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Skeletal Maturity Of Youths 12-17 Years
United States

Skeletal age (hand-wrist), onset of ossification and bone-specific skeletal ages by chronological age and sex of boys and girls 12-17 years of age as assessed by the Health Examination Survey Standard based primarily on the Greulich-Pyle Radiographic Atlas.

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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 YOUTHS 12-17 YEARS

Alex F. Roche, M.D., *Fels Research Insitute*, Jean Roberts and Peter V. V. Hamill, M.D., *Division of Health Examination Statistics*

INTRODUCTION

This report presents national estimates of the levels of skeletal maturity of the hand-wrist for noninstitutionalized United States youths age 12-17 years based on findings from the Health Examination Survey of 1966-70. This is the first time estimates of skeletal maturity have been made for the youth age span in this or any other country, but national estimates from a corresponding study of children age 6-11 years in the United States in 1963-65 have been reported previously.[1,2] These national studies provide estimates of known reliability against which future possible changes in skeletal maturation rates for the country as a whole can be judged.

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 United States population.

Four types of survey programs are used to carry out the intent of the National Health Survey.[3] The Health Interview Survey, collecting information from samples of people by household interview, is focused primarily on the impact of illness and disability within various population groups. The programs in the Divisions of Health Resources Utilization Statistics and Health Manpower and Facilities Statistics 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 examinations, 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 many 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.[4,5]

For the second cycle or program, a probability sample of the noninstitutionalized children 6-11 years of age in the United States was selected and examined in 1963-65. The examination in this cross-sectional study primarily assessed health factors related to growth and development as described in a previous report.[6]

The third cycle, on which findings in this report are based, was designed as in the preceding children's program to collect data on the health status of the youth population with particular emphasis on factors and conditions related to their growth and development. For this, a probability sample of the noninstitutionalized youths 12-17 years in the United States was selected for examination. The questionnaires and examination content and procedures were similar enough to those in the children's program to obtain comparable information through adolescence for many variables but were supplemented, as necessary, to obtain data specifically related to adolescent health. Included were a physical examination given by a pediatrician assisted by a nurse, an examination by a dentist, tests adminstered by a psychologist, and a variety of tests and measurements by laboratory X-ray technicians. The survey plan, sample design, examination content, and operation of this survey program have been described in a previous report.[7]

Field collection operations for this youths' cycle, which started in March 1966, were completed in March 1970. Of the 7,514 selected in the sample, 6,768 youths, or 90 percent, were examined. This national sample is representative, and the examined group closely representative, of the 22.7 million noninstitutionalized youths 12-17 years of age in the United States with respect to age, sex, race, geographic region, population size of place of residence, and rate of change in size of population of place of residence from 1950 to 1960. The sample design for the youths' survey used the same sampling areas and housing units as the preceding survey among children. As a result, nearly one-third of the youths in the latter study had been examined in the children's survey also. The time lapse between the two examinations ranged from 28 months to 5 years with a median lapse of about 4 years.

The examinations were conducted consecutively in 40 different locations throughout the United States. During his single visit, each youth was given a standardized examination by the team in the mobile units specially designed for use in the survey. The only examinees given any additional followup procedures were girls whose urine specimens were found to be positive for bacteriuria, who were then brought back for repeat urine tests. Prior to the examination, demographic and socioeconomic data on household members as well as medical history, behavioral, and related data on the youth to be examined were obtained from his parents. Also an additional Health Habits and History form was completed by the youth before he arrived for the examination and a Health Behavior form was completed by him while in the examination center. Ancillary data were requested from the school attended by the youth, including his grade placement, teacher's ratings of his behavior and adjustment, and health problems known to his teacher. A birth certificate was obtained for each youth for verification of his age and for information related to his condition at birth.

As for the preceding national survey among children, some measure of skeletal age or maturation was considered essential to this study of health factors related to the normal growth and development of youths. In planning for the preceding study among children, the advice of clinicians and directors of long-term studies of growth and development had been 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, had recommended that Dr. S. Idell Pyle assemble a standard for the assessment of skeletal maturity from their radiographic series, specifically for use in the National Health Examination Survey.

At the formal request of the National Center for Health Statistics, the 1964 manual—the preliminary edition of *The Radiographic Standard of Reference for the Growing Hand and Wrist*[8]—was 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 made by medical students with special training in this method at Case Western Reserve University under the supervision of Dr. Pyle.

The same measure of skeletal maturation used in the preceding children's program was used in the youths' examination program also. The general concept of skeletal maturity, the methodology by which radiographs were taken and later assessed, and the quality control measures used were all identical to those in the children's study and have been described and discussed in the first report on skeletal maturity of children 6-11 years.[1]

The present analysis concerns age and sex differences in skeletal maturity levels for the United States population 12-17 years. For this purpose, satisfactory radiographs were available for assessment for 6,736 of the 6,768 examined youths. This represents 99.5 percent of the examined youths or 89.6 percent of the total probability sample selected for the national study. Among the youths examined, only 32 were not radiographed or had radiographs taken at the examination that were unsuitable for assesment.

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

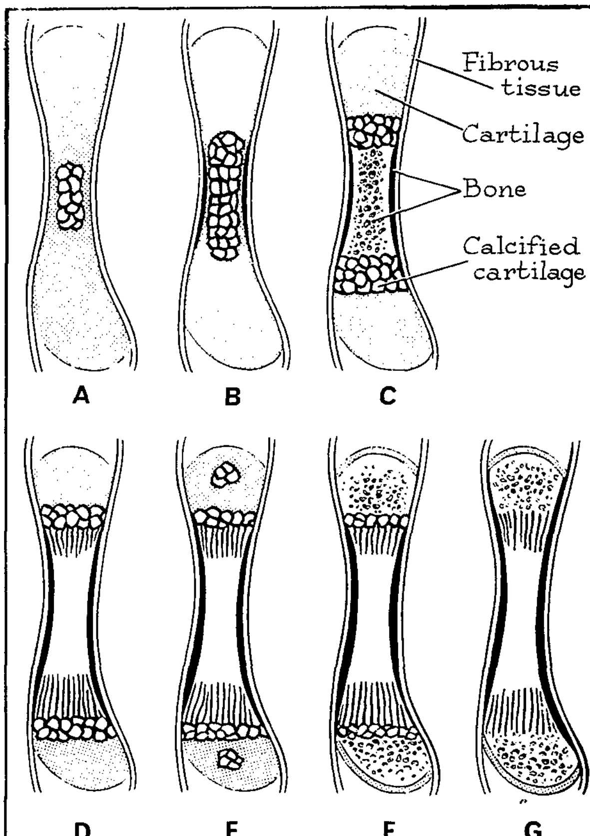
THE NATURE OF SKELETAL MATURATION

Generally, maturation of the skeleton is considered to begin when skeletal rudiments can be recognized first in the embryo; maturation is complete when comparative stability of skeletal form and function is attained in young adulthood. During maturation there is an increase in the number of specialized cells and biochemical mechanisms become more complex. The skeletal changes during senescence include a reduction in the number of specialized cells; this can be described 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.[9] The condensed connective tissue of the model is replaced by cartilage; this occurs first in the central part of each model.[10] The connective tissue around this cartilage becomes a well-defined layer called the perichondrium, the inner layer of which contains cells that can mature into chondrocytes or osteocytes. These cartilaginous models resemble in shape the adult bones they precede,[11,12] and they enlarge by apposition from the perichondrium, from the connective tissue related to their ends, and by the division of chondrocytes within the model.[10]

The chondrocytes in the central parts of the models hypertrophy and vacuolize at about the sixth prenatal week[10,13,14] (as shown in figure 1-A). The later calcification of this area[15,16] constitutes the first stage of skeletal maturation that can be observed radiographically. The area of hypertrophic chondrocytes and calcified cartilage enlarges more rapidly than the model. Consequently, these areas occupy a greater proportion of the model (figure 1-B). Ossification commences when a collar of bone forms deep to the perichondrium around the central part of the cartilaginous model (figure 1-B). Soon afterwards, ossification begins in the central part of the model by replacement of calcified cartilage (figure 1-C). The early stages



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.

of endochondral and subperiosteal ossification cannot be distinguished radiographically.

The ossified areas extend along the cartilaginous model both centrally (endochondral) and on its surface (subperiosteal) until they reach the future epiphyseal zones (epiphyseo-diaphyseal junctions) at each end of the model (figure 1-D). After this stage of maturation has been reached, the ossified area is called the diaphysis or shaft of the bone. Before this occurs, a marrow cavity forms by resorption in the central part of the ossified area. Marrow cavity information is not suitable for inclusion in a radiographic method of skeletal age assessment. For a considerable period after the diaphysis reaches the epiphyseal zones, the ossified area does not extend further, relative to the total length of the bone, but radiographically visible changes 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. 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).

At first, an epiphyseal ossification center enlarges rapidly in all directions. Later it enlarges more rapidly in some directions than others,[10,17] and its shape gradually resembles that of the cartilaginous end of the bone.[18] These changes in shape 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.[19,20] 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 in diaphyseal elongation and in the radiographic assessment of maturity.

The aspect of the epiphyseal ossification center in contact with the epiphyseal zone increases in cross-sectional area more rapidly than either the end of the diaphysis or the epiphyseal zone cartilage. There is convincing evidence that 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 epiphyseal zone.[21,22,23]

The increased cross-sectional area of this zone is associated with increases in the cross-sectional areas of the adjacent aspects of the epiphysis and of the diaphysis (flaring). The relationships between these changes are used in assessment.[24,25]

After an epiphyseal zone is present, the adjacent surfaces of the epiphyseal center and of the diaphysis gradually become reciprocal in contour. These 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 that 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 separating it from the calcified cartilage of the epiphyseal zone.[26] This layer of bone and the adjoining calcified cartilage together cause a dense radio-opaque line that is used in assessment. The ridges that develop at the limits of some muscular attachments cause radio-opaque lines that are used in assessment, e.g., of the distal portion of the ulnar diaphysis.[27]

The final phase of the maturation of a long bone is bony fusion between the epiphysis and the diaphysis. This is preceded by the formation of a thick layer of calcified cartilage in the epiphyseal zone.[28] This calcified cartilage is replaced by bone and, progressively, the remaining epiphyseal zone cartilage is calcified and replaced by bone. Ossification of the peripheral part of the 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 original cartilaginous model. The bone has now attained adult maturity and further elongation is not normally possible (figure 1–G).

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 ossification centers. Each carpal bone develops first as a condensation of embryonic connective tissue. Subsequently, cavitation occurs in this tissue in the regions 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 some surfaces and is covered by a well-defined perichondrium on other surfaces (figures 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.[29] At first, the ossified area expands rapidly in all directions;[10] later growth is more rapid in some directions than others (figure 2-D, 2-F).

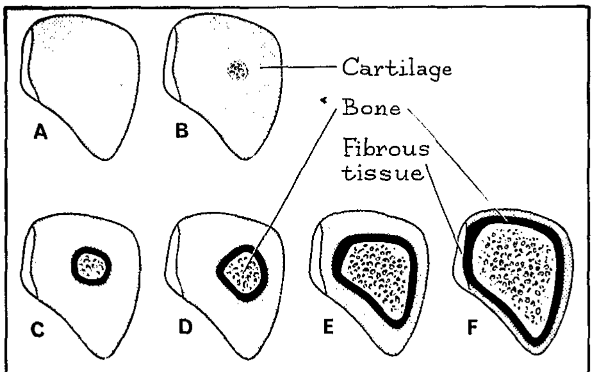
Radiographic Changes

Knowledge of skeletal maturation increased rapidly after radiographic techniques allowed serial studies of normal children. The early work of Rotch,[30] Bardeen,[31] Pryor,[32] and Hellman[33] led to the elaboration of the Todd[34] and Greulich-Pyle [27,35] methods of assessment.

The radiologically visible changes used to assess skeletal maturity are called "maturity indicators;" skeletal maturity cannot be seen in radiographs. By definition, these indicators appear in a fixed sequence for each bone, [27,36,37] although the sequence is not fixed for an area, e.g., hand-wrist that includes many bones.[38-40] Each indicator must appear during maturation in every child to be useful in the assessment of skeletal maturity.[37]

The radiographic assessment of skeletal maturity depends on the presence and relative radiodensity of areas of calcification or ossification. These differences in radiodensity reflect the 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 radiographic beam cause dense white zones on a radiograph.

The changes in contour during maturation, as bones become more adult in shape, are important in the radiographic assessment of maturity. These changes reflect different rates of bone apposition at various areas. Although the changes in shape are associated with changes in size, the elements of size used to assess maturity concern relative size (shape), not absolute size. Use of absolute size would lead to the unacceptable conclusion that adults differ in maturity.



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.

Scale of Maturity

The scale used in radiographic assessment is based on the assumptions that skeletal maturity is absent at conception, that all young adults are completely mature, and that normally individuals pass through the same sequence of maturity stages. By these premises, each individual achieves the same amount of maturation between conception and adulthood, although the rates of maturation differ among individuals. In practice, the origin of the scale is the onset of ephiphyseal or carpal ossification, as observed radiographically. Probably some radio-opaque epiphyseal or carpal centers consist of calcified cartilage rather than bone when assessors regard them as "ossified." The only incontrovertable radiographic evidence that bone is present is the recognition of trabeculae; 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 epiphyseal fusion in bones that have epiphyses and the attainment of final adult shape in carpal bones.

The skeletal maturity scales for individual bones cannot be divided into units 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. These standards represent the central tendencies of skeletal maturity level in healthy children and youths grouped by chronological 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 must 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 not known whether a boy with a skeletal age of 2 years is twice as mature as a boy with a skeletal age of 1 year. 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 (e.g., skeletal age, 9 years) have achieved the same percentage of adult maturity, although the actual percentage cannot be calculated because it is based on an ordinal scale. 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 by the fact that adults differ in weight and, therefore, one should not infer that two boys each weighing 60 kilograms have achieved the same percentages of their adult weights.

The scale used to assess the radiographs from Cycles II and III is presented in the radiographic standard of reference of Pyle et al.,[8] referred to in this report as the HES Standard. This scale was derived principally from the Greulich-Pyle Atlas,[27] which contains reproductions of ordered sets of radiographs for each sex. Each of these radiographic standards is accompanied by skeletal age equivalents in months or years for each bone and for the whole hand-wrist area.[a]

[a]The method by which the standard radiographs were selected is described by Greulich and Pyle[27] and Pyle et al.[8]

THE USEFULNESS OF SKELETAL MATURITY ASSESSMENTS

This topic will be outlined separately for various professional groups despite the obvious overlap between their needs and interests. National normative data are essential for each of these groups.

Pediatricians.—There is increasing awareness of genetically determined syndromes in many of which the rates and pattern of skeletal maturation are abnormal. Skeletal age assessments are necessary to define these syndromes better, to assist tentative diagnosis, and to increase understanding of the temporal and topographic aspects of the associated skeletal changes. They are significant also in relation to the more than 2 million youths in the United States who are outside the 5th to the 95th percentile range for stature. Commonly, there is concern on the part of youth and parent about the deviant present stature of the youth and the possibility that his mature stature will be deviant also. This concern can be responsible for considerable adverse psychological effects, especially near the usual age of puberty, when many short or tall youths become increasingly deviant in stature. The management of youths with unusual statures should begin with assessments of present size and maturity and be directed towards diagnosis.

Assessments of skeletal maturity are necessary in selecting children for therapy, more effective regulation of therapeutic agent dosage, and more accurate estimates of therapeutic effects on potentials for growth in stature. Selection for therapy is particularly difficult when the therapeutic agent is scarce, e.g., human growth hormone. In this selection, not only diagnosis but need must be considered; reliable estimates of mature stature are necessary to identify those children most in need from a physical viewpoint. At many ages these estimates must be based on the assessment of skeletal maturity.[41] To take another example: an artificially induced pseudopuberty may be psychologically necessary in a girl with Turner's syndrome, although this treatment may reduce her potential for growth in stature. Clinical judgment is necessary in each individual case, and will remain necessary, to decide when and whether to induce a pseudopuberty.

This judgment should depend, in part, on assessments of skeletal maturity to determine her present status and her potential for growth in stature. The more reliably her mature stature could be predicted, and if serial predictions are obtained during therapy, the sounder would be the pediatrician's judgment. These predictions depend upon estimates of potentials for growth in stature and, in turn, these estimates require assessments of skeletal maturity.[42,43]

Some short children are treated with "anabolic" steroids that have high anabolic-androgenic ratios when the latter are measured by the current unsatisfactory methods. The inadequacy of these ratios to indicate therapeutic effectiveness has been reviewed in detail.[44] When such therapy is used in attempts to increase the growth potentials of short children, its effects on skeletal maturation must be monitored carefully. Similar considerations apply to the regulation of dosage during therapy with thyroxin and many other therapeutic agents. Also skeletal maturation assessments assist investigations of the determinants of skeletal morphology and the effects of drugs, hormones, malnutrition, and illness.

Pediatric surgeons.—Assessments of skeletal maturity provide significant help to orthopedists through their application to disassociations between the rates of skeletal elongation and skeletal maturation during pubescence, when "catchup growth" occurs or when the blood supply to all or part of the skeleton is abnormal, e.g., in congenital heart disease or in peripheral arteriovenous anastomoses. The associations between the rates of skeletal maturation and skeletal elongation are important in estimating the growth-related effects of cardiac surgery and in selecting ages for this surgery. They are essential in selecting the sites and ages for surgical induction of epiphyseal fusion in children with legs of unequal length.

Speech therapists.—Some children who cannot achieve palatopharyngeal closure differ from normal in cranial base flexion or in the lengths of cranial base segments. The management of these and other children can be improved by the intelligent use of assessments of skeletal maturity. There is considerable evidence that growth potential in the cranial base is related to the maturity of other parts of the skeleton.[45-50]

Orthodontists and craniofacial surgeons.—Orthodontic diagnosis and treatment depend, in part, on the interpretation of metric data derived from standardized cephalometric radiographs. The relationships in normal children between metric variables of direct concern to orthodontists and their changes across time should be considered in relation to skeletal maturity status. Assessments of skeletal maturity are important also in determining whether pubertal spurts have already occurred in the craniofacial area of an individual and if not, the chronological ages at which they are to be expected. The occurrence of these spurts has been demonstrated recently.[50-53] Similar considerations apply to craniofacial surgery in individuals who are still growing.

Nutritionists.—Anthropometric data, e.g., stature, body weight, and subcutaneous fat thickness are used to recognize and grade malnutrition and to assess the effectiveness of intervention programs. Generally, it is considered that the effects of intervention are favorable if there is catchup growth.[54-56] Usually these spurts (catchup growth)in anthropometric variables are considered in relation to chronological age. It would be more meaningful to use biological age as a time base, and the best available biological age for this purpose is skeletal age. Alternative clinical approaches have included the use of multiple regression techniques to obtain a biological age from a combination of anthropometric variables and skeletal age.[57,58] The wisdom of this approach is doubtful, especially if an inadequate measure of skeletal maturity is employed. Catchup growth is favorable only if it is not associated with excessive skeletal maturation and thus a reduction in the potential for growth in stature.

Human biologists.—There is a need for studies of associations between elongation and maturation within and between bones. These associations are of real interest to human biologists apart from their health-related significance. This is clear from the abundant literature relating separately to each, but there have been surprisingly few studies of their associations. Assessments of skeletal maturity are also of use as a measure of biological age to classify data on biological and behavioral characteristics of children in addition to the usual chronological age categories. Other aspects of concern to human biologists include genetic and environmental influences on skeletal maturation rates and possible secular changes in skeletal maturation levels. Proper study of the latter topic requires data from successive national probability samples. Much of the reported data, relating to secular changes, is difficult to interpret because of vagaries of sampling, the generally small group sizes, and differences in the methodology of assessment and analysis.

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 both for the children's survey and the present one of youths 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. This standard is based on the premises that the process of growth implies maturation, that there are marked individual differences in the timing and rates of maturation but not its sequence, and that the rate of skeletal maturation in the hand-wrist is an acceptable indicator, for the purposes of this survey, of the overall rate of skeletal maturation of a child or youth. The standard further assumes that the transitional, ossifying features and articular facets (maturity indicators), identifiable on radiographs, are generally the same for both sexes and all races but that the age intervals between which these features develop are not uniform. It is well known that maturation occurs more slowly in males than in females who are on the same developmental schedule relative to norms for their own sex.

The HES Standard for the hand-wrist has been based on and in part abstracted from the 1959 Greulich and Pyle Radiographic Atlas.[27] 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 between the ages of 3 months and 18 years. It includes radiographic standards at intervals of 3 to approximately 12 months. Their spacing depends upon the modal rate of maturation in the period. The Atlas contains a series of standards (modal radiographs) and skeletal ages for males and another series 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.[27] With appropriate modification and supplementation, they provided a series of typically occurring discernible features of developing hand-wrist bones—a series spaced at irregular age intervals from 3.8 months to 228 months of skeletal age. These features were related, as accurately as possible, to the chronological age levels at which they appeared in the modal position for the Cleveland boys and girls 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 HES Standard for the male hand-wrist.

Although each plate in the published HES Standard shows the skeletal age equivalents for both males and females, those who assessed the national survey radiographs were not told the sex or chronological age of the children or youths whose radiographs were being assessed. The skeletal ages assigned were based on the male equivalents accompanying each standard plate. In this report, the skeletal age data for girls are shown both as 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 throughout this survey among youths, as in the previous one among children, to obtain national estimates of the comparative levels of skeletal maturation between the two sexes.

METHOD

At each of the 40 preselected locations throughout the United States used consecutively in this study, the youths were brought to the centrally located mobile examination center for a standardized examination that lasted about 3½ hours. Six youths were examined in the morning and six in the afternoon. When each youth entered the examination center, his oral temperature was taken and a screening for acute illness was made. If such illness were detected, the youth was sent home and reexamined later. Each examinee changed into gymnasium-type shorts, cotton sweat socks, and a robe; for girls only, also a light sleeveless topper. Then all six proceeded to designated different stations for the start of the examination. The examination was divided into six 35-minute time periods, each consisting of one or more detailed examinations at a designated location, except for the psychological component, which consisted of two consecutive time periods (70 minutes). At the end of each period the youths rotated to another station so that during the 3½ hours each youth had essentially the same examinations by the same examiners but in a different sequence. Four of the examination time periods were allocated to examinations by a pediatrician, a dentist, and a psychologist, and the other two were allocated to a group of tests and examinations performed by highly trained technicians. This last group of examinations consisted of radiographs of the chest and hand-wrist, hearing tests, measures of respiratory function, a 12-lead electrocardiogram, a submaximal exercise tolerance test on a treadmill with chest leads to a continuous electrocardiogram, a battery of body measurements, determination of grip strength, examination of blood, and a privately administered health behavior and attitude questionnaire, and on girls only urine cultures for bacteria.

The time of each part of the examination was recorded, but as in the children's examination, there is no reason to believe that diurnal or sequence effects would be present in the composition or quality of the radiographic data.

Field Radiography

The methods used in field radiography were identical to those in the preceding children's program of examinations. Each youth was scheduled to have a 10" X 12" radiograph of the right hand and wrist, at a tube-film distance of 36 inches, for which the positioning was otherwise in accordance with specifications in the Greulich and Pyle Atlas.[27] The fact that some radiographs were made using other film sizes when the 10" X 12" size was scarce would not have influenced the findings. Technically inadequate films could be repeated because they were developed immediately in the field. Hence each youth's record contained a single radiograph showing the dorso-palmar view of his entire hand-wrist with its full complement of ossifying parts at his examination age.

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. When selected Greulich-Pyle Atlas standards and those from other sources were reproduced in the HES Standard, they were reversed photographically so they could be used in right-side assessments. Previous reported research by Roche[59] 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.

Training of Assessors

The assessment of skeletal age from the hand-wrist radiographs of youths 12-17 years of age in the Health Examination Survey of 1966-70 was made by nine medical students at Case Western Reserve University. These included five of the six medical students who had done the assessments in the 1963-65 national survey among children age 6-11 years.[1] This work was also done under contract, with Dr. P. Wesley Dupertius as Project Director, for the National Center for Health Statistics. Prior to their training under the 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 in the Greulich-Pyle Atlas.[27]

The practice procedures used in training were based on 30 contact-size prints of hand-wrist radiographs used with the 1959 edition of the Greulich-Pyle 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 practice, each assessor first arranged the 30 prints into what he considered the ascending skeletal maturity order. The bone-specific skeletal ages for each print were assessed according to the *male standards* in the Greulich-Pyle Atlas 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 these hand-wrist skeletal ages and the new array was assessed according to the *female standards* in the Greulich-Pyle Atlas. Then the first set of bone-specific skeletal ages, based on the *male standards*, was 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 the assessments 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 of Dr. Pyle—the majority of differences were within 4 months—the new assessor began his assessment of the survey radiographs. Reported evidence[60] suggests that, at the end of this training procedure, the interobserver and the intraobserver differences in skeletal maturity ratings should have been similar to those for experienced assessors.

Assessment Procedure

The radiographs from the survey examination were assessed by comparison with prints of the series of standards for the male hand-wrist selected from those in the Greulich-Pyle Atlas[27] and other sources which have been reversed so they appear to be of the right hand-wrist as shown in the *Radiographic Standard of Reference* of Pyle et al.[8] This standard contains the male skeletal age equivalents that were used during the assessment of radiographs for children and youths in Cycle II (6-11 years) and Cycle III (12-17 years), with some very slight modification to smooth the skeletal age trend for a few bones.

In making the assessments the readers did not have access to the chronological age, sex, or any other information about the youth. The assessor rated each bone separately and interpolated between the standards to monthly intervals when this appeared appropriate.

As a quality control measure and to permit determination of the level of reliability of the assessments throughout this study, independent replicates were obtained on approximately one out of each 11 films. One randomly selected radiograph in 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. The time lapse between the first and the reassessment was sufficiently long that there was little likelihood of recall. Furthermore, there was no indication to the assessor that he was making a reassessment. 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. The limits that were applied in the survey are in table A. For example, a trapezoid is not visible until Plate 12 of the HES Standard, where the hand-wrist skeletal age (male) is equivalent to 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: the minimum ages for the pisiform and the adductor and flexor sesamoids were placed 2 months above the levels of last plates in which these bones were not radio-opaque. These exceptions were made because the limits were set *after* the assessments had been made and, for many radiographs, the

Table A. Minimum and maximum acceptable skeletal ages in months using the HES male standards: Health Examination Survey, 1966-70

Hand-wrist bone	Minimum[1]	Maximum[2]
	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 Phalanx 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

[1]Minimum age (according to standard) of radio-opacity of epiphysis or carpal.

[2]1 month below "adult" age.

assigned ages for 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 the skeletal ages in months for each bone beyond which only the designation "adult" can be applied. Because the assessments were made to 1-month intervals, the maximum value for each bone was 1 month below its adult value. The maximum values 1 month below these "adult" skeletal ages are shown in table A.

It should be noted that the limits in table A refer to *male* skeletal ages only, because these were assigned to all the survey radiographs, irrespective of sex. The assessors did not know the sex of the youths. 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 essentially 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.[8] 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[27] 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 presented both in terms of the male age equivalents as assigned and also in terms of female equivalent skeletal ages. The conversion was done by computer, bone by bone, using the equivalency data in the HES Standard with interpolation between the published values to monthly intervals. The skeletal ages for the hand-wrist area as a whole, for boys and girls, were determined by averaging the ages assigned to each ossifying hand-wrist bone for each youth.

