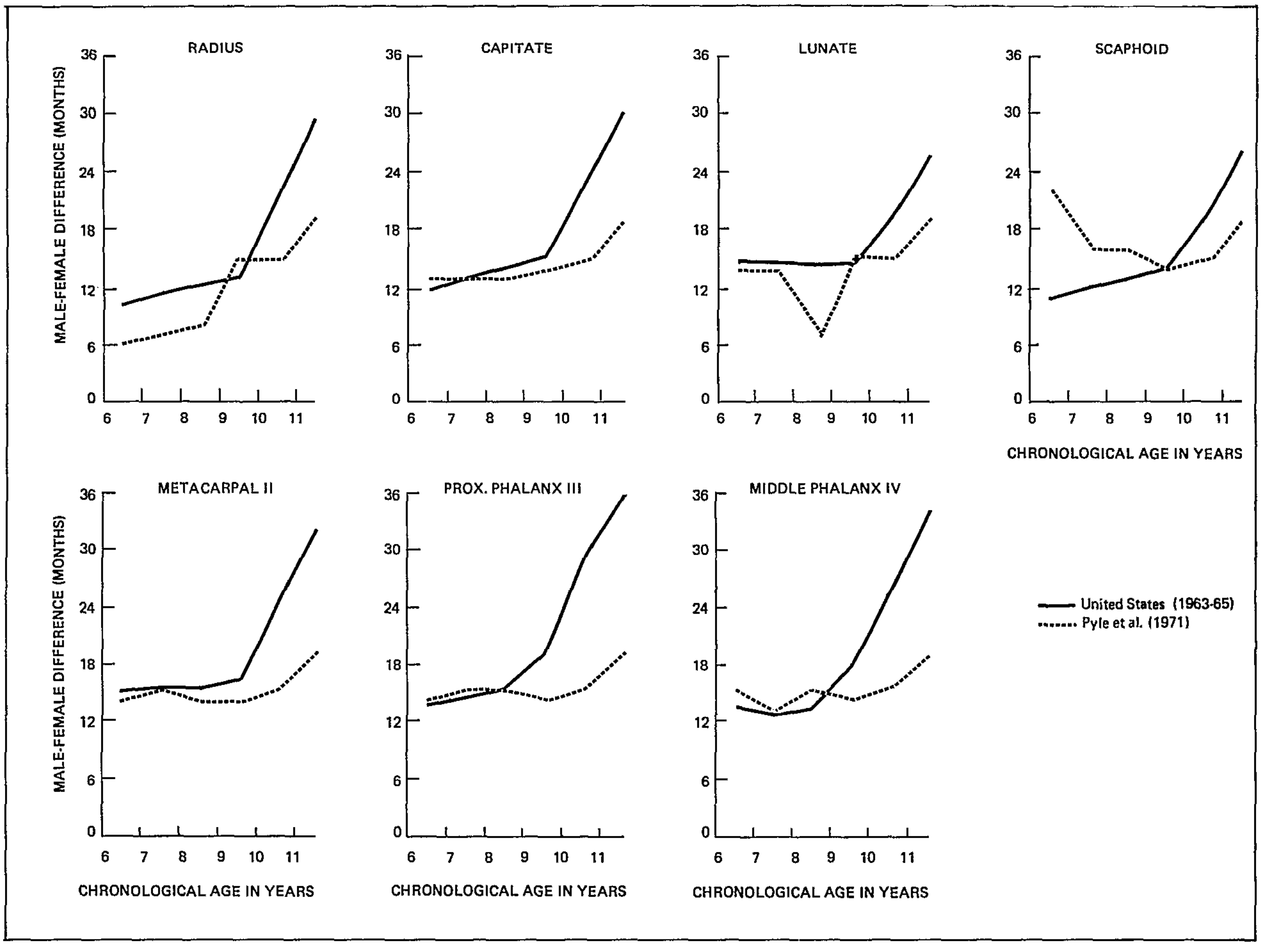


Figure 12. Mean differences between boys and girls in selected bone-specific skeletal ages on male HES standard for United States children from the national study (1963-65) and from data of Pyle et al.[6] by chronological age.

Other Measures of Biological Age

Skeletal age can be applied over wider age ranges than other possible measures of biological age. Two common biological ages are related to menarche and peak height velocity (the midpoint of the year with the largest increment in stature during pubescence). These two biological ages can be applied only to children who are near the end of growth and for whom serial data are available. Consequently they are of limited use in a clinical setting. Furthermore age in relation to menarche is limited to girls.

Body shape does change during maturation with perhaps the most obvious alterations being the pubertal growth in the shoulder width of boys and the hip width of girls. These and other shape measures are inappropriate as biological ages because they differ widely even among people who are clearly adult.

Secondary sex characteristics have received much attention. Grading methods will be described, but these are useful only during the age ranges when they discriminate among individuals, that is, about 9-16 years. Dental maturity can be graded either by counting the number of teeth erupted, recording which teeth are erupted, or assessing the degree of root formation of individual teeth. The latter provides an uninterrupted scale over a wide age range but it requires specialized radiographic equipment and training. There are also some difficulties in using dental maturity as a biological age. Other biological age scales agree in showing that girls are more advanced than boys within chronological age groups. However, sex differences in deciduous dental development are not significant,[86-89] and dental development has not previously been found to be related closely to either stature or skeletal age in preschool children.[87] Findings from the Health Examination Survey in 1963-65 among 6-11 year-old children in the United States show that tooth eruption is more rapid in girls than boys.[90] Further assessment of sex differences in the rate of maturation for permanent teeth is complicated by the fact that these sex differences vary among teeth.[91,92]

For these reasons, skeletal age has been used more commonly than other biological ages. Its usefulness will be increased further by the reliable estimates for the whole United States population aged 6-11 years provided by this national survey.

SUMMARY

This report contains national estimates of the skeletal maturity status of noninstitutionalized children 6-11 years of age in the United States based on assessments of radiographs of the right hand-wrists of children examined in the Health Examination Survey of 1963-65. A probability sample of 7,417 children representative of the nearly 24 million noninstitutionalized children in the United States was selected. Of these, 7,119 children, or 96 percent, of the sample were examined, and radiographs suitable for assessment were obtained from 6,962 (98 percent of the examined group, or 94 percent of the total sample).

These radiographs were assessed by specially trained medical students who knew neither the age nor the sex of any child whose radiograph was assessed. This removed several sources of bias. All assessments were made against male standards; later the skeletal ages were adjusted, bone by bone, using the sex-associated differences in maturity reported by Pyle et al.[6]

When assessed against the specially assembled HES Standard, the skeletal ages of the boys tend to be less than their chronological ages by amounts that increased with chronological age from a mean difference of 2.5 months at 6 years to 13.8 months at 11 years. The differences between skeletal and chronological age in girls are smaller than in boys but are in the same direction after the skeletal ages of the girls had been adjusted for the reported sex differences. The increase in these differences with chronological age for girls is from 1.0 month at age 6 years to 9.8 months at 11 years. These important findings indicate that the Greulich and Pyle Atlas[5] scale does not match the modal skeletal ages for the total United States noninstitutionalized child population because the Atlas was based on a study group that was not representative of that total United States population.

As expected, skeletal maturation tended to be more advanced in girls than in boys when both were assessed against the same male standards or when the numbers of centers ossified were compared.

The distribution of skeletal ages within chronological age groups is close to normal with the standard deviations tending to increase with age for the girls but not the boys.

These national survey data provide means and standard deviations for the skeletal age of each of the 31 hand-wrist bones. For the first time, there are reliable national estimates for these levels in United States children (6-11 years) and the normal ranges of bone-specific skeletal ages within the hand-wrists of individual children are known.

A major advance in knowledge from the present data relates to sex-associated differences in skeletal maturity when radiographs of boys and girls are assessed against a single set of standards. These differences for the hand-wrist as a whole and for most of the individual bones match closely those reported by Pyle et al.,[6] up to 8 years. The sex-associated differences estimated from the national survey data were considerably larger at later ages.

Necessarily, comparisons with previous reports from smaller less representative samples have been made throughout this report. It should not be overlooked, however, that the present data allow reliable estimates of skeletal maturity for the total population of the United States within the age range considered. Such estimates are not available for any other country.

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LIST OF DETAILED TABLES

Table 1. Mean, standard deviation (s_x), and standard error of mean ($s_{\bar{x}}$) for skeletal age (hand-wrist) of boys and girls, by chronological age in years at last birthday; mean and standard deviation for skeletal age (hand-wrist) for boys and girls within 6-month chronological age intervals, and number of boys and girls at each chronological year of age: United States, 1963-65

Chronological age	Boys (male standard)			Girls (male standard)			Girls (female equivalent value)			Population	
	Mean	s_x	$s_{\bar{x}}$	Mean	s_x	$s_{\bar{x}}$	Mean	s_x	$s_{\bar{x}}$	Boys	Girls
	Skeletal age (hand-wrist) in months									Number in thousands	
6 years	75.5	11.16	0.47	90.0	12.15	0.53	77.0	10.40	0.45	2,082	2,016
7 years	86.9	11.21	0.55	101.2	11.59	0.48	88.1	10.09	0.42	2,074	2,010
8 years	96.9	11.25	0.45	111.3	11.97	0.53	96.3	10.36	0.46	2,026	1,960
9 years	105.8	10.91	0.43	122.7	14.29	0.68	107.7	12.54	0.60	2,012	1,945
10 years	113.4	9.87	0.44	137.7	16.25	0.70	116.8	13.78	0.59	1,963	1,904
11 years	124.2	12.53	0.55	156.5	14.45	0.61	128.2	11.84	0.50	1,924	1,868
Age in 6-month intervals											
6 years:											
0-5 months	73.9	11.46	---	88.1	11.58	---	75.1	9.87	---	---	---
6-11 months	78.1	10.83	---	92.7	12.62	---	79.7	10.85	---	---	---
7 years:											
0-5 months	84.4	10.77	---	99.1	12.29	---	86.1	10.68	---	---	---
6-11 months	90.3	11.62	---	104.2	10.85	---	90.2	9.39	---	---	---
8 years:											
0-5 months	94.6	11.47	---	109.0	12.97	---	95.0	11.30	---	---	---
6-11 months	99.9	11.94	---	114.8	10.82	---	99.8	9.41	---	---	---
9 years:											
0-5 months	103.7	11.19	---	119.1	13.19	---	104.1	11.53	---	---	---
6-11 months	108.5	10.66	---	127.7	15.41	---	110.8	13.36	---	---	---
10 years:											
0-5 months	111.6	9.75	---	133.9	15.20	---	114.9	13.04	---	---	---
6-11 months	116.2	9.99	---	142.7	17.32	---	119.8	14.53	---	---	---
11 years:											
0-5 months	121.1	11.29	---	153.9	14.57	---	126.4	11.93	---	---	---
6-11 months	127.9	13.37	---	159.8	14.66	---	129.9	11.91	---	---	---

Table 2. Mean and standard deviation for skeletal age (hand-wrist) in months of boys and girls, by chronological age in months: United States, 1963-65

Sex and year of chronological age	Month in chronological year of age											
	0	1	2	3	4	5	6	7	8	9	10	11
	Mean skeletal age (hand-wrist) in months											
Boys (male standard)												
6 years	68.1	71.1	75.3	74.3	74.3	77.0	76.3	77.4	77.1	79.3	78.1	80.6
7 years	81.9	82.5	85.6	83.2	85.1	87.6	88.4	89.5	88.5	91.2	93.8	89.5
8 years	87.0	95.1	96.0	97.3	92.5	97.1	98.9	98.5	102.3	100.7	99.7	99.7
9 years	101.3	104.7	103.9	103.1	102.7	106.8	105.7	107.3	107.9	109.9	110.2	110.4
10 years	111.6	112.0	109.8	110.8	112.0	114.1	115.8	114.4	115.9	116.9	119.2	115.5
11 years	117.2	121.2	118.8	121.7	124.0	123.6	124.3	127.2	129.8	128.1	126.8	129.7
12 years	131.5	...	...	...	...	...	...	...	...	...	...	...
Girls (male standard)												
6 years	90.1	83.3	87.0	85.7	87.7	94.1	91.2	91.5	90.4	92.0	93.3	97.5
7 years	97.6	94.6	97.6	102.7	103.3	100.8	104.4	102.2	103.7	103.8	105.4	105.7
8 years	108.7	108.2	107.2	109.5	110.1	110.6	114.4	114.2	112.2	114.6	116.1	118.6
9 years	115.7	120.7	114.5	120.6	119.7	124.8	128.2	121.6	125.3	128.0	131.4	131.5
10 years	131.0	128.4	134.9	134.9	137.3	139.2	134.8	138.6	141.5	147.4	148.6	145.6
11 years	151.8	152.2	151.5	152.0	155.7	162.5	155.6	156.5	157.7	159.2	162.2	163.5
12 years	161.7	...	...	...	...	...	...	...	...	...	...	...
	Standard deviation of skeletal age in months											
Boys (male standard)												
6 years	10.41	13.00	11.45	10.00	11.69	11.17	10.42	9.67	11.15	9.41	11.38	12.50
7 years	11.98	10.55	11.01	10.48	11.93	9.01	11.89	11.33	9.70	11.61	12.61	11.98
8 years	10.24	11.54	9.92	11.79	13.68	11.47	10.62	12.00	10.60	9.47	12.26	10.93
9 years	12.08	11.76	11.30	11.97	9.57	9.36	9.19	10.87	11.17	11.61	13.33	6.85
10 years	8.67	9.67	9.01	12.24	8.53	9.41	10.23	11.42	8.08	10.43	11.42	7.12
11 years	9.53	10.76	13.50	10.83	11.85	11.32	10.11	12.00	16.06	15.72	12.44	13.43
12 years	15.46	...	...	...	...	...	...	...	...	...	...	...
Girls (male standard)												
6 years	8.18	9.72	9.01	12.39	13.16	13.25	10.85	13.78	12.46	13.57	12.79	11.66
7 years	12.88	11.75	10.84	12.55	14.66	11.73	9.17	10.57	10.86	11.97	11.57	10.34
8 years	9.43	16.37	13.10	13.01	12.48	10.63	9.92	12.42	7.74	9.87	12.48	12.05
9 years	12.77	13.82	9.83	12.36	15.02	15.15	17.28	13.02	14.03	14.09	16.57	16.74
10 years	17.09	14.27	15.32	13.66	16.35	14.30	13.85	18.22	16.88	19.34	17.81	16.58
11 years	14.79	15.23	16.20	15.67	11.90	14.22	17.23	14.55	14.73	16.53	13.53	10.38
12 years	11.95	...	...	...	...	...	...	...	...	...	...	...

Table 3. Percent distribution and selected percentiles for skeletal age (hand-wrist) in months of boys and girls by chronological age in years at last birthday: United States, 1963-65

Skeletal age (hand-wrist) in months	Boys—chronological age in years					
	6	7	8	9	10	11
	Percent distribution—male standard					
Below 42	0.2	-	-	-	-	-
42-47	0.3	-	-	-	-	-
48-53	2.1	-	0.2	-	-	-
54-59	5.8	1.0	-	-	-	-
60-65	9.5	2.1	0.8	-	-	-
66-71	18.4	5.3	1.6	0.4	-	-
72-77	21.6	13.2	3.8	0.4	-	-
78-83	17.6	17.9	7.1	2.1	-	-
84-89	14.7	21.5	12.9	5.4	1.4	0.3
90-95	5.3	15.8	16.8	11.2	3.5	-
96-101	3.0	10.2	16.1	11.3	5.1	1.3
102-107	0.9	7.5	20.7	21.0	13.2	2.2
108-113	0.3	4.7	15.6	23.4	29.0	14.8
114-119	-	0.8	3.7	17.5	22.6	26.0
120-125	0.3	-	0.2	4.3	14.8	18.7
126-131	-	-	0.3	2.1	6.3	12.1
132-137	-	-	0.2	0.3	2.1	8.2
138-143	-	-	-	0.1	1.3	5.8
144-149	-	-	-	0.2	0.1	4.2
150-155	-	-	-	0.2	0.6	4.2
156-161	-	-	-	-	-	1.6
162-167	-	-	-	-	-	0.4
168-173	-	-	-	0.1	-	-
174-179	-	-	-	-	-	0.2
180-185	-	-	-	-	-	-
186-191	-	-	-	-	-	-
192-195	-	-	-	-	-	-
Percentile	Skeletal age (hand-wrist) in months					
P_{95}	94.7	108.2	113.4	122.1	131.0	150.8
P_{75}	83.8	95.0	107.1	113.9	120.1	131.6
P_{50}	75.6	87.0	98.3	107.6	113.6	121.6
P_{25}	68.5	79.1	89.5	98.8	108.3	115.5
P_{5}	57.2	69.6	75.5	87.4	96.1	108.9
Approximate test for normality						
X^2_{24}	0.21	0.24	1.42	0.42	0.55	3.58

Table 3. Percent distribution and selected percentiles for skeletal age (hand-wrist) in months of boys and girls by chronological age in years at last birthday: United States, 1963-65—Con.

Girls—chronological age in years						Girls—chronological age in years					
6	7	8	9	10	11	6	7	8	9	10	11
Percent distribution—male standard						Percent distribution—female equivalent					
-	-	-	-	-	-	0.2	-	-	-	-	-
-	-	-	-	-	-	0.6	-	-	-	-	-
0.2	-	-	-	-	-	1.8	-	-	-	0.1	-
-	-	-	-	-	-	6.2	1.0	0.4	-	-	-
1.9	-	-	-	0.1	-	11.2	3.2	0.6	0.2	-	-
4.7	0.7	0.4	-	-	-	15.8	6.7	1.9	0.2	-	-
9.4	1.7	0.2	0.2	-	-	18.0	11.0	1.9	1.2	-	-
17.2	5.8	2.2	0.2	-	-	15.9	13.9	5.9	2.1	0.3	-
17.8	11.7	1.8	1.2	-	-	14.0	13.9	10.1	2.2	0.5	-
15.2	13.3	4.6	1.6	0.3	-	10.6	25.5	23.4	9.2	2.0	0.1
14.0	11.8	8.2	2.0	0.2	-	3.6	18.8	26.7	21.2	8.6	0.6
10.8	18.5	13.4	3.0	1.2	-	1.7	4.5	16.5	21.3	11.4	2.1
5.6	22.4	26.1	16.0	4.0	0.5	0.2	0.9	9.2	22.8	21.0	6.3
2.4	11.4	23.8	25.5	11.4	0.8	0.2	0.5	2.0	8.3	15.8	8.4
0.6	1.9	10.7	16.3	11.0	2.9	-	0.1	0.5	5.6	14.2	15.2
-	0.2	5.1	13.4	13.4	4.3	-	-	0.7	3.8	19.3	30.3
-	0.3	1.4	5.4	11.0	4.0	-	-	-	1.3	4.8	19.7
0.2	0.2	0.7	4.7	8.6	6.0	-	-	-	0.6	1.5	9.4
-	-	0.5	3.1	8.5	7.8	-	-	-	-	0.2	5.0
-	0.1	0.4	3.4	10.1	14.1	-	-	-	-	0.3	1.2
-	-	0.3	1.8	11.1	18.6	-	-	0.2	-	-	1.5
-	-	-	1.2	6.0	19.9	-	-	-	-	-	0.2
-	-	-	1.0	2.2	11.5	-	-	-	-	-	-
-	-	-	-	0.6	6.3	-	-	-	-	-	-
-	-	-	-	0.3	1.4	-	-	-	-	-	-
-	-	0.2	-	-	1.5	-	-	-	-	-	-
-	-	-	-	-	0.4	-	-	-	-	-	-
Skeletal age (hand-wrist) in months											
111.9	117.6	130.8	153.9	164.6	177.5	96.9	102.6	112.9	126.4	133.6	145.5
99.1	111.0	118.0	129.6	153.4	166.9	86.1	96.0	103.0	112.3	126.2	134.9
89.7	104.1	112.4	120.1	135.8	159.7	76.7	90.1	97.4	105.1	115.9	129.9
81.5	92.7	106.3	114.3	124.3	149.3	67.5	79.7	92.3	99.3	108.6	123.6
71.1	81.0	91.3	101.6	112.9	127.3	57.1	67.0	78.3	88.3	97.9	110.6
0.28	1.28	1.37	3.46	2.69	1.82	...	...	...	...	...	...

Table 4. Percent distribution for skeletal age (hand-wrist) in months of boys and girls by chronological age at last birthday in 6-month intervals: United States, 1963-65

Skeletal age (hand-wrist) in months	Chronological age in months												
	72-77	78-83	84-89	90-95	96-101	102-107	108-113	114-119	120-125	126-131	132-137	138-143	144-145
Boys	Percent distribution of skeletal age—male standard												
Below 42--------	-	0.3	-	-	-	-	-	-	-	-	-	-	-
42-47-----------	0.6	-	-	-	-	-	-	-	-	-	-	-	-
48-53-----------	3.8	0.3	-	-	-	0.4	-	-	-	-	-	-	-
54-59-----------	7.6	3.9	1.2	0.8	-	-	-	-	-	-	-	-	-
60-65-----------	12.6	6.2	2.5	1.7	1.6	-	-	-	-	-	-	-	-
66-71-----------	19.3	17.6	8.4	2.3	2.0	1.2	0.5	0.3	-	-	-	-	-
72-77-----------	20.7	22.4	17.6	8.9	5.6	2.2	1.0	-	-	-	-	-	-
78-83-----------	15.4	19.9	20.7	15.3	9.6	4.9	3.0	1.3	-	-	-	-	-
84-89-----------	12.9	16.6	21.3	21.7	16.4	9.7	7.4	3.7	2.1	0.6	0.6	-	-
90-95-----------	3.6	7.1	12.3	19.2	19.3	14.6	14.6	8.2	4.6	2.4	-	-	-
96-101----------	2.6	3.4	9.2	11.2	15.0	17.1	14.2	8.7	6.4	3.8	2.6	-	-
102-107---------	0.5	1.4	4.2	10.7	14.4	26.6	19.4	22.3	17.3	9.2	3.0	1.7	-
108-113---------	-	0.6	2.2	7.1	13.8	17.1	23.8	23.3	32.9	25.0	18.9	11.7	4.5
114-119---------	-	-	0.4	1.1	2.0	5.3	12.1	22.2	18.3	27.0	29.8	22.3	27.3
120-125---------	0.4	0.3	-	-	-	0.3	1.8	6.5	12.2	17.5	19.2	19.2	10.4
126-131---------	-	-	-	-	-	0.6	1.7	2.4	3.4	9.2	9.3	14.4	17.0
132-137---------	-	-	-	-	0.3	-	0.3	0.2	1.9	2.3	7.6	8.9	8.2
138-143---------	-	-	-	-	-	-	-	0.2	0.5	2.1	4.1	6.8	12.0
144-149---------	-	-	-	-	-	-	-	0.4	-	0.2	2.6	4.9	11.0
150-155---------	-	-	-	-	-	-	-	0.3	0.4	0.7	1.2	7.0	5.9
156-161---------	-	-	-	-	-	-	-	-	-	-	1.1	2.2	-
162-167---------	-	-	-	-	-	-	-	-	-	-	-	0.9	-
168-173---------	-	-	-	-	-	-	0.2	-	-	-	-	-	-
174-179---------	-	-	-	-	-	-	-	-	-	-	-	-	3.7
180-185---------	-	-	-	-	-	-	-	-	-	-	-	-	-
186-191---------	-	-	-	-	-	-	-	-	-	-	-	-	-
192-195---------	-	-	-	-	-	-	-	-	-	-	-	-	-
Percentile	Skeletal age (hand-wrist) in months												
P_{75} ------------	81.6	85.2	91.5	98.4	105.2	107.8	112.0	115.2	117.0	122.2	126.3	135.2	143.6
P_{50} ------------	73.8	77.7	83.8	89.9	94.7	102.0	104.8	109.4	111.3	115.5	118.9	124.3	128.6
P_{25} ------------	66.2	70.8	75.6	82.5	86.2	92.3	95.5	101.0	107.0	110.2	114.0	117.2	116.5
Girls	Percent distribution of skeletal age—male standard												
Below 42--------	-	-	-	-	-	-	-	-	-	-	-	-	-
42-47-----------	-	-	-	-	-	-	-	-	-	-	-	-	-
48-53-----------	-	0.4	-	-	-	-	-	-	-	-	-	-	-
54-59-----------	-	-	-	-	-	-	-	-	-	-	-	-	-
60-65-----------	2.2	1.6	-	-	-	-	-	-	-	0.2	-	-	-
66-71-----------	5.8	3.7	1.4	-	0.9	-	-	-	-	-	-	-	-
72-77-----------	13.4	5.9	2.2	1.2	0.3	-	-	0.4	-	-	-	-	-
78-83-----------	20.3	14.4	8.5	3.0	3.0	1.4	0.3	-	-	-	-	-	-
84-89-----------	16.7	19.0	15.1	8.2	3.0	0.6	2.2	-	-	-	-	-	-
90-95-----------	17.1	13.5	13.1	13.6	5.8	3.4	2.7	0.4	0.2	0.3	-	-	-
96-101----------	12.0	15.8	15.5	8.2	11.4	4.9	3.0	1.0	0.4	-	-	-	-
102-107---------	6.2	14.7	15.0	22.0	15.5	11.3	3.2	2.6	2.2	0.3	-	-	-
108-113---------	3.3	7.6	19.2	25.6	29.0	22.8	20.0	11.6	6.4	1.6	1.0	-	-
114-119---------	2.6	2.3	7.1	15.6	19.7	27.9	29.1	21.6	14.8	7.8	0.7	1.0	-
120-125---------	0.4	0.8	1.9	2.0	5.9	15.8	15.7	17.2	10.1	12.1	4.0	2.3	-

Table 4. Percent distribution for skeletal age (hand-wrist) in months of boys and girls by chronological age at last birthday in 6-month intervals: United States, 1963-65—Con.