FINDINGS

Skeletal Age (Hand-Wrist)

The trend and extent of variation in the timing and velocity of skeletal maturation among United States boys and girls age 6-11 years, as measured by the HES Standard for the hand-wrist using the Greulich-Pyle method, have been described and analyzed.[1] Those national estimates are based on findings from the Health Examination Survey in 1963-65 among a national probability sample representative of noninstitutionalized children in this country. The scale used, both in that report and the present one, 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. Those bones that have reached complete maturity or the "adult" stage—epiphyseal fusion completed in bones that have epiphyses or final adult shape in the carpals—are excluded in determining skeletal age. Among those of 6-11 years, none of the boys and less than 1 percent of the girls had any "adult" hand-wrist bones.

National estimates for skeletal age (hand-wrist) of youths 12-17 years, based on findings from the Health Examination Survey of 1966-70 among the national probability sample representative of civilian noninstitutionalized youths, are limited to those who have at least 1 of the 31 hand-wrist bones still maturing (i.e., not yet "adult"). The proportion of boys consequently excluded in this determination because all 31 bones had reached adult maturity increases from zero at ages 12-14 years to 10 percent at age 17 years. Among girls, the proportion excluded increases from zero at age 12 years to 22 percent at age 17 years. As a result, at age 17 the skeletal age comparisons in this report are based on almost all the boys (90 percent) but only about three-fourths (78 percent) of the girls—the less rapidly maturing.

Due to the difficulty of accurately assessing skeletal age within the 6 months preceding the final adult stage, the readers arbitrarily assigned values of "A-6" to those bones that were considered to be within 6 months of the adult stage. In boys it can be assumed that such a bone would have become adult within the next 6 calendar months; in girls the corresponding changes would have required no more than 5 calendar months because girls mature more rapidly than boys. This sex-associated difference in maturation rates was taken into account when transforming the male values assigned to the girls to female equivalent values. However, the use of the designation A-6 for the entire last 6-month interval results in a

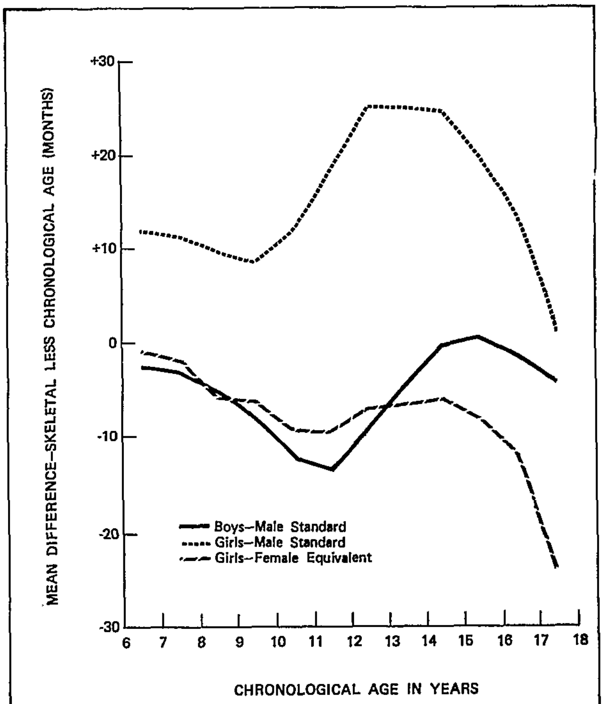


Figure 3. Mean difference in months between skeletal age (hand-wrist) and chronological ages of boys and girls against the male standard and female equivalent values for girls, by chronological age in years for ages 6-17 years: United States, 1963-70.

slight but increasing underestimate in the skeletal ages for older youths as they approach skeletal maturity. The extent of underestimation will necessarily be slightly greater among girls when assessed against the male standard than among boys but will be less than 2 months, on the average, even at 17 years of age for girls, where the effect will be at a maximum.

The mean skeletal age (hand-wrist) of boys in the United States increases consistently with chronological age from 11.7 years (140.2 months) for those 12 years of age at their last birthday (mean chronological age 12.5 years or 150 months) to 17.1 years (205.4 months) at chronological age 17 years (mean chronological age 17.5 years or 210 months) (table 1 and figure 3). The yearly increment in skeletal age is greatest among the younger boys age 12-13 years, when it reaches a maximum of 17 months, or just slightly greater than at 11-12 years and 13-14 years (where the increments were 16 months), then decreases to 10 and 9 months at ages 16 and 17 years or to about the same level of increment as that found in the 1963-65 national survey among boys 6-11 years old.

The lag of mean skeletal age (hand-wrist) behind chronological age for boys which had increased from 2.5 months at age 6 years to 13.8 months at age 11 years (from the 1963-65 national survey) drops from that peak to 9.8 months at age 12 years and continues decreasing to become less than 1 month behind at 14 years and 0.5 month in advance of chronological age at 15 years. At 16 and 17 years the mean skeletal age of boys again lags behind their chronological age by 1.6 and 4.6 months, respectively (figure 3). The apparent lag in skeletal age among older boys may, at least in part, be an artifact of the method used for this determination. By excluding bones that are mature (adult), a smaller base remains for the determination of skeletal age (hand-wrist). Furthermore, as mentioned earlier, boys were excluded if all the hand-wrist bones were adult. Among boys, the mean number of bones that are still maturing (not yet adult) decreases consistently from 29 at ages 12 and 13 years to 6 at age 17 years (table 5 and figures 4 and 5).

Among girls, when assessment is made against the HES Standard for males by readers not knowing the sex of the youth, the mean skeletal age (hand-wrist) increases from 14.6 years (174.9 months) at chronological age 12 years (mean 12.5 years or 150 months) to 17.6 years (211.3 and 211.5 months) at ages 16 and 17 years (when the means for chronological ages were 16.5 years or 198 months and 17.5 years or 210 months, respectively). The yearly increment in skeletal age for girls in the age span 12-17 years is consistently less than that for boys, in contrast to findings among children 8-12 years. For girls it is maximal between 10 and 11 years (18.8 months) from the 1963-65 national survey and then steadily decreases to less than 1 month between 16 and 17 years. This decrease in yearly increments is largely artifactual due to the exclusion of hand-wrist bones that had become adult in the older girls. The skeletal age ratings against the male standard consistently exceed the chronological age of U.S. girls by mean values ranging from less than 2 months at age 17 to 24-25 months at 12-14 years.

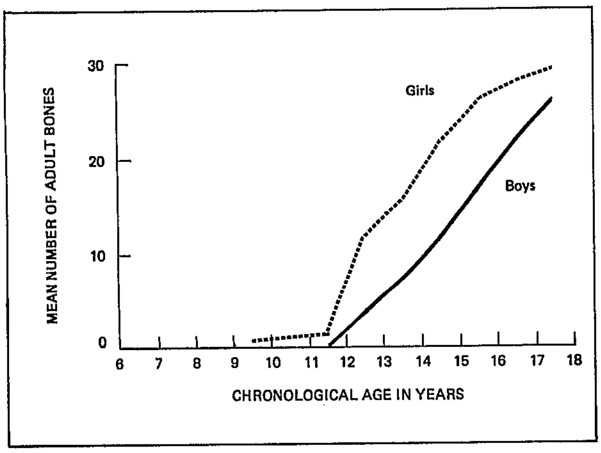


Figure 4. Mean number of adult bones in the hand-wrist of children and youths ages 6-17 years by chronological age in years and sex: United States, 1963-70.

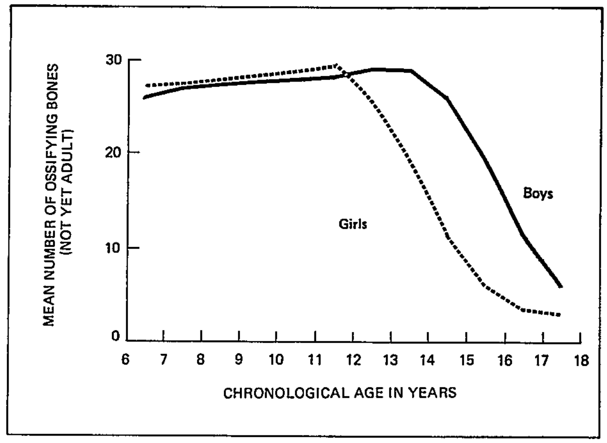


Figure 5. Mean number of ossifying (not yet adult) bones in the hand-wrist of children and youths ages 6-17 years by chronological age in years and sex: United States, 1963-70.

After transformation to female equivalent skeletal ages as described in the *Methods* section, the mean skeletal age (hand-wrist) of U.S. girls increases with chronological age from 11.9 years (142.9 months) at age 12 years (mean 12.5 years or 150 months) to 15.5 years (185.6 and 186.0 months) at chronological ages 16 and 17 years, respectively. The lag of skeletal age (female equivalent values) behind chronological age for girls of age 12 years is slightly less than the maximum value for the female children which occurred at age 11 years in the 1963-65 national survey (7.1 months at age 12 years compared with 9.8 months at age 11 years) and decreases slightly to a minimum of 6.0 months at age 14 years. From age 15 years on, the lag of skeletal age behind chronological age becomes progressively greater, reaching a maximum value of 24 months at chronological age 17 years, in sharp contrast to the findings for boys.

These deviant findings among older girls reflect the substantial exclusion of the bones in which skeletal maturation was more rapid. The mean number of bones on which skeletal age determinations were made for U.S. girls decreased from 26 bones at age 12 years to 5.9, 3.6, and 3.4 bones at ages 15, 16, and 17 years, respectively. As a result, the estimates for the hand-wrist skeletal age for the older girls would be less reliable than for younger girls and are based on bones last to become adult. In addition, nearly 22 percent of the 17-year-old girls were excluded from the group for whom skeletal age (hand-wrist) was determined because *all* 31 hand-wrist bones in these girls were rated as adult.

The extent to which the mean hand-wrist skeletal ages for youths 12-17 years of age have been affected by the exclusion of youths in whom *all* the hand-wrist bones have reached adult levels of maturity can be estimated if it is assumed that the maximum adult skeletal age is equivalent to about 19.1 years or 229 months (male adult value for the radius, which is the last hand-wrist bone to become adult). This value was chosen arbitrarily to maximize the skeletal age of the hand-wrist in each excluded youth. The effects of these adjustments (table B) would be to increase the mean skeletal age (hand-wrist) for all 17-year-old boys by 2.5 months and to reduce the lag behind their mean chronological age from 4.6 to 2.1 months. For girls the adjustment would be negligible until age 17 years, when skeletal age (hand-wrist), as determined from the male standard, would be increased by 3.8 months and the female equivalent values would be increased by 2.7 months. At age 17 this would leave the mean skeletal age (hand-wrist) for girls on the male standard nearly half a year (5.3 months), on the average, in advance of their chronological age (rather than 1.5 months) and would reduce the mean lag of the female equivalent value behind the chronological age from 24.0 months to 21.3 months. *It is stressed that these adjustments were not actually made for any of the data in this report.* The data in table B illustrate, however, the maximum effect that could have resulted from the exclusion of youths in whom all the hand-wrist bones were adult.

An alternative procedure was considered but was not adopted. The median of all bone-specific skeletal ages could have been used instead of the mean—this value would have been less affected than the mean by the exclusion of values for bones

Table B. Mean skeletal age (hand-wrist) of youths age 12-17 years as determined from those youths with some bones still maturing and also as determined from the "total sample" of youths: United States, 1966-70

Chronological age at last birthday	Boys		Girls (male standard)		Girls (female equivalent)	
	Some bones still maturing	Total sample[1]	Some bones still maturing	Total sample[1]	Some bones still maturing	Total sample[1]
	Mean skeletal age (hand-wrist) in months					
12 years	140.2	140.2	174.9	174.9	142.9	142.9
13 years	157.4	157.4	186.6	186.7	155.2	155.3
14 years	173.6	173.6	198.0	198.1	168.0	168.1
15 years	186.5	186.6	205.6	205.9	177.6	177.8
16 years	196.4	196.7	211.3	211.9	185.6	186.1
17 years	205.4	207.9	211.5	215.3	186.0	188.7

[1]The "total sample" includes youths with all 31 hand-wrist bones rated as adult. For these youths, a skeletal age of 229 months on the male standard and of 207 for the female equivalent has been assigned.

that had become adult. This procedure was not used because it implies that all "adult" bones are at the upper end of the scale in skeletal age months (which is not true for some bones, e.g., distal phalanges) and it would have introduced inconsistencies between the present method of analysis and that applied earlier to the data from children.[1]

In contrast to the findings among 6-11 year old children, the lag of skeletal age behind chronological age diminishes with chronological age from 12-14 years, markedly for boys and very slightly for girls (female equivalent values for the latter). When the data for the girls assessed against the male standards are considered, there is scarcely any change in the extent of their advancement of skeletal age over chronological age during the 12-14 year age span (i.e., points plotted at 12.5-14.5 years in figure 3). After age 14, the mean skeletal-chronological age differences for the boys decrease slightly until 15 years and then increase so that at 17 years the mean skeletal age is about 5 months less than the chronological age.

When the girls are assessed against the male standards, the mean skeletal ages exceed the chronological ages but by an amount that decreases sharply after 14 years to a difference of only about 1 month at 17 years. However, when the female equivalent values are considered, there is a sharp increase in the mean amounts by which the skeletal ages are less than the corresponding chronological ages. This occurs, in part, because the male-female differences that were used to transform the data for girls to female equivalent values are essentially constant across age after 15 years. Put another way, among these older girls, the mean hand-wrist skeletal ages (female equivalent values) become increasingly lower than chronological age as chronological age increases. For girls 15-17 years old, the rate of change in the difference between skeletal and chronological age, with chronological age, is substantially greater than during childhood (6-11 years).

The sex-associated differences in skeletal maturity are shown more clearly by the mean differences between the skeletal ages assigned to the boys and to the girls when all are assessed against the same set of male standards. These differences (in months of skeletal age, male) are about 32 months at 11 years and 35 months at 12 years. As later ages are considered, these mean differences decrease progressively until 17 years, when the difference is about 6 months.

The mean hand-wrist skeletal ages of girls, after transformation to female equivalent values, are about 3 months more advanced than those of boys at age 12 years, continuing the trend present among children 10 and 11 years old.[1] However, from age 13 years on the mean values for boys become increasingly greater than those for girls by values ranging from 2 months at 13 years to over 19 months at age 17 years.

To illustrate these sex differences better figure 6 is presented as a transformation of figure 3. In figure 6 the male skeletal age values have been placed at the zero line by making the mean skeletal ages for the males equal to their mean chronological ages. Consequently, both sets of female values in this figure (those read on the male scale and those based on female equivalent values) represent, at any age, the mean difference from

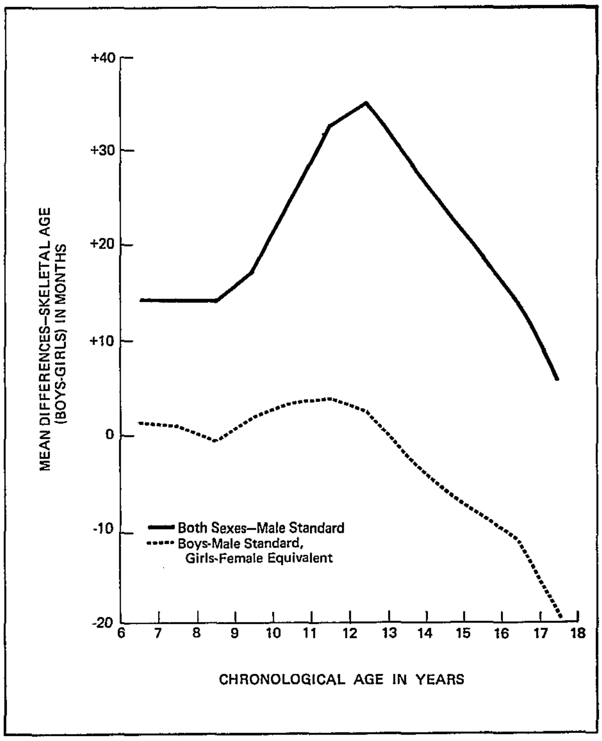


Figure 6. Mean differences in skeletal age (hand-wrist) between boys and girls based on (1) determinations against the male standard for both sexes and (2) after conversion to female equivalent values for the girls at chronological ages 6-17 years: United States, 1963-70.

the male values. As a result of this transformation, the pubertal spurt of skeletal maturation in the girls is shown more clearly. The female equivalent values are close to zero from 6 to 13 years, showing that the transformation from the values obtained by assessments against the male standards was appropriate. It can be seen also that the female equivalent values fall below zero at about 13 years, indicating that at later ages the "standards" are set too high or the sex differences that were applied were too large. Of course, the national survey data would allow a more exact transformation to make the female equivalent values equal to zero in figure 6 (mean chronological age equal to mean skeletal age). This has not been done.

When the rate of skeletal maturation of youths is considered over 6-monthly rather than yearly chronological age intervals, the trend is similar but slightly less consistent (table 1 and figure 7). Mean half-year increments range from a maximum of 11 months (skeletal age) for boys during their 13th year (12 to 13) to a minimum of 2 months during their 18th year (17 to 18) of chronological age. The 6-month increments for girls, either on the male standards or using female equivalent values, are similar to the findings at yearly age intervals. Generally, they are less than those for boys and are slightly greater among younger (12 and 13 years) than older (16 and 17 years) girls (5-7 months compared with 2 months or less).

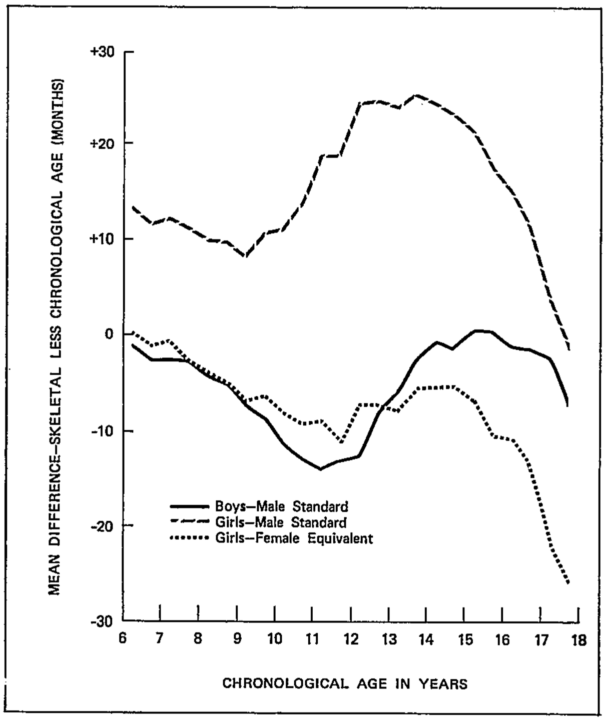


Figure 7. Mean difference in months between skeletal age (hand-wrist) and chronological age of boys and girls against the male standard and female equivalent values for girls at 6 months of chronological age for ages 6-17 years: United States, 1963-70.

The mean skeletal ages for both boys and girls show a similar but less consistent decreasing trend when considered in single-month intervals of chronological age (table 2). This would be expected because the sample is too small to provide reliable estimates within these brief age intervals.

Variability in skeletal age (hand-wrist) has been compared using the standard deviations. These are substantially greater among boys 12-16 years of age than among those 6-11 years of age from the 1963-65 national survey. When calculated for annual intervals, the standard deviations range from a maximum of 18 months at age 13 years to a minimum of 11 months at 17 years. An increase in variability in boys became evident at age 11 years in the earlier study of children, when the standard deviation increased from nearly 10 months at age 10 years to more than 12 months at age 11. By age 12 and 13 years the standard deviation increases to 17 and 18 months, respectively, but later decreases gradually to a level similar to that found among children (11 months).

Among girls the maximum variability during the entire age span 6-17 years, as measured by the standard deviation, is reached at age 10 years, both for skeletal age recorded on the male standard and for the transformed female equivalent values. The level of variability at age 12 years (nearly 15 months on the male standard values) is similar to that at 11 years but then decreases to a minimum (for the entire age range 6-17 years) of about 9 months at 15 years and remains just slightly above this level at 16 and 17 years (table 1).

The relative variability in relation to the mean was measured by the coefficient of variation (100 times the standard deviation divided by the mean), which was calculated for each annual interval. In

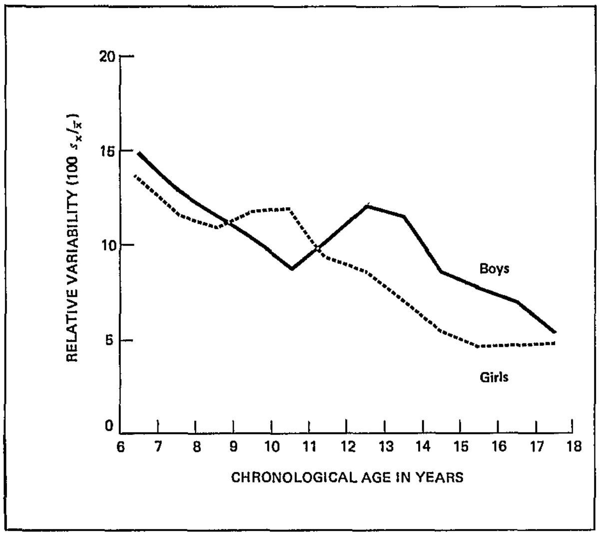


Figure 8. Relative variability in skeletal age (hand-wrist) by chronological age in years for boys and girls ages 6-17 years: United States, 1963-70.

boys, after reaching a minimum value (less than 9) at age 10 years, these coefficients increase to a maximum of 12 at 12 years of age and then steadily decrease to the minimum value of 5 at age 17 years. For girls, when assessed against the same male standards, these coefficients decrease steadily from nearly 12 at 10 years of age to about 5 at 15-17 years (figure 8). Boys are consistently more variable than girls throughout the age range 12-17 years. Considering the combined age ranges (6-17 years) of the previous survey of children and the present one of youth, the findings show that boys are more variable in skeletal age than girls at all ages except at 9 and 10 years. The patterns of change are essentially the same in each sex, but the alterations occur about 2 years earlier in the girls. This would indicate that the relative variability is the same for each sex at the same actual stage of maturation.

The distribution of skeletal ages within each chronological year of age tends to be fairly symmetrical and close to normal among younger boys and girls 12-14 years of age (tables 3 and 4 and figure 9). At no point, over the 12-17 year age range, do the mean and median values in the distributions of skeletal ages for boys or girls differ by more than 3 months, which is similar to the findings among children 6-11 years in the 1963-65 national survey. Among the older girls, particularly, and to a lesser extent among the older boys, the distributions become progressively more skewed to the right (toward the maximum values) as more of the youths approach skeletal maturity. The greater effect in the girls reflects the fact that their skeletons are maturing more rapidly than those of boys.

Previous reported data for youths in the United States.—Comparison with findings from previous investigations has been restricted to those studies that included at least 25 boys or 25 girls at each annual age interval. Many of these studies have been described earlier in the report concerning children;[1] in this account there are some changes in sample size and birth dates because of the different age range to which reference is made. In some of these investigations radiographs were taken of the right hand-wrist but the possible small lateral differences in skeletal maturity have been disregarded in this review.

Mean level.—To facilitate comparisons, the data reported by various investigators have been adjusted to a common Greulich-Pyle baseline (figures 10-13). To achieve this adjustment, the standard plates of Flory[61] and Todd[34] have been assessed using the Greulich-Pyle Atlas[27] to assign bone-specific ages, interpolating when this appeared desirable. This is a rather unsatisfactory procedure towards 17 years (chronological age) when many bones have become adult and the reliability of assessments is necessarily reduced. In addition, some plates in the Flory Atlas are reproduced so indistinctly that the carpals cannot be assessed. The maturity levels assigned to the Flory and Todd plates, in common with the Greulich and Pyle standards, are modal values rather than means. Most investigators have reported means and standard deviations for skeletal age within chronological age groups,[27,62-64] but Maresh[65] reported medians.

The Greulich and Pyle skeletal maturity standards were selected from radiographs of white youths of upper socioeconomic status living in Cleveland. These youths were born between 1917 and 1942 and were radiographed close to their birthdays and half birthdays. The method by which the 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.[27]

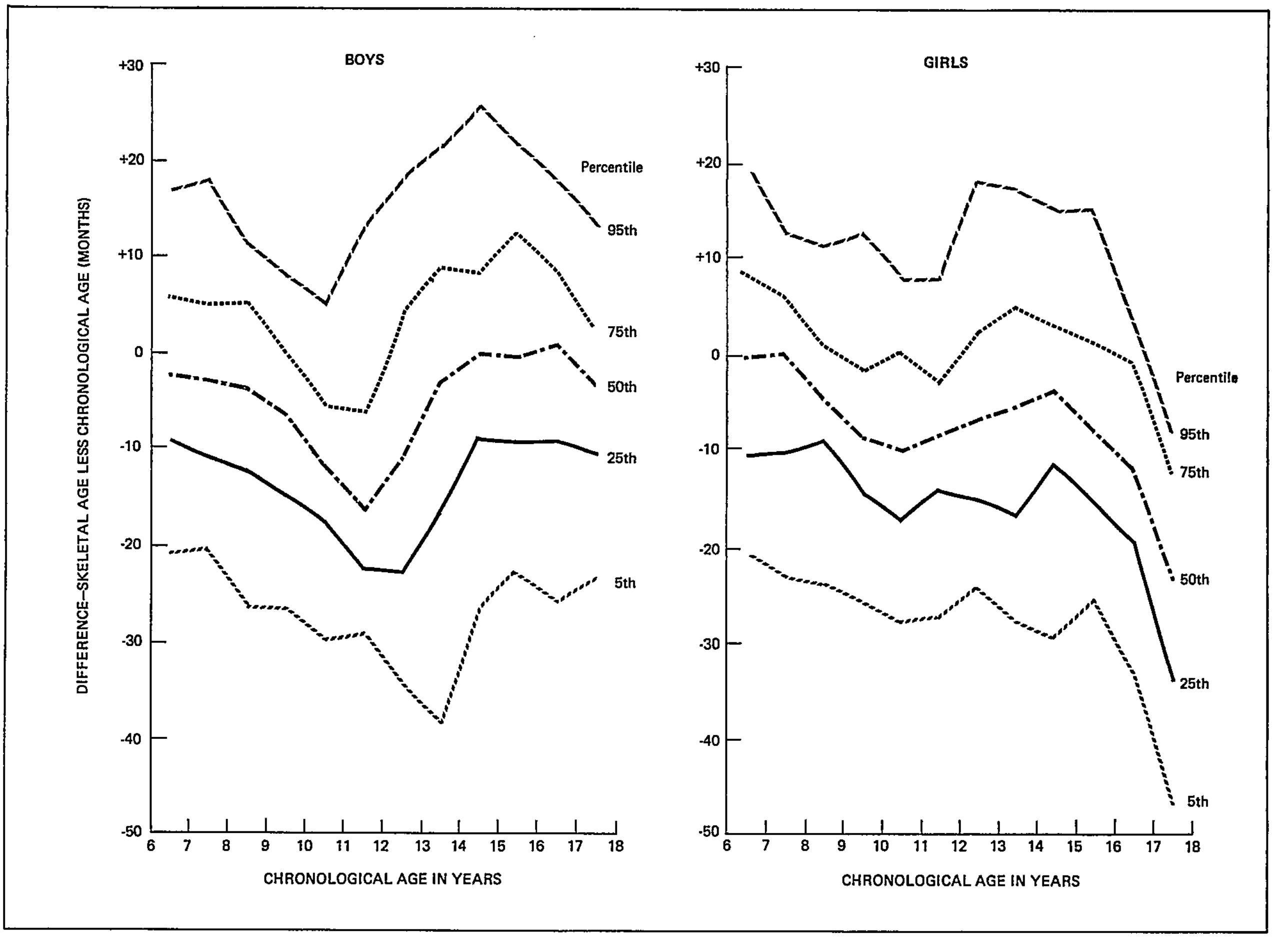


Figure 9. Selected percentiles in the distribution of differences between skeletal (hand-wrist) and chronological age 6-17 years for boys and girls (female equivalent values for the latter) by chronological age in years: United States, 1963-70.