Skeletal age (hand-wrist) in months	Chronological age in months												
	72-77	78-83	84-89	90-95	96-101	102-107	108-113	114-119	120-125	126-131	132-137	138-143	144-145
Girls—Con.	Percent distribution of skeletal age—male standard												
126-131	-	-	0.4	-	2.5	7.8	11.3	15.6	16.3	10.0	6.3	2.5	2.6
132-137	-	-	0.4	0.3	1.6	1.3	4.9	6.0	10.0	12.1	5.2	3.3	-
138-143	-	0.3	-	0.3	0.6	0.9	2.5	7.1	10.2	6.8	5.6	6.4	6.2
144-149	-	-	-	-	-	1.1	2.2	4.0	9.5	7.3	8.3	6.9	10.2
150-155	-	-	0.2	-	0.2	0.5	1.1	5.9	10.3	9.9	16.9	12.6	4.5
156-161	-	-	-	-	0.2	0.3	0.7	3.0	6.7	15.7	19.7	16.9	22.0
162-167	-	-	-	-	-	-	0.8	1.8	2.1	10.3	19.2	19.3	29.2
168-173	-	-	-	-	-	-	0.3	1.8	0.3	4.2	7.1	16.4	9.8
174-179	-	-	-	-	-	-	-	-	0.5	0.8	4.5	7.6	9.6
180-185	-	-	-	-	0.4	-	-	-	-	0.6	0.7	1.5	5.9
186-191	-	-	-	-	-	-	-	-	-	-	0.8	2.5	-
192-195	-	-	-	-	-	-	-	-	-	-	-	0.8	-
Percentile	Skeletal age (hand-wrist) in months												
P_{75}	95.9	102.2	108.9	112.2	115.6	120.8	125.1	136.4	147.2	158.4	164.0	169.8	170.2
P_{50}	87.2	93.1	99.8	106.7	109.8	114.8	118.1	124.7	131.8	143.1	156.7	161.6	162.9
P_{25}	79.2	83.6	89.2	95.5	102.3	108.8	112.6	116.9	120.7	128.0	145.0	152.1	156.5
Girls	Percent distribution of skeletal age—female equivalent												
Below 42	-	0.4	-	-	-	-	-	-	-	-	-	-	-
42-47	1.0	0.3	-	-	-	-	-	-	-	-	-	-	-
48-53	1.6	2.0	-	-	-	-	-	-	-	0.2	-	-	-
54-59	8.3	4.4	1.7	0.2	0.9	-	-	-	-	-	-	-	-
60-65	16.3	6.7	5.3	1.0	1.2	-	-	0.4	-	-	-	-	-
66-71	17.9	13.8	8.2	5.2	2.4	1.4	0.3	-	-	-	-	-	-
72-77	16.6	19.1	14.0	8.1	3.1	0.6	2.2	-	-	-	-	-	-
78-83	15.6	16.2	15.7	12.1	7.6	4.3	3.6	0.4	0.6	0.3	-	-	-
84-89	11.4	16.3	14.1	13.7	14.5	5.6	3.0	1.4	0.6	-	-	-	-
90-95	7.4	13.5	21.2	29.8	24.7	22.0	11.0	7.2	2.7	1.2	0.2	-	-
96-101	1.5	5.5	15.0	22.6	26.2	27.0	26.1	16.0	11.8	5.0	1.0	0.2	-
102-107	2.4	1.1	3.2	5.8	10.8	22.2	24.2	18.2	13.2	9.5	2.2	2.3	-
108-113	-	0.4	1.0	0.9	5.6	13.1	17.4	28.5	23.0	18.9	9.6	3.3	2.6
114-119	-	0.3	0.4	0.6	2.1	1.8	6.3	10.5	16.8	14.8	8.6	8.5	6.2
120-125	-	-	0.2	-	0.2	1.1	3.3	8.5	15.8	12.6	17.4	13.6	10.2
126-131	-	-	-	-	0.3	0.9	1.5	6.0	13.2	25.9	33.0	27.3	31.4
132-137	-	-	-	-	-	-	1.1	1.6	1.8	8.0	18.7	20.3	24.3
138-143	-	-	-	-	-	-	-	1.3	0.5	2.7	4.5	13.3	16.9
144-149	-	-	-	-	-	-	-	-	-	0.3	3.6	6.4	5.2
150-155	-	-	-	-	-	-	-	-	-	0.6	0.4	1.8	3.2
156-161	-	-	-	-	0.4	-	-	-	-	-	0.8	2.5	-
162-167	-	-	-	-	-	-	-	-	-	-	-	0.5	-
168-173	-	-	-	-	-	-	-	-	-	-	-	-	-
174-179	-	-	-	-	-	-	-	-	-	-	-	-	-
180-185	-	-	-	-	-	-	-	-	-	-	-	-	-
186-191	-	-	-	-	-	-	-	-	-	-	-	-	-
192-195	-	-	-	-	-	-	-	-	-	-	-	-	-
Percentile	Skeletal age (hand-wrist) in months												
P_{75}	82.9	88.6	94.9	97.2	100.6	105.8	109.1	116.2	122.6	129.2	133.0	137.8	138.2
P_{50}	74.2	80.1	86.8	92.7	95.4	99.8	103.1	108.8	113.4	120.0	128.4	130.8	131.9
P_{25}	65.2	70.4	76.2	82.5	88.6	94.8	97.6	101.9	105.7	111.0	121.0	125.1	128.2

Table 5. Percent of boys and girls showing the number of radio-opaque hand-wrist bones—ossifying and adult—by chronological age in years at last birthday: United States, 1963-65

Stage of maturation and number of hand-wrist bones	Boys—chronological age in years						Girls—chronological age in years					
	6	7	8	9	10	11	6	7	8	9	10	11
	Percent of children											
Total-------	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Children with 1 or more bones not yet adult--	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.0	96.7	88.0
10 or fewer-------	-	-	-	-	-	-	-	-	0.2	0.2	-	0.2
15 or fewer-------	0.1	0.2	0.2	0.1	-	-	-	-	0.2	0.2	-	0.5
20 or fewer-------	0.3	0.4	0.2	0.5	0.2	0.2	-	0.1	0.2	0.2	0.3	1.7
21 or fewer-------	0.9	0.5	0.2	0.5	0.2	0.2	-	0.1	0.2	0.2	0.3	1.7
22 or fewer-------	3.0	0.7	0.4	0.5	0.2	0.2	0.2	0.1	0.2	0.2	0.3	2.3
23 or fewer-------	9.4	3.1	1.0	0.8	0.2	0.2	0.8	0.1	0.2	0.2	0.9	2.7
24 or fewer-------	27.9	9.6	2.4	1.2	0.2	0.2	3.0	0.3	0.7	0.4	1.2	4.6
25 or fewer-------	42.7	17.6	5.3	1.4	0.2	0.2	6.0	1.0	1.5	0.4	1.7	5.7
26 or fewer-------	53.6	26.7	9.1	2.6	0.6	0.4	10.8	2.2	2.3	1.1	2.2	7.2
27 or fewer-------	79.7	48.5	24.9	6.5	1.5	1.1	30.4	12.3	3.9	2.4	3.4	8.4
28 or fewer-------	99.6	99.0	95.4	83.4	61.0	36.9	94.0	81.9	55.1	26.6	12.8	11.6
29 or fewer-------	100.0	100.0	100.0	99.4	99.4	89.4	99.8	99.8	96.5	84.6	56.3	30.8
30 or fewer-------	100.0	100.0	100.0	99.7	99.8	97.4	100.0	99.9	98.9	95.3	83.3	65.1
31 or fewer-------	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.0	96.7	88.0
Children with 1 or more adult bones---	-	-	-	-	-	-	-	-	0.2	1.0	3.3	12.0
Only 1-----------	-	-	-	-	-	-	-	-	-	-	1.5	1.5
2 or fewer--------	-	-	-	-	-	-	-	-	-	0.5	2.1	5.4
3 or fewer--------	-	-	-	-	-	-	-	-	-	0.5	2.3	6.2
4 or fewer--------	-	-	-	-	-	-	-	-	-	0.8	2.5	6.8
5 or fewer--------	-	-	-	-	-	-	-	-	-	1.0	2.7	7.8
6 or fewer--------	-	-	-	-	-	-	-	-	-	1.0	2.9	8.9
7 or fewer--------	-	-	-	-	-	-	-	-	-	1.0	3.3	10.1
8 or fewer--------	-	-	-	-	-	-	-	-	-	1.0	3.3	10.6
12 or fewer-------	-	-	-	-	-	-	-	-	-	1.0	3.3	11.2
15 or fewer-------	-	-	-	-	-	-	-	-	-	1.0	3.3	11.4
16 or fewer-------	-	-	-	-	-	-	-	-	-	1.0	3.3	11.5
17 or fewer-------	-	-	-	-	-	-	-	-	-	1.0	3.3	11.8
23 or fewer-------	-	-	-	-	-	-	-	-	-	1.0	3.3	12.0
28 or fewer-------	-	-	-	-	-	-	-	-	0.2	1.0	3.3	12.0

Table 6. Mean, standard deviation (s_x), and standard error of mean ($s_{\bar{x}}$) of bone-specific skeletal ages for the 31 individual hand-wrist bones of boys and girls and number of children, by chronological age in years at last birthday: United States, 1963-65

Hand-wrist bone and value	Boys—chronological age in years					
	6	7	8	9	10	11
	Bone-specific skeletal age in months—male standard					
Radius:						
mean	75.0	85.6	95.7	106.2	113.7	124.2
s_x	13.26	12.75	12.88	12.26	11.22	13.32
$s_{\bar{x}}$	0.66	0.53	0.56	0.48	0.53	0.49
Ulna:						
mean	85.8	91.2	97.3	105.4	112.7	123.4
s_x	9.08	10.09	10.77	11.87	11.22	12.92
$s_{\bar{x}}$	0.73	0.53	0.45	0.42	0.42	0.55
Capitate:						
mean	76.1	86.4	96.2	105.3	114.2	124.6
s_x	12.79	12.21	12.72	12.10	11.38	14.27
$s_{\bar{x}}$	0.55	0.57	0.50	0.49	0.56	0.63
Hamate:						
mean	75.9	85.8	95.6	104.9	114.5	125.9
s_x	12.46	11.21	12.06	11.75	11.78	14.34
$s_{\bar{x}}$	0.54	0.47	0.51	0.45	0.59	0.62
Triquetral:						
mean	73.8	86.1	97.1	106.6	114.3	124.1
s_x	17.78	15.76	14.85	11.44	10.47	12.89
$s_{\bar{x}}$	0.86	0.57	0.51	0.35	0.50	0.50
Lunate:						
mean	70.2	82.7	94.7	105.5	114.5	125.1
s_x	17.76	18.36	18.03	15.18	12.64	12.96
$s_{\bar{x}}$	1.02	0.81	0.62	0.60	0.50	0.61
Scaphoid:						
mean	83.5	91.0	99.2	106.9	114.1	124.2
s_x	11.55	12.84	13.27	12.00	11.01	12.43
$s_{\bar{x}}$	0.60	0.63	0.52	0.45	0.47	0.51
Trapezium:						
mean	76.8	83.3	92.5	101.8	110.0	121.5
s_x	11.77	13.73	15.42	14.98	13.33	14.44
$s_{\bar{x}}$	0.57	0.77	0.69	0.65	0.65	0.68
Trapezoid:						
mean	80.6	88.0	97.0	106.2	113.1	123.1
s_x	10.30	11.98	13.27	11.34	10.19	13.49
$s_{\bar{x}}$	0.47	0.56	0.59	0.50	0.42	0.52
Metacarpal I:						
mean	71.8	83.7	94.3	104.3	111.9	123.0
s_x	14.48	14.75	14.10	12.90	11.60	13.95
$s_{\bar{x}}$	0.60	0.74	0.62	0.39	0.60	0.57
Metacarpal II:						
mean	75.1	86.3	95.7	105.4	112.7	122.7
s_x	14.57	13.55	13.75	13.02	11.51	13.44
$s_{\bar{x}}$	0.69	0.62	0.51	0.55	0.52	0.50
Metacarpal III:						
mean	74.8	86.2	95.6	105.2	112.4	123.1
s_x	14.34	13.41	13.49	13.30	12.02	14.05
$s_{\bar{x}}$	0.71	0.62	0.46	0.59	0.57	0.50
Metacarpal IV:						
mean	74.1	85.9	95.3	104.9	112.1	122.7
s_x	14.64	13.71	13.57	13.56	11.76	14.15
$s_{\bar{x}}$	0.65	0.62	0.49	0.58	0.53	0.48
Metacarpal V:						
mean	73.6	85.8	95.4	104.8	112.2	123.0
s_x	14.94	14.15	13.79	13.76	12.08	14.56
$s_{\bar{x}}$	0.65	0.71	0.51	0.57	0.55	0.55
Proximal phalanx I:						
mean	76.5	87.4	96.7	105.0	113.2	124.6
s_x	12.78	12.03	12.63	13.58	13.12	15.63
$s_{\bar{x}}$	0.55	0.56	0.53	0.67	0.64	0.71

Table 6. Mean, standard deviation (s_x), and standard error of mean ($s_{\bar{x}}$) of bone-specific skeletal ages for the 31 individual hand-wrist bones of boys and girls and number of children, by chronological age in years at last birthday: United States, 1963-65—Con.