The system of assessing skeletal maturity by comparing radiographs with standards was introduced soon after the development of radiography. Early workers to publish sets of standards included Wilms[66] and Woodrow.[67] Howard[68] published standards selected from radiographs of Atlanta public school youths born between 1912 and 1916. These standards were chosen from samples of 50 radiographs for each annual interval in each sex. The maturity levels of these standards, for the age range 12-14 years, are about 2 years below those of the Greulich-Pyle standards. The data have not been included in figures 10 and 12 because neither the ethnic origin nor socioeconomic status of the sample was reported. Furthermore, the sample was too small for a reliable selection of standards, particularly considering that these radiographs were taken at random chronological ages.

A mixed longitudinal study of white Chicago youths of above average socioeconomic status born between 1904 and 1917 was reported by Flory.[61] Radiographs taken within 2 weeks of a birthday were available for 100 youths of each sex at each age. The plates selected by Flory as best representing the central tendencies in his groups are about one skeletal age year below the corresponding Greulich-Pyle standards for each sex. This difference tends to fluctuate with chronological age in both boys and girls without showing a regular trend (figures 10 and 12).

Dearborn and Rothney[69] reported mean hand-wrist skeletal ages of 233 boys and 371 girls who had been examined annually. These youths were

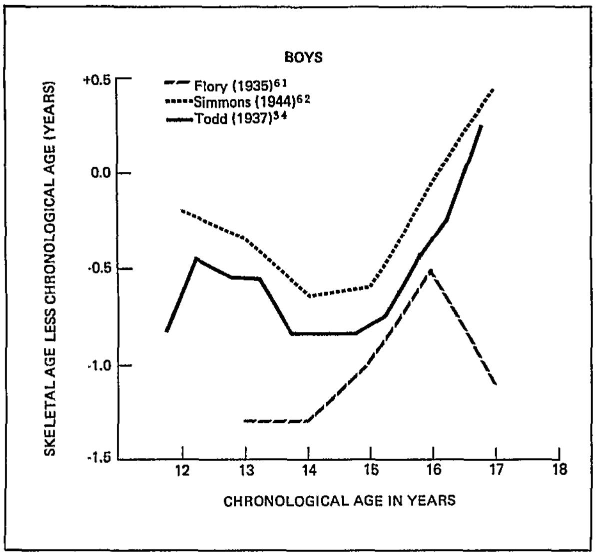


Figure 10. Differences between skeletal and chronological ages of boys 12-17 years in studies of Flory (1936), Simmons (1944), and Todd (1937).

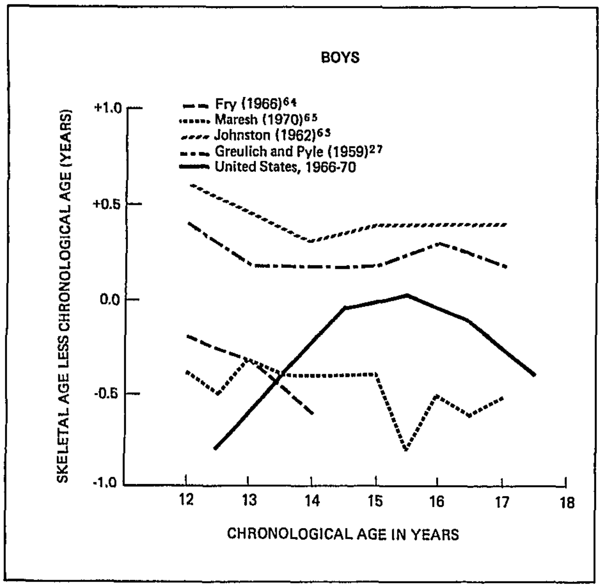


Figure 11. Differences between skeletal and chronological ages of boys 12-17 years in studies of Fry (1966), Maresh (1971), Johnston (1962), Greulich-Pyle (1959) and United States youths (1966-70).

slightly above average in socioeconomic status and were living in or near Boston. They were mainly of North European or Italian ethnic origin and had been born about 1917. The skeletal age assessments were made using unpublished Todd

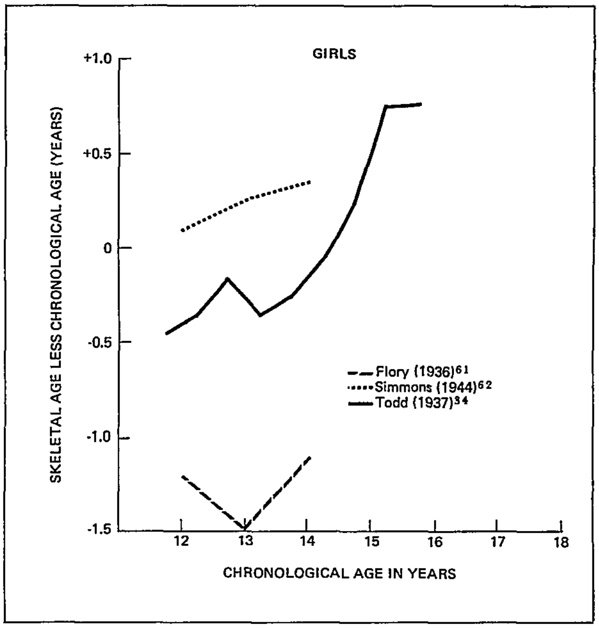


Figure 12. Differences between skeletal and chronological ages of girls 12-17 years in studies of Flory (1936), Simmons (1944), and Todd (1937).

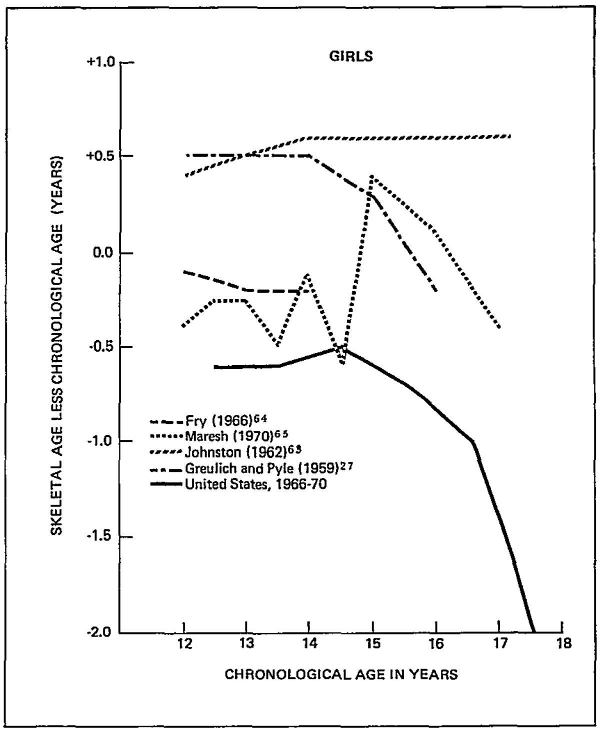


Figure 13. Differences between skeletal and chronological ages of girls 12-17 years in studies of Fry (1966), Maresh (1971), Johnston (1962), Greulich-Pyle (1959) and United States youths (1966-70).

standards. Consequently, it is impossible to transform, with reasonable reliability, the reported data to the common Greulich-Pyle base line that is being used to compare the findings from different studies. For this reason, these reported data have not been included in figures 10-13.

Simmons[62] reported mixed longitudinal data from Cleveland youths of above average socioeconomic status who were born between 1917 and 1940 and examined on or near their birthdays. The number of radiographs assessed for each year of age varied from 68 to 198 in each sex except for girls aged 15 years or more. Radiographs of older girls were not assessed if they had "surpassed the upper limits for the standards." Consequently, the data of Simmons are highly selected for older girls and they have been omitted from figure 12 for chronological ages after 14 years. 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 except at 14 and 15 years in boys, when the differences are slightly larger. This close correspondence is not surprising because the radiographs used by Simmons formed part of the group used by Greulich and Pyle. The means of Simmons are lower than those of Greulich and Pyle except at 17 years in boys and 12-14 years in girls.

Todd's Atlas[34] was based on radiographs of Cleveland youths, "from all grades of society, except the destitute," who were born between 1915 and 1936 and examined serially near each birthday or half birthday. The standard plates were selected from groups of 42 to 161 youths 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, (figure 10 and 12) except towards the end of the 12-17 year range, when they are slightly higher than the Greulich-Pyle standards. Expectedly, the maturity levels of Todd[34] are lower than those of Simmons,[62] but the means from the two studies are remarkably parallel across age in each sex. Although there was some overlap between the groups of radiographs used by these two investigators, Simmons used only those of youths of high socioeconomic status and Todd used radiographs of youths from almost all socioeconomic levels.

Mixed longitudinal data from the Harvard Growth Study were reported by Greulich and Pyle.[27] These radiographs were of white middle class Boston youths who were born between 1930 and 1939 and examined near each birthday. The size of the group varied from 60 to 65 at each age in each sex. Data for girls were not included after 15 years because, in a majority of the girls at these ages, most of the hand-wrist bones were adult in maturity. All the mean skeletal ages were within 0.4 year of the corresponding Greulich-Pyle standards, with a slight tendency to advancement that was more marked in the girls than the boys.

Johnston[63] reported mixed longitudinal data from middle and upper middle class Philadelphia white youths who were born between 1931 and 1950. The size of the group varied from 23 to 50 for each annual interval in each sex. The only exception was at 17 years, when the group was much smaller in each sex (10 boys, 13 girls). Consequently, the means reported for youths age 17 years have been omitted from figures 11 and 13. The radiographic examinations were made at random chronological ages; the data relating to, for example, "9 years chronological age," were derived from youths ranging in age from 8.5 to 9.49 years. The mean skeletal ages for each sex were advanced, relative to the Greulich-Pyle standards, by 0.3 to 0.6 year within chronological age groups.

Skeletal age data from middle class white youths in Nebraska, born between 1952 and 1954 and examined cross-sectionally at random ages between 12 and 14 years, have been reported by Fry.[64] The group for each annual interval included 25 boys and 25 girls. Many of these youths (65 percent) were twins so more than half of these would have been like-sexed. The mean skeletal ages for the boys were below the Greulich-Pyle standards by amounts that varied between 0.2 and 0.6 skeletal age year. The mean skeletal ages for the girls were above the Greulich-Pyle standards by 0.1 to 0.2 years (figures 11 and 13). The mean levels for the two sexes tended to diverge with advancing age—presumably variability among the various age groups were largely responsible for this.

Maresh reported mixed longitudinal data from middle class white youths living in Denver. These data were obtained from radiographs taken close to birthdays and half birthdays. Although these youths were born between 1915 and 1955, most of the radiographs were taken after 1947. The size of the groups varied from 21 to 43 for each 6-month age interval from 12 to 17 years in each sex, with the exception of 15.5 and 16.5 years in the girls when the group was smaller.[65] The median skeletal ages for the boys were 0.3 to 1.1 years below the Greulich-Pyle standards during the age range 12-17 years. During this same age range the medians for the girls were generally below the Greulich-Pyle standards but differed from them by no more than 0.6 year.

Figures 10 and 11 show differences between modal skeletal ages and chronological ages for these several groups of boys and for boys included in the national survey. When converted to a common Greulich-Pyle baseline, the atlas standards of Flory and Todd are retarded by more than 0.5 year at 12-15 years but the differences are less for the Todd Atlas at all ages. Figure 10 contains the modal ages reported by Simmons, after these have been adjusted to compensate for her use of the Todd Atlas. The skeletal retardation in the Simmons group paralleled that of the Todd Atlas, but it was less at all ages. As noted earlier, this reflects differences in subject selection.

The data in figure 11 differ markedly. The mean skeletal ages exceeded the chronological ages by about 0.5 years in the boys studied by Johnston,[63] but the mean skeletal ages were very close to the mean chronological ages in the Boston youths for whom data were reported by Greulich and Pyle.[27] There was a definite tendency to retardation of skeletal maturation for the boys in the group of Fry and Maresh, with a trend to increasing retardation at older chronological ages. The marked irregularities in the data of Maresh, at ages after 15 years, probably reflect fluctuations in group composition. The trends of the mean levels for U.S. boys obtained from the national survey do not correspond with any of those reported previously, but the present national estimates are somewhat closer from 14 years on to the data from the later (figure 11) rather than the earlier studies (figure 10). Corresponding figures illustrate the reported data for girls (figures 12 and 13). The levels of the Todd standards are somewhat closer to those of the corresponding Greulich-Pyle standards for girls than for boys, but the Todd standards for girls particularly tend to increase in relative level with chronological age. The data of Simmons show a similar trend and, as for boys, these are in advance of the Todd standards. The levels of the Flory plates, for girls aged 12-14 years, are more than a year behind the Greulich-Pyle standards.

The data for girls in figure 13 are generally similar to those for boys in figure 11. The modal skeletal ages for the group of Johnston were about 0.5 year in advance of the Greulich-Pyle standards, but the modal ages reported by Maresh,[65] Fry,[64] and Greulich and Pyle[27] were, with few exceptions, within 0.5 year of the Greulich-Pyle standards. As for the boys, these previous mean values for groups of girls do not match the National Health Examination Survey data closely either in levels or trends.

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 groups in studies considered in this review were similar in ethnic origin, but those of Flory[61] and Simmons[62] alone were of upper class youths. The median birth dates for the Flory group are 18 years earlier than those for the group of Simmons. The skeletal maturity levels reported by Flory were considerably lower than those reported by Simmons, indicating a possible secular trend. Equally, the apparent trend could reflect differences between these investigators in their criteria for selecting youths as upper class. The approximate median birth dates for the group of middle class youths were: Greulich and Pyle (Harvard data), 1935; Johnston, 1940; Fry, 1953; and Maresh, 1955.[27,63-65] These median birth dates are not the same as those given in an earlier report[1] because the age range considered is different. 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 *could* suggest a *negative* secular trend, but the data are difficult to interpret because the level of comparability between assessors is unknown, there are severe sampling deficiencies, and it is reasonable to assume that there were variations among investigators in what was considered "middle class."

Table C. Relative variability[a] in skeletal ages (hand-wrist) among youths within selected chronological age groups, by age and sex, from selected studies

Chronological age	Flory, 1936[61]	Simmons, 1944[62]	Greulich and Pyle, 1959[27]	Johnston, 1962[63]	Fry, 1966[64]	United States, 1966-70
Boys	Coefficient of variation					
12 years	9.4	7.3	7.2	5.9	8.8	12.1
13 years	7.0	6.9	7.1	6.7	8.2	11.5
14 years	8.6	6.7	7.1	6.8	6.6	8.7
15 years	8.1	6.5	7.8	6.8	---	7.7
16 years	7.5	6.7	7.9	5.4	---	7.0
17 years	6.7	6.2	7.4	---	---	5.4
Girls						
12 years	10.3	7.2	9.0	8.6	11.9	8.5
13 years	9.8	6.7	9.1	8.8	9.2	7.0
14 years	6.7	6.5	7.3	6.3	8.8	5.5
15 years	---	---	6.0	7.8	---	4.6
16 years	---	---	---	5.7	---	4.7
17 years	---	---	---	---	---	4.7

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

Variability.—Means and standard deviations of skeletal ages, within chronological age groups, have been reported for most of the earlier investigations considered. Hence it is possible, as was done in the previous report on these findings among children, to compare the relative variability in skeletal age in relation to the size of the mean values for youths in these studies. Greater variability might have been expected for youths in the present national survey 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. However, this greater relative variability in skeletal maturity of youths in the national survey is evident only among younger boys 12-14 years of age while the girls tend to be less variable than those in the smaller groups studied previously (table C). This same factor of taking the radiographs throughout the year could be responsible for the relatively greater variability at some ages reported by Fry,[64] but variability reported by Johnston,[63] who also assessed youths at random ages, is not large. The variability in the group reported by Fry would be expected to have been somewhat reduced because of the inclusion of a large number of twins.

The relative variability in the skeletal ages reported by Simmons[62] and Johnston[63] tends to be the smallest of those reported and among boys, but not girls, is smaller than for those in the present national survey when the latter are grouped into annual age intervals. Presumably, the lesser relative variability in skeletal maturity in the Cleveland and Philadelphia groups reflects a combination of factors: greater socioeconomic and ethnic homogeniety in these groups than in the national survey youths, the use of fewer assessors in these previous studies than in the national survey, and differences between these studies in the timing of radiographic examinations in relation to chronological age. The effect of the latter can be estimated using the means and standard deviations calculated for 1-month intervals of chronological age from the national survey data (table 2). These standard deviations are about 6 percent lower than those calculated for annual intervals, while the average of mean values approximates the mean for the annual age interval. All these same factors also differ between the sample of Greulich and Pyle[27] and that of the national survey, but the relative variability reported by Greulich and Pyle is generally as low as that reported by Simmons[62] and Johnston.[63]

When data are available for each sex in the group, the relative variability in skeletal maturity levels from previous studies shows a tendency to be less for boys than girls except among Simmon's group, where the differences are reversed but negligible (table C). These previous reports of greater variability in girls are in complete contrast with the findings of the present national survey where boys are the more variable in skeletal maturity across the age span 6-17 years except at ages 9 and 10 years. When comparisons are made between girls and boys, with girls 2 years younger than boys, boys at 8-11 years are slightly less variable while those from 12-15 years are slightly more variable than girls 2 years younger, reflecting the fact that the actual appearance of the skeleton (and thus the assigned skeletal ages using the same male standard) tend to be similar in each sex, with about that degree of retardation in boys.

Nicholson and Hanley [70] reported the distributions of chronological ages at which boys reached the skeletal ages of 12.75 and 16.25 years and girls reached the skeletal ages of 11.25, 14.75, and 17.25 years. These distributions were close to normal. The youths (n = 61 to 95 in each group) studied by Nicholson and Hanley [70] were enrolled in the Guidance Study (Berkeley, California); the skeletal ages of the hand-wrist had been assessed using the Todd Atlas.[34] Others,[63, 65, 69] with much smaller groups than that used in the national survey have reported positive skewness of hand-wrist skeletal ages within chronological age groups. In the national survey data the distributions were essentially normal except in older youths in whom an increasing number of bones had reached the maximum on the skeletal maturity scale.

The apparent conflict between the findings of Nicholson and Hanley [70] and those reported by some others results from differences in methodology. Nicholson and Hanley reported distributions of chronological ages at which particular skeletal ages were reached. This approach avoids problems of truncation due to the end of the skeletal age scale being reached; there is no effective limit to the chronological age scale. Also it avoids problems associated with the ordinal nature of the skeletal age scale.

Bone-Specific Skeletal Ages

In the Greulich-Pyle method of assessment, as used in the U.S. national surveys among children and youths, skeletal ages are assigned each radio-opaque bone. The skeletal age (hand-wrist) is determined as the mean of these bone-specific ages. In the survey among children, at least 21 of the 31 bones had become radio-opaque at 11 years in 99 percent of both boys and girls. Consequently, skeletal ages could be determined for each of these bones. By age 12 years all but three of the later forming bones (pisiform, adductor, and flexor sesamoids) were available for assessment in more than 80 percent of the boys and almost all of the girls. As in the determination of a single skeletal age for each hand-wrist, the bones that have become adult are excluded in the analyses of skeletal age for individual bones. As a result of these analyses, national reference data have become available for levels, variability, distributions, and ranges of bone-specific skeletal ages.

The means and standard deviations of the bone-specific skeletal ages for each of the 31 hand-wrist bones of boys and girls 12-17 years of age in the United States as determined from the survey male standard, and for girls also in terms of the female equivalent values, are shown in table 6 at 1-year chronological age intervals and in table 7 for selected bones at 6-month chronological age intervals.

Selected percentiles in the distributions for all of the 31 bone-specific skeletal ages within single years of chronological age are given in table 8. In interpreting these tables it must be recalled that bones that were "adult" did not have skeletal ages assigned to them and that such bones are common towards the end of the age range considered, particularly in girls.

While there is a consistent increase in mean skeletal age of youths, with increasing chronological age, for each of the 31 bones in the hand-wrist, the annual rate of increase generally diminishes with increasing age from 12-17 years for both boys and girls (figure 14 and table 6).

Among boys the maximum annual increase is reached between ages 12 and 13 years (24 bones) or between 11 and 12 years (5 bones). The

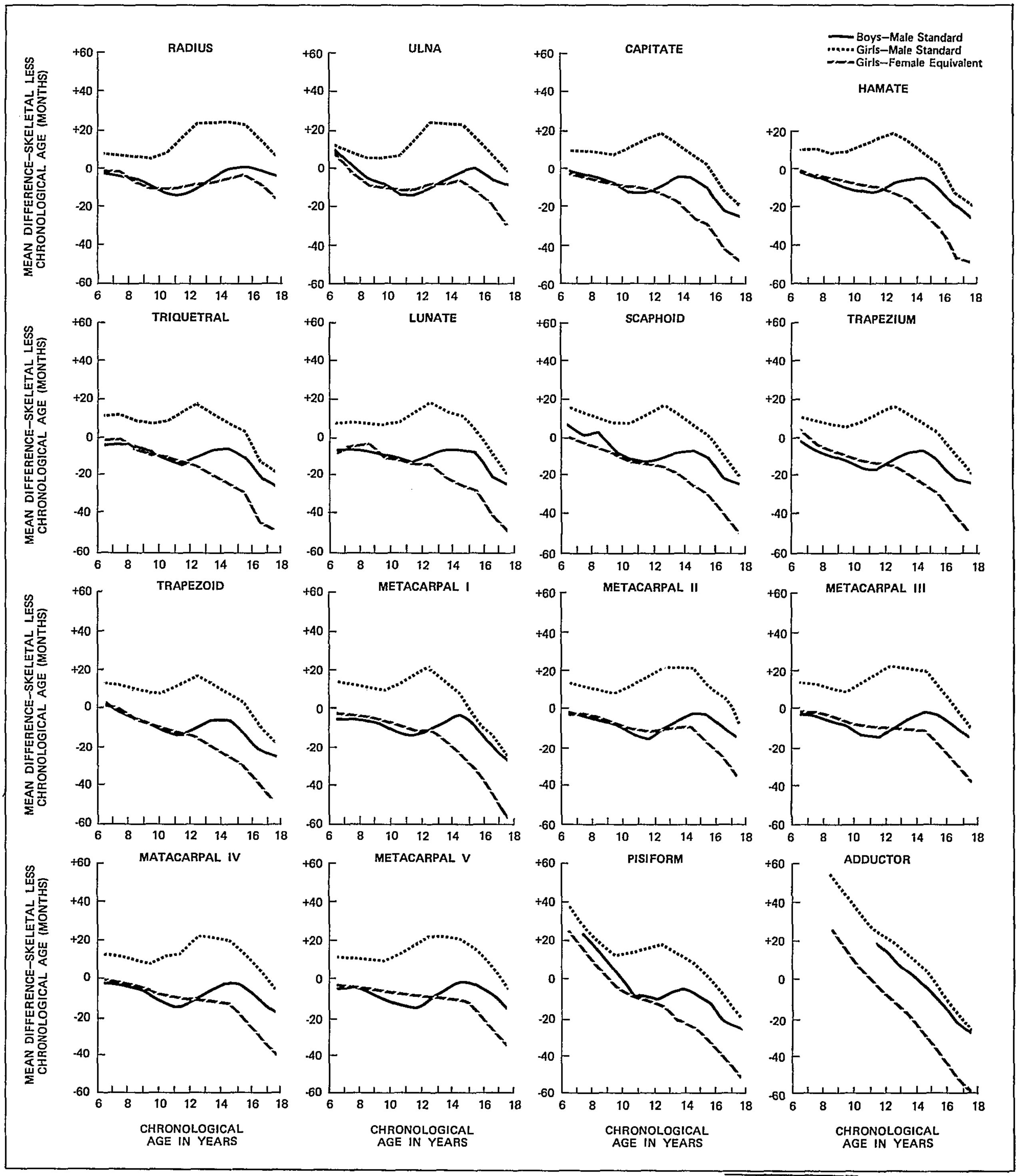


Figure 14. Mean difference in months between bone-specific skeletal ages and chronological age for the 31 hand-wrist bones on the male standard for boys and girls and female equivalent values for girls by chronological ages 6-17 years: United States, 1963-70.

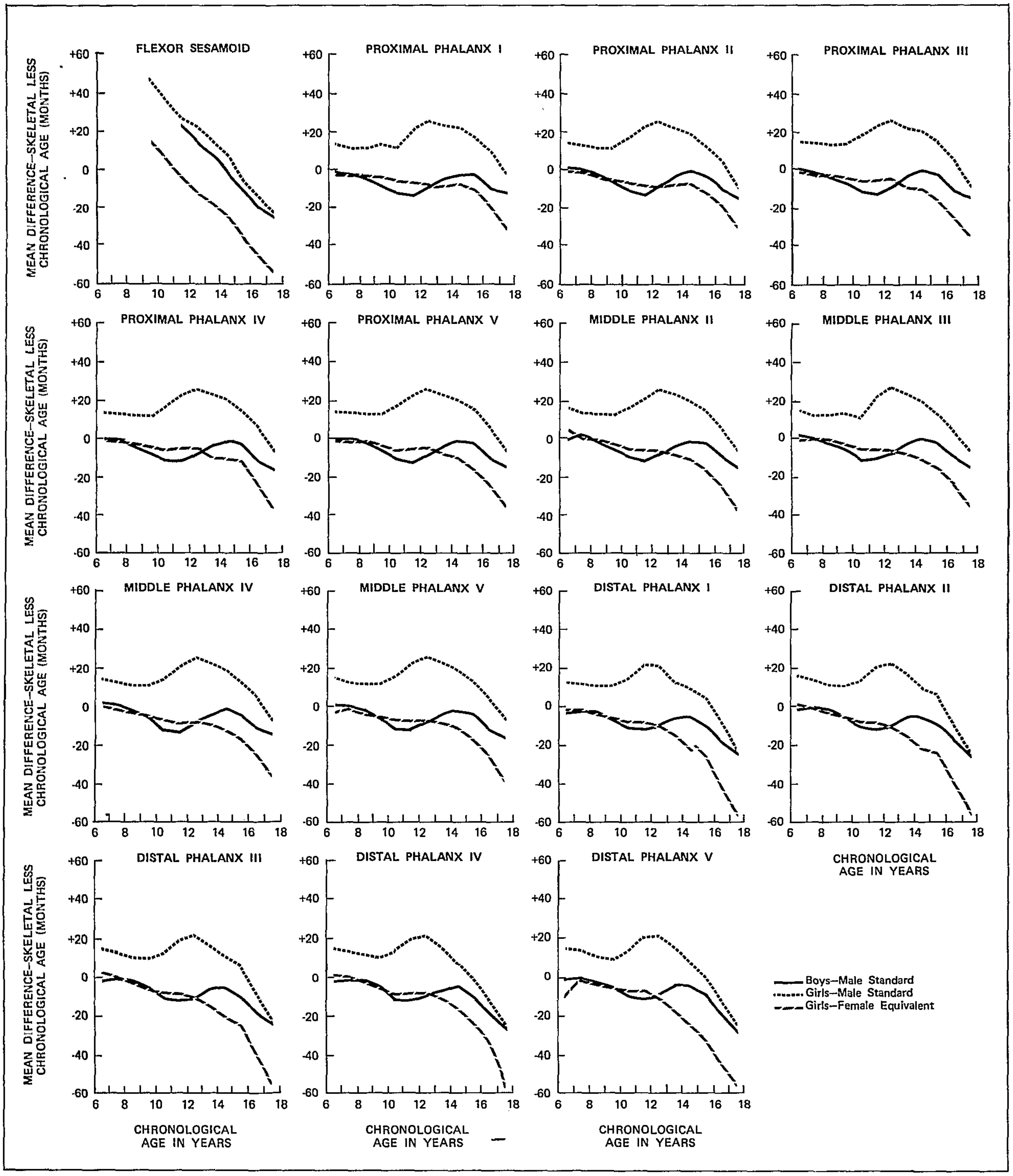


Figure 14. Mean difference in months between bone-specific skeletal ages and chronological age for the 31 hand-wrist bones on the male standard for boys and girls and female equivalent values for girls by chronological ages 6-17 years: United States, 1963-70.–Con.

latter can be seen by comparing the data from the present survey of youths with those from the earlier survey of children,[1] as shown in figure 14. Only the later ossifying adductor and flexor sesamoids in boys do not show this pattern of diminishing rate of maturation. Generally the annual increment between 15-16 and 16-17 years is about half or less than that between 12-13 years of chronological age.