Girls—chronological age in years						Girls—chronological age in years					
6	7	8	9	10	11	6	7	8	9	10	11
Bone-specific skeletal age in months—male standard						Bone-specific skeletal age in months—female equivalent					
85.4	97.2	108.2	119.1	134.3	154.2	77.6	88.3	95.1	104.1	115.2	127.2
13.78	13.43	13.12	15.68	18.72	16.11	12.52	12.20	11.53	13.71	16.06	13.29
0.57	0.55	0.40	0.63	0.78	0.58	0.52	0.50	0.35	0.55	0.67	0.48
90.5	98.4	107.2	119.1	133.1	151.7	86.8	87.9	93.2	104.1	113.6	125.7
9.51	11.43	12.55	13.92	16.20	15.90	9.12	10.21	10.91	12.17	13.83	13.17
0.49	0.61	0.52	0.69	0.72	0.56	0.45	0.54	0.45	0.60	0.61	0.46
87.9	99.6	110.1	120.9	136.4	154.5	75.9	86.6	96.0	105.9	116.4	127.5
13.32	13.16	12.42	15.56	18.58	16.18	11.50	11.44	10.83	13.63	15.86	13.35
0.60	0.56	0.53	0.75	0.89	0.72	0.52	0.49	0.46	0.66	0.76	0.59
87.4	99.5	110.2	122.5	138.4	155.2	75.4	85.8	96.2	107.2	117.4	128.1
12.47	13.08	12.55	15.56	17.36	13.97	10.76	11.28	10.96	13.62	14.73	11.53
0.47	0.57	0.59	0.76	0.72	0.59	0.41	0.49	0.51	0.67	0.61	0.49
89.5	102.0	111.1	121.1	134.0	150.5	76.5	88.0	96.1	105.6	115.0	124.8
16.26	13.44	10.70	13.98	16.77	15.85	13.90	11.60	9.26	12.19	14.39	13.14
0.45	0.64	0.45	0.58	0.59	0.59	0.38	0.55	0.39	0.51	0.51	0.49
85.0	97.5	109.1	120.3	133.7	150.8	70.0	85.8	98.4	105.3	114.7	124.9
18.18	16.49	15.42	14.67	17.29	16.43	14.97	14.51	13.91	12.84	14.83	13.61
0.87	0.76	0.60	0.63	0.63	0.66	0.72	0.67	0.54	0.55	0.54	0.55
94.4	103.3	111.7	120.9	133.3	150.3	77.4	86.4	96.7	105.4	113.6	124.6
12.29	11.71	9.92	12.54	15.32	15.53	10.08	9.79	8.59	10.93	13.06	12.87
0.50	0.50	0.34	0.58	0.54	0.64	0.41	0.42	0.29	0.51	0.46	0.53
89.2	99.5	109.2	119.0	133.2	151.8	82.6	86.8	95.2	104.0	114.1	125.4
12.67	13.30	11.48	13.01	17.05	15.84	11.73	11.60	10.01	11.37	14.61	13.09
0.56	0.64	0.50	0.61	0.74	0.65	0.52	0.56	0.44	0.53	0.63	0.54
90.7	102.0	110.4	120.1	133.3	150.9	77.7	90.0	95.7	105.1	114.3	124.9
12.09	11.99	10.78	12.69	16.70	15.40	10.36	10.58	9.34	11.10	14.31	13.57
0.35	0.54	0.48	0.70	0.65	0.71	0.30	0.48	0.42	0.61	0.56	0.59
90.6	101.7	111.0	122.3	137.1	155.3	75.6	86.7	97.0	107.2	116.6	128.2
14.07	12.84	12.70	16.34	18.32	15.97	11.74	10.95	11.10	14.32	15.58	13.18
0.57	0.53	0.43	0.75	0.67	0.72	0.48	0.45	0.38	0.66	0.57	0.59
89.6	101.7	110.8	121.6	136.0	154.2	74.6	86.7	95.8	106.6	116.0	127.6
14.56	13.99	13.04	15.93	18.25	16.62	12.12	11.93	11.27	13.96	15.57	13.75
0.60	0.66	0.46	0.66	0.71	0.67	0.50	0.56	0.40	0.59	0.61	0.55
89.6	101.7	110.8	121.8	136.8	155.1	74.8	87.7	96.8	106.8	116.4	128.0
14.54	13.88	13.29	16.36	18.46	16.36	12.14	11.97	11.61	14.35	15.71	13.50
0.63	0.63	0.48	0.74	0.70	0.66	0.53	0.54	0.42	0.65	0.60	0.54
89.2	101.2	110.4	121.7	136.6	155.1	74.2	86.2	95.4	106.7	116.3	128.0
14.36	13.84	13.51	16.49	18.68	16.39	11.95	11.79	11.67	14.46	15.90	13.53
0.59	0.63	0.49	0.74	0.72	0.69	0.49	0.54	0.42	0.65	0.61	0.57
89.1	100.9	110.4	122.2	138.1	156.4	74.1	85.9	95.4	106.6	117.1	128.7
15.10	14.02	14.02	17.05	19.01	16.17	12.56	11.94	12.12	14.87	16.12	13.31
0.63	0.59	0.56	0.73	0.74	0.65	0.52	0.50	0.48	0.64	0.63	0.53
89.9	100.8	112.8	126.4	141.9	160.5	74.9	85.8	98.8	109.7	119.4	130.8
13.65	14.10	15.93	18.88	18.67	15.82	11.37	12.00	13.95	16.39	15.71	12.89
0.59	0.54	0.65	0.85	0.78	0.75	0.49	0.46	0.57	0.74	0.66	0.61

Table 6. Mean, standard deviation (s_x), and standard error of mean ($s_{\bar{x}}$) of bone-specific skeletal ages for the 31 individual hand-wrist bones of boys and girls and number of children, by chronological age in years at last birthday: United States, 1963-65—Con.

Hand-wrist bone and value	Boys—Chronological age in years					
	6	7	8	9	10	11
	Bone-specific skeletal age in months—male standard					
Proximal phalanx II:						
mean	78.8	89.8	98.9	106.8	114.2	125.1
s_x	12.39	12.86	12.48	12.56	11.41	14.50
$s_{\bar{x}}$	0.55	0.57	0.48	0.47	0.51	0.63
Proximal phalanx III:						
mean	78.1	89.1	98.5	106.6	114.3	125.1
s_x	12.24	13.18	12.92	12.92	11.79	14.64
$s_{\bar{x}}$	0.56	0.54	0.50	0.50	0.52	0.66
Proximal phalanx IV:						
mean	77.2	88.9	98.5	106.7	115.0	125.7
s_x	12.66	13.41	12.94	13.23	12.07	14.62
$s_{\bar{x}}$	0.58	0.55	0.53	0.53	0.48	0.65
Proximal phalanx V:						
mean	77.8	89.5	99.1	106.9	115.0	125.9
s_x	13.03	13.32	12.79	13.12	11.76	14.44
$s_{\bar{x}}$	0.58	0.57	0.52	0.52	0.45	0.61
Middle phalanx II:						
mean	80.8	91.3	100.3	108.2	115.5	126.7
s_x	12.25	12.57	12.55	12.70	11.96	14.16
$s_{\bar{x}}$	0.47	0.62	0.54	0.55	0.43	0.56
Middle phalanx III:						
mean	79.1	89.7	99.2	107.5	115.0	126.4
s_x	12.57	12.64	12.80	12.97	12.14	14.32
$s_{\bar{x}}$	0.48	0.59	0.51	0.53	0.47	0.59
Middle phalanx IV:						
mean	79.6	90.6	99.7	107.4	114.5	125.4
s_x	12.92	12.93	12.61	12.46	11.60	13.95
$s_{\bar{x}}$	0.50	0.64	0.56	0.52	0.47	0.60
Middle phalanx V:						
mean	78.9	90.2	99.8	107.7	114.8	126.0
s_x	14.00	13.93	13.52	12.85	12.09	14.38
$s_{\bar{x}}$	0.51	0.70	0.56	0.55	0.46	0.63
Distal phalanx I:						
mean	74.2	87.1	99.1	107.6	114.8	125.8
s_x	14.08	14.48	13.79	12.73	11.88	14.71
$s_{\bar{x}}$	0.58	0.63	0.64	0.52	0.57	0.63
Distal phalanx II:						
mean	77.0	89.7	100.5	108.3	115.2	125.3
s_x	12.65	13.50	12.99	11.18	10.35	14.12
$s_{\bar{x}}$	0.56	0.74	0.54	0.40	0.47	0.60
Distal phalanx III:						
mean	76.3	89.4	100.2	108.2	115.3	125.4
s_x	13.08	14.02	13.04	11.48	10.22	14.16
$s_{\bar{x}}$	0.53	0.80	0.54	0.39	0.48	0.61
Distal phalanx IV:						
mean	75.8	89.3	100.2	108.3	115.2	125.6
s_x	13.56	14.31	13.37	11.83	10.34	14.34
$s_{\bar{x}}$	0.58	0.78	0.55	0.44	0.48	0.62
Distal phalanx V:						
mean	76.2	89.1	99.9	108.2	115.1	125.9
s_x	13.34	14.18	13.38	12.00	10.59	14.51
$s_{\bar{x}}$	0.58	0.75	0.55	0.48	0.50	0.62
Pisiform:						
mean	*	112.7	115.4	117.5	119.0	126.8
s_x	-	2.10	13.12	7.53	8.24	13.69
$s_{\bar{x}}$	*	1.65	1.11	0.84	0.57	0.67
Adductor sesamoid:						
mean	-	-	-	*	*	15.66
s_x	-	-	-	*	*	5.87
$s_{\bar{x}}$	-	-	-	*	*	0.78
Flexor sesamoid:						
mean	-	-	-	*	*	161.0
s_x	-	-	-	*	*	6.11
$s_{\bar{x}}$	-	-	-	*	*	1.04

Table 6. Mean, standard deviation (s_x), and standard error of mean ($s_{\bar{x}}$) of bone-specific skeletal ages for the 31 individual hand-wrist bones of boys and girls and number of children, by chronological age in years at last birthday: United States, 1963-65—Con.

Girls—chronological age in years						Girls—chronological age in years					
6	7	8	9	10	11	6	7	8	9	10	11
Bone-specific skeletal age in months—male standard						Bone-specific skeletal age in months—female equivalent					
92.4	103.4	113.8	125.8	141.7	160.4	77.4	88.4	98.8	108.8	119.7	130.7
14.70	13.48	14.12	17.60	18.40	15.74	12.31	11.52	12.26	15.22	15.54	12.83
0.64	0.48	0.60	0.81	0.83	0.71	0.54	0.41	0.52	0.70	0.70	0.58
91.9	103.0	113.7	125.8	141.9	160.6	76.9	88.0	98.7	109.4	119.4	132.6
14.97	13.85	14.25	17.85	18.80	16.01	12.53	11.83	12.37	15.52	15.82	13.22
0.65	0.51	0.64	0.82	0.80	0.70	0.54	0.44	0.56	0.71	0.67	0.58
91.7	103.1	114.0	126.1	142.0	160.8	76.7	88.1	99.0	109.6	119.5	132.8
15.10	14.14	14.69	17.61	18.37	16.15	12.63	12.08	12.76	15.31	15.46	13.34
0.67	0.49	0.73	0.80	0.75	0.75	0.56	0.42	0.63	0.70	0.63	0.62
92.2	103.2	114.4	126.4	142.2	160.9	77.2	88.2	100.4	109.7	119.6	131.4
15.02	13.89	14.61	17.55	18.19	15.82	12.58	11.87	12.82	15.23	15.30	12.92
0.69	0.46	0.70	0.82	0.76	0.71	0.58	0.39	0.61	0.71	0.64	0.58
93.7	103.5	114.4	126.4	141.7	160.2	78.7	89.5	100.1	109.7	119.4	131.1
14.12	13.43	14.22	16.90	18.19	15.91	11.86	11.61	12.44	14.67	15.33	13.02
0.67	0.40	0.60	0.70	0.81	0.75	0.56	0.35	0.52	0.61	0.68	0.61
92.4	102.6	113.5	125.9	141.4	160.2	77.7	88.6	98.8	109.4	119.2	131.1
14.36	13.94	14.52	17.29	18.49	16.30	12.08	12.04	12.64	15.02	15.59	13.34
0.64	0.39	0.68	0.76	0.80	0.73	0.54	0.34	0.59	0.66	0.67	0.60
93.0	102.8	113.1	125.1	140.3	159.6	78.0	88.8	98.2	109.0	118.6	130.8
14.42	13.49	13.87	16.96	18.62	16.87	12.09	11.65	12.04	14.78	15.74	13.83
0.63	0.42	0.66	0.72	0.83	0.77	0.53	0.36	0.57	0.63	0.70	0.63
93.3	102.9	113.4	125.5	140.8	160.2	74.6	88.8	98.4	108.5	118.8	130.7
14.50	13.97	14.00	17.39	18.97	16.55	11.59	12.06	12.15	15.03	16.01	13.50
0.66	0.43	0.62	0.72	0.89	0.76	0.53	0.37	0.54	0.62	0.75	0.62
91.0	102.1	113.0	125.0	139.9	158.7	75.0	87.1	98.0	108.0	117.9	130.4
15.32	13.96	14.15	17.88	19.21	15.14	12.63	11.91	12.27	15.45	16.19	12.44
0.65	0.52	0.54	0.81	0.84	0.64	0.54	0.44	0.47	0.70	0.71	0.53
93.5	104.0	112.9	124.0	138.1	157.1	78.5	89.0	97.9	108.0	117.1	129.1
13.88	12.33	11.84	16.07	18.47	16.23	11.65	10.55	10.27	14.00	15.66	13.34
0.61	0.40	0.49	0.70	0.80	0.76	0.51	0.34	0.42	0.61	0.68	0.62
93.0	103.7	112.7	124.0	138.5	157.4	79.0	90.0	98.7	108.0	117.5	129.4
14.19	12.83	12.29	16.24	18.64	15.96	12.05	11.14	10.76	14.14	15.81	13.12
0.65	0.45	0.51	0.73	0.78	0.72	0.55	0.39	0.45	0.64	0.66	0.59
92.9	103.7	112.7	124.0	138.8	157.8	78.9	90.0	98.7	108.0	117.8	129.8
14.44	12.92	12.42	16.44	18.81	16.22	12.26	11.21	10.88	14.32	15.96	13.34
0.70	0.47	0.51	0.73	0.78	0.74	0.59	0.41	0.45	0.64	0.66	0.61
92.9	103.5	112.5	123.9	138.9	158.2	77.9	88.5	97.5	107.9	117.9	130.2
14.20	13.03	12.32	16.79	19.06	16.16	11.91	11.14	10.68	14.62	16.18	13.30
0.64	0.51	0.53	0.74	0.80	0.71	0.54	0.44	0.46	0.64	0.68	0.58
116.6	117.0	120.1	126.1	138.4	153.9	102.8	103.0	105.1	110.0	117.4	126.9
6.87	6.36	8.63	12.40	15.99	15.90	6.06	5.60	7.55	10.82	13.56	13.11
1.79	0.72	0.53	0.64	0.68	0.72	1.58	0.63	0.46	0.56	0.58	0.59
*	*	154.6	156.8	158.5	162.9	*	*	127.6	128.9	130.2	132.9
*	*	6.93	6.42	6.73	8.21	*	*	5.72	5.28	5.53	6.70
*	*	1.94	0.64	0.38	0.30	*	*	1.60	0.53	0.31	0.24
-	*	*	161.3	162.4	165.9	-	*	*	131.6	132.4	134.4
-	*	*	7.10	7.38	8.65	-	*	*	5.79	6.02	7.01
-	*	*	0.70	0.51	0.44	-	*	*	0.57	0.42	0.36

Table 6. Mean, standard deviation (s_x), and standard error of mean ($s_{\bar{x}}$) of bone-specific skeletal ages for the 31 individual hand-wrist bones of boys and girls and number of children, by chronological age in years at last birthday: United States, 1963-65—Con.

Hand-wrist bone	Boys—chronological age in years					
	6	7	8	9	10	11
	Number of children in thousands					
Radius	1,999	2,007	1,968	1,937	1,935	1,903
Ulna	562	1,232	1,681	1,871	1,932	1,903
Capitate	1,999	2,007	1,965	1,942	1,935	1,903
Hamate	1,999	2,007	1,965	1,942	1,935	1,903
Triquetral	1,936	1,996	1,964	1,938	1,931	1,903
Lunate	1,792	1,924	1,940	1,932	1,931	1,903
Scaphoid	1,166	1,645	1,821	1,927	1,931	1,903
Trapezium	1,079	1,510	1,751	1,896	1,919	1,899
Trapezoid	1,187	1,671	1,880	1,925	1,935	1,899
Metacarpal I	1,995	2,004	1,965	1,942	1,935	1,903
Metacarpal II	1,999	2,007	1,968	1,942	1,932	1,906
Metacarpal III	1,999	2,007	1,968	1,942	1,935	1,906
Metacarpal IV	1,999	2,007	1,968	1,942	1,935	1,906
Metacarpal V	1,999	2,007	1,968	1,942	1,935	1,906
Proximal phalanx I	1,996	2,006	1,961	1,940	1,935	1,906
Proximal phalanx II	2,002	2,008	1,964	1,940	1,935	1,906
Proximal phalanx III	2,002	2,008	1,964	1,944	1,935	1,906
Proximal phalanx IV	2,002	2,008	1,964	1,944	1,935	1,906
Proximal phalanx V	2,002	2,008	1,964	1,944	1,935	1,906
Middle phalanx II	2,002	2,003	1,964	1,934	1,931	1,906
Middle phalanx III	1,998	2,003	1,964	1,931	1,931	1,906
Middle phalanx IV	1,998	2,003	1,964	1,937	1,931	1,906
Middle phalanx V	1,992	1,999	1,939	1,933	1,931	1,897
Distal phalanx I	1,996	1,996	1,958	1,936	1,931	1,906
Distal phalanx II	1,993	2,001	1,961	1,931	1,931	1,906
Distal phalanx III	1,989	2,001	1,961	1,934	1,931	1,903
Distal phalanx IV	1,989	2,001	1,961	1,937	1,931	1,903
Distal phalanx V	1,989	1,997	1,961	1,937	1,931	1,906
Pisiform	7	23	91	329	749	1,176
Adductor sesamoid	-	-	-	11	15	228
Flexor sesamoid	-	-	-	6	2	52

Table 6. Mean, standard deviation (s_x), and standard error of mean ($s_{\bar{x}}$) of bone-specific skeletal ages for the 31 individual hand-wrist bones of boys and girls and number of children, by chronological age in years at last birthday: United States, 1963-65—Con.

Girls—chronological age in years						Girls—chronological age in years					
6	7	8	9	10	11	6	7	8	9	10	11
Number of children in thousands											
1,962	1,986	1,918	1,885	1,872	1,844	...	...	...	...	...	...
1,419	1,796	1,883	1,878	1,870	1,844	...	...	...	...	...	...
1,962	1,986	1,918	1,881	1,840	1,744	...	...	...	...	...	...
1,962	1,986	1,914	1,881	1,845	1,777	...	...	...	...	...	...
1,955	1,986	1,908	1,860	1,823	1,641	...	...	...	...	...	...
1,927	1,982	1,911	1,871	1,827	1,769	...	...	...	...	...	...
1,830	1,966	1,903	1,885	1,856	1,784	...	...	...	...	...	...
1,809	1,957	1,903	1,873	1,844	1,730	...	...	...	...	...	...
1,869	1,969	1,914	1,876	1,842	1,730	...	...	...	...	...	...
1,962	1,986	1,914	1,881	1,870	1,828	...	...	...	...	...	...
1,962	1,983	1,914	1,881	1,872	1,834	...	...	...	...	...	...
1,962	1,983	1,914	1,881	1,872	1,834	...	...	...	...	...	...
1,962	1,983	1,914	1,881	1,872	1,834	...	...	...	...	...	...
1,957	1,983	1,914	1,881	1,872	1,834	...	...	...	...	...	...
1,962	1,986	1,908	1,881	1,870	1,828	...	...	...	...	...	...
1,962	1,984	1,914	1,881	1,869	1,835	...	...	...	...	...	...
1,962	1,984	1,914	1,881	1,869	1,835	...	...	...	...	...	...
1,958	1,986	1,914	1,881	1,869	1,823	...	...	...	...	...	...
1,962	1,986	1,914	1,881	1,869	1,820	...	...	...	...	...	...
1,962	1,980	1,902	1,878	1,866	1,835	...	...	...	...	...	...
1,962	1,984	1,914	1,881	1,866	1,842	...	...	...	...	...	...
1,958	1,984	1,914	1,881	1,866	1,842	...	...	...	...	...	...
1,949	1,976	1,908	1,863	1,856	1,822	...	...	...	...	...	...
1,956	1,976	1,896	1,871	1,859	1,752	...	...	...	...	...	...
1,957	1,977	1,897	1,875	1,862	1,767	...	...	...	...	...	...
1,957	1,980	1,902	1,878	1,864	1,760	...	...	...	...	...	...
1,954	1,984	1,904	1,878	1,866	1,769	...	...	...	...	...	...
1,962	1,977	1,905	1,872	1,861	1,769	...	...	...	...	...	...
120	370	862	1,382	1,618	1,568	...	...	...	...	...	...
3	4	67	316	872	1,516	...	...	...	...	...	...
-	2	16	89	290	648	...	...	...	...	...	...

Table 7. Mean and standard deviation (s_x) of bone-specific skeletal ages for selected hand-wrist bones of boys and girls, by chronological age in 6-month intervals: United States, 1963-65

Sex and chronological age	Radius		Ulna		Scaphoid	
	Mean	s_x	Mean	s_x	Mean	s_x
Boys—male standard	Bone-specific skeletal age in months					
6 years:						
0-5 months	72.4	13.34	84.8	9.79	82.5	12.14
6-11 months	77.6	12.62	86.6	8.47	84.4	11.02
7 years:						
0-5 months	82.5	11.91	88.9	9.40	88.3	13.06
6-11 months	88.6	12.83	93.0	10.60	93.4	12.65
8 years:						
0-5 months	92.7	13.09	94.3	10.89	96.4	13.57
6-11 months	98.3	12.08	99.7	10.66	101.5	13.01
9 years:						
0-5 months	104.5	12.69	102.7	12.38	104.9	12.88
6-11 months	107.7	11.66	107.6	11.40	108.6	11.18
10 years:						
0-5 months	111.6	11.07	110.4	11.21	112.2	11.10
6-11 months	115.9	10.96	115.1	11.24	116.1	10.93
11 years:						
0-5 months	121.0	11.80	119.8	11.97	120.7	11.58
6-11 months	126.8	13.72	126.1	13.59	126.8	13.02
12 years:						
0-1 month	130.3	15.20	131.5	14.74	131.9	14.52
Girls—female equivalent						
6 years:						
0-5 months	76.0	11.60	86.0	8.21	75.4	10.01
6-11 months	79.6	13.12	87.1	9.69	79.1	10.13
7 years:						
0-5 months	86.0	12.78	87.7	9.99	83.6	10.52
6-11 months	91.2	10.97	88.2	10.41	90.4	9.12
8 years:						
0-5 months	93.6	12.23	91.6	11.17	95.4	8.62
6-11 months	96.3	10.09	94.9	10.65	98.6	8.61
9 years:						
0-5 months	100.2	11.93	99.8	11.47	102.9	9.94
6-11 months	107.4	14.42	107.5	12.76	108.6	11.97
10 years:						
0-5 months	111.8	14.67	110.8	13.46	112.0	12.24
6-11 months	118.2	16.24	116.6	14.22	117.1	14.03
11 years:						
0-5 months	124.9	12.98	123.6	12.67	122.9	13.04
6-11 months	128.8	13.61	127.3	13.84	125.6	12.98
12 years:						
0-1 month	132.4	7.88	128.4	11.84	127.7	10.70

Table 7. Mean and standard deviation (s_x) of bone-specific skeletal ages for selected hand-wrist bones of boys and girls, by chronological age in 6-month intervals: United States, 1963-65—Con.

Metacarpal I		Proximal phalanx II		Middle phalanx II		Distal phalanx II	
Mean	s_x	Mean	s_x	Mean	s_x	Mean	s_x
Bone-specific skeletal age in months							
69.6	14.43	76.9	12.38	78.8	12.13	74.9	12.19
74.2	14.15	80.7	12.09	83.0	12.00	79.2	12.74
80.6	13.34	87.2	12.44	88.6	12.11	86.4	12.99
86.7	15.43	92.3	12.75	93.9	12.44	92.9	13.19
91.0	13.98	96.4	12.80	97.6	12.82	97.8	13.67
97.3	13.54	101.1	11.76	102.7	11.79	102.9	11.84
101.4	13.46	103.8	12.69	105.3	12.07	106.0	11.34
106.8	11.82	109.5	11.81	110.8	12.69	110.3	10.66
109.6	11.49	112.0	11.06	112.7	11.45	113.2	9.86
114.2	11.23	116.5	11.31	118.2	11.83	117.2	10.42
119.4	12.22	121.3	12.34	123.3	13.08	121.9	12.36
125.9	14.41	128.2	15.16	129.5	14.15	128.1	14.72
129.8	15.77	131.5	17.30	133.1	15.76	130.9	16.01
73.0	11.41	74.8	11.94	77.4	11.60	76.1	11.52
77.8	11.70	79.8	12.31	80.4	11.98	80.6	11.47
83.7	11.34	86.2	12.09	87.2	12.24	86.7	11.32
90.6	9.99	90.7	10.58	91.4	10.54	91.3	9.30
95.1	11.54	95.5	12.19	96.6	12.48	95.1	10.50
99.5	10.04	101.6	11.49	102.3	11.69	100.7	9.41
103.0	12.91	105.7	14.04	106.9	13.51	105.2	12.42
110.0	14.41	112.4	15.32	113.4	14.78	110.5	14.67
113.8	14.13	116.8	14.49	116.8	14.27	115.0	14.42
120.3	16.08	121.9	15.73	122.0	15.55	120.5	16.22
126.5	13.42	129.2	12.77	128.8	12.59	127.9	13.53
129.8	12.87	131.9	12.63	131.9	12.84	130.4	13.02
130.6	10.45	134.2	11.19	134.9	11.83	132.4	11.95

Table 8. Selected percentiles in the distribution of bone-specific skeletal ages for each of the 31 hand-wrist bones of boys and girls, by chronological age in years at last birthday: United States, 1963-65

Hand-wrist bone and percentile	Boys—chronological age in years					
	6	7	8	9	10	11
	Bone-specific skeletal age in months—male standard					
Radius:						
P_{75}	83.7	94.4	106.0	115.2	120.1	130.6
P_{50}	75.3	85.3	95.0	108.8	114.8	122.9
P_{25}	68.4	77.8	89.2	98.3	108.1	116.1
Ulna:						
P_{75}	89.6	98.8	106.8	114.7	118.6	132.4
P_{50}	85.2	90.7	97.3	107.0	114.7	120.0
P_{25}	80.4	84.2	88.0	96.9	106.9	115.6
Capitate:						
P_{75}	84.7	93.8	108.3	114.0	120.6	130.7
P_{50}	78.1	86.5	94.5	108.4	114.1	122.2
P_{25}	69.8	79.3	88.6	96.5	108.9	115.5
Hamate:						
P_{75}	84.3	92.9	105.8	114.1	120.5	136.2
P_{50}	78.4	86.0	94.1	106.5	114.8	121.1
P_{25}	68.9	79.2	88.3	94.9	108.4	115.5
Triquetral:						
P_{75}	86.3	95.5	110.2	113.7	119.8	132.0
P_{50}	77.3	87.4	99.2	110.3	114.2	120.8
P_{25}	63.4	78.1	88.4	101.1	110.2	115.2
Lunate:						
P_{75}	84.8	96.5	110.2	116.6	120.3	130.6
P_{50}	70.8	85.8	98.4	110.4	116.5	122.5
P_{25}	54.9	70.6	83.6	98.4	110.6	116.9
Scaphoid:						
P_{75}	92.5	102.5	110.8	114.6	120.7	129.9
P_{50}	82.4	91.4	102.7	110.8	114.5	122.2
P_{25}	73.5	80.3	90.3	101.6	110.4	115.5
Trapezium:						
P_{75}	85.7	92.8	108.2	113.4	117.7	128.7
P_{50}	76.6	84.2	93.1	106.7	112.9	118.6
P_{25}	68.9	71.6	81.5	92.1	105.6	114.1
Trapezoid:						
P_{75}	88.9	94.8	110.3	114.3	118.1	130.3
P_{50}	78.8	87.6	96.7	110.6	113.9	118.6
P_{25}	72.3	78.9	88.6	96.7	110.3	114.7
Metacarpal I:						
P_{75}	81.9	93.1	107.0	112.8	117.9	130.0
P_{50}	72.2	84.0	94.3	108.1	112.6	119.0
P_{25}	63.7	73.7	86.3	96.8	106.6	114.5
Metacarpal II:						
P_{75}	84.8	94.1	109.7	114.5	118.4	129.0
P_{50}	78.1	86.9	94.6	110.1	113.8	118.9
P_{25}	66.1	78.4	87.0	94.9	110.1	114.7
Metacarpal III:						
P_{75}	84.8	93.8	108.9	114.0	118.1	130.0
P_{50}	77.9	86.9	94.7	109.6	114.0	119.0
P_{25}	66.0	78.5	86.9	94.7	108.6	114.7
Metacarpal IV:						
P_{75}	84.6	92.9	108.8	113.8	117.9	128.9
P_{50}	76.7	86.9	94.3	109.2	113.6	118.8
P_{25}	64.2	78.6	86.7	94.3	108.6	114.4
Metacarpal V:						
P_{75}	84.5	94.1	108.7	113.8	117.8	130.2
P_{50}	74.9	86.6	94.9	108.8	113.4	118.7
P_{25}	62.8	76.9	86.4	94.6	108.3	114.2
Pisiform:						
P_{75}	134.8	116.5	118.8	120.3	122.8	132.9
P_{50}	134.1	111.8	116.1	116.2	117.7	123.0
P_{25}	115.6	110.9	112.3	113.1	113.7	116.6

Table 8. Selected percentiles in the distribution of bone-specific skeletal ages for each of the 31 hand-wrist bones of boys and girls, by chronological age in years at last birthday: United States, 1963-65—Con.