For girls, when assessed against the male standards, the maximum annual increase in skeletal age is generally reached 2 years earlier than for the boys—between ages 10 and 11 years[1] for 27 of the bones and between ages 11 and 12 years for the remaining 4 bones.

The differences between the bone-specific mean values for boys and girls (female equivalent values), which had been small at all ages over the age range 6-11 years in the 1963-65 national survey, remains small at age 12 years in the present national study (differences of 4 or 5 months or less) for all but the later ossifying adductor and flexor sesamoids. Because these three bones are relatively late to ossify, they could be assessed in only the skeletally advanced boys, thus explaining why the values for these three bones in boys are so markedly in advance of the female equivalent values at age 12 years.

For about half of the bones (15) at age 12 years, the mean skeletal age for boys is less than for girls (female equivalent values) continuing the pattern found among the children (6-11 years) for all the hand-wrist bones except the lunate and adductor and flexor sesamoids. However, from age 13 years onwards for these 15 bones and from 12 years onwards for the remainder, the mean bone-specific skeletal ages for boys become increasingly greater than those for girls. By age 17 years the bone-specific skeletal ages for boys are about 18-32 months in advance of the female equivalent means for girls. The only exception is the radius, where the mean difference is only about 13 months. Much of these differences among bones are artifactual. At older ages, there are some youths in whom the radius (typically the last hand-wrist bone to become adult) is the only bone that can be assesed. Consequently, the exclusion of bones that had become adult would be less common for the radius than for other hand-wrist bones. The necessity to exclude bones that are adult chooses the slowest maturing girls. In addition, the scale for boys extends further (in skeletal age months) than does the scale for girls. The maximum skeletal ages assigned are greater in boys than in girls because boys take longer to reach adult levels.

The differences between the mean bone-specific skeletal ages for boys and those for girls (when both are assessed as boys) continue to increase through age 12 years for about half of the hand-wrist bones (15), as had been found for almost all the bones among children 6-11 years old (1963-65 national study). From ages 11 or 12 years on, the mean differences in skeletal age between boys and girls become progressively less, decreasing from about 32 months on the skeletal age scale for boys at age 12 years to 10 months or less at age 17 years (figures 3 and 14). Some of this decrease is artifactual due to selective exclusion of rapidly maturing girls. However, much of the decrease is real, as will be discussed later.

Variability.—The variability of these bone-specific skeletal ages, as measured by the standard deviations and the interquartile range (P_{75} - P_{25}), is generally greater among boys than girls (the latter assessed against male standards) but tends to decrease in both sexes between ages 12 and 17 years (tables 6-8). Among the youngest boys (12 years of age), the variability in skeletal ages for the adductor and flexor sesamoids (standard deviation of 6-7 months) is less than half that for the other 29 bones (standard deviations of 16-18 months). This relative lack of variability occurs because it is only in skeletally advanced boys at 12 years that those bones can be assessed. By age 17 years there was slightly greater variability shown for the radius, metacarpal II, and proximal phalanx I (standard deviation of about 11 months) and substantially less variability in skeletal ages for metacarpal I and distal phalanges IV and V (standard deviation of 4 months) than for the remainder (standard deviations of 7-10 months).

The standard deviations of bone-specific skeletal ages for the girls at 12 years, assessed against the male standards, range from 12-15 months for all the bones except the adductor and flexor sesamoids (8-9 months). At 17 years the range of standard deviations is from 0-1 month (capitate, hamate, triquetral, trapezium, trapezoid, metacarpal I, pisiform, and distal phalanges IV-V) to 7 months (metacarpals II and V and the flexor and adductor sesamoids). The marked differences between metacarpal I and metacarpals II-V in the variability of skeletal age at 17 years reflects differences in the mean ages at which these bones reach adult levels of maturity (table D).

For girls at age 12 years (female equivalent values), the skeletal ages for the adductor and flexor sesamoids were also substantially less variable (standard deviations of 7-8 months) than for the other 29 bones (standard deviations of 10-13 months), similar to their findings from the male standard values. This occurs because the adductor and flexor sesamoids were ossified and could be assessed only in the most rapidly maturing girls in whom little variance of the ages assigned to these bones would be expected. By age 17 years variability was negligible (standard deviations of less than 1 month) for nine of the bones—capitate, hamate, triquetral, trapezium, trapezoid, pisiform, metacarpal I, and distal phalanges IV and V. This reflects the fact that these bones had become adult in almost all these older girls and the few remaining bones that could be assessed were almost adult. For these remaining bones the variability in skeletal age, as measured by the standard deviation, ranged from 1-6 months.

The distributions of the bone-specific skeletal ages (both sexes assessed against male standards and also female equivalent values for girls) are described in table 8 by the use of selected percentiles. The distributions of skeletal age tend to be skewed for many of the bones but the direction of the skewness differs both among bones within a sex at one age and also from one age to another for particular bones. For example, metacarpal V in boys is skewed slightly to the left at 13 years, to the right at 14 years, and to the left at 15 years.

No previous studies even of small groups provide comparable information on bone-spe-

Table D. Modal ages for epiphyseal fusion in the hand-wrist from various studies

Bone	Boys	Girls	United States	
			Boys	Girls
	Modal ages from previous studies			
Radius	17.2[74] 18.0[93] 18.3[18]	15.8[74,93] 18.5[18]	*	*
Ulna	16.8[74] 17.8[93] 18.5[18]	15.2[74] 15.9[93] 18.5[18]	*	16.2
Met. I	15.0[18] 15.4[74] 16.3[91,93]	13.5[74] 14.1[91,93]	15.8	13.8
Met. II-III	15.0[18] 15.4[74] 16.4[91] 16.5[93]	13.5[74] 14.5[93] 14.6[91]	16.6	14.8
Met. IV	15.0[18] 15.4[74] 16.4[91,93]	13.5[74] 14.4[93] 14.6[91]	16.5	14.8
Met. V	15.0[18] 15.4[74] 16.5[91,93]	13.5[74] 14.4[93] 15.0[91]	16.6	14.9
PP I	15.5[18] 16.2[17,93] 16.3[91]	14.2[93] 14.3[17] 14.4[91] 14.5[18]	16.3	14.0
PP II	15.5[18] 16.3[91] 16.4[93]	14.2[91,93] 14.5[18]	15.9	14.0
PP III	15.5[18] 16.2[17] 16.3[91,93]	14.2[93] 14.3[17] 14.5[18,91]	16.1	14.1
PP IV	15.5[18] 16.2[91] 16.5[93]	14.2[91,93] 14.5[18]	16.1	14.1
PP V	15.5[18] 16.2[91,93]	14.2[91,93] 14.5[18]	15.9	14.0
MP II	15.5[18] 16.4[91,93]	14.4[91,93] 15.0[18]	16.2	14.0
MP III	15.5[18] 16.4[91] 16.5[93]	14.4[93] 14.5[91] 15.0[18]	16.4	14.1
MP IV	15.5[18] 16.4[91,93]	14.3[93] 14.5[91] 15.0[18]	16.4	14.1
MP V	15.5[18] 16.3[93] 16.4[91]	14.2[93] 14.3[91] 15.0[18]	16.3	14.0
DP I	15.0[18] 15.7[91] 15.9[93]	13.5[18,91] 13.6[93]	15.7	13.4
DP II	14.7[91] 15.0[18] 15.7[17] 15.8[93] 16.0[91]	12.5[71] 13.5[18] 13.6[91,93] 13.7[17]	15.7	13.4
DP III	15.0[18] 16.0[91,93]	13.5[18] 13.6[91,93]	15.8	13.4
DP IV	15.0[18] 15.8[93] 16.0[91]	13.5[18] 13.6[91,93]	15.6	13.4
DP V	15.0[18] 15.9[93] 16.0[91]	13.5[18] 13.6[91,93]	15.7	13.4

*Estimates of median age not possible or not sufficiently reliable for publication. The radius had reached the "adult" stage for only 26 percent of boys and 53 percent of girls and the ulna in only 51 percent of boys by 17.9 years.

NOTES: Met. = metacarpal; PP = proximal phalanx; MP = middle phalanx; and DP = distal phalanx.

Modal ages for studies of Greulich and Pyle[27] and Pyle et al.[17] have been increased by 0.5 to be more nearly comparable with assessment methods used in the other studies (see pages 17 and 20).

cific skeletal ages of youths in the United States or other countries.

Range of Bone-Specific Skeletal Ages

As stated earlier, the present assessments were made bone by bone. In almost every youth there were variations among the skeletal ages assigned to the hand-wrist bones. The data for girls in table 9 are for skeletal ages assessed against male standards. At each age in each sex, there is skewness to the left in the distributions of the ranges with the means being greater than the medians. Within each hand-wrist the median ranges tend to be larger in boys than in girls (table 9). This sex difference is rather small at 12-14 years (mean differences less than 2 months) but at later ages the difference is greater (exceeding 3 months). It is maximal at 16 years where the ranges are 8.8 months in the boys and 2.3 months in the girls. The median ranges tend to decrease with age in each sex; this occurs more rapidly in girls than boys (table 9). Presumably this greater reduction in the range for the girls reflects the effects of several factors. In older girls fewer bones could be assessed because many had become adult and the remaining bones differed little in maturity because all were close to the end of the scale of maturity. There are corresponding decreases with age in the other percentiles of these ranges except for some irregularity in the 95th percentile level for the girls. This would reflect the uncertainty of these estimates at the edge of the distributions. The variability, as measured by the standard deviation, of these ranges is greater in the girls than in the boys at all corresponding ages. The differences between the sexes in variability are relatively small at younger ages (at 12 years it is minimal; boys 6.83 months, girls 7.42) but become larger as progressively older ages are considered. At 16 years the difference is maximal with standard deviations 8.94 months for the boys and 12.25 for the girls. The variability was marked. When variability is considered as the coefficient of variation in relation to the magnitude of the mean ($100s_x/\bar{x}$) it exceeded 100, i.e., standard deviation greater than the mean, in older youths of both sexes (boys 17 years, girls 15-17 years).

No previous studies provide information about the ranges of bone-specific skeletal ages in the youths of the United States or any other country.

Onset of Ossification

From the skeletal age assessments among youths in the present national study, it is possible to obtain reliable estimates of the ages of onset of ossification for the two bones in the hand-wrist that generally are the last to become radio-opaque—the adductor and flexor sesamoids (table E). Data on the age of onset of ossification for the

Table E. Modal ages in years for onset of ossification in selected late appearing bones from various studies

Bone and sex	Modal ages from previous studies					United States, 1966-70
Boys						
Adductor sesamoid	12.1[71]	12.6[17]	12.7[72]	12.8[73]	13.2[27]	12.5
Flexor sesamoid	13.5[27]					14.2
Girls						
Adductor sesamoid	10.5[72]	10.7[73]	10.8[27]	11.0[17]	11.2[93]	10.7
Flexor sesamoid	11.0[27]					13.0

NOTE: Modal ages for studies of Greulich and Pyle [27] and Pyle et al. [17] have been increased by 0.5 to be more nearly comparable with assessment methods used in the other studies (see pages 17 and 20).

adductor sesamoid among girls, which could be reliably estimated from the preceding national study among children age 6-11 years, are included in this table for comparative purposes.

While all of the later-forming bones that normally ossify during the age period 6-17 years tend to ossify earlier in girls than in boys, these median ages of onset for the flexor sesamoid show the least acceleration of girls over boys.

Previous studies of onset of ossification have included three types of modal ages: (1) median ages at onset, (2) mean ages at onset, and (3) the percentage incidence of ossified centers within age intervals. The latter data allow the calculation of modal ages after plotting on probability paper. To facilitate comparison, it has been assumed that any systematic differences between corresponding mean and median ages and ages when the center is present in 50 percent of youths, that are due to the method of analysis, can be disregarded. The only bones with modal ages at onset of ossification in the age range 12-17 years are the adductor sesamoid and the flexor sesamoid in boys.

The data of Greulich and Pyle[27] were obtained from the Brush Foundation Study of Cleveland youths; these were of high socioeconomic status. These investigators had available mixed longitudinal data from more than 200 boys at each age. A subgroup of these youths (30 boys) was used by Buehl and Pyle[71] to obtain the mean age of ossification of the adductor sesamoid. Pyle et al.[17] reported data from the group of Boston boys described earlier in reference to the skeletal age data of Greulich and Pyle.[27] Many of the boys in this group were included among those studied by Harding.[72] The mixed longitudinal data of Garn et al.[73] were derived from middle socioeconomic class white youths in Southwestern Ohio born between 1929 and 1966. The group included about 180 boys who were radiographed near birthdays and half-birthdays.

Lurie et al.[74] reported cross-sectional data from 1,129 Cincinnati white youths born between 1920 and 1940. These youths 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 youths with endocrine disturbances or marked nutritional deficiences were excluded, the normality of the remainder of the group is questionable. Consequently, these data have been excluded from the present review. Similarly, the data of Howard[68] have not been included because the ethnic nature of this group was not reported. It should be noted, however, that his data show a modal age for onset of ossification of the adductor sesamoid in boys of 13.25 years.

Considerable variation would be expected between findings from these reports because the studies differ in many respects, particularly selection of subjects and the methodology of radiography and data analysis. Furthermore, while Garn et al.[73] and Harding[72] reported data relating to the age at which a center was seen to be ossified, Greulich and Pyle[27] and Pyle et al.[17] recorded an age for onset of ossification in each youth 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[27] and by Pyle et al.[17] are systematically about 0.5 year in advance of those that would have been reported had the alternative procedure been followed. The report by Buehl and Pyle[71] does not state whether an interpolated age was used.

The modal ages based on reported data that are included in table E should be interpreted with care because of these methodological differences. In compiling this table, 0.5 year was added to the ages reported by Greulich and Pyle[27] and Pyle et al.[17] After this adjustment, the various reports concerning the adductor sesamoid are in reasonably close agreement except for the earliest and the latest ages, which are from the Brush Foundation[27] and the Harvard Growth Study.[17] This unexpected difference is not likely to be associated with the observer because Pyle was intimately involved with each study. It could reflect a possible lack of interpolation by Buehl and Pyle or that the subsample used by these authors was unrepresentative of the total Brush study group. It is noteworthy that only one previous report has been made of the age at onset of ossification in the flexor sesamoid.[27]

The modal age at onset of ossification of the adductor sesamoid in the boys included in the national survey is within the range of ages reported previously for smaller nonrepresentative groups of United States youths. However, the ages for the onset of ossification in the flexor sesamoid, both in the boys and girls, are considerably later in the HES data than in the data reported previously by others. The onset of ossification in the adductor sesamoid can be recognized easily. Consequently, observer reliability is high and the radiographic quality can vary within wide limits without markedly affecting the data. The recognition of early ossification in the flexor sesamoid is more difficult because, commonly, its radiographic image is superimposed on that of the head of the first metacarpal. Review of some of the national survey radiographs indicated that they were of unusually good quality and that even very small areas of ossification in the cartilaginous models of the hand-wrist bones had been recognized by the assessors.

Epiphyseal Fusion

Each bone of the hand-wrist, except the carpals, reaches adult levels of maturity when fusion is completed between the epiphysis and the diaphysis. This stage of maturation was not recorded as such in the national survey, but, as was done for onset of ossification, it can be calculated from the skeletal ages that were assigned. Making the obvious assumption that fusion had been completed in any of these bones that were assessed as adult, and using the percentage incidence of such bones across age, estimates were made of the ages at which epiphyseal fusion was complete in 50 percent of the youths for each bone (table 10).

In interpreting these estimates, it should be recalled that they refer to the total noninstitutionalized U.S. population of youths 12-17 years. As expected, the data show that fusion tended to occur earlier in girls than in boys. The median ages at fusion for boys ranged from 15.6 years for distal phalanx IV to 16.6 years for metacarpals II, III, and V among the 19 hand-wrist bones for which such values could be determined. Among girls, the median age at fusion for these same 19 bones ranged from 13.4 years for the distal phalanges I-V to 14.9 years for metacarpal V and to 16.2 years for the ulna. The number of boys and girls in whom fusion had occurred in the radius, and the number of boys in whom fusion had occurred in the ulna by age 17 years is insufficient to provide a reliable base for determining the median ages at fusion for these later maturing bones.

Girls tend to reach the adult level of maturity for these 19 hand-wrist bones about 2 years earlier than boys. The greatest spread between boys and girls—26 months or more—is for the proximal phalanx I, middle phalanges II-V, and distal phalanges I-V; the least difference is observed for the metacarpals IV and V—20 months.

These findings can be considered together with those for the mean skeletal maturity of the total hand-wrist. The mean of the separate median ages when fusion was complete for the individual bones for which estimates were possible within this age range in the national survey of youths was about 16.2 years for the boys and 14 years for the girls (table D). At these chronological ages, the mean skeletal ages are, by interpolation from table 1, about 193.4 months for the boys and 192.3 months for the girls. The close correspondence between these two values attests to the internal consistency of the present data. Since both sexes were assessed against the same set of male standards, the means of the assigned skeletal ages should have been similar, but not necessarily identical, in the two sexes at the ages when fusion had occurred in 50 percent of the boys and girls. A similar picture emerges if a corresponding analysis is made for the ages when half of all hand-wrist bones have become adult (table 5).

Previously reported ages at epiphyseal fusion for children in the United States.—Considering the importance of epiphyseal fusion as the last sequential maturational change in a long or short bone, and its significance in relation to the cessation of elongation, the paucity of previous data is surprising. In part this reflects the tendency for selection or "sampling" in growth studies to be based on readily available subjects, for example, kindergarten groups or children of cooperative parents. In general epiphyseal fusion occurs during the latter years of enrollment at high school; it is more difficult to obtain the cooperation of these youths.

Despite the relative lack of reported data, the importance of this stage of maturation has been realized. Schemes for grading the progressive stages of fusion within a bone have been developed.[18, 33, 75-80] In essence, all these were based on the early work of Hasselwander.[81]

But why were these schemes not applied more widely? Apart from the problems of obtaining subjects, it is difficult to interpret radiographs, in respect of epiphyseal fusion, towards the end of the maturation of a bone. As has been pointed out, even minor variations in radiographic positioning can cause appearances on a radiograph that are interpreted as fusion when, in fact, fusion has not occurred.[82, 83] There is truth in the claim of Sahay[84] that it is quite easy to give an ununited epiphysis the appearence of union by directing the cone of X-rays obliquely. However, the difficulties can be exaggerated.[18, 34, 85, 86] For example, it is surprising to find a colleague of Todd claiming that one cannot rely too confidently upon the apparent condition of union or of nonunion in a radiograph because it is merely a confusing medley of shadows.[75] To some extent the uncertainty of classification can be overcome.[25]

Other difficulties result from the fact that workers have differed in the criteria they have applied for the recognition of epiphyseal fusion. When fusion occurs, there is no longer a radiolucent zone at the level of the junction between the epiphysis and diaphysis. Instead a thick radio-opaque line forms at this level. Some have interpreted the presence of this line as indicating that fusion occurred recently;[27] others have considered that fusion is incomplete while this line is present.[87] These views are unreasonable because the line can remain for very long periods.[78, 84, 88-91] In most studies, the persistence of a radio-opaque line at the level of fusion has not precluded classification as "fusion completed."[89, 90, 92] However, it has been fairly standard practice not to regard fusion as complete if a notch remains in the cortex of the bone between the epiphysis and diaphysis.[89, 90]

The modal ages reported for epiphyseal fusion in the hand-wrist from selected studies of groups of United States children have been included in table D. Although many ages are given in the table, the lack of satisfactory data cannot be overemphasized. The data of Lurie et al.[74] have been included despite doubts as to the clinical normality of the children in the groups, as stated earlier. These authors did not report their radiographic criteria for the recognition of fusion. Pryor[32] reported data from 145 youths examined cross-sectionally. He concluded that epiphyseal fusion occurred 3-4 years earlier in girls than in boys but did not report ages for individual bones except the radius and ulna, which he considered fused at 17.25 years in girls.

The group studied by Hansman[93] consisted of white youths of above average socioeconomic status who were radiographed at 6-monthly intervals in the Child Research Council, Denver, Colorado. These youths were born between 1915 and 1941, and the group from which relevant observations could be made exceeded 30 in each sex for each bone except the radius and ulna. Hansman considered fusion was present when epiphyseal union was complete, although the line of fusion might still be visible. The data of Todd[18] have been included in table D despite difficulties of interpretation because so few other data have been reported. His analysis was based on findings in 200 skeletons of known age and sex, after excluding the obviously abnormal. He reported the "usual range" for age at fusion; the midpoint of this range for each bone has been included in the table.

The group of Pyle et al.[17] consisted of youths living in or near Boston who were enrolled in the Harvard Growth Study. These middle class white youths were born between 1930 and 1939 and were radiographed annually. It was considered that fusion was present when all the epiphyseal cartilage had been replaced. The size of the group was very small, varying between 11 and 13 for each bone in each sex. In interpreting these data it is necessary to consider the statement by Pyle et al.[17] that the 34 boys include the relatively earlier maturing males because the study was discontinued before all boys had matured.

Accordingly, the group of 44 girls included a more representative sampling of later maturing individuals than did the group of boys. Furthermore, the ages recorded by these authors were midway between those of the annual radiographs in which fusion first appeared and the last in which it was still absent. To make the reported data more comparable across studies, 0.5 year was added to each of the mean ages reported by Pyle et al.[17] before these ages were included in table D.

The data of Buehl and Pyle[71] were obtained from annual serial radiographs of 30 boys and 30 girls in the Brush Foundation Study. These were upper class white youths living in Cleveland.

Garn et al.[91] reported findings from 6-monthly serial radiographs of 107 white youths in Southwestern Ohio who were above average socioeconomically. Fusion was considered present when the epiphyseal plate was completely replaced by bone.

Ages at epiphyseal fusion in the macerated skeletons of United States male war dead have been reported by Vandervael[94] and McKern and Stewart.[95] The age ranges of these groups do not allow reliable estimates of modal ages at fusion.

The investigators whose reported data are included in table D and who based their studies on radiographs have differed in their verbal descriptions of the criteria they used to categorize "fusion." Nevertheless, the differences between these criteria appear slight.

The data in table D show, as expected, that fusion tends to occur at younger chronological ages in girls than in boys. The only dissenting view is that of Todd,[18, 34, 76] who considered, as a general rule, that there were no sex-associated differences in maturity levels at chronological ages after 16.5 years. His view was in conflict with that of several other workers, especially Pryor.[32] Possible reasons for this conflict that are associated with the nature of the skeletal age scale are considered in the "Discussion."

Despite methodological differences and inadequate samples, there is fair replication across the reported studies and fair agreement with the findings from the national survey. Generalizing, in each sex the order of mean ages of fusion for rows of bones is distal phalanges, first metacarpal, middle and proximal phalanges, the remainder of the metacarpals, radius, and ulna. There is, however, no difference between the proximal and middle phalanges in their mean ages of fusion in the national survey girls. Comparison with data from the large group studied by Garn et al.[91] shows good agreement in regard to patterns of mean ages, but those reported by Garn et al. are about 0.3 year later. There is no evidence of a trend for the mean ages of fusion to differ across rays, e.g., for an order from the radial to the ulnar side of the hand-wrist. A ray is a metacarpal with its associated proximal, middle, and distal phalanges. In general, the ages reported by Todd are earlier, with the major exceptions of the radius and ulna in girls. For these bones he reported very late ages that were equal to, or almost equal to, the ages for the boys. In contrast to Todd, the ages reported by Hansman,[93] Pyle et al.,[17] and Garn et al.[91] are in close agreement for almost all bones. The sex difference in the timing of fusion is about 2 years for each bone—the difference is similar for the study of Pyle et al.[17] despite differences in sampling between the two sexes that might have reduced the difference. Perhaps similar sampling bias of over-representation of early maturing boys was present in the studies by others but went unrecognized. In the national survey data, the sex difference in the timing and fusion is also about 2 years for each bone.

The reported data provide little basis for a comment about variability. Standard deviations of 0.9 to 1.1 years were reported by Pyle et al.,[17] but because of the extremely small sample size and the unrepresentative nature of the group of boys studied, little reliance can be placed on these figures.

YOUTHS ALSO EXAMINED AS CHILDREN

As previously indicated the Health Examination Survey among youths in 1966-70 utilized the same sampling areas and housing units as the previous Health Examination Survey among children in 1963-65. As a result, 2,177, nearly one-third, of the 6,768 youths in the present study had been examined in the children's survey also. Radiographs satisfactory for skeletal maturity assessment were available from *both* survey examinations for 2,106 of these youths. This group included about 52 percent boys and 48 percent girls, as did the total sample of examined youths. At the younger ages of 12-14 years these skeletal maturity data at two points in time were available for about 50 percent of all examined youths in those chronological ages but only about one-fourth at 15 years and only 1 percent at 16 years. The time lapse between the two examinations ranged from 28 months to 5 years, with a median time lapse of about 4 years.

The skeletal maturity levels for the entire hand-wrist and for the individual bones among this subgroup of youths at the second examination are similar to those for all youths in the present study. At each chronological year of age from 12 through 15 years, the mean values for all youths and those also examined as children are in close agreement (tables 1, 6, and 11). Only a few of the younger 16-year-old youths and none of the 17-year-olds had been in the preceding survey.

Because of the fact that not all eligible children returned for reexamination in the youths' survey, comparison of their skeletal maturity levels as children with all children in the previous survey is more difficult. The 12-year-old youths would have been 7-10 years of age, the 13-year-olds 8-11 years, the 14-year-olds 9-11 years, and the 15-year-olds 10-11 years. Comparison of the mean skeletal maturity levels at the time they were children in 1963-65 for the three youngest age groups of youths, 12-14 years, show them to have been more advanced in this respect than all the children 8-10 years of age examined in 1963-65.[1] This is not inconsistent with their method of selection. There is no evidence of systematic differences in the assessment methods used in the separate surveys of children and youths. In fact, every effort was made to apply exactly the same assessment methods to both sets of radiographs.