Girls—chronological age in years						Girls—chronological age in years					
6	7	8	9	10	11	6	7	8	9	10	11
Bone-specific skeletal age in months—male standard						Bone-specific skeletal age in months—female equivalent					
94.6	108.3	116.2	125.9	151.3	164.5	86.6	95.2	101.2	109.4	125.3	134.2
86.1	96.7	111.5	117.0	130.7	156.7	78.6	87.8	96.5	102.0	112.7	128.8
76.0	89.2	100.8	112.5	118.7	148.4	70.0	81.2	91.4	97.5	103.7	123.7
96.2	108.0	115.6	125.5	148.1	163.0	87.6	94.0	99.9	108.8	123.1	132.5
88.9	98.7	108.5	117.5	132.4	152.9	85.4	87.9	94.2	102.5	113.2	126.9
84.6	88.5	98.5	112.1	118.5	142.8	79.6	84.8	98.9	97.1	103.5	119.8
94.9	112.2	116.7	126.8	156.1	164.9	82.9	97.3	102.4	109.9	128.6	134.4
87.6	98.7	112.4	118.4	132.9	159.4	75.6	85.7	97.6	103.4	113.9	131.2
80.0	90.3	104.7	112.9	122.0	148.8	68.0	78.3	90.7	98.4	107.0	123.9
94.4	112.5	117.2	129.6	154.7	163.9	81.6	97.8	102.2	111.8	127.7	133.9
87.6	98.7	112.9	118.8	140.2	157.9	75.6	85.4	97.9	103.8	118.6	129.9
80.1	90.1	103.0	114.0	122.4	152.3	67.2	78.1	89.0	99.0	107.2	126.2
103.1	112.7	116.7	126.9	148.7	164.9	89.1	97.7	101.7	109.9	123.7	134.4
89.6	107.7	112.9	118.8	132.2	152.6	76.6	93.7	97.9	103.8	113.6	125.8
80.4	92.7	108.8	113.5	121.1	142.1	68.4	79.7	94.4	98.5	105.6	119.6
96.7	112.5	118.5	126.9	152.1	162.7	84.7	99.2	103.5	110.3	126.0	132.7
87.1	100.3	114.9	119.6	129.4	154.9	72.1	90.4	99.3	104.6	112.2	127.9
75.2	86.7	104.3	115.4	120.4	140.5	64.1	71.7	97.1	100.4	105.4	118.8
104.4	112.8	117.8	126.5	150.2	161.6	88.1	97.8	102.8	110.2	124.6	131.8
94.3	108.4	113.3	119.2	128.8	152.9	77.3	94.4	98.3	103.6	111.8	125.9
85.1	94.4	109.2	114.3	121.4	140.6	68.2	77.4	95.1	99.3	106.2	119.2
98.7	112.0	116.2	123.3	150.3	164.4	86.4	97.5	101.2	107.3	124.6	133.7
87.5	102.8	112.7	116.8	128.9	156.7	81.5	89.8	98.6	101.8	111.4	128.8
82.0	89.0	104.7	113.4	118.4	141.5	71.0	82.5	90.8	99.2	103.4	119.2
98.8	112.7	116.6	124.5	150.3	164.2	87.7	97.7	101.6	108.5	124.6	133.6
90.8	105.3	113.2	117.6	129.6	154.2	77.8	91.6	98.2	102.6	112.3	127.6
81.7	93.0	106.5	114.1	118.1	140.8	68.7	81.0	92.5	99.1	103.1	118.8
102.1	112.4	117.2	128.7	154.3	168.4	87.1	98.4	102.2	110.8	127.6	136.7
89.4	106.3	112.5	118.8	132.9	158.8	74.4	92.3	98.5	103.8	113.9	130.4
80.7	92.0	105.8	113.8	123.7	147.7	65.7	77.0	91.8	99.4	107.8	122.8
98.1	113.2	117.2	127.7	152.8	166.2	84.6	98.2	102.2	110.7	126.8	135.2
88.8	108.1	113.1	118.7	130.8	158.2	73.8	93.6	98.1	103.7	112.9	130.1
80.8	90.4	108.0	114.2	122.0	146.6	65.8	75.4	93.5	99.2	107.0	122.3
96.9	113.3	117.4	128.2	153.2	166.8	82.8	99.3	103.4	111.2	127.1	135.4
89.0	108.0	112.8	118.8	132.6	158.8	74.5	94.0	98.8	104.4	113.8	130.4
80.7	90.4	107.8	114.2	121.8	148.1	65.7	75.6	93.8	100.2	106.8	123.6
96.8	112.8	117.0	127.6	154.1	166.9	82.7	97.8	102.0	110.6	127.6	135.9
88.5	106.7	112.7	118.6	132.4	159.4	73.5	91.8	97.7	103.6	113.7	130.7
80.8	90.2	105.5	113.7	121.2	148.3	65.8	75.2	91.2	98.7	106.2	123.3
96.9	112.6	117.3	128.7	156.4	168.1	82.9	97.6	102.3	110.8	128.4	136.1
89.0	106.2	112.5	118.8	135.8	160.6	74.0	91.2	97.5	103.8	115.4	131.8
80.2	90.2	105.5	113.4	122.8	149.0	65.2	75.2	90.5	98.4	106.9	124.0
120.2	120.3	124.7	132.5	153.0	168.7	105.2	105.3	108.7	113.8	126.5	136.7
115.0	116.1	118.4	123.4	136.5	158.8	102.0	102.6	104.2	107.7	116.2	130.4
111.0	113.0	114.8	117.3	124.9	144.6	99.0	100.5	101.8	103.3	108.9	121.3

Table 8. Selected percentiles in the distribution of bone-specific skeletal ages for each of the 31 hand-wrist bones of boys and girls, by chronological age in years at last birthday: United States, 1963-65—Con.

Hand-wrist bone and percentile	Boys—chronological age in years					
	6	7	8	9	10	11
	Bone-specific skeletal age in months—male standard					
Adductor sesamoid:						
P_{75}	-	-	-	154.8	161.6	160.4
P_{50}	-	-	-	154.1	157.0	157.1
P_{25}	-	-	-	152.5	151.2	152.6
Flexor sesamoid:						
P_{75}	-	-	-	155.4	150.8	164.2
P_{50}	-	-	-	153.7	150.5	160.2
P_{25}	-	-	-	153.4	150.2	156.3
Proximal phalanx I:						
P_{75}	84.9	94.3	106.5	114.2	122.1	132.7
P_{50}	76.8	87.3	96.6	106.1	113.0	123.3
P_{25}	68.9	80.2	88.7	94.9	105.7	114.7
Proximal phalanx II:						
P_{75}	86.6	99.0	110.1	115.2	119.8	132.7
P_{50}	78.6	89.3	100.6	109.9	114.8	122.0
P_{25}	72.6	81.3	90.6	98.6	109.0	115.6
Proximal phalanx III:						
P_{75}	84.6	96.9	110.1	115.1	120.4	132.9
P_{50}	78.3	88.6	100.4	109.3	114.5	122.3
P_{25}	72.2	80.7	90.1	97.0	108.9	115.3
Proximal phalanx IV:						
P_{75}	84.7	96.8	109.8	115.6	122.2	134.1
P_{50}	77.0	88.5	100.6	109.0	115.3	123.7
P_{25}	69.7	80.7	90.0	96.8	110.0	116.2
Proximal phalanx V:						
P_{75}	86.3	97.7	110.6	115.4	121.2	135.0
P_{50}	78.2	89.2	101.0	110.2	115.1	123.9
P_{25}	70.2	80.9	90.4	97.0	110.2	115.8
Middle phalanx II:						
P_{75}	88.8	101.3	109.4	116.1	123.2	135.4
P_{50}	80.6	90.9	105.0	108.9	115.5	125.0
P_{25}	74.3	83.6	92.3	100.4	108.5	116.7
Middle phalanx III:						
P_{75}	86.7	99.5	108.7	116.2	123.1	135.3
P_{50}	78.9	90.2	102.5	108.3	115.5	125.3
P_{25}	71.5	81.6	91.3	99.2	108.1	116.8
Middle phalanx IV:						
P_{75}	87.4	100.5	109.2	115.9	121.0	133.0
P_{50}	79.1	91.6	103.5	108.5	115.0	123.7
P_{25}	72.2	81.8	92.7	100.0	108.3	116.2
Middle phalanx V:						
P_{75}	88.3	102.2	109.5	116.0	121.8	136.6
P_{50}	80.0	91.0	104.5	108.5	114.8	124.3
P_{25}	70.6	81.3	92.6	100.6	107.8	116.2
Distal phalanx I:						
P_{75}	82.8	96.3	110.8	116.0	120.9	134.1
P_{50}	74.4	87.3	102.8	110.6	115.1	123.4
P_{25}	64.5	78.9	90.3	100.6	110.3	116.1
Distal phalanx II:						
P_{75}	85.8	99.9	110.9	115.3	120.0	132.9
P_{50}	76.4	89.4	104.5	110.9	114.6	122.0
P_{25}	69.0	80.8	92.2	104.2	110.8	115.7
Distal phalanx III:						
P_{75}	84.7	100.0	110.9	115.4	120.1	132.9
P_{50}	76.2	88.8	104.3	110.9	114.5	122.3
P_{25}	68.3	80.5	92.1	103.5	110.9	115.7
Distal phalanx IV:						
P_{75}	84.5	100.2	111.0	115.3	120.3	134.1
P_{50}	75.8	89.0	104.3	111.2	114.8	122.5
P_{25}	66.8	80.3	92.1	103.0	110.7	115.6
Distal phalanx V:						
P_{75}	84.7	100.3	110.8	115.8	120.0	135.4
P_{50}	76.4	89.0	104.1	110.9	114.8	122.8
P_{25}	67.6	80.2	90.3	103.4	110.7	115.7

Table 8. Selected percentiles in the distribution of bone-specific skeletal ages for each of the 31 hand-wrist bones of boys and girls, by chronological age in years at last birthday: United States, 1963-65—Con.