Comparison of the ranges of increases in skeletal and chronological ages for those youths examined at two ages shows the expected greater range in skeletal ages (male standards) than chronological ages for both boys and girls (figure 15). For both sexes, increases in chronological ages range from 24 through about 59 months, while increases in skeletal age for these same youths range from a minimum of 18 months to about 83 months. The proportion showing small skeletal age increases of 18-35 months is substantially lower in the girls than the boys (both based on assessments against the male standards), while proportionally more girls than boys show increases of 48-83 months in skeletal maturity during the roughly comparable time period (figure 16).

Comparison of the increase in skeletal age (hand-wrist) within 6-month chronological age intervals shows the extent and pattern of agreement in these two measures of age in girls and boys (table 12). The skeletal age data for both sexes are in terms of the male standard. On this basis, boys were more than twice as likely as girls to show skeletal age increases that were

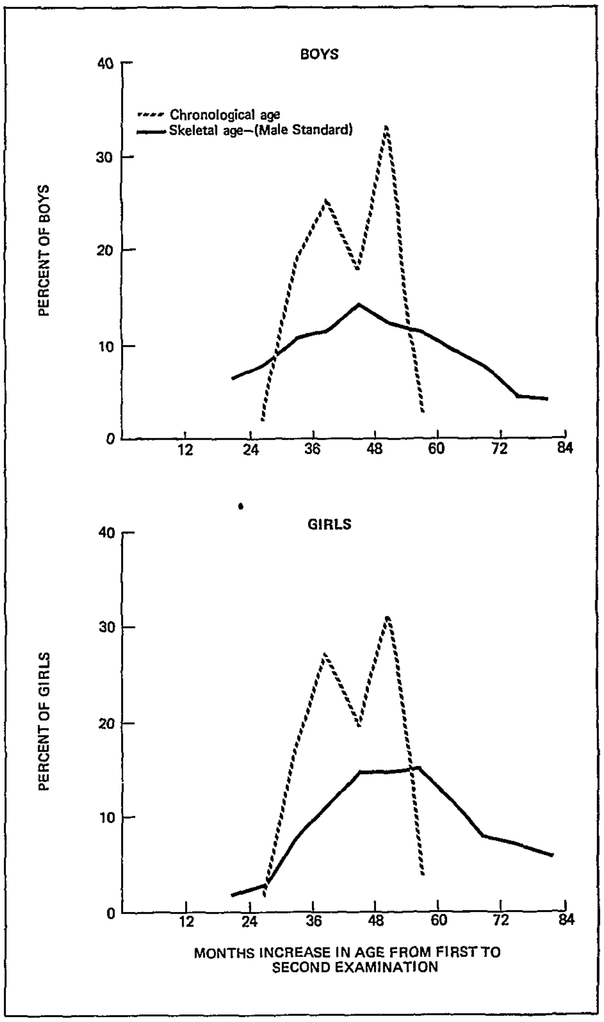


Figure 15. Percent distribution of months increase in chronological and skeletal ages (male standard) between first and second examination for boys and for girls in both the Health Examination Surveys of 1963-65 and 1966-70.

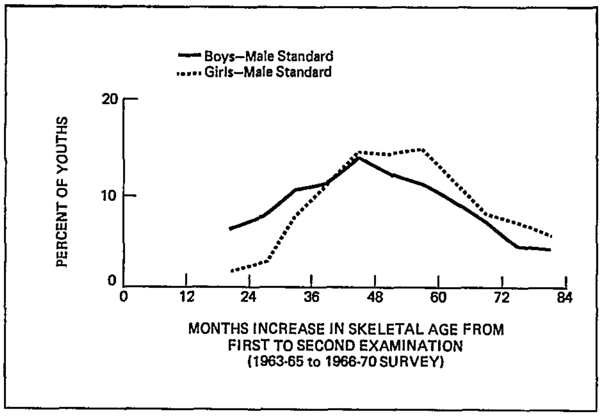


Figure 16. Percent distribution of months increase in skeletal age (male standard) from the first to the second examination for boys and girls in both the Health Examination Surveys of 1963-65 and 1966-70.

3 months or more less than their chronological age increases between the two examinations (25 percent for boys compared with 10 percent for girls); girls were slightly more likely than boys to have a skeletal age increase 3 months or more greater than their actual increase in age between the two examinations (55 percent compared with 46 percent). Nearly 33 percent of girls and 29 percent of boys had skeletal age and chronological age increases between the two examinations that agree within 3 months.

A comparison of skeletal maturity in relation to chronological age (skeletal age less chronological age) for youths included in both surveys is given in table 13 and figure 17. There are changes in the distributions of these differences between the two surveys. A greater proportion of the boys show marked advancement of skeletal age at the second than at the first examination—this would be expected from the general trends in these differences when data from the whole sample at 7-11 years are compared with those at 11-15 years (figure 3). The pattern of greater advancement in skeletal age than in chronological age for the girls (table 12) is reflected in table 13 and figure 17. At the time of the second examination, smaller proportions of girls had skeletal ages that were less than the chronological ages; correspondingly, more of the girls had skeletal ages that were in advance of their chronological ages. This is in agreement with the data for the complete samples. These showed much higher levels of skeletal maturity (expressed as skeletal age less chronological age) for girls aged 11-15 years than for girls aged 7-11 years.

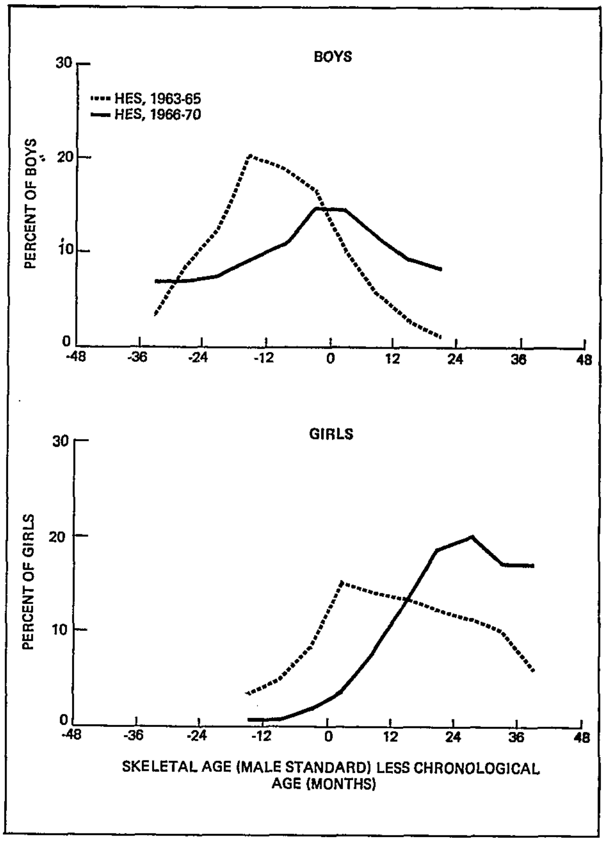


Figure 17. Percent distribution of differences between skeletal and chronological ages at the time of the first and the second examinations for boys and girls in both the Health Examination Surveys of 1963-65 and 1966-70.

These findings should *not* be interpreted as showing secular trends. Rather, as discussed at length in relation to figure 3, they reflect the lack of correspondence between the age equivalents assigned to the standards of reference that were used and the actual levels of skeletal maturity in the national probability samples that were examined.

DISCUSSION

To interpret the findings included in this report, it is necessary for the reader to be fully aware of the sampling and weighting methods employed and system of radiographic assessment applied. Reference has been made to these subjects under "Method," and some aspects are considered more fully in appendix I. In summary, radiographs of the right hand-wrist were assessed for skeletal age. These radiographs had been obtained by examination of a cross-section of noninstitutionalized youths 12-17 years in the United States. A probability sample of 7,514 youths was selected and 6,768 of these (90 percent) were examined. However, 32 of the radiographs were not taken or were unsuitable for skeletal age assessment. The very small number of missing or unsatisfactory radiographs attests to the high quality of the field procedures. The sample examined is closely representative of the total United States population of youths 12-17 (22.7 million). Nevertheless, estimates from the present sample of youths are slightly less reliable than those from the previous survey of children because 96 percent of the selected children were examined.

Data were not estimated for those selected in the sample who were not examined. Instead, it has been assumed that the distribution of skeletal maturity levels for the nonexamined would be similar to that among the examined youths of the same chronological age, sex, race, geographic region, and socioeconomic background. Finally, the data from each examined youth were weighted with the reciprocal of the sampling ratio used for that part of the total population he was selected to represent. This weighting allowed national estimates appropriate for the total population of noninstitutionalized youths. The same sampling and weighting procedure had been followed in the previous analysis of skeletal age in U.S. children 6-11 years.[1] Consequently, direct comparisons can be made between the reports for children and youths and in combination they provide national estimates for the age range from 6 to 17 years. These sampling and weighting procedures should be recalled when the findings from the national survey are compared with earlier reports by others. Earlier studies have been of much smaller groups of children selected on the basis of convenience, e.g., attendance at schools near the investigator.

The radiographs were assessed using the HES set of standards that was prepared for the survey.[8] Each bone was assessed to the nearest month of skeletal age by medical students who were trained by Dr. S.I. Pyle and whose reliability was monitored throughout the period when assessments were being made (appendix I).

The method of skeletal age assessment selected for the survey, on the advice of anthropologist consultants, is essentially the same as that applied when the well-known Greulich and Pyle Atlas[27] is used. Most of the plates in the HES Standard were taken from the Greulich-Pyle Atlas, but they appear to be of right hand-wrist because they were turned over photographically.

There was one important departure from standard practice. The assessors did not know the chronological age, sex, or race of any child whose radiograph was being assessed. All children were assessed against standards for males; all were assigned male skeletal ages. This approach has obvious advantages and some disadvantages. It can provide a much better estimate of sex-associated differences in the skeletal maturity levels of youths than has been available previously. These differences are unbiased and are expressed in months of skeletal age (male). Typically, girls mature more rapidly than boys and, consequently, within chronological age groups, the mean skeletal ages for the girls exceed those of boys when both are assessed against the same set of standards. In the usual method, boys and girls are assessed against sex-appropriate standards and the sex differences between the mean skeletal ages for groups of the same chronological ages are generally small.

In the Health Examination Survey the data for girls were transformed, bone by bone for each youth, to "female equivalent values." The data used for this transformation were provided by Dr. Pyle. As will be discussed later, these data appear to allow appropriate transformations at most ages considered but not near the "adult" end of the skeletal maturity scale.

When skeletal age assessments are made, there are limits to the range of ages that can be applied to each bone. Bones that are not radio-opaque cannot be assessed; the youngest age that can be applied to a bone is between the level of the last standard in which it is not radio-opaque and the level of the first standard in which it is radio-opaque. The maximum age that can be assigned is 1 month less than the "adult" level. Application of these minimum and maximum levels (table A) resulted in some bones being excluded when the mean of the bone-specific skeletal ages was calculated to obtain a single value for each hand-wrist. Additionally, some youths were excluded completely because all their hand-wrist bones had become adult. The proportion of youths that was excluded for this reason was zero in each sex at 12 years but increased to 10 percent in boys and 22 percent in girls at 17 years. This exclusion resulted in an underestimation of the skeletal maturity of older youths, but the effect of this was small. On the male standards, when means for age groups are considered, the effect could be no greater than 2.5 months in boys and 3.8 months in girls, even at 17 years.

Mean Skeletal Age (Hand-Wrist)

In the previous study of children 6-11 years,[1] the mean skeletal ages for boys were lower than the corresponding chronological ages by increasing amounts until the difference was 13.8 months at 11 years. Some retardation is present in boys 12-17 years but, in general, the amount decreases with age from 9.8 months at 12 years to an advancement of 0.5 month at 15 years and a retardation of 4.6 months at 17 years. It is emphasized that these changes with increasing chronological age cannot be due to assessor bias or variations in the survey sampling, but the changes from 15-17 years are mostly artifactual. They are due to the scale by which skeletal maturity is assessed and to the fact that the maturity levels of most of the boys were near the end of the scale. However, if the *maximum* allowance is made for the exclusion of boys in whom all the hand-wrist bones were adult, a retardation still develops between 16 and 17 years in respect of the standards against which they were assessed.

The mean skeletal ages of the girls, assessed against the male standards, are advanced (greater than the chronological ages). The extent of this advancement increases from age 9-11 years in the earlier study of children,[1] and this increase continues to 12 years. At 12 years, the mean skeletal age exceeds the mean chronological age by 24.9 months. Later, the amount of advancement decreases until it is only 1.5 months at 17 years. This decrease is due partly to the exclusion of girls (22 percent at 17 years) in whom all the hand-wrist bones were adult. The estimates of skeletal age for 6-monthly chronological age intervals from the survey of children for the age range 11 years to 11 years 5 months and from the survey of youths for the age range 12 years to 12 years 5 months are in excellent agreement for boys (a mean increment of skeletal age of 6.5 months during the 6-month interval), but the agreement for girls is less good (a mean increment of 11.8 months in skeletal age during the 6-month interval).

The occurrence of mean differences between the chronological and skeletal ages demonstrates that the calibration of the scale is imperfect when used to assess a national probability sample of United States youths. This study does not, however, provide any information as to whether the *order* of maturity indicators is correct within the maturity scale of Pyle et al.[8]

One major advantage of the method of assessment employed was that direct unbiased estimates of sex-associated differences were obtained. This was possible because all assessments were made against a single set of standards by observers who did not know the sex of any child. The mean differences found (in male skeletal age months) increase slightly from 32 months at 11 years to 35 months at 12 years, but then they decrease gradually to reach 6 months at 17 years. The general consistency of the national survey data is attested by the close correspondence between the estimated sex differences at the junction between the age spans studied in the survey of children and the present survey of youths.

The differences reported previously are compared with these values in table F. The method by which Pyle et al.[8] estimated these sex-associated differences is described in detail in their text. At 12 and 13 years their values are close to those obtained in the national survey, but later the survey differences are considerably

Table F. Sex differences in skeletal age months (male) from various studies, by chronological age

Chronological age	Pyle et al., 1961[17]	Todd, 1931[96]	A Roche, 1968[97]	B Roche, 1968[97]	United States, 1966-70
	Skeletal age in months				
12 years	32	15	19	19	34.7
13 years	31	4	23	23	29.2
14 years	30	---	24	24	24.4
15 years	27	---	24	23	19.1
16 years	24	---	23	20	14.9
17 years	22	---	24	23	6.1

A = based on the Greulich-Pyle Atlas (1959).[27]
B = based on the method of Tanner et al. (1962).[98]

larger. The estimates made by Todd[96] are much smaller than those from the national survey. Todd had data from only a small group of children and it is not clear how he arrived at these estimates. Roche[97] estimated these differences by assessing the female standards in one copy of the Greulich-Pyle Atlas against the male standards in another copy. The estimates obtained are considerably smaller than the survey estimates at 12 and 13 years and considerably larger at 16 and 17 years. Roche[97] also estimated these differences from the skeletal age equivalents for each sex assigned to particular scores by Tanner et al.[98] These differences are very similar to those obtained by the same investigator when using two copies of the Greulich-Pyle Atlas.

The occurrence of smaller differences in the national survey data than in those reported by others for 16 and 17 years may be partly artifactual. If the *maximum* allowance were made for those youths excluded because *all* the bones of the hand-wrist were completely adult, the differences in the survey data would become 15.2 months at 16 years and 8.4 months at 17 years (table B). It is clear that this factor was not of major importance. A further artifact, almost certainly trivial, results from the use of "A-6" to designate a maturity level within 6 months of the adult level. This procedure would have led to a slight underestimate, and the effect would have been more common in older girls than in older boys. The sex differences in skeletal ages towards the end of the scale, as recorded in the present survey, vary considerably from those reported by earlier workers, but they are certainly not entirely artifactual. This is shown by the close correspondence between the sex differences in mean skeletal ages and those in the median ages at onset of ossification in specified numbers of bones (table 5 in the report of the children's survey and table 5 in the present report) both at younger and older ages.

It will be recalled that in the national survey bones that had reached adult levels of maturity were excluded when the mean hand-wrist skeletal ages were calculated for individuals. In each sex there is general agreement among previous reports that the last hand-wrist bones in which epiphyseal fusion occurs are the radius, ulna, metacarpals, and proximal phalanges.[18, 74, 93] At older ages the survey data became more dependent on these bones because the other hand-wrist bones had become adult. However, the data of Pyle et al.[8] and of Roche[97] indicate that the sex-associated differences for these bones are similar to those for the whole hand-wrist at 16 and 17 years. Consequently, it is unlikely that the dependence of the survey means on these bones at older ages would be responsible for the differences between the present and previous findings.

These variations between the present findings and those reported by others could not be explained entirely by the absence of bias in the survey data. Presumably they are due to inadequacies in the maturity scales for boys and girls towards the end of maturation. Nevertheless, they are puzzling because the median ages at which fusion occurs in the hand-wrist in youths examined serially differ, between boys and girls, by about 2 years (Roche, unpublished data). Because of these problems with the sex-associated differences near the upper end of the maturity scale, there is doubt about the accuracy of the female equivalent values at these ages. Consequently, in this discussion the emphasis has been placed on the data obtained when the radiographs for each sex were assessed against the male standards. It is considered that the findings for girls assessed against the male standards represent more accurately the real biological changes that occur than do those obtained after transformation to female equivalent values.

The changes across age in the mean differences between skeletal age and chronological age are shown at yearly intervals in figure 3 and at 6-month intervals in figure 7. Considering ages as originally assessed from the male standards, there are prepubertal decelerations and pubertal accelerations in each sex. The maximum advancement (SA>CA) is reached at 12 years in girls and 15 years in boys; later there are decreases in each sex. It is apparent that the male HES Standard, against which both the boys and girls were assessed, does not match the mean skeletal maturity levels for the national sample of boys. If the data for the girls are adjusted for these differences between the national survey boys and the male set of standards, as is done in figure 6, the mean differences between skeletal and chronological age for the girls, assessed against male standards, show a very definite spurt, with a peak at 12 years. These curves are difficult to interpret because the skeletal maturity scale is ordinal. However, due to the transformation of the data for girls to a male set of standards with a markedly improved calibration, a pubertal spurt in girls has been demonstrated even more clearly than in the original data.

This transformation, so that the mean skeletal ages for the boys matched their mean chronological ages, was not ideal because it obscured the pubertal spurt in the boys. This directs attention to one problem with the present scales of skeletal maturity. Essentially, these were constructed by selecting the youth at the median skeletal maturity level in each chronological age group. This procedure tends to bury any pubertal spurt in the scale and makes it more difficult to demonstrate a spurt when the scale is applied.

The adjustment of the mean skeletal ages for the girls, assessed against the male standards, to what they would have been if each mean skeletal age had equaled the corresponding chronological age in the boys, is an improvement because the boys' scale is then calibrated to match exactly the mean levels in the national probability sample. However, it is not ideal. The data in figures 3 and 6 demonstrate a definite pubertal spurt in the girls and a much smaller spurt in the boys. If a cardinal scale were available, it is probable that the spurt would be of similar magnitude in each sex and it would tend to occur about 2 years earlier in girls than boys. Furthermore, even an ideal scale developed from cross-sectional data would not reflect accurately the pubertal changes in individuals. The latter would be more abrupt than those for a group in which some "averaging" occurs across age due to variations in the timing of pubescence. This effect is well known for measures such as height and weight.[99]

One further step could be taken in adjusting the survey data. If it is assumed that the pubertal spurt in maturity is of similar magnitude in each sex, it is clear that part of the spurt in the boys has been concealed in the male skeletal maturity scale because the apparent spurt is much smaller in boys than girls (figure 3). If an adjustment were made for this, the girls' spurt would be slightly less marked and the deceleration would be more rapid than in the original curve or the previously adjusted curve (figures 3 and 6). Furthermore, if this new adjustment were made, the peak of the curve would shift to 11 years, which would be plotted at 11.5 years. This possible additional adjustment has not been made in figure 3 or figure 6.

The effect of scale selection on apparent spurt size would be demonstrated if *all* the survey radiographs were assessed against a single standard for girls. It is hypothesized that, if this were done, the apparent spurt in the boys would be much greater than that in the girls. These sex differences in the apparent size of the spurt would not be evident if the timing of the spurt were the same in each sex.

Scale selection may have less influence on the timing of the apparent pubertal spurts in skeletal maturity. When the national survey radiographs were all assessed against the male standards of Pyle et al.,[8] the peaks of the spurts (mean values) occurred at 12 years in girls and 14 years in boys. These ages, and the difference between them, are close to what would be expected.

If a pubertal spurt in skeletal maturation occurs, as suggested by Todd[18] and Flory,[61] and if this were built into the male skeletal maturity scale, several effects would be expected in data of the present type. If the maturity scale were ideal, the mean differences between the skeletal and chronological ages for the boys would be zero at all ages. The scale is, however, set much too high for boys aged 9-13 years (figures 18 and 19). If the girls were assessed on an ideal boy's scale, it would be expected that the mean differences between skeletal age and chronological age would change during pubescence in the way observed in the national survey. That is, girls would show advancement during their pubescence but later the mean differences would decrease rapidly when the boys became pubescent.

There is no clear evidence in the previous literature that a spurt occurs in skeletal maturation during pubescence but there is reason to believe this is so. Roche[97] reported findings obtained by assessing the female standards in one copy of several standard atlases against the male standards in another copy. The findings showed an increase and subsequent decrease in these differences for the hand-wrist at about the time of puberty using either the Greulich-Pyle[27] or Tanner-Whitehouse[98] method, but there were no corresponding changes in these differences during pubescence for the knee[37] or foot-ankle.[100] Using data from a small group of children and youths, Todd[96] reported sex-associated differences in skeletal maturity levels for the hand-wrist, knee, and elbow that support the view that a pubescent spurt occurs. Evidence of a pubertal spurt in the maturation of the hip joint[40] has been reported also. It is well known that testosterone and estrogens, when given to boys or girls, can markedly accelerate skeletal maturation.[101, 102] Consequently, the occurrence of a pubescent spurt in skeletal maturation, associated with increased levels of circulating steroids, is biologically reasonable.

Another feature of interest in the national survey data concerns the mean differences between skeletal and chronological age in the girls when female equivalent values are used. The mean differences between boys and girls (female equivalent values for the latter) in "skeletal age less chronological age" are comparatively small until 13.5 years. Later there is a rapid increase in these mean differences until the difference is 19.4 months at 17.5 years. It is important to note that an average of only 3.4 bones in each hand-wrist could be assessed in the girls at 17.5 years and that all the bones of the hand-wrist had become adult in 22 percent of the girls at that age. Nevertheless, the findings are not entirely due to the exclusion of hand-wrist

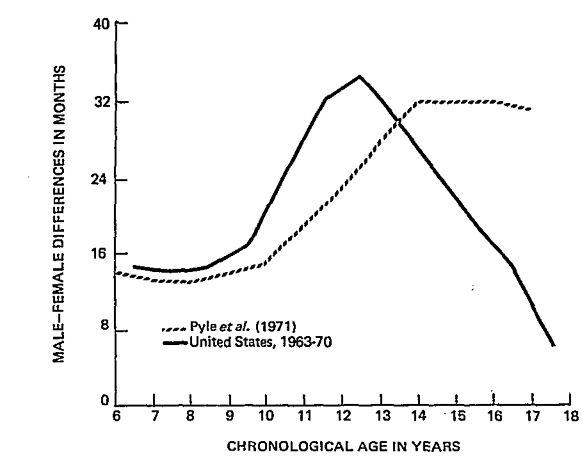


Figure 18. Mean differences between boys and girls in skeletal age (hand-wrist) on the male HES standard for the United States children and youths from the national studies (1963-70) and from data of Greulich and Pyle by chronological age.

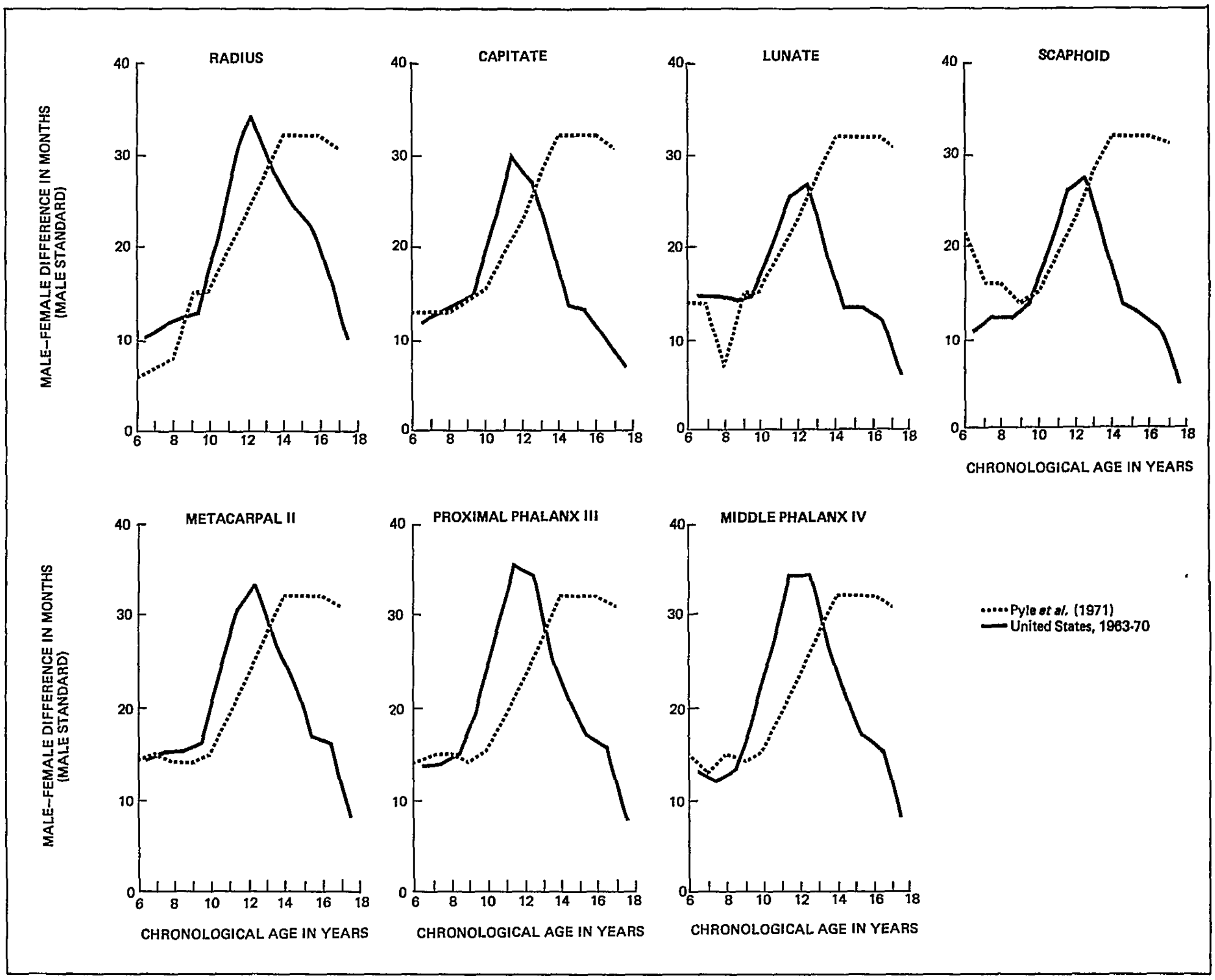


Figure 19. Mean differences between boys and girls in selected bone-specific skeletal ages on the male HES standard for United States children and youths from the national studies (1963-70) and from data of Greulich and Pyle by chronological age.

bones that had become adult or of girls in whom all these bones had become adult.

To some extent, these findings reflect problems with the method of transformation from male skeletal ages to female equivalent values as the end of the skeletal maturity scale is approached. These problems are real, but their importance should not be overemphasized. They occur only near the end of maturation when application of the skeletal maturity scale is less important clinically. Comparisons between the skeletal ages for boys and the female equivalent values for the girls indicate a sex-associated increase in the mean sex differences in skeletal maturity levels from 10.5 to 12.5 years and then a decrease to 17.5 years. However, this decrease appears to be too slight as the end of the scale is approached. The difficulty becomes apparent when boys begin to have pubescent spurts and when substantial numbers of bones in the girls become adult and therefore, for the reasons given earlier, are not used in calculating means. The problems encountered with the female equivalent values, towards the end of the scale, are associated with the truncation of the distributions of skeletal ages within older age groups. The difficulties are, of course, not due to a marked acceleration of the Cleveland group of older youths; this would have been reflected in the findings for both boys and girls. Due to doubts about the accuracy of the female equivalent values towards the end of the skeletal maturity scale *only*, the emphasis in this discussion is on the original data obtained by assessment against the male standard for both sexes. The decision, made long ago, to assess against a single standard has introduced difficulties of interpretation but it has allowed a remarkably objective measure of sex differences and has provided new insights regarding the nature of the skeletal maturity scale.

When previous data for mean skeletal ages in United States youths are compared with the present national survey findings, it is noted that the levels for boys in the Todd Atlas[34] and those reported by Simmons[62] are closer to the present levels than those in the Greulich-Pyle Atlas.[27] Those of Flory[61] and Maresh[65] are markedly lower at most ages, while those of Johnston[63] are higher. Comparisons for girls are more tentative because they can be made only by using the female equivalent values and, towards the end of the maturity scale, there is doubt about the accuracy of these transformations.

Variability of Means

When variability is expressed as the coefficient of variation, the pattern of change ~~with~~ age is similar in both sexes for the period 6-17 years. Increases in variability associated with pubescence thus imply the existence of a pubescent spurt in skeletal maturation. These occur about 2 years earlier in the girls than the boys. Boys are more variable than girls throughout the whole 12-17 range. This is due, in part, to the later occurrence of pubescence in boys and to the fact that the distribution of girls becomes truncated as the adult end of the skeletal maturity scale is approached. In younger children (6-7 years) also, the coefficient of variation is greater in boys than girls. At these ages it is probable that this difference reflects the higher incidence, in boys than in girls, of bones that have just become radio-opaque. It is well known that the timing of this phase of skeletal maturation is very variable.[27]

In the national survey, the distributions of skeletal age, within chronological age groups, were near normal except at older ages when the distributions tended to be skewed to the right particularly in girls. This effect was more marked in the girls because more of them reached the maximum values. Comparisons with previously reported data are of limited value because the groups studied by others were relatively small.

The standard deviations from the national survey are higher than those reported by others for groups of United States boys at 12-14 years. Later there is a more marked decrease in variability in the national survey data than in those reported by others. In the girls (female equivalent values), however, the standard deviations are, with one exception, lower than those reported previously for groups of United States youths. It is not clear why variability differs among the studies in ways that are not the same for both sexes. It is also puzzling to find that the national survey data indicate that variability is more marked in boys than girls, whereas the opposite has been reported by others. Differences in methodology (the present assessors did not know the age or sex of the youths and all youths were assessed against male standards) may have been a factor. Also, it should be recalled that the national sample was large and the reliability of the assessments was particularly high.

Bone-Specific Skeletal Ages

This national survey has provided reference data for the skeletal ages of each hand-wrist bone in U.S. youths 12-17 years. For almost every bone, the mean skeletal age increases with increasing chronological age, but the annual increments tend to decrease, partly because adult bones did not have skeletal ages assigned to them. These bones have been excluded from the analysis. This pattern of smaller annual increments at older ages is absent for the later ossifying bones (adductor sesamoid in boys; flexor sesamoid in each sex). Except for these bones, the patterns of change across age in the three skeletal ages (males and females assessed as males, female equivalent values) for each bone are generally similar to those for the mean skeletal age of the hand-wrist.

The bone-specific skeletal ages obtained in the national survey allow a judgment about the applicability of the Greulich-Pyle Atlas standards to the whole United States population. In addition, these ages will assist the recognition of clinical conditions in which maturation is dysharmonic.[103-105] Despite the need for normative data concerning bone-specific skeletal ages, these were not available for United States youths, nor are such data available for the youths of any other country.

It is preferable to consider the sex differences in skeletal maturity for individual bones using assessments for each sex against the same set of male standards. In the earlier study of children,[1] these sex differences tended to increase with age for almost all the bones. In the youths, they decrease gradually with increasing age. It is considered that much of this decrease is real, for reasons that have been discussed fully in regard to mean skeletal age.

The variability of these bone-specific skeletal ages tended to decrease with age and was generally greater in boys than girls. The low variability of the adductor and flexor sesamoids in boys at 12 years reflects the fact that, in most boys, these sesamoids would have just ossified. The variability of these bone-specific skeletal maturity levels, across age, was influenced by the exclusion of bones that had become adult to such an extent that the standard deviations are less than 1 month for nine bones in the girls at 17 years. Variability is low also for bones that had just become radio-opaque in girls at 12 years. In general, the standard deviations for girls range from 12-15 months. In the boys they range from 16-18 months.

Reference data have not been reported previously concerning the range of bone-specific skeletal ages within the hand-wrist areas of individual United States youths. It has been claimed that the skeleton of the healthy adequately nourished child develops as a unit and its bones differ little in skeletal maturity levels.[36] One purpose of the present national survey was to determine the extent to which this statement is correct for the whole population of United States youths. Others have suggested that the range from the least mature to the most mature bone varies directly with the difference between hand-wrist skeletal age and chronological age,[105] but convincing proof has not been reported. Pyle et al.[106] graphed the extreme bone-specific skeletal ages for each radiograph against chronological age, in addition to the mean skeletal age, and claimed that the most mature bone-specific age indicates the youth's potential for skeletal maturation level. Application of this method would assign, to almost all youths, a potential well in advance of the Greulich-Pyle standards. This attitude of Pyle et al.[106] accords, however, with Todd's[34] statement that in assessment one should utilize the most advanced centers, not the average of all. Few have followed the suggestion of Pyle et al.[106] because reference data are lacking and because the usefulness of these graphs has not been demonstrated.

The bone-specific skeletal ages that were obtained in the national survey allowed calculation of the range of these ages within each hand-wrist. These ranges are necessarily truncated, particularly in older girls, by the exclusion of bones that had become adult. This could be largely responsible for the finding that the median ranges tend to be larger in the boys (table 9). However, the communality indices of ages at onset of ossification in the primary centers during prenatal life and in the epiphyses during infancy and childhood are higher in girls than boys.[39,107,108] Clearly the range is a function of the possible spread on the scale and the number of bones assessed, in addition to biological factors. Although the median ranges are greater in boys, the variability of these ranges is greater in girls at all ages. With increasing age, there is a tendency for variability to increase and for the sex differences in variability to increase. What factors were responsible for these changes in the variability of these ranges are not understood.

Many workers assign 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 or youth the hand-wrist bones differ in skeletal age. These differences are partly genetically determined.[38, 109-111] They are not due entirely to the effects of illness and other environmental factors that were emphasized by Todd.[34] Largely because of the attitude of Todd,[34] it has been suggested that the bones within a hand-wrist with aberrant maturity levels should be ignored.[72] Others have claimed that dysharmonic bones should be recorded on the assumption that they can provide data about the normality of the previous nutrition and illness history of the child.[106]

Various combinations of the same bone-specific skeletal ages yield different area skeletal ages, either for individuals or groups.[112] However, it is not known which is the best method of combining these bone-specific skeletal ages. One particularly difficult problem concerns the occurrence of familial late ossification of particular centers, without retardation in other centers.[113] The problem of combining bone-specific skeletal ages to a single value becomes particularly difficult at each end of the scale. This occurs because skeletal ages, expressed in years, cannot be assigned to centers that are not yet radio-opaque or are already adult. The aim of combining bone-specific skeletal ages should be to describe the data parsimoniously. Pragmatically, the best combination is the one that works best, but this may vary with the purpose and with the youths studied. Such an approach is likely to add further confusion to a biological area that does not need it.

It has been claimed that the carpals should be excluded because they reach adult levels of maturity before most other bones.[61, 114, 115] Furthermore, their inclusion reduces the replicability of overall but not bone-specific assessments.[60, 115, 116] Certainly, it seems unacceptable to assign skeletal ages to carpals on the basis suggested by Tanner,[117] i.e., to view the hand as a whole and when epiphyseal closure is underway to deduce that the carpal bones are adult and rate them accordingly. Some consider the carpals should be omitted because their maturity levels vary widely within chronological age groups,[34, 39, 107] but variability is desirable. Its absence would make assessments unnecessary.

Onset of Ossification

Data recorded between 12 and 17 years are suitable for determining the age of onset of ossification of the adductor and flexor sesamoids in boys and the flexor sesamoid in girls. These ages from the national survey data are slightly later than those reported by Greulich and Pyle[27] for the flexor sesamoid in boys, but they are earlier than the Greulich-Pyle estimate for the adductor sesamoid. In girls, they are markedly later for the flexor sesamoid.

Epiphyseal Fusion

Median ages for the completion of epiphyseal fusion in the radius, ulna, and each short bone of the hand were calculated from the national survey data. These ages from the Health Examination Survey were later in boys (15.6 to 16.6 years) than in girls (13.4 to 14.9) when the radius and ulna were excluded. Sex comparisons were not possible for the latter two bones. In general, the order of fusion was distal phalanges, proximal and middle phalanges, metacarpals, radius, and ulna, which is in agreement with the order from previous studies. However, some bones, particularly metacarpal I, fused earlier than other bones in the same row. There is a tendency for these ages to be slightly earlier than those reported by Garn et al.[91]

Youths Also Examined as Children

About one-third (2,177) of the youths in the present survey had been examined earlier in the survey of children. These serial data, obtained using the same methodology in both surveys, show that increases in skeletal age that were less than the changes in chronological age were more common in the boys than the girls. The opposite changes (increases in skeletal ages greater than those in chronological age) were more common in the girls.

The distributions of the differences between skeletal age and chronological age (skeletal age less chronological age) changed between the two examinations. More youths, both male and female, were markedly advanced in skeletal maturity at the second than at the first examination. This reflects the patterns of change in the complete samples during the 4-year period considered. The skeletal maturity scale against which the radiographs were assessed is much too high for the total United States population aged 7 to 11 years, but it is only slightly too high for youths aged 11 to 15 years.

Conclusion

The skeletal maturity levels provided in this report are useful to a wide variety of health-related professions. Pediatricians use skeletal age in the recognition of syndromes and in the diagnosis and management of youths who are growing at unusual rates. Pediatric surgeons need skeletal age assessments to monitor the effects of some procedures, e.g., cardiac surgery, and to plan some operations, especially those designed to equalize leg length. Skeletal age assessments are important also for those (speech therapists, orthodontists, craniofacial surgeons) who work with youths in whom the length of the cranial base may be abnormal. Nutritionists and human biologists need skeletal age assessments both to describe populations and to analyze the associations between skeletal maturation and skeletal elongation.

For the first time, each of these groups now has available national estimates for skeletal maturity levels both for the hand-wrist and for each of its constituent bones in U.S. youths aged 12 to 17 years.

SUMMARY

The data in this report were obtained during the examination, from 1966 to 1970, of a national probability sample of United States youths aged 12-17 years. The 7,514 youths selected in the sample were representative of the 22.7 million noninstitutionalized youths, in the same age range, in the United States. The sample examined included 6,768 of these youths, or 90 percent of those selected. National estimates for the variables considered could be obtained because the data from each youth were weighted differentially depending on the part of the total population of youths that he represented.

A radiograph was taken of the right hand-wrist of each youth. These radiographs were assessed by medical students who received special training in the assessment of skeletal maturity and whose levels of reliability were high when applying these techniques. When making these assessments, the students did not know the age or sex of any youth. Consequently, several potential sources of bias were absent from the data. All the assessments were made against a single set of maturity standards for males that was prepared for the survey by Dr. S.I. Pyle. Later, the values for girls were transformed, for each bone separately, to female equivalent values using the sex-associated differences reported by Pyle et al.[8]

As expected, when all the youths are assessed against the same set of male standards, the skeletal ages of the girls tend to be more advanced than those of the boys. The mean values for boys are less than the chronological ages for most of the age range 12-17, but the differences between the mean skeletal and chronological ages decrease as chronological age advances. These age related changes show that the scale of maturity used was imperfect when applied to a national probability sample of U.S. boys. The mean skeletal ages for the girls exceed the chronological ages by 24.9 months at 12 years, but this advancement decreases with increasing age until it is only 1.5 months at 17 years.

The differences between the mean skeletal and chronological ages show pubertal accelerations in each sex, with the maximum advancement at 15.5 years in boys and 12.5 years in girls. The spurt in the girls, assessed as boys, becomes even more marked if adjustments are made for the failure of the set of male standards to match this sample of youths in mean skeletal maturity levels. These findings confirm earlier reports that a pubertal spurt occurs in skeletal maturation. Also they direct attention to another problem with the scale of maturity. Not only is the scale set too high for boys, it is not precise in its scaling because, if the scale were ideal, a spurt would not be apparent in cross-sectional data.

When the data for the girls are transformed to female equivalent values, the mean sex differences are comparatively small to 13.5 years, but later they increase rapidly to reach 25.5 months at 17 years, with the values for the girls being less than those for the boys. This rapid increase in the differences between the sexes is not due entirely to the more common exclusion of adult bones among girls than among boys. Partly it reflects problems with the method of obtaining the female equivalent values near the adult end of the skeletal maturity scale. Due to this problem with the transformation of data, most of the conclusions in this report are based on data for both sexes assessed against the same male standards. These findings have been compared with data reported previously. When these comparisons are evaluated, it is difficult to overemphasize one major difference between this and previous studies. The earlier investigations have been of comparatively small groups of youths chosen on a basis of convenience rather than by rigorous sampling procedures. Consequently, the findings from them are less reliable and generalizations from them to the total U.S. population of youths is fraught with danger.

From 12 to 17 years, skeletal age was more variable in boys than in girls, partly because of the later occurrence of pubescence in boys and partly because the distributions become truncated in girls near the end of the scale. The variability of skeletal age, within chronological age groups, increases during the pubescent spurt in each sex. Presumably, this is associated with variations among individuals in the magnitude and timing of the spurt.

The mean skeletal ages, within chronological age groups, were distributed in an almost normal fashion except in older girls, where the right ends of the distributions were truncated because the hand-wrists of some of the girls had become adult. In general, the standard deviations of the means from the national survey data are lower than those reported by others and lower for girls than for boys. These sex differences are in the opposite direction to those reported by others.

Reference data are provided for bone-specific skeletal ages from 12 to 17 years. These increase with chronological age but the annual increments tend to become smaller as 17 years is approached. The ranges of these ages, within individual hand-wrists, tend to be larger in the boys but the ranges themselves are more variable in the girls.

There are only three hand-wrist bones (both sexes combined) that typically have their onsets of ossification during the age range of the present survey. The national estimates of these ages for the adductor sesamoid (boys) and the flexor sesamoid (boys) are in good general agreement with data from other studies. The estimated age at onset of ossification in the flexor sesamoid in girls is, however, markedly later in the national survey data than the only value reported previously for a group of United States girls.[27]

Epiphyseal Fusion

The Health Examination Survey data allowed the estimation of median ages for epiphyseal fusion for all the short bones of the hand and for the ulna in girls. The order in which fusion occurred closely matched that reported previously. The ages from the present national study tend to be slightly earlier than those of Garn et al.[91] who are the only previous workers to have studied a large group of children in this country. Data from the national survey are in general agreement with those reported from earlier studies of groups of youths in this country. The mean order of fusion for rows of bones is the same in each sex: distal phalanges, proximal phalanges, middle phalanges, metacarpals, radius, and ulna. However, metacarpal I fuses early relative to the other bone in the same row. The median sex difference in the timing of fusion is 2.2 years.

Youths Also Examined as Children

Data from more than 2,000 of the youths who were examined also as children are consistent with the cross-sectional data from the total samples. The serial changes in the recorded skeletal ages are influenced by the patterns of changes across age in the differences between the skeletal age equivalents of the standards against which the radiographs were assessed and the actual maturity levels of the United States population.

As a result of this survey, national estimates are available for many aspects of hand-wrist maturity in United States youths. This extends the age range of the previous survey of children[1] and, together with the Health Examination Survey findings of 1963-65, provides reference data for the age range 6-17 years.

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Chronological age at last birthday	Boys (male standard)			Girls (male standard)			Girls (female equivalent)			Population with ossifying bones	
	Mean	s_x	$s_{\bar{x}}$	Mean	s_x	$s_{\bar{x}}$	Mean	s_x	$s_{\bar{x}}$	Boys	Girls
Age in years	Skeletal age (hand-wrist) in months									Number in thousands	
12 years	140.2	17.02	0.65	174.9	14.84	0.69	142.9	12.12	0.56	2,024	1,953
13 years	157.4	18.05	0.86	186.6	12.97	0.62	155.2	10.79	0.52	2,003	1,943
14 years	173.6	15.12	0.75	198.0	10.82	0.60	168.0	9.18	0.51	1,948	1,881
15 years	186.5	14.29	0.61	205.6	9.16	0.49	177.6	7.91	0.42	1,883	1,774
16 years	196.4	13.81	0.74	211.3	9.95	0.48	185.6	8.74	0.42	1,792	1,565
17 years	205.4	11.08	0.48	211.5	9.95	0.61	186.0	8.75	0.54	1,574	1,344
Age in 6-month intervals											
12 years:											
0-5 months	134.4	16.08	0.98	171.6	14.01	1.13	139.6	11.40	0.92	908	928
6-11 months	145.0	16.26	1.04	177.9	14.92	0.91	145.9	12.24	0.75	1,117	1,025
13 years:											
0-5 months	153.1	18.15	1.18	183.2	12.66	0.96	151.2	10.45	0.79	1,072	1,026
6-11 months	162.3	16.60	0.96	190.4	12.25	0.94	159.4	10.26	0.79	931	917
14 years:											
0-5 months	171.7	14.91	0.87	195.6	11.12	0.89	165.6	9.41	0.75	971	974
6-11 months	175.5	15.09	1.13	200.6	9.84	0.66	171.6	8.42	0.56	977	907
15 years:											
0-5 months	183.7	14.75	0.93	204.6	9.02	0.88	176.2	7.77	0.76	976	856
6-11 months	189.5	13.12	0.83	206.5	9.20	0.36	178.5	7.95	0.31	907	918
16 years:											
0-5 months	193.7	13.78	1.02	210.3	9.46	0.87	184.3	8.29	0.76	980	825
6-11 months	199.5	13.17	0.96	212.4	10.36	0.60	187.8	9.16	0.53	812	740
17 years:											
0-5 months	204.7	11.09	0.69	210.9	9.07	0.75	184.9	7.95	0.66	825	722
6-11 months	206.2	11.00	0.96	212.2	10.84	0.87	187.4	9.57	0.77	748	622

Table 2. Mean and standard deviation for skeletal age (hand-wrist) of youths, by chronological age in months and sex: United States, 1966-70

Chronological age at last birthday and sex	Months of chronological age (after last birthday)											
	0	1	2	3	4	5	6	7	8	9	10	11
	Mean skeletal age (hand-wrist) in months											
Boys (male standard)												
12 years	121.9	134.8	138.0	130.4	134.4	135.5	142.3	140.0	144.2	146.4	148.6	147.5
13 years	146.2	145.6	157.1	152.8	160.5	156.1	160.3	159.9	164.0	162.7	162.4	164.8
14 years	169.4	168.8	172.1	172.9	171.5	174.9	175.1	168.6	173.5	178.1	173.3	182.0
15 years	177.7	181.2	183.8	188.8	182.8	186.4	187.5	187.5	191.0	188.1	188.3	195.0
16 years	190.0	194.6	190.0	196.4	195.2	196.9	197.6	194.6	201.7	201.0	199.9	204.2
17 years	201.4	204.9	202.0	205.3	208.1	205.6	205.9	206.3	203.7	209.4	208.0	204.5
18 years	208.1	191.3	...	...	...	...	...	...	...	...	...	...
Girls (male standard)												
12 years	158.8	173.8	168.6	169.7	172.9	174.6	173.2	175.7	181.4	177.6	183.1	176.7
13 years	180.0	181.2	182.5	185.1	185.5	185.9	186.5	191.2	191.0	190.7	192.2	192.1
14 years	194.9	195.9	196.6	194.1	195.1	197.5	201.5	200.9	199.8	200.6	199.2	202.1
15 years	204.8	203.4	207.7	202.6	206.1	204.0	203.9	204.5	206.7	208.3	207.6	208.4
16 years	207.0	207.6	209.8	212.3	214.1	214.1	209.3	211.7	212.8	212.4	213.8	213.7
17 years	211.4	212.6	209.4	207.9	213.1	211.1	210.9	211.7	212.5	218.2	211.6	214.9
18 years	209.0	206.0	...	...	...	...	...	...	...	...	...	...
Girls (female equivalent)												
12 years	129.4	141.8	136.6	137.7	140.9	142.6	141.2	143.7	149.4	145.6	151.1	144.7
13 years	148.0	149.2	150.5	153.1	153.5	153.9	155.0	160.2	160.0	159.7	161.2	161.1
14 years	164.8	165.9	166.6	163.2	165.1	167.5	172.5	171.9	170.8	171.6	170.2	173.1
15 years	176.6	174.4	180.4	173.6	178.1	175.0	174.9	176.0	178.7	181.3	180.2	181.4
16 years	179.0	180.2	183.6	187.6	190.1	190.1	182.6	186.4	188.6	187.8	189.8	189.7
17 years	185.8	188.2	182.8	180.8	189.1	185.2	184.9	186.4	188.0	194.4	186.2	190.9
18 years	182.0	178.0	...	...	...	...	...	...	...	...	...	...
	Standard deviation in skeletal age (hand-wrist) in months											
Boys (male standard)												
12 years	5.92	16.91	17.26	13.06	15.33	16.34	15.75	15.34	16.16	16.61	16.73	14.49
13 years	19.16	17.89	17.98	17.30	14.55	16.84	16.57	17.49	16.26	15.49	19.05	12.58
14 years	12.80	16.64	13.16	15.28	17.20	11.73	12.69	15.07	18.19	13.16	12.36	14.38
15 years	16.18	13.33	15.79	12.23	14.44	13.57	12.14	11.84	13.82	11.66	16.59	10.38
16 years	15.45	14.71	14.45	11.57	11.68	11.51	13.77	12.80	15.00	12.64	13.20	9.59
17 years	12.19	11.29	12.12	9.63	9.94	10.08	9.44	7.30	15.28	8.89	10.64	9.60
18 years	8.87	11.10	...	...	...	...	...	...	...	...	...	...
Girls (male standard)												
12 years	18.96	14.21	14.49	14.07	11.95	13.00	16.14	15.11	14.31	15.77	13.27	12.98
13 years	11.53	15.02	10.97	13.04	11.45	11.64	11.87	11.63	12.17	13.33	11.71	11.26
14 years	11.45	10.89	9.19	13.83	10.09	8.97	8.47	10.88	10.23	9.05	9.67	10.17
15 years	8.58	7.58	8.71	9.99	7.60	10.85	8.46	9.23	8.47	9.25	9.88	9.06
16 years	10.27	9.92	9.04	8.63	6.57	8.27	10.51	7.64	16.20	8.17	7.22	8.26
17 years	7.46	8.04	9.87	9.72	8.23	9.75	9.68	12.04	10.97	3.73	10.54	8.18
18 years	15.85	-	...	...	...	...	...	...	...	...	...	...

Table 3. Percent distribution and selected percentiles for skeletal age (hand-wrist) of youths, by chronological age in years at last birthday and sex: United States, 1966-70

Skeletal age (hand-wrist) in months	Boys—chronological age in years					
	12	13	14	15	16	17
	Percent distribution—male standard					
Below 90[1]	0.1	-	-	-	-	-
90-95	0.1	-	-	-	-	-
96-101	0.1	-	-	-	-	-
102-107	0.5	-	-	-	-	-
108-113	2.8	0.8	-	-	-	-
114-119	8.1	2.0	-	0.1	-	-
120-125	10.7	3.4	0.5	-	-	0.2
126-131	14.7	5.3	0.4	-	0.2	-
132-137	11.2	4.3	0.6	0.2	-	-
138-143	9.5	6.3	1.8	-	0.1	-
144-149	10.5	8.0	2.3	0.6	-	-
150-155	10.6	12.2	5.6	1.0	0.2	-
156-161	9.5	12.7	10.0	1.9	1.2	-
162-167	6.5	14.3	10.9	5.4	2.1	0.1
168-173	3.5	13.4	17.9	9.0	3.3	0.2
174-179	1.1	9.4	20.0	17.4	7.5	2.2
180-185	0.4	5.0	11.4	15.0	5.7	2.2
186-191	-	1.6	6.1	8.9	10.4	5.9
192-197	0.1	1.0	6.1	15.4	15.0	9.9
198-203	-	0.1	4.3	12.7	22.4	19.6
204-209	-	0.1	1.8	9.9	18.2	20.4
210-215	-	-	0.3	1.5	8.4	21.3
216-221	-	0.1	-	0.8	3.1	11.7
222-223	-	-	-	0.2	2.2	6.3
Percentile	Skeletal age (hand-wrist) in months					
P_{95}	168.3	183.3	199.6	207.9	216.2	223.1
P_{75}	154.4	170.6	182.1	198.0	206.2	212.8
P_{50}	139.4	158.9	174.0	185.7	198.9	206.8
P_{25}	127.2	145.2	165.0	176.6	188.7	199.3
P_5	115.5	123.5	147.5	163.5	172.0	186.3

[1]Lowest value 89 months - boys aged 12 years.

Table 3. Percent distribution and selected percentiles for skeletal age (hand-wrist) of youths, by chronological age in years at last birthday and sex: United States, 1966-70—Con.