Girls—chronological age in years						Girls—chronological age in years					
6	7	8	9	10	11	6	7	8	9	10	11
Bone-specific skeletal age in months—male standard						Bone-specific skeletal age in months—female equivalent					
152.8	154.6	160.2	162.3	162.7	166.9	125.8	127.2	131.2	132.3	132.7	134.9
152.5	150.9	153.4	156.9	159.4	163.0	125.5	124.9	126.4	128.9	130.7	133.0
152.2	150.5	150.6	152.5	154.0	159.1	125.2	124.5	124.6	125.8	127.0	130.6
-	160.8	171.5	165.0	164.8	171.3	-	131.4	139.2	134.0	133.9	139.2
-	160.5	152.8	158.1	160.7	164.5	-	131.2	125.9	130.0	131.4	133.8
-	160.2	150.7	152.1	153.6	160.3	-	131.1	124.7	125.6	126.6	131.2
99.8	112.1	120.9	137.0	158.4	172.3	84.8	98.1	105.9	116.0	129.7	139.3
88.9	102.8	112.9	124.5	142.2	164.2	74.8	87.8	98.9	108.5	119.6	133.6
80.8	90.5	104.7	114.8	127.6	153.0	65.9	75.5	89.7	100.4	110.6	127.0
106.0	114.1	119.9	136.3	156.9	171.3	91.0	99.1	104.9	115.6	128.9	138.3
92.1	107.3	114.3	121.9	141.4	164.1	77.1	92.4	99.3	105.9	119.4	133.1
81.5	92.7	108.8	115.3	128.1	152.8	66.5	77.7	94.7	100.3	110.6	126.4
105.7	114.0	120.2	136.1	158.1	172.2	90.7	99.0	105.2	115.6	131.0	141.2
91.0	107.6	114.2	122.1	142.7	164.1	76.0	92.9	99.2	106.6	119.8	134.4
80.8	92.3	108.5	115.4	127.1	152.9	65.8	77.3	94.2	100.4	110.0	126.9
104.6	114.2	120.7	136.5	156.5	172.9	89.6	99.2	105.7	115.8	128.8	141.9
91.6	106.4	114.7	123.6	141.0	164.4	76.6	91.4	99.7	107.6	119.0	134.5
80.9	92.4	108.1	116.0	128.4	152.4	65.9	77.4	93.6	101.0	110.7	126.4
105.3	114.1	122.1	137.8	156.4	172.7	90.3	100.1	107.0	116.9	128.7	140.7
91.5	106.7	114.5	124.4	141.3	164.3	76.5	91.7	100.5	108.4	119.4	133.6
81.3	92.7	108.9	115.6	129.0	152.4	66.3	77.7	94.8	101.6	112.0	126.4
105.6	114.1	122.7	136.5	156.5	170.9	91.3	99.6	107.4	116.2	128.8	137.9
92.6	106.6	114.9	124.5	142.1	163.1	77.8	91.8	100.8	108.5	119.6	132.1
84.3	93.9	107.3	115.8	128.4	151.2	71.6	78.9	92.3	101.4	111.4	125.1
103.0	113.6	122.3	135.5	156.9	171.0	89.0	98.9	107.2	115.8	128.9	138.0
91.5	105.2	114.5	124.4	140.8	163.4	77.2	91.1	100.2	108.4	118.9	132.4
82.5	92.3	106.0	115.9	128.2	151.5	70.2	77.6	91.5	101.4	111.2	125.2
105.2	113.1	120.6	134.6	156.1	170.9	91.1	98.2	105.6	115.3	128.1	137.9
92.7	106.0	114.3	123.0	140.2	163.3	77.8	91.5	100.0	107.5	118.6	132.3
82.5	94.0	106.3	115.3	126.7	150.5	70.2	79.0	91.6	101.2	109.8	124.8
105.9	113.6	120.7	136.8	156.3	172.2	91.4	98.6	105.7	115.9	128.3	140.2
92.9	106.0	114.2	122.8	140.7	163.3	74.8	91.5	99.2	106.8	118.7	133.2
82.3	92.8	106.5	114.8	128.2	150.8	63.3	74.7	91.8	99.8	110.6	124.9
104.3	113.5	119.0	134.9	157.2	170.9	89.3	98.5	104.0	115.4	129.2	138.9
90.6	106.2	113.8	120.8	138.9	163.0	74.6	91.2	98.8	105.8	117.4	133.0
80.5	92.5	107.0	114.1	125.3	152.6	66.5	76.5	92.0	99.1	108.3	125.8
105.3	113.9	118.4	132.3	154.4	170.5	90.3	98.9	103.4	113.3	127.7	138.2
93.6	108.1	114.1	118.8	136.5	161.9	78.6	93.6	99.1	103.8	116.2	131.9
84.1	95.5	108.9	114.4	122.9	148.1	69.1	80.5	94.8	99.4	107.4	123.1
104.7	114.1	118.5	132.5	154.9	170.6	91.6	100.1	103.8	113.8	127.9	138.6
92.9	107.8	114.2	118.9	137.4	162.3	78.8	93.8	100.2	103.9	116.7	132.3
82.9	94.5	108.7	114.6	123.4	148.6	67.9	80.5	94.7	100.6	107.7	123.6
104.4	114.0	118.5	132.4	156.1	170.9	91.1	100.0	103.8	113.7	128.6	138.9
93.0	108.0	114.2	119.0	137.6	162.6	79.0	94.0	100.2	104.0	116.8	132.6
82.8	94.4	108.6	114.4	123.5	148.8	67.8	80.4	94.6	100.4	107.8	123.8
104.8	113.8	118.3	132.8	156.4	171.0	89.8	98.8	103.3	113.9	128.8	138.0
92.9	107.2	114.1	118.9	137.8	162.4	77.9	92.3	99.1	103.9	116.9	133.2
82.6	94.6	108.2	114.2	123.2	150.7	67.6	79.6	93.8	99.2	107.6	124.8

Table 9. Selected percentiles in the distribution of the individual child's range in bone-specific skeletal ages for the radio-opaque (not adult) bones in the hand-wrist for boys and girls, by chronological age in years at last birthday: United States, 1963-65

Sex and chronological age in years	Percentile points				
	P_{95}	P_{75}	P_{50}	P_{25}	P_5
	Bone-specific skeletal age in months—male standard				
Boys					
6 years	50.6	37.3	29.4	22.5	12.0
7 years	50.1	36.1	28.3	20.6	12.1
8 years	46.6	34.3	26.4	19.1	10.3
9 years	43.4	29.9	22.2	14.8	8.1
10 years	38.5	26.6	20.1	13.9	8.1
11 years	38.8	26.4	19.2	13.9	7.6
Girls					
6 years	46.7	34.5	27.3	20.6	11.5
7 years	44.5	31.9	23.9	15.5	8.2
8 years	41.9	29.2	21.5	14.5	7.0
9 years	40.9	30.4	22.1	15.4	7.4
10 years	44.2	32.1	24.6	17.6	7.5
11 years	43.3	32.8	24.5	17.3	7.4

APPENDIX I

STATISTICAL NOTES

The Survey Design

The sample design for the second cycle of the Health Examination Survey, similar to the one used for the first cycle, was that of a multi-stage, stratified probability sample of loose clusters of persons in land-based segments. Successive elements dealt with in the process of sampling are primary sampling unit (PSU), census enumeration district (ED), segment, household, eligible child (EC), and finally, the sample child (SC).

At the first stage, the nearly 2,000 PSU's into which the United States (including Hawaii and Alaska) has been divided and then grouped into 357 strata for use in the Current Population Survey and the Health Interview Survey were further grouped into 40 superstrata for use in Cycle II of the Health Examination Survey. The average size of each Cycle II stratum was 4.5 million persons, and all fell between the limits of 3.5 and 5.5 million. Grouping into 40 strata was done in a way that maximized homogeneity of the PSU's included in each stratum, particularly with regard to degree of urbanization, geographic proximity, and degree of industrialization. The 40 strata were classified into four broad geographic regions (each with 10 strata) of approximately equal population and cross-classified into four broad population density groups (each having 10 strata). Each of the 16 cells contained either two or three strata. A single stratum might include only one PSU (or only part of a PSU, as for example New York City, which represented two strata) or several score PSU's.

To take account of the possible effect that the rate of population change between the 1950 and 1960 censuses might have had on health, the 10 strata within each region were further classified into four classes ranging from those with no increase to those with the greatest relative increase. Each such class contained either two or three strata.

One PSU was then selected from each of the 40 strata. A controlled selection technique was used in which the probability of selection of a particular PSU was proportional to its 1960 population. In the controlled selection an attempt was also made to maximize the spread of the PSU's among the States. While not every one of the 64 cells in the 4x4x4 grid contributes a PSU to the sample of 40 PSU's, the controlled selection technique ensured the sample's matching the marginal distributions in all three dimensions and being closely representative of all cross-classifications.

Generally 20 ED's were selected within a particular PSU. The probability of selection of a particular ED was proportional to its population in the age group 5-9 years in the 1960 census, which by 1963 roughly approximated the population in the target age group for Cycle II. A similar method was used for selecting one segment (cluster of households) in each ED. Each of the resultant 20 segments was either a bounded area or a cluster of households (or addresses). All the children in the age range 6-11 years normally resident at each household or address were considered EC's. Operational considerations made it necessary to reduce the number of prospective examinees at any one location to a maximum of 200. The EC's to be excluded for this reason from the SC group were determined by systematic subsampling.

The total sample thus selected for the examination included 7,417 children from 25 different States in the age group 6-11 years with approximately 1,000 in each of the single years of age.

Reliability

Measurement and assessment processes employed in the survey were highly standardized and closely controlled. Of course this does not mean that the correspondence between the real world and the survey results is exact. Data from the survey are imperfect for three major reasons: (1) results are subject to sampling error, (2) the actual conduct of a survey never agrees perfectly with the design, and (3) the measurement or assessment processes themselves are inexact even though standardized and controlled.

The first report on Cycle II[4] describes in detail the faithfulness with which the sampling design was carried out. It notes that 7,119 out of the 7,417 sample children were examined. This is a response rate of 96 percent. The examined children were a highly representative sample of this age in the noninstitutional population of the United States. The response levels for the various demographic subgroups, including those for age, sex, race, geographic region, population density, parent's educational level, and family income show no marked differentials. Hence it appears unlikely that nonresponse could have biased the findings markedly in these respects. Further description of the sample design and estimation procedures are contained in a subsequent report.[93]

The general measures used to control the quality of data from this survey have been cited previously;[4,94] those relating specifically to the assessment of skeletal age are outlined in this report.

Data recorded for each sample child are inflated in the estimation process to characterize the larger universe of which the sample child is representative. The weights used in this inflation process are a product of the reciprocal of the probability of selecting the child, an adjustment for nonresponse cases, and a poststratified ratio adjustment which increases precision by bringing survey results into closer alignment with known United States population figures by color and sex within single years of age 6-11.

In the second cycle of the Health Examination Survey the sample was the result of three stages of selection—the single PSU from each stratum, the 20 segments from each sample PSU, and the sample children from the eligible children. The probability of selecting an individual child is the product of the probability of selection at each stage.

Since the strata are roughly equal in population size and a nearly equal number of sample children was examined in each sample PSU, the sample design is essentially self-weighting with respect to the target population, that is, each child 6-11 years old had about the same probability of being drawn into the sample.

The adjustment upward for nonresponse is intended to minimize the impact of nonresponse on final estimates by imputing to nonrespondents the characteristics of "similar" respondents. Here "similar" respondents were judged to be examined children in a sample PSU having the same age in years and sex as children not examined in that sample PSU.

The poststratified ratio adjustment used in the second cycle achieved most of the gains in precision that would have been attained if the sample had been drawn from a population stratified by age, color, and sex and made the final sample estimates of population agree exactly with independent controls prepared by the Bureau of the Census for the noninstitutionalized population of the United States as of August 1, 1964 (approximately midsurvey point), by color and sex for each single year of age 6-11. The weights of every responding sample child in each of the 24 age, color, and sex classes is adjusted upward or downward so that the weighted total within the class equals the independent population control.

In addition to children not examined at all, there were 157 for whom the radiograph could not be assessed. The age and sex distribution for these 157 children as well as for the 6,962 for whom assessments were made is shown in table I. No attempt was made to estimate the skeletal age for the group of children without usable radiographs. Hence it is assumed that the distribution of their skeletal ages is similar to that for the remaining 6,962. In other words they were treated as if they were nonrespondents.

Table I. Number of examined children whose hand-wrist radiographs were assessed and those that were not assessed for skeletal age by chronological age in years and sex: Health Examination Survey, 1963-65

Chronological age at last birthday	Radiographs assessed		Radiographs not assessed	
	Boys	Girls	Boys	Girls
	Number of children			
Total	3,545	3,417	87	70
6 years	554	521	21	15
7 years	615	602	17	7
8 years	602	600	16	13
9 years	582	562	21	19
10 years	570	576	6	8
11 years	622	556	6	8

Among the 6,962 children with usable radiographs, there were a few for which the film quality was not good enough to permit assessment of all ossifying or ossified bones. In general these would have been bones that had become radio-opaque recently. The numbers of children for whom bone-specific skeletal ages were assessed and in which the bone was considered as ossifying or completely ossified (adult) are shown in table II.

Sampling and Measurement Error

In the present report, reference has been made to efforts to minimize bias and variability of measurement techniques.

The probability design of the survey makes possible the calculation of sampling errors. The sampling error is used here to determine how imprecise the survey test results may be because they come from a sample rather than from the measurements of all elements in the universe.

The estimation of sampling errors for a study of the type of the Health Examination Survey is difficult for at least three reasons: (1) measurement error and "pure" sampling error are confounded in the data—it is not easy to find a procedure which will either com-

Table II. Number of boys and girls for whom skeletal age assessments were made on each of the 31 hand-wrist bones: Health Examination Survey, 1963-65

Bone	Radio-opaque, not adult[a]		Adult	
	Boys	Girls	Boys	Girls
	Number of children			
Radius	3,540	3,417	-	-
Ulna	2,806	3,201	-	-
Capitate	3,540	3,375	-	26
Hamate	3,540	3,387	-	24
Triquetral	3,518	3,322	-	62
Lunate	3,448	3,363	-	25
Scaphoid	3,151	3,352	-	19
Trapezium	3,046	3,311	-	32
Trapezoid	3,180	3,338	-	32
Metacarpal I	3,538	3,409	-	6
Metacarpal II	3,541	3,411	-	3
Metacarpal III	3,542	3,411	-	3
Metacarpal IV	3,542	3,411	-	3
Metacarpal V	3,542	3,410	-	3
Proximal phalanx I	3,539	3,407	-	6
Proximal phalanx II	3,542	3,410	-	4
Proximal phalanx III	3,543	3,410	-	4
Proximal phalanx IV	3,543	3,406	-	7
Proximal phalanx V	3,543	3,406	-	8
Middle phalanx II	3,538	3,405	-	4
Middle phalanx III	3,536	3,411	-	2
Middle phalanx IV	3,538	3,410	-	2
Middle phalanx V	3,526	3,388	-	6
Distal phalanx I	3,533	3,371	-	18
Distal phalanx II	3,532	3,380	-	19
Distal phalanx III	3,531	3,383	-	20
Distal phalanx IV	3,532	3,387	-	18
Distal phalanx V	3,532	3,382	-	17
Pisiform	746	1,789	-	56
Adductor sesamoid	88	837	-	9
Flexor sesamoid	21	321	-	6

[a]In long and short bones, radio-opaque refers to the epiphyses.

pletely include both or treat one or the other separately, (2) the survey design and estimation procedure are complex and accordingly require computationally involved techniques for the calculation of variances, and (3) thousands of statistics come from the survey, many for subclasses of the population for which there are few cases. Estimates of sampling error are obtained from the sample data and are themselves subject to sampling error which may be large when the number of cases in a cell is small or occasionally even when the number of cases is substantial.

Estimates of approximate sampling variability for selected statistics used in this report are presented in the detailed tables. These estimates have been prepared by a replication technique that yields overall variability through observation of variability among random subsamples of the total sample. The method reflects both "pure" sampling variance and a part of the measurement variance.

In accordance with usual practice, the interval estimate for any statistic may be considered the range within one standard error of the tabulated statistic with 68-percent confidence or the range within two standard errors of the tabulated statistic with 95-percent confidence. The latter is used as the level of significance in this report.

An approximation of the standard error of a difference $d = x - y$ of two statistics x and y is given by the formula $S_d = (S_x^2 + S_y^2)^{1/2}$ where S_x and S_y are the sampling errors, respectively of x and y.

Small Categories

In some tables magnitudes are shown for cells for which the sample size is so small that the sampling error may be several times as great as the statistic itself. Obviously in such instances the statistic has no meaning in itself except to indicate that the true quantity is small. Such numbers, if shown, have been included in the belief that they may help to convey an impression of the overall story of the table.

APPENDIX II

RELIABILITY OF ASSESSMENT

To provide the basis for determining the level of reliability of the bone-specific skeletal age assessments made by the six medical students at Case Western Reserve University from hand-wrist radiographs of the children 6-11 years old who were examined in the Health Examination Survey of 1963-1965, a randomly selected sample of one in 24 films was reassessed by the same reader and approximately one in 24 independently randomly selected films was reassessed by another. Before starting these final assessments, all six readers were trained by Dr. Pyle in the Greulich-Pyle method using the HES Standard to the point that their ratings were in close agreement with hers. In all, 297 self-replicate assessments and 288 cross-replicate assessments were obtained. Thus each reader made approximately the same number of self-replicate and cross-replicate assessments.

All six readers maintained a high level of consistency in their own assessments throughout all 40 stands of examinations in the survey. The mean difference in self-replicate assessments for all six readers combined was 0.8 month for all 31 bones and just slightly less—0.7 month—if the bones that are late to ossify (the pisiform, adductor sesamoid, and flexor sesamoid) are excluded. Considering data from all 31 bones the mean difference per reader between his original and self-replicate assessments ranged from 0.0 to 1.4 months (combining data for the two sexes). For the 28 bones that ossify relatively early, the mean differences ranged from 0.0 to 1.5 months among the six readers (table III).

A consistently high level of agreement in bone-specific skeletal age assessments was also maintained among the six readers, but as expected, the level was

Table III. Mean difference in cross- and self-replicate assessments of bone-specific skeletal ages from hand-wrist radiographs of examinees 6-11 years old at last birthday, by reader: Health Examination Survey, 1963-65

Assessor	Self-replicates				Cross-replicates				Type of replication	
	Range in mean differences		Average mean difference		Range in mean differences		Average mean difference			
	31 bones	28 bones[a]	31 bones	28 bones[a]	31 bones	28 bones[a]	31 bones	28 bones[a]	Cross	Self
	Months of skeletal age								Number of bones assessed	
Both sexes										
Assessor 1---	0.0-1.8	0.0-1.8	0.0	0.0	0.7-10.7	0.7-10.7	3.6	3.7	724	758
Assessor 2---	0.0-7.0	0.0-2.5	0.3	0.3	0.04-10.5	0.04-7.5	2.9	2.9	1,771	1,694
Assessor 3---	0.1-3.0	0.1-2.1	0.7	0.7	0.03-5.6	0.03-5.6	-2.2	-2.2	2,130	1,869
Assessor 4---	0.1-2.4	0.1-2.4	0.6	0.6	0.1-13.1	0.1-7.7	-1.2	-1.3	970	936
Assessor 5---	0.1-4.7	0.1-4.7	0.7	0.7	0.1-7.0	0.1-6.3	-3.3	-3.2	1,395	1,293
Assessor 6---	0.6-3.6	0.6-3.6	1.4	1.5	0.2-5.1	0.2-5.1	1.4	1.5	1,415	1,597
Boys										
Assessor 1---	0.1-1.8	0.1-1.8	0.2	0.2	0.6-10.7	0.6-10.7	3.8	3.9	360	384
Assessor 2---	0.0-7.0	0.0-2.5	0.3	0.1	0.03-7.5	0.03-7.5	2.8	2.6	932	869
Assessor 3---	0.1-3.0	0.1-2.1	0.3	0.7	0.3-5.5	0.3-5.5	-2.5	-2.5	1,063	889
Assessor 4---	0.0-2.1	0.0-2.1	0.4	0.8	0.1-6.7	0.1-6.7	-1.0	-1.4	461	477
Assessor 5---	0.1-4.7	0.1-4.7	1.0	0.9	0.1-6.5	0.1-6.3	-3.6	-3.0	502	710
Assessor 6---	0.1-3.5	0.1-3.5	1.6	1.2	0.7-5.1	0.7-5.1	1.7	2.0	863	612
Girls										
Assessor 1---	0.0-1.0	0.0-0.9	0.0	0.0	0.2-5.5	0.2-5.5	3.3	3.5	364	374
Assessor 2---	0.03-1.7	0.03-1.7	0.3	0.4	0.6-10.5	0.6-5.5	2.9	3.3	839	825
Assessor 3---	0.1-1.6	0.1-1.6	0.8	0.6	0.3-5.6	0.3-5.6	-2.0	-2.0	1,067	980
Assessor 4---	0.1-2.4	0.1-2.4	0.8	0.4	1.6-13.1	1.6-7.7	-1.4	-1.2	509	459
Assessor 5---	0.1-2.7	0.1-2.7	0.5	0.6	0.2-7.0	0.2-5.6	-3.9	-3.9	893	583
Assessor 6---	0.6-3.6	0.6-3.6	0.8	1.7	1.0-3.8	1.0-3.8	1.2	1.1	552	985

[a]Excluding the pisiform, adductor sesamoid, and flexor sesamoid.

somewhat lower than that for the individual readers with themselves. On all 31 hand-wrist bones, the mean cross-replicate differences between the original and the replicate assessment by another reader was 0.0 months. It ranged between +1.4 and +3.6 months for three of the readers and -1.2 to -3.3 for the other three readers. When only the 28 centers that ossify relatively early are considered, the overall mean difference was nearly identical to that for all 31 bones (table IV).

A further independent test of the validity and reliability of the skeletal age assessments in this study was made on a randomly selected group of 50 hand-wrist radiographs among the 11-year-old boys in the national study. These 50 films were reassessed independently by an assessor at Fels Research Institute who was proficient in the use of the Greulich-Pyle method but had not been trained by Dr. Pyle. The assessor at Fels Institute was not told the age or sex of the children nor did she have access to the previous skeletal age assessments. Her mean skeletal age (hand-wrist) for the 50 radiographs was 0.7 month lower than the original assessment for them in the national study. Her mean bone-specific skeletal ages ranged from 3.6 months greater on the scaphoid to 2.9 months less on the ulna than the original assessments (table V).

The aspects considered include consistency within observers (intraobserver differences), comparability between observers (interobserver differences), and differences resulting from variations in the way the Greulich-Pyle Atlas was used. This review is restricted to reports based on samples of at least 10 radiographs and in the chronological age range 6-11 years.

While it is impossible to determine the true maturity level of the bones visualized in a radiograph, the reliability of assessments should be defined both within and between observers. Greulich and Pyle[5] contend that though the ability to duplicate assessments

Table IV. Mean differences among six assessors in cross- and self-replicate assessments of bone-specific skeletal ages from hand-wrist radiographs of examinees 6-11 years old at last birthday, by bone: Health Examination Survey, 1963-65

Hand-wrist bone	Self-replicates			Cross-replicates		
	Total	Boys	Girls	Total	Boys	Girls
	Months of skeletal age					
Radius	0.8	0.4	0.9	0.0	0.1	0.0
Ulna	0.3	0.2	0.3	0.0	0.0	0.1
Capitate	0.2	0.5	0.2	0.0	0.0	0.1
Hamate	0.4	0.3	0.5	0.1	0.0	0.2
Triquetral	1.2	1.6	0.6	0.0	0.0	0.1
Lunate	0.1	0.0	0.2	0.5	0.6	0.4
Scaphoid	0.2	0.2	0.2	0.1	0.0	0.2
Trapezium	0.3	0.2	0.3	0.3	0.5	0.2
Trapezoid	0.4	0.5	0.4	0.0	0.1	0.0
MetacarpalI	0.9	1.0	0.9	0.0	0.0	0.1
Metacarpal II	1.0	1.1	1.1	0.6	0.7	0.6
Metacarpal III	0.6	0.7	0.7	0.0	0.0	0.1
Metacarpal IV	0.7	0.8	0.7	0.0	0.0	0.1
Metacarpal V	0.7	0.9	0.6	0.0	0.0	0.1
Proximal phalanx I	0.8	0.5	1.2	0.0	0.0	0.1
Proximal phalanx II	0.3	0.2	0.4	0.0	0.0	0.1
Proximal phalanx III	0.4	0.3	0.6	0.0	0.0	0.1
Proximal phalanx IV	0.8	0.9	0.7	0.0	0.0	0.1
Proximal phalanx V	0.4	0.5	0.4	0.0	0.0	0.1
Middle phalanx II	0.6	0.8	0.5	0.0	0.0	0.1
Middle phalanx III	0.5	0.7	0.3	0.0	0.0	0.1
Middle phalanx IV	0.5	0.7	0.3	0.0	0.0	0.1
Middle phalanx V	0.9	1.0	0.8	0.0	0.1	0.0
Distal phalanx I	0.2	0.5	0.2	0.0	0.0	0.1
Distal phalanx II	0.4	0.5	0.3	0.0	0.1	0.0
Distal phalanx III	0.6	0.5	0.6	0.0	0.1	0.0
Distal phalanx IV	0.7	0.9	0.6	0.0	0.1	0.0
Distal phalanx V	0.5	0.7	0.4	0.0	0.0	0.1
Pisiform	0.3	0.4	0.2	0.0	0.1	0.0
Adductor sesamoid	0.5	0.2	0.4	0.0	0.0	0.0
Flexor sesamoid	0.4	0.3	0.6	3.6	-	3.6

Table V. Mean difference on 50 radiographs of 11-year-old boys between original assessment at Western Reserve University and reassessment at Fels Institute: Health Examination Survey, 1963-65

Hand-wrist bone	Mean difference
	In months
Total	-0.7
Radius	-0.1
Ulna	-2.9
Capitate	-2.8
Hamate	-1.6
Triquetral	+0.9
Lunate	+1.0
Scaphoid	+3.6
Trapezium	+1.7
Trapezoid	+0.9
Metacarpal I	+1.4
Metacarpal II	+0.3
Metacarpal III	+0.5
Metacarpal IV	0.0
Metacarpal V	-0.3
Proximal phalanx I	-1.3
Proximal phalanx II	-2.6
Proximal phalanx III	-1.2
Proximal phalanx IV	-1.5
Proximal phalanx V	-1.5
Middle phalanx II	+0.9
Middle phalanx III	-0.3
Middle phalanx IV	-1.7
Middle phalanx V	-0.7
Distal phalanx I	+1.2
Distal phalanx II	-1.6
Distal phalanx III	-1.9
Distal phalanx IV	-1.6
Distal phalanx V	-2.0
Pisiform	-2.6
Adductor sesamoid	-0.5
Flexor sesamoid	-

with a good degree of consistency must be possessed by a competent assessor, it alone is not enough. It is even more important that the assessments be made correctly, that is, that they be made according to the method recommended by the particular radiographic atlas on which they purport to be based. Unfortunately, the suggestion by Moore[95] that sets of duplicate radiographs which have been assessed by recognized experts be available to those who wish to measure their level of comparability has not been implemented.

Area Skeletal Ages

It is not easy to compare reported findings because workers have analysed their data in different ways. For intraobserver differences, 95-percent confidence limits of 7.2 months[96] and mean differences ranging from 1.2 to 6.6 months have been reported,[53,97-100] in addition to variable errors of 1.4 to 4.2 months.[101,102] The median intraobserver differences range from zero to 4 months.[103-105] A report of zero median differences seems surprising at first, but it is possible because Moed and his coworkers made overall assessments to the nearest atlas standard. The reliability of the HES data compares favorably with the preceding studies. Todd's claim[45] that interobserver differences of less than 6 months could be achieved readily appears justified. Reported mean interobserver differences range from 1.3 to 4.2 months.[53,106,107] In addition, a root mean square of 6.2 months and confidence limits of 7.4 months have been reported.[96,100] Reported incidences of particular interobserver differences indicate that the medians were less than 3 months for the study by Hansman and Maresh[108] and less than 6 months for the study by Moed et al.[103] The mean interobserver differences among readers in the Health Examination Survey are toward the lower end of the sample values reported by others.

Bone-Specific Skeletal Ages

Few have reported relevant data. The intraobserver differences were almost all less than 3 months in the study of Sproul and Peritz.[105] Moore[95] reported interobserver differences that were less than 12 months in 94 percent of bones.

Factors Influencing Replicability

There is no indication that the level of replicability is related to the difference between chronological and skeletal age.[98,101] However, the range of maturity between the bones of a hand-wrist influences the replicability of overall but not bone-specific assessments.[53,98] The quality of the radiographs (exposure, positioning) has no effect on replicability within the range usual in research studies,[53] but unusually poor radiographic quality does reduce replicability.[101] The method by which the Greulich-Pyle Atlas[5] is used has an effect. Maresh[60] reported a technical error of 3.0 months between overall assessments and those obtained as the means of bone-specific skeletal ages. The direction of these differences was not reported. Sproul and Peritz[78] considered assessment more difficult in short or tall children and in the hamate and second metacarpal than in other hand-wrist bones. The latter statement has not been confirmed in the Health Examination Survey on either self- or cross-replication data.

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