Girls—chronological age in years						Girls—chronological age in years					
12	13	14	15	16	17	12	13	14	15	16	17
Percent distribution—male standard						Percent distribution—female equivalent					
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	0.2	-	-	-	0.1	-
-	-	-	-	-	-	0.2	-	-	-	-	-
-	-	-	-	-	-	0.3	-	-	-	-	-
0.4	-	-	-	0.1	-	2.0	-	0.2	-	-	-
-	-	-	-	-	-	3.1	0.3	-	-	-	-
0.2	-	-	-	-	-	12.7	3.5	0.3	0.1	-	0.3
1.3	-	-	-	-	-	15.4	5.9	0.9	-	-	-
1.2	-	0.2	-	-	-	18.0	11.9	2.7	-	-	0.2
1.9	-	-	-	-	-	19.1	17.7	5.4	0.3	0.8	0.9
3.8	0.5	-	-	-	-	8.8	9.8	4.5	2.2	0.2	1.2
8.5	3.0	0.2	-	-	0.3	9.0	14.5	9.2	4.3	1.8	1.0
10.8	3.5	0.6	0.1	-	-	6.6	15.3	20.1	15.0	6.6	4.9
17.5	10.2	2.0	-	-	-	2.2	10.6	21.4	14.3	9.4	12.1
20.6	16.5	5.0	0.2	0.6	0.2	1.6	6.0	19.0	21.2	9.7	10.2
12.1	14.0	5.0	1.7	0.4	1.1	0.7	3.6	10.2	17.4	20.7	13.7
9.1	13.3	7.0	3.4	0.8	1.1	-	0.4	3.2	10.7	12.7	15.8
8.0	17.9	23.4	16.5	7.7	5.8	0.1	0.5	2.2	8.6	18.4	16.5
2.8	12.2	25.7	17.4	10.8	12.7	-	-	0.7	5.9	19.6	23.2
1.0	6.5	19.9	25.6	16.0	13.8	-	-	-	-	-	-
0.7	1.9	8.1	20.6	25.8	25.5	-	-	-	-	-	-
0.1	0.5	2.2	8.6	18.5	16.8	-	-	-	-	-	-
-	-	0.7	5.9	19.3	22.7	-	-	-	-	-	-
Skeletal age (hand-wrist) in months											
197.8	207.2	212.9	223.0	223.7	223.8	167.8	179.4	188.8	201.0	201.7	201.8
184.5	196.8	205.1	212.0	220.3	220.7	152.5	166.8	177.1	187.0	197.3	197.7
175.2	187.3	199.4	206.1	212.1	212.9	143.2	156.3	170.4	178.1	186.2	186.9
166.7	177.3	193.4	199.2	206.4	205.1	134.7	145.3	162.4	170.4	178.4	176.2
150.0	166.1	176.7	191.5	195.4	194.4	124.0	134.1	144.7	160.5	164.8	163.4

Table 4. Percent distribution and selected percentiles for skeletal age (hand-wrist) in months of youths, by chronological age at last birthday in 6-month intervals and sex: United States, 1966-70

Skeletal age (hand-wrist) in months	Boys—chronological age in months											
	144-149	150-155	156-161	162-167	168-173	174-179	180-185	186-191	192-197	198-203	204-209	210 or more
	Percent distribution—male standard											
Below 90	0.3	-	-	-	-	-	-	-	-	-	-	-
90-95	0.3	-	-	-	-	-	-	-	-	-	-	-
96-101	0.3	-	-	-	-	-	-	-	-	-	-	-
102-107	0.7	0.3	-	-	-	-	-	-	-	-	-	-
108-113	5.2	0.9	1.5	-	-	-	-	-	-	-	-	-
114-119	11.8	5.1	3.4	0.3	-	-	-	0.2	-	-	-	-
120-125	14.1	7.9	3.6	3.2	0.3	0.7	-	-	-	-	-	0.4
126-131	19.1	10.9	6.7	3.7	0.7	-	-	-	0.4	-	-	-
132-137	11.4	10.9	5.8	2.5	0.6	0.5	0.3	-	-	-	-	-
138-143	7.7	10.9	9.0	3.2	2.4	1.3	-	-	0.2	-	-	-
144-149	10.8	10.2	9.1	6.8	3.4	1.3	1.2	-	-	-	-	-
150-155	7.1	13.4	12.7	11.5	5.8	5.4	1.6	0.3	0.3	-	-	-
156-161	6.0	12.5	13.1	12.5	12.1	8.0	2.9	0.9	1.8	0.4	-	-
162-167	1.7	10.5	12.1	16.6	11.7	9.9	7.7	3.0	3.3	0.6	0.2	-
168-173	2.5	4.3	11.9	15.0	18.0	17.8	11.4	6.4	4.1	2.4	0.3	-
174-179	0.8	1.4	7.5	11.6	19.6	20.6	20.2	14.3	5.3	10.1	2.9	1.5
180-185	-	0.8	1.7	8.8	12.4	10.3	13.6	16.5	8.1	2.8	3.5	0.8
186-191	-	-	0.8	2.5	3.8	8.4	5.7	12.5	11.9	8.6	7.0	4.6
192-197	0.2	-	0.9	1.2	3.1	9.1	13.4	17.4	19.4	9.7	10.3	9.4
198-203	-	-	-	0.3	4.3	4.2	13.8	11.6	22.7	22.3	19.7	19.6
204-209	-	-	-	0.3	1.4	2.3	6.8	13.3	14.6	22.5	18.3	22.8
210-215	-	-	-	-	0.4	0.2	0.9	2.1	5.6	11.7	19.4	23.4
216-221	-	-	0.2	-	-	-	0.2	1.5	0.8	5.9	12.5	10.8
222-223	-	-	-	-	-	-	0.3	-	1.5	3.0	5.9	6.7
Percentile	Skeletal age (hand-wrist) in months											
P_{75}	145.3	157.8	166.5	173.9	180.1	185.2	197.2	199.5	203.3	208.9	212.6	213.2
P_{50}	131.5	145.3	155.4	165.3	172.3	175.8	181.6	190.0	196.3	202.1	205.9	207.4
P_{25}	121.5	131.9	142.0	152.7	161.8	167.1	173.9	179.9	186.8	192.0	198.6	199.9

Table 4. Percent distribution and selected percentiles for skeletal age (hand-wrist) in months of youths, by chronological age at last birthday in 6-month intervals and sex: United States, 1966-70—Con.

Skeletal age (hand-wrist) in months	Girls—chronological age in months									
	144-149	150-155	156-161	162-167	168-173	174-179	180-185	186-191	192-197	198-203
	Percent distribution—male standard									
Below 90	-	-	-	-	-	-	-	-	-	4.4
90-95	-	-	-	-	-	-	-	-	-	-
96-101	-	-	-	-	-	-	-	-	-	-
102-107	-	-	-	-	-	-	-	-	-	-
108-113	-	-	-	-	-	-	-	-	-	0.3
114-119	0.4	0.4	-	-	-	-	-	-	-	0.9
120-125	-	-	-	-	-	-	-	-	-	1.3
126-131	0.4	-	-	-	-	-	-	-	-	1.8
132-137	2.1	0.6	-	-	-	-	-	-	-	1.5
138-143	0.8	1.6	-	-	0.4	-	-	-	-	1.7
144-149	1.5	2.3	-	-	-	-	-	-	-	2.0
150-155	5.9	1.9	0.6	0.4	-	-	-	-	-	2.9
156-161	10.0	7.0	4.9	1.0	0.3	-	-	-	-	4.1
162-167	15.0	7.0	4.3	2.6	0.8	0.4	-	0.2	-	4.7
168-173	20.5	14.6	15.0	5.0	3.2	0.7	-	-	-	6.6
174-179	19.2	21.9	17.4	15.3	5.8	4.1	0.4	-	1.2	8.6
180-185	9.2	14.5	15.0	12.9	7.3	2.6	2.7	0.7	-	6.2
186-191	7.9	10.1	14.7	11.8	7.7	6.3	3.4	3.4	0.8	5.5
192-197	4.0	11.8	14.2	22.0	25.1	21.4	17.3	15.8	9.2	10.2
198-203	1.9	3.7	10.2	14.4	27.9	23.4	20.3	14.8	14.4	10.9
204-209	0.9	1.2	2.9	10.5	15.1	25.0	25.7	25.5	12.6	10.1
210-215	0.3	1.1	0.5	3.4	5.5	11.0	16.6	24.3	28.0	8.2
216-221	-	0.3	0.3	0.7	0.9	3.6	10.4	6.9	18.5	4.3
222-223	-	-	-	-	-	1.5	3.2	8.4	15.3	3.8
<u>Percentile</u>	Skeletal age (hand-wrist) in months									
P_{75}	179.1	189.0	193.4	200.0	203.2	207.8	211.3	212.5	216.9	204.5
P_{50}	171.7	178.3	182.3	192.3	197.8	202.1	205.0	207.2	211.4	189.1
P_{25}	163.7	170.6	174.1	180.4	191.4	195.0	198.4	200.6	203.5	166.9

Table 4. Percent distribution and selected percentiles for **skeletal age (hand-wrist)** in months of youths, by chronological age at last birthday in 6-month intervals and sex: United States, 1966-70—Con.

Skeletal age (hand-wrist) in months	Girls—chronological age in months									
	144-149	150-155	156-161	162-167	168-173	174-179	180-185	186-191	192-197	198-203
	Percent distribution—female equivalent									
Below 90	-	-	-	-	-	-	-	-	-	4.5
90-95	-	-	-	-	-	-	-	-	-	0.1
96-101	-	0.4	-	-	-	-	-	-	-	0.5
102-107	0.4	-	-	-	-	-	-	-	-	1.4
108-113	0.4	0.2	-	-	-	-	-	-	-	2.6
114-119	2.9	1.1	-	-	0.4	-	-	-	-	2.5
120-125	2.3	3.7	0.2	0.4	-	-	-	-	-	3.8
126-131	16.3	9.2	5.8	1.0	0.5	-	-	0.2	-	6.3
132-137	21.8	9.5	8.4	3.1	1.4	0.4	-	-	-	6.1
138-143	18.6	17.4	15.1	8.3	3.8	1.6	-	-	-	6.8
144-149	17.5	20.5	19.6	15.6	7.2	3.4	0.4	0.3	1.2	8.7
150-155	7.1	10.4	9.8	10.0	5.5	3.4	3.7	0.8	-	4.6
156-161	6.6	11.2	15.2	13.8	10.2	8.1	2.8	5.7	2.1	6.1
162-167	3.0	10.1	12.1	18.8	21.7	18.6	17.0	13.2	8.0	8.8
168-173	1.9	2.6	9.1	12.1	23.5	19.1	17.6	11.3	12.9	9.5
174-179	0.9	2.3	2.7	9.7	17.1	21.0	21.6	20.7	9.0	8.6
180-185	0.3	1.1	1.7	5.7	6.0	14.7	13.4	21.1	21.0	7.0
186-191	-	-	-	0.8	1.8	4.6	9.9	11.3	12.1	4.0
192-197	-	0.3	0.3	0.7	0.9	3.6	10.4	6.9	18.4	4.3
198-203	-	-	-	-	-	1.5	3.2	8.5	15.3	3.8
204-209	-	-	-	-	-	-	-	-	-	-
210-215	-	-	-	-	-	-	-	-	-	-
216-221	-	-	-	-	-	-	-	-	-	-
222-223	-	-	-	-	-	-	-	-	-	-
<u>Percentile</u>	Skeletal age (hand-wrist) in months									
P_{75}	147.1	158.0	162.4	170.0	174.2	179.8	185.3	187.5	192.9	175.5
P_{50}	139.7	146.3	150.3	161.3	167.8	173.1	177.0	179.2	185.4	158.1
P_{25}	132.7	138.6	142.1	148.4	160.4	164.0	168.4	171.6	174.5	135.0

Table 5. Percent of youths showing the number of radio-opaque hand-wrist bones—ossifying and adult—by chronological age in years at last birthday and sex: United States, 1966-70

Number of hand-wrist bones ossifying	Boys—chronological age in years						Girls—chronological age in years					
	12	13	14	15	16	17	12	13	14	15	16	17
Total with one or more bones ossifying[1]	Percent of youths											
Only one	-	0.1	-	0.6	6.5	22.4	0.1	0.3	4.0	16.6	42.1	46.8
2 or less	-	0.4	3.0	12.9	33.0	56.5	3.1	9.2	27.2	53.0	70.1	70.1
3 or less	-	0.4	3.8	15.4	39.8	61.8	3.7	11.8	32.4	57.5	75.1	76.3
4 or less	-	0.4	4.0	17.3	43.1	64.6	3.8	12.8	36.9	61.3	78.0	78.9
5 or less	-	0.4	4.2	18.9	45.4	66.4	4.7	14.5	40.2	64.1	80.2	82.5
6 or less	-	0.5	5.2	22.1	51.0	72.2	5.2	18.4	48.5	69.8	85.0	86.9
7 or less	-	0.5	5.5	23.3	52.2	74.8	5.7	19.9	51.9	74.9	86.7	88.6
8 or less	-	0.5	5.8	24.4	53.3	76.6	6.2	22.7	53.9	76.9	88.4	90.1
9 or less	-	0.5	6.0	25.2	54.0	77.6	6.3	24.1	55.5	78.9	89.4	90.8
10 or less	-	0.5	6.5	27.2	56.5	78.4	6.5	24.7	56.8	81.8	90.4	91.9
11 or less	-	0.7	7.6	28.2	58.2	79.9	7.0	25.9	59.9	82.6	92.3	92.4
12 or less	-	0.7	7.8	29.2	59.2	81.5	7.5	28.0	61.4	84.2	92.6	93.5
13 or less	-	0.7	8.5	30.0	59.9	83.5	7.9	29.7	64.2	85.4	93.7	94.4
14 or less	-	0.7	8.5	31.8	61.0	84.3	8.7	30.9	66.1	86.8	94.5	95.4
15 or less	-	0.8	9.8	34.2	63.7	85.5	10.3	34.3	69.2	88.1	95.0	96.2
16 or less	0.1	1.7	12.1	38.3	69.1	88.1	14.9	39.9	72.9	91.1	96.5	97.3
17 or less	0.1	1.8	13.4	40.1	70.2	89.5	16.1	42.0	74.6	92.0	96.9	97.9
18 or less	0.1	2.0	14.5	41.7	72.2	90.4	17.3	44.7	77.0	93.6	97.6	97.9
19 or less	0.1	2.1	15.0	42.5	73.5	90.9	18.5	46.5	78.1	94.5	97.8	99.0
20 or less	0.1	2.4	16.2	45.8	75.2	92.0	20.2	47.9	80.4	95.5	98.6	99.4
21 or less	0.2	3.7	22.4	53.3	78.9	93.2	22.8	50.2	83.1	95.9	98.8	99.4
22 or less	0.2	5.1	24.2	55.2	80.0	93.2	24.4	51.4	83.8	96.0	99.0	99.4
23 or less	0.5	7.5	27.8	58.5	81.0	93.9	29.4	56.2	84.5	96.4	99.0	99.7
24 or less	0.6	8.2	30.0	59.6	82.0	94.1	31.2	57.8	85.0	97.7	99.0	99.7
25 or less	0.6	8.6	30.6	60.9	82.7	94.8	32.8	59.4	86.0	97.9	99.4	99.7
26 or less	0.6	9.0	31.8	61.8	83.4	95.8	34.9	62.0	87.0	97.9	99.6	100.0
27 or less	0.6	9.8	32.4	62.7	84.8	96.4	36.7	63.6	87.6	98.2	99.6	100.0
28 or less	16.6	16.6	34.8	65.2	85.9	97.1	38.7	67.3	89.0	98.6	99.8	100.0
29 or less	63.3	40.5	42.5	70.4	88.3	97.7	45.1	72.3	89.9	98.8	100.0	100.0
30 or less	85.2	63.2	57.8	75.5	90.4	98.3	62.4	78.9	93.0	99.0	100.0	100.0
31 or less	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Number of bones ossifying per youth												
Mean	29.3	29.1	26.1	19.3	11.7	6.3	25.7	19.5	11.2	5.9	3.6	3.4
s_x	1.08	3.28	7.55	10.55	10.49	7.49	7.48	10.11	9.62	6.46	4.25	4.25

[1]Radio-opaque but not yet "adult."

Table 5. Percent of youths showing the number of radio-opaque hand-wrist bones—ossifying and adult—by chronological age in years at last birthday and sex: United States, 1966-70—Con.

Number of hand-wrist bones "adult"	Boys—chronological age in years						Girls—chronological age in years					
	12	13	14	15	16	17	12	13	14	15	16	17
Total with one or more bones "adult"	Percent of youths											
Only one	39.5	19.6	12.8	7.5	5.2	0.4	8.5	5.1	3.7	2.6	2.0	-
2 or less	58.5	31.2	20.2	14.5	10.2	1.2	11.6	10.4	7.0	4.9	3.8	-
3 or less	74.6	39.7	25.4	18.2	12.9	1.8	15.2	14.6	10.1	7.1	5.6	-
4 or less	74.6	44.3	27.9	20.0	14.5	2.0	19.4	17.5	12.0	8.5	6.7	-
5 or less	79.5	46.6	30.5	21.9	16.0	3.0	24.2	21.3	14.7	10.4	8.2	0.2
6 or less	79.5	48.6	32.5	23.8	17.4	3.6	27.3	23.9	16.5	11.7	9.2	0.2
7 or less	79.5	52.8	37.4	26.8	19.7	3.8	34.1	27.9	19.1	13.8	10.9	0.2
8 or less	89.8	71.7	49.6	35.0	25.1	4.4	44.2	35.6	23.8	17.2	13.4	0.4
9 or less	89.8	76.8	54.7	38.7	27.8	4.4	47.0	37.6	25.2	18.2	14.2	0.4
10 or less	96.5	85.4	67.4	50.3	36.4	5.5	53.4	41.8	28.9	20.8	16.3	0.4
11 or less	96.5	87.0	69.9	53.7	39.2	6.5	57.4	44.4	31.5	22.9	18.1	0.8
12 or less	96.5	87.8	71.1	54.9	40.5	6.9	60.1	47.1	33.5	24.6	19.4	1.6
13 or less	96.5	88.6	73.4	57.1	42.7	7.8	62.5	50.4	36.5	27.1	21.5	1.8
14 or less	96.5	90.5	76.3	59.8	44.9	9.0	66.8	53.9	39.3	29.3	23.3	2.1
15 or less	100.0	95.2	82.1	65.5	50.7	11.4	77.0	62.4	45.9	34.8	27.7	2.9
16 or less	100.0	96.0	84.1	68.3	53.4	12.5	80.3	66.4	49.6	37.7	30.1	3.8
17 or less	100.0	96.0	84.1	69.6	54.7	13.4	81.5	67.9	51.6	39.5	31.6	4.6
18 or less	100.0	96.0	85.2	70.7	55.8	15.2	82.4	69.5	53.5	41.2	33.2	5.3
19 or less	100.0	96.0	85.5	71.6	56.6	16.5	83.6	72.0	55.8	43.2	34.8	5.9
20 or less	100.0	97.0	88.1	73.7	58.9	18.0	84.9	73.1	57.7	44.8	36.4	6.3
21 or less	100.0	97.0	88.6	75.3	60.7	18.8	85.3	73.8	58.9	46.5	37.9	7.2
22 or less	100.0	97.0	89.1	76.2	61.5	19.5	85.5	75.3	60.4	48.2	39.4	7.7
23 or less	100.0	97.0	89.7	77.3	62.8	21.1	86.7	78.1	62.9	50.5	41.5	8.9
24 or less	100.0	97.0	90.4	78.5	63.9	23.7	87.8	79.6	65.5	54.0	44.6	10.4
25 or less	100.0	97.8	91.9	81.6	68.2	29.0	89.5	83.9	71.6	59.8	50.1	13.8
26 or less	100.0	97.8	92.4	83.4	70.4	30.7	91.4	85.7	74.3	62.4	52.5	16.4
27 or less	100.0	97.8	93.5	85.2	72.9	33.0	91.4	86.6	77.0	65.6	55.6	18.5
28 or less	100.0	97.8	95.5	88.2	78.2	39.2	93.1	89.8	81.5	70.7	60.6	23.6
29 or less	100.0	99.3	99.8	99.1	96.1	69.6	99.6	99.4	97.8	92.4	83.1	42.5
30 or less	100.0	100.0	100.0	99.7	99.0	89.5	100.0	99.8	99.6	98.6	96.4	78.2
31 or less	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Number of "adult" bones per youth with adult bones												
Mean	3.5	7.2	11.6	16.4	21.8	25.8	11.7	15.4	21.7	25.5	27.7	28.4
s_x	3.48	5.89	8.14	9.38	8.68	6.64	7.91	9.11	7.98	5.94	4.56	4.01

Table 5. Percent of youths showing the number of radio-opaque hand-wrist bones—ossifying and adult—by chronological age in years at last birthday and sex: United States, 1966-70—Con.

Number of hand-wrist bones not yet radio-opaque	Boys—chronological age in years						Girls—chronological age in years					
	12	13	14	15	16	17	12	13	14	15	16	17
Total with one or more bones not yet radio-opaque	Percent of youths											
Only one	21.7	22.9	20.8	17.3	15.2	3.7	19.7	14.8	12.0	10.4	8.8	1.9
2 or less	67.8	56.5	45.3	36.1	30.6	3.9	24.0	17.3	13.8	11.8	9.9	2.3
3 or less	83.4	67.2	52.5	41.7	35.1	-	24.4	17.5	13.9	11.9	10.0	2.3
4 or less	83.4	67.2	52.5	41.7	35.1	4.1	24.6	17.6	13.9	11.9	10.0	2.3
Number of unformed bones per youth												
Mean	1.6	0.8	0.3	0.1	0.1	0.1	0.3	0.1	0.1	0.1	0.0	0.0
s_x	0.91	0.94	0.56	0.31	0.27	1.01	0.58	0.34	0.24	0.24	0.13	0.15

Table 6. Mean, standard deviation(s_x), and standard error of mean($s_{\bar{x}}$) bone-specific skeletal ages for the 31 individual hand-wrist bones of youths and the number of youths, by chronological age in years at last birthday and sex: United States, 1966-70

Radio-opaque (not adult) hand-wrist bone and value	Boys—chronological age in years					
	12	13	14	15	16	17
	Bone-specific skeletal age in months—male standard					
Radius:						
Mean	139.8	157.2	173.5	186.3	197.3	207.1
s_x	16.52	17.66	15.72	14.72	14.98	11.96
$s_{\bar{x}}$	0.69	0.86	0.71	0.63	0.73	0.49
Ulna:						
Mean	140.0	156.8	173.0	185.7	194.4	201.9
s_x	16.28	17.72	15.50	14.55	13.42	8.46
$s_{\bar{x}}$	0.67	0.86	0.72	0.63	0.81	0.55
Capitate:						
Mean	140.9	155.8	167.8	175.0	176.9	184.9
s_x	16.91	16.76	12.54	11.31	11.93	8.46
$s_{\bar{x}}$	0.69	0.97	0.90	1.06	1.54	1.79
Hamate:						
Mean	142.0	156.5	168.4	175.6	178.1	185.2
s_x	16.94	16.65	12.10	10.96	11.13	8.07
$s_{\bar{x}}$	0.66	0.97	0.88	1.07	1.44	1.70
Triquetral:						
Mean	140.6	155.1	167.3	174.6	176.9	185.6
s_x	16.73	17.43	12.90	11.49	11.97	7.76
$s_{\bar{x}}$	0.70	0.96	0.97	1.11	1.40	1.65
Lunate:						
Mean	140.4	155.3	167.4	174.4	176.4	185.3
s_x	17.25	17.16	12.79	11.12	12.08	8.06
$s_{\bar{x}}$	0.65	0.89	0.95	1.03	1.61	1.69
Scaphoid:						
Mean	139.0	154.5	167.0	174.8	176.6	185.8
s_x	17.27	17.84	13.61	11.46	12.15	8.14
$s_{\bar{x}}$	0.63	0.93	0.94	1.07	1.61	1.69
Trapezium:						
Mean	138.2	154.5	167.2	174.7	176.7	185.2
s_x	18.20	18.75	13.31	11.52	11.37	8.28
$s_{\bar{x}}$	0.62	1.01	0.90	1.00	1.44	1.79
Trapezoid:						
Mean	138.8	154.9	167.4	174.8	176.4	185.2
s_x	17.68	18.53	12.82	11.56	11.65	8.20
$s_{\bar{x}}$	0.65	1.00	0.90	1.04	1.49	1.79
Metacarpal I:						
Mean	138.6	155.4	169.3	176.4	178.9	183.2
s_x	17.52	18.00	12.67	9.44	9.27	4.11
$s_{\bar{x}}$	0.61	0.79	0.65	0.56	0.83	0.50
Metacarpal II:						
Mean	138.5	155.6	171.4	182.1	187.6	196.0
s_x	17.54	18.25	15.21	14.43	14.62	10.60
$s_{\bar{x}}$	0.67	0.89	0.81	0.62	1.23	0.92
Metacarpal III:						
Mean	139.2	156.1	171.6	181.6	187.2	194.2
s_x	17.91	18.39	14.46	13.24	13.56	9.35
$s_{\bar{x}}$	0.65	0.85	0.76	0.54	1.12	0.83
Metacarpal IV:						
Mean	139.1	156.1	171.7	181.6	187.1	193.4
s_x	17.93	18.57	14.60	13.15	13.45	9.19
$s_{\bar{x}}$	0.68	0.87	0.75	0.62	0.93	0.78
Metacarpal V:						
Mean	139.5	156.5	172.0	182.3	189.0	196.0
s_x	18.13	18.48	14.55	13.73	14.29	10.44
$s_{\bar{x}}$	0.69	0.85	0.74	0.66	0.92	0.87
Pisiform:						
Mean	141.1	155.9	167.3	174.3	176.8	185.7
s_x	17.10	17.65	13.64	11.29	12.61	7.50
$s_{\bar{x}}$	0.64	0.64	0.94	1.17	1.75	2.25
Adductor sesamoid:						
Mean	159.7	165.0	170.4	175.0	177.1	183.6
s_x	7.22	9.49	9.63	9.41	10.57	8.21
$s_{\bar{x}}$	0.50	0.49	0.42	0.62	1.08	1.56

Table 6. Mean, standard deviation(s_x), and standard error of mean($s_{\bar{x}}$)bone-specific skeletal ages for the 31 individual hand-wrist bones of youths and the number of youths, by chronological age in years at last birthday and sex: United States, 1966-70—Con.

Girls—chronological age in years						Girls—chronological age in years					
12	13	14	15	16	17	12	13	14	15	16	17
Bone-specific skeletal age in months—male standard						Bone-specific skeletal age in months—female equivalent					
173.9	185.8	198.0	208.6	214.2	217.1	141.9	153.8	168.6	182.2	190.4	194.1
15.03	13.36	12.45	10.18	10.68	5.83	12.23	11.06	10.60	8.89	9.49	5.21
0.73	0.65	0.53	0.50	0.42	0.34	0.60	0.54	0.45	0.44	0.37	0.30
173.5	185.4	196.6	203.7	206.4	208.4	141.5	153.4	167.2	174.4	179.4	181.4
15.42	13.54	11.37	7.52	6.14	4.08	12.58	11.20	9.67	6.44	5.34	3.55
0.76	0.69	0.63	0.40	0.55	0.35	0.62	0.57	0.54	0.34	0.48	0.30
168.2	175.8	181.5	188.1	186.7	191.7	136.2	143.8	149.0	157.0	155.4	161.7
13.20	10.38	10.17	5.66	8.95	0.71	10.69	8.49	8.35	4.72	7.45	0.60
0.71	0.74	0.90	1.80	2.21	0.40	0.57	0.61	0.74	1.50	1.84	0.34
169.1	176.5	181.5	188.7	184.9	191.6	137.1	144.5	149.5	157.7	152.9	161.6
12.68	10.02	10.42	4.96	13.50	0.76	10.28	8.20	8.58	4.15	11.16	0.64
0.65	0.79	1.02	1.71	3.73	0.53	0.53	0.65	0.84	1.43	3.08	0.45
167.5	174.9	181.3	188.4	184.8	191.7	136.2	141.9	149.3	156.4	152.8	161.7
12.93	10.80	10.61	5.40	13.31	0.76	10.51	8.76	8.74	4.48	11.01	0.64
0.70	0.72	0.98	2.05	3.87	0.50	0.57	0.58	0.81	1.70	3.20	0.42
167.4	174.8	180.8	187.9	188.7	191.2	136.2	141.8	148.8	156.8	157.7	160.2
13.16	10.66	10.57	5.60	5.46	1.58	10.71	8.65	8.70	4.67	4.56	1.32
0.62	0.71	0.98	2.19	1.32	*60.47	0.50	0.58	0.81	1.83	1.10	*50.67
166.7	174.7	180.7	187.6	188.0	190.8	134.7	142.7	148.7	156.2	157.0	159.8
13.88	10.90	10.83	6.30	5.48	2.90	11.22	8.90	8.91	5.24	4.58	2.43
0.60	0.77	0.99	2.22	1.45	1.36	0.48	0.63	0.81	1.85	1.21	1.14
166.7	175.0	180.7	188.6	189.1	192.0	134.9	142.0	148.7	156.6	157.1	161.0
13.82	10.07	10.78	5.27	4.64	-	11.18	8.17	8.87	4.38	3.85	-
0.63	0.63	0.95	1.66	0.92	-	0.51	0.51	0.78	1.38	0.76	-
166.9	175.0	181.0	188.4	189.0	192.0	135.0	142.0	149.0	156.4	157.0	161.0
13.86	10.31	10.58	5.55	4.39	-	11.21	8.37	8.71	4.61	3.65	-
0.60	0.70	0.89	1.84	1.07	-	0.49	0.57	0.73	1.53	0.89	-
170.3	177.4	181.0	185.2	185.5	185.9	138.3	145.4	149.0	154.2	154.5	154.9
12.74	8.88	7.38	2.13	2.12	0.61	10.35	7.28	6.08	1.77	1.77	0.51
0.65	0.51	0.51	0.28	0.48	0.13	0.53	0.42	0.42	0.23	0.40	0.11
171.7	183.4	194.2	198.8	203.3	204.3	139.7	151.4	164.2	168.8	174.3	175.3
15.19	14.08	12.76	9.01	7.42	7.18	12.36	11.62	10.79	7.65	6.36	6.16
0.74	0.60	0.78	0.86	0.85	1.29	0.60	0.50	0.66	0.73	0.73	1.11
172.3	182.9	192.7	196.7	200.3	200.4	140.3	150.9	161.7	166.7	170.3	170.4
14.69	12.87	11.41	6.88	5.24	4.98	11.96	10.62	9.57	5.83	4.46	4.23
0.70	0.63	0.58	0.62	0.65	1.21	0.57	0.52	0.49	0.53	0.55	1.03
171.9	182.7	192.5	197.2	200.3	200.6	139.9	150.7	162.0	167.2	170.3	170.6
14.74	12.72	11.30	7.05	5.45	4.77	12.00	10.49	9.51	5.98	4.63	4.06
0.68	0.66	0.58	0.57	0.75	1.11	0.55	0.54	0.49	0.48	0.64	0.94
172.4	183.4	194.3	199.3	203.1	205.1	140.4	151.4	162.6	169.3	173.2	176.1
14.88	13.31	12.52	8.94	7.12	6.53	12.12	10.99	10.48	7.59	6.07	5.61
0.70	0.62	0.63	0.64	0.91	0.96	0.57	0.51	0.53	0.54	0.78	0.82
167.1	174.8	182.0	186.0	188.2	192.0	135.6	141.8	150.0	154.0	156.2	160.0
13.42	9.76	9.60	6.42	5.93	-	10.89	7.92	7.91	5.32	4.92	-
0.64	0.63	0.90	1.35	1.33	-	0.52	0.51	0.74	1.12	1.10	-
169.8	174.4	179.0	179.9	181.1	184.1	137.8	142.4	147.0	147.9	149.1	152.1
9.48	9.27	9.60	7.95	8.67	6.75	7.69	7.57	7.88	6.54	7.14	5.58
0.59	0.59	0.72	1.03	1.54	1.92	0.48	0.48	0.59	0.85	1.27	1.59

Table 6. Mean, standard deviation(s_x), and standard error of mean($s_{\bar{x}}$) bone-specific skeletal ages for the 31 individual hand-wrist bones of youths and the number of youths, by chronological age in years at last birthday and sex: United States, 1966-70—Con.

Radio-opaque (not adult) hand-wrist bone and value	Boys—chronological age in years					
	12	13	14	15	16	17
	Bone-specific skeletal age in months—male standard					
Flexor sesamoid:						
Mean	165.2	168.5	172.0	175.5	177.2	185.4
s_x	6.07	8.13	8.09	8.70	9.94	8.33
$s_{\bar{x}}$	0.56	0.68	0.40	0.70	1.06	2.30
Proximal phalanx I:						
Mean	140.6	157.5	172.7	182.8	188.1	198.3
s_x	18.00	18.66	15.19	14.22	14.34	11.09
$s_{\bar{x}}$	0.73	0.81	0.85	0.79	1.26	1.15
Proximal phalanx II:						
Mean	140.6	158.0	172.3	182.3	187.1	195.5
s_x	17.98	18.71	14.67	13.17	13.58	9.02
$s_{\bar{x}}$	0.69	0.87	0.92	0.68	1.47	1.00
Proximal phalanx III:						
Mean	140.8	158.3	172.4	182.6	186.7	195.7
s_x	17.91	18.73	14.61	13.14	13.22	8.85
$s_{\bar{x}}$	0.68	0.89	0.95	0.71	1.36	1.02
Proximal phalanx IV:						
Mean	140.6	158.1	172.6	182.5	187.1	195.1
s_x	17.72	19.10	15.05	13.22	13.39	9.06
$s_{\bar{x}}$	0.72	0.93	0.96	0.76	1.21	1.05
Proximal phalanx V:						
Mean	140.9	158.1	172.3	182.5	186.8	195.2
s_x	17.54	18.92	14.90	13.34	13.54	9.26
$s_{\bar{x}}$	0.72	0.93	0.92	0.69	1.30	1.06
Middle phalanx II:						
Mean	141.6	158.0	172.3	181.8	187.2	194.9
s_x	17.31	18.24	14.65	12.48	12.66	8.98
$s_{\bar{x}}$	0.69	0.91	0.81	0.77	1.03	0.90
Middle phalanx III:						
Mean	141.6	158.1	172.4	182.3	187.2	195.5
s_x	17.32	18.28	14.61	12.52	12.43	8.84
$s_{\bar{x}}$	0.69	0.91	0.84	0.72	1.08	0.74
Middle phalanx IV:						
Mean	140.9	157.6	172.3	182.0	187.0	195.1
s_x	17.46	18.68	15.01	12.32	12.25	8.89
$s_{\bar{x}}$	0.69	0.92	0.86	0.70	0.96	0.80
Middle phalanx V:						
Mean	141.2	157.7	172.2	182.0	187.0	194.6
s_x	17.41	18.55	14.75	12.46	12.53	9.09
$s_{\bar{x}}$	0.67	0.96	0.84	0.63	0.99	0.86
Distal phalanx I:						
Mean	139.9	155.8	168.4	175.7	179.5	186.3
s_x	17.66	17.41	12.26	10.24	11.10	8.08
$s_{\bar{x}}$	0.69	0.88	0.69	0.62	1.10	0.93
Distal phalanx II:						
Mean	140.0	156.3	168.7	175.7	179.2	186.0
s_x	17.49	17.33	12.16	9.86	10.62	7.46
$s_{\bar{x}}$	0.63	0.86	0.68	0.60	1.00	0.77
Distal phalanx III:						
Mean	139.9	156.0	168.6	175.4	178.7	185.9
s_x	17.43	17.47	11.93	9.68	10.57	7.88
$s_{\bar{x}}$	0.63	0.89	0.66	0.62	1.00	0.83
Distal phalanx IV:						
Mean	140.2	156.2	168.8	175.0	177.9	183.4
s_x	17.40	17.27	12.01	8.88	9.15	4.34
$s_{\bar{x}}$	0.64	0.86	0.63	0.55	0.89	0.56
Distal phalanx V:						
Mean	140.2	156.2	168.6	174.8	178.2	183.1
s_x	17.55	17.19	11.94	8.88	9.05	4.59
$s_{\bar{x}}$	0.64	0.86	0.65	0.53	0.91	0.61

Table 6. Mean, standard deviation (s_x), and standard error of mean ($s_{\bar{x}}$) bone-specific skeletal ages for the 31 individual hand-wrist bones of youths and the number of youths, by chronological age in years at last birthday and sex: United States, 1966-70—Con.

Girls—chronological age in years						Girls—chronological age in years					
12	13	14	15	16	17	12	13	14	15	16	17
Bone-specific skeletal age in months—male standard						Bone-specific skeletal age in months—female equivalent					
172.0	175.8	180.1	180.8	183.6	187.5	140.0	143.8	148.1	148.8	151.6	156.0
8.43	8.31	8.42	6.29	7.10	6.88	6.86	6.80	6.92	5.18	5.86	5.72
0.53	0.63	0.82	1.16	1.05	1.74	0.43	0.52	0.67	0.95	0.87	1.45
174.9	184.9	195.5	203.4	206.5	207.8	141.9	152.9	165.5	174.4	178.5	179.8
14.44	13.76	13.48	8.90	5.92	5.51	11.72	11.38	11.41	7.63	5.12	4.77
0.66	0.80	0.86	0.94	0.98	1.09	0.54	0.66	0.73	0.81	0.85	0.94
175.1	183.8	193.0	199.1	201.9	203.1	142.1	150.9	163.0	169.1	171.9	173.1
14.49	12.53	12.07	7.15	4.78	4.12	11.76	10.29	10.19	6.07	4.07	3.51
0.66	0.64	0.64	0.51	0.85	0.84	0.54	0.53	0.54	0.43	0.72	0.72
175.3	184.0	193.6	199.5	202.4	203.4	144.3	152.0	163.6	170.0	173.4	174.8
14.40	12.42	11.89	7.03	4.44	3.86	11.85	10.26	10.05	5.99	3.80	3.32
0.66	0.68	0.59	0.52	0.81	0.68	0.54	0.56	0.50	0.44	0.69	0.58
175.7	184.3	193.4	199.3	202.5	203.1	144.4	152.3	163.4	169.6	173.5	174.2
14.92	12.66	11.74	7.12	4.32	3.85	12.26	10.46	9.92	6.06	3.70	3.30
0.64	0.74	0.66	0.56	0.79	0.65	0.53	0.61	0.56	0.48	0.68	0.56
175.9	184.3	193.4	200.0	202.3	203.5	143.9	152.3	162.4	170.0	173.2	173.8
14.80	12.60	11.95	6.93	4.36	3.50	12.11	10.41	10.03	5.89	3.73	2.99
0.64	0.71	0.56	0.55	0.53	0.56	0.52	0.59	0.47	0.47	0.45	0.48
175.3	184.3	192.6	199.5	202.3	203.0	143.3	152.3	162.2	170.2	172.6	174.0
14.21	12.40	11.41	6.48	4.28	3.44	11.62	10.25	9.61	5.53	3.65	2.95
0.65	0.86	0.65	0.58	0.72	0.65	0.53	0.71	0.55	0.49	0.61	0.56
175.5	184.5	193.3	199.0	201.8	203.1	143.0	152.5	162.3	170.0	172.8	174.1
14.01	11.94	11.36	6.56	4.57	3.40	11.42	9.87	9.54	5.60	3.91	2.91
0.59	0.75	0.61	0.62	0.71	0.63	0.48	0.62	0.51	0.53	0.61	0.54
175.2	184.6	193.1	198.9	202.3	203.1	142.2	152.6	162.1	169.8	173.3	174.1
14.41	11.89	11.15	6.62	4.27	3.36	11.70	9.83	9.36	5.65	3.66	2.88
0.64	0.74	0.61	0.57	0.65	0.60	0.52	0.61	0.51	0.49	0.56	0.51
175.2	184.1	192.6	198.7	202.2	203.0	143.2	152.1	162.2	168.7	172.2	173.0
14.59	12.11	11.57	7.22	4.48	3.52	11.93	10.01	9.74	6.13	3.82	3.00
0.66	0.81	0.60	0.74	0.69	0.64	0.54	0.67	0.51	0.63	0.59	0.55
170.8	178.4	183.4	191.0	189.3	187.4	138.8	146.4	151.2	161.0	158.6	155.2
12.89	10.92	10.64	8.48	6.95	5.12	10.48	8.96	8.77	7.15	5.82	4.24
0.63	0.84	0.90	1.40	1.20	0.91	0.51	0.69	0.74	1.18	1.01	0.75
170.9	178.7	183.7	191.3	189.5	187.4	138.9	145.4	151.7	161.3	157.5	155.4
12.85	10.84	10.17	8.84	7.20	5.20	10.44	8.82	8.40	7.45	5.98	4.31
0.65	0.85	0.76	1.44	1.48	0.97	0.53	0.69	0.63	1.21	1.23	0.80
170.7	178.4	183.5	191.3	189.7	187.4	138.7	146.4	151.5	161.3	158.7	155.4
12.68	10.78	10.17	8.92	7.34	4.96	10.30	8.85	8.40	7.52	6.14	4.11
0.61	0.78	0.78	1.50	1.56	0.96	0.50	0.64	0.64	1.26	1.31	0.80
170.5	176.4	180.8	185.8	186.0	185.9	138.5	144.4	148.8	152.4	153.0	153.0
12.38	8.40	7.75	0.72	-	0.36	10.06	6.88	6.38	0.59	-	0.30
0.59	0.82	0.53	0.09	-	0.07	0.48	0.67	0.44	0.07	-	0.06
170.5	176.6	180.9	185.7	186.0	185.9	138.5	143.6	148.9	153.7	154.0	153.9
12.60	8.60	7.73	0.90	-	0.50	10.24	6.99	6.36	0.74	-	0.41
0.61	0.85	0.56	0.12	-	0.09	0.50	0.69	0.46	0.10	-	0.07

Table 6. Mean, standard deviation(s_x), and standard error of mean($s_{\bar{x}}$)bone-specific skeletal ages for the 31 individual hand-wrist bones of youths and the number of youths, by chronological age in years at last birthday and sex: United States, 1966-70—Con.

Hand-wrist bone	Boys—chronological age in years					
	12	13	14	15	16	17
	Number of youths in thousands					
Radius	2,015	2,000	1,948	1,883	1,770	1,544
Ulna	2,015	1,998	1,948	1,864	1,642	1,138
Capitate	2,015	1,815	1,373	769	351	103
Hamate	2,013	1,807	1,345	752	328	103
Triquetral	2,010	1,822	1,373	768	336	106
Lunate	2,007	1,825	1,356	764	337	106
Scaphoid	2,015	1,844	1,376	778	328	106
Trapezium	2,011	1,842	1,367	760	337	103
Trapezoid	2,009	1,843	1,354	755	317	103
Metacarpal I	2,024	1,981	1,755	1,239	631	194
Metacarpal II	2,024	1,993	1,869	1,513	939	498
Metacarpal III	2,024	1,993	1,858	1,491	939	433
Metacarpal IV	2,024	1,993	1,867	1,497	933	415
Metacarpal V	2,024	1,990	1,867	1,547	1,031	518
Pisiform	1,657	1,638	1,305	689	305	83
Adductor sesamoid	795	1,338	1,346	805	396	115
Flexor sesamoid	336	857	1,080	739	348	84
Proximal phalanx I	2,017	1,996	1,823	1,386	791	397
Proximal phalanx II	2,024	1,993	1,800	1,361	762	329
Proximal phalanx III	2,024	1,993	1,797	1,369	752	341
Proximal phalanx IV	2,024	1,993	1,801	1,363	761	303
Proximal phalanx V	2,024	1,990	1,788	1,355	738	319
Middle phalanx II	2,024	1,993	1,805	1,376	793	351
Middle phalanx III	2,024	1,993	1,813	1,412	830	376
Middle phalanx IV	2,024	1,993	1,819	1,400	827	373
Middle phalanx V	2,024	1,993	1,804	1,392	821	351
Distal phalanx I	2,023	1,952	1,594	1,031	503	210
Distal phalanx II	2,023	1,963	1,651	1,076	517	213
Distal phalanx III	2,023	1,958	1,645	1,083	528	203
Distal phalanx IV	2,023	1,951	1,643	1,036	483	188
Distal phalanx V	2,019	1,954	1,639	1,047	513	181

Table 6. Mean, standard deviation (s_x), and standard error of mean($s_{\bar{x}}$) bone-specific skeletal ages for the 31 individual hand-wrist bones of youths and the number of youths, by chronological age in years at last birthday and sex: United States, 1966-70—Con.

Girls—chronological age in years					
12	13	14	15	16	17
Number of youths in thousands					
1,953	1,943	1,878	1,755	1,549	1,278
1,950	1,935	1,793	1,403	776	481
1,347	874	305	67	37	29
1,326	860	296	64	37	25
1,338	861	305	60	37	25
1,347	845	319	70	33	22
1,360	876	332	72	34	36
1,369	884	323	80	35	36
1,350	874	319	68	35	36
1,735	1,287	513	227	65	80
1,847	1,643	1,120	503	242	158
1,851	1,628	1,079	488	223	122
1,851	1,611	1,103	517	230	143
1,865	1,682	1,217	610	299	208
1,266	825	345	89	41	39
1,413	976	459	191	78	73
1,097	851	389	135	67	74
1,816	1,458	832	379	166	142
1,800	1,399	730	362	135	112
1,807	1,412	777	385	147	122
1,799	1,417	776	367	153	143
1,791	1,390	734	351	168	136
1,809	1,416	740	317	138	98
1,822	1,463	808	352	149	108
1,822	1,466	814	362	150	107
1,803	1,370	720	294	146	96
1,520	957	418	228	133	120
1,549	983	440	220	110	120
1,537	978	438	219	105	116
1,504	888	368	167	93	107
1,502	879	375	153	97	119

Table 7. Mean and standard deviation (s_x) of bone-specific skeletal ages for selected hand-wrist bones of youths, by chronological age in 6-month intervals and sex: United States, 1966-70

Chronological age and sex	Radius		Ulna		Scaphoid		Metacarpal I	
	Mean	s_x	Mean	s_x	Mean	s_x	Mean	s_x
Boys (male standard)	Bone-specific skeletal age in months							
12 years:								
0-5 months	134.6	16.04	134.8	15.81	133.6	16.10	132.7	16.68
6-11 months	144.1	15.66	144.2	15.42	143.4	16.92	143.4	16.72
13 years:								
0-5 months	153.2	17.79	152.6	17.81	150.7	17.82	151.2	18.29
6-11 months	161.9	16.31	161.5	16.36	159.1	16.75	160.2	16.38
14 years:								
0-5 months	171.6	15.26	171.1	15.20	165.4	13.73	168.0	12.66
6-11 months	175.3	15.95	175.0	15.55	168.8	13.26	170.8	12.52
15 years:								
0-5 months	183.5	15.15	183.0	15.08	173.4	11.28	174.9	9.89
6-11 months	189.4	13.60	188.7	13.35	177.4	11.32	178.4	8.40
16 years:								
0-5 months	193.8	14.82	192.2	13.99	175.8	13.60	178.6	10.41
6-11 months	201.6	14.04	197.4	11.96	178.2	8.36	179.5	6.54
17 years:								
0-5 months	205.5	12.06	200.3	9.26	185.4	8.42	183.2	4.31
6-11 months	208.9	11.63	203.9	6.81	187.3	4.63	183.3	3.60
Girls (female equivalent)								
12 years:								
0-5 months	138.5	11.92	137.9	12.19	133.5	10.98	136.6	10.56
6-11 months	144.5	11.97	144.6	12.35	136.7	11.31	140.2	9.88
13 years:								
0-5 months	150.3	10.97	151.0	11.34	141.1	8.28	144.1	7.53
6-11 months	158.8	10.26	158.6	10.38	145.0	9.45	147.4	6.55
14 years:								
0-5 months	165.6	10.89	164.8	10.14	147.3	9.32	147.9	6.80
6-11 months	170.5	9.74	169.6	8.74	151.4	7.51	151.7	4.37
15 years:								
0-5 months	180.4	9.34	173.2	7.04	154.9	5.24	153.9	1.92
6-11 months	183.7	8.32	175.8	5.64	158.2	4.95	154.5	1.48
16 years:								
0-5 months	189.2	10.18	179.0	5.13	158.4	3.20	155.0	-
6-11 months	192.3	8.57	179.9	5.59	152.7	5.97	153.9	2.62
17 years:								
0-5 months	193.6	5.05	181.4	3.48	157.9	2.83	155.0	-
6-11 months	194.7	5.35	181.3	3.65	161.0	-	154.8	0.67

Table 7. Mean and standard deviation (s_x) of bone-specific skeletal ages for selected hand-wrist bones of youths, by chronological age in 6-month intervals and sex: United States, 1966-70—Con.

Chronological age and sex	Pisiform		Adductor		Flexor	
	Mean	s_x	Mean	s_x	Mean	s_x
<u>Boys (male standard)</u>	Bone-specific skeletal age in months					
12 years:						
0-5 months	135.5	15.74	158.1	6.39	163.0	5.64
6-11 months	145.3	16.86	160.4	7.46	166.0	6.02
13 years:						
0-5 months	152.5	17.28	163.1	8.97	166.9	7.54
6-11 months	159.8	17.25	166.8	9.63	170.1	8.35
14 years:						
0-5 months	166.5	13.18	169.2	9.49	171.4	7.77
6-11 months	168.2	14.13	171.6	9.63	172.7	8.38
15 years:						
0-5 months	172.4	11.28	174.0	9.58	174.3	8.34
6-11 months	177.5	10.56	176.7	8.91	177.4	8.93
16 years:						
0-5 months	175.4	13.86	177.1	11.10	176.4	10.50
6-11 months	179.6	9.08	177.2	9.53	178.9	8.37
17 years:						
0-5 months	185.1	7.81	183.6	8.23	184.3	8.78
6-11 months	188.0	5.67	183.5	8.12	189.4	4.56
<u>Girls (female equivalent)</u>						
12 years:						
0-5 months	135.1	10.22	136.1	7.35	138.4	6.40
6-11 months	136.2	11.58	139.6	7.79	141.7	7.05
13 years:						
0-5 months	140.7	7.81	141.1	7.38	142.7	6.50
6-11 months	144.8	7.73	144.2	7.59	145.4	7.00
14 years:						
0-5 months	148.7	8.35	146.2	8.29	147.2	6.97
6-11 months	152.3	6.66	148.3	7.04	149.7	6.65
15 years:						
0-5 months	152.2	5.62	149.2	5.72	149.0	4.79
6-11 months	158.1	1.97	145.7	7.28	148.5	5.75
16 years:						
0-5 months	156.7	4.20	148.1	7.51	152.6	5.23
6-11 months	155.2	6.08	151.4	5.79	149.9	6.63
17 years:						
0-5 months	160.0	-	152.7	4.77	153.8	6.69
6-11 months	160.0	-	153.4	5.89	157.7	4.56

Table 7. Mean and standard deviation (s_x) of bone-specific skeletal ages for selected hand-wrist bones of youths, by chronological age in 6-month intervals and sex: United States, 1966-70—Con.

Chronological age and sex	Proximal phalanx II		Middle phalanx II		Distal phalanx II	
	Mean	s_x	Mean	s_x	Mean	s_x
	Bone-specific skeletal age in months					
Boys (male standard)						
12 years:						
0-5 months	134.5	16.80	135.9	16.46	134.1	16.38
6-11 months	145.5	17.39	146.3	16.57	144.7	16.94
13 years:						
0-5 months	153.6	18.76	153.7	17.96	152.2	17.49
6-11 months	163.0	17.35	163.0	17.27	161.0	15.88
14 years:						
0-5 months	170.5	14.40	170.4	14.37	167.7	12.25
6-11 months	174.1	14.73	174.3	14.66	169.8	11.95
15 years:						
0-5 months	180.5	13.97	180.1	13.14	174.1	10.36
6-11 months	184.8	11.55	184.1	11.16	177.9	8.62
16 years:						
0-5 months	186.8	14.40	186.7	13.38	178.5	11.90
6-11 months	187.6	11.96	188.0	11.30	180.3	7.82
17 years:						
0-5 months	194.0	9.19	193.8	9.02	185.8	7.87
6-11 months	198.0	8.00	197.0	8.37	186.3	6.89
Girls (female equivalent)						
12 years:						
0-5 months	139.2	11.15	139.7	10.65	136.9	9.85
6-11 months	144.8	11.90	145.9	12.05	141.1	10.77
13 years:						
0-5 months	149.0	10.02	149.9	10.30	144.8	8.64
6-11 months	155.8	9.89	154.8	9.42	149.7	8.78
14 years:						
0-5 months	159.8	10.76	160.2	10.21	150.3	8.57
6-11 months	164.3	8.72	164.8	8.22	154.2	7.67
15 years:						
0-5 months	168.5	6.34	170.0	5.81	161.6	7.73
6-11 months	170.1	5.56	170.6	5.01	161.0	6.99
16 years:						
0-5 months	172.2	3.27	173.2	3.13	160.4	6.74
6-11 months	171.5	5.07	172.0	4.34	155.3	3.90
17 years:						
0-5 months	173.3	1.82	174.3	2.08	154.0	-
6-11 months	172.9	4.47	173.2	3.87	157.1	6.19

Table 8. Selected percentiles in the distribution of bone-specific skeletal ages for each of the 31 hand-wrist bones of youths, by chronological age in years at last birthday and sex: United States, 1966-70

Hand-wrist bone and percentile	Boys—chronological age in years					
	12	13	14	15	16	17
	Bone-specific skeletal age in months—male standard					
Radius:						
P_{75}	152.6	171.0	184.3	198.4	208.7	216.3
P_{50}	140.5	159.7	175.0	186.7	200.1	210.0
P_{25}	127.0	146.9	163.0	177.0	189.2	199.4
Ulna:						
P_{75}	152.5	170.6	183.6	198.1	204.9	209.9
P_{50}	140.8	157.0	174.6	185.2	198.6	204.9
P_{25}	126.9	146.2	162.9	176.7	186.5	198.0
Capitate:						
P_{75}	156.0	168.3	176.7	184.1	186.9	192.4
P_{50}	140.8	159.5	168.9	176.8	176.8	186.9
P_{25}	128.3	144.9	160.9	168.6	170.5	180.3
Hamate:						
P_{75}	156.3	168.5	177.0	184.7	187.6	192.4
P_{50}	142.9	160.0	170.3	176.9	178.9	186.9
P_{25}	129.3	147.2	162.2	170.1	172.6	180.5
Triquetral:						
P_{75}	154.4	168.5	176.8	183.2	186.8	192.5
P_{50}	141.2	156.7	168.6	176.4	176.9	190.1
P_{25}	128.2	144.5	160.5	168.4	168.8	180.7
Lunate:						
P_{75}	154.5	168.4	176.6	180.9	187.2	192.4
P_{50}	142.2	157.2	168.9	176.2	176.8	190.3
P_{25}	127.3	144.5	160.3	168.5	170.0	180.0
Scaphoid:						
P_{75}	152.7	168.5	176.8	183.1	187.5	192.0
P_{50}	139.2	156.5	168.9	176.3	176.8	192.5
P_{25}	126.0	142.4	160.1	168.7	172.1	192.0
Trapezium:						
P_{75}	153.0	168.6	176.9	180.9	186.5	192.4
P_{50}	139.0	156.9	168.8	176.3	176.9	190.3
P_{25}	122.7	142.9	160.4	168.8	169.5	180.5
Trapezoid:						
P_{75}	153.3	168.6	176.6	181.0	186.4	192.4
P_{50}	140.1	158.0	168.8	176.3	176.6	190.0
P_{25}	123.0	143.4	160.7	168.9	170.3	180.6
Metacarpal I:						
P_{75}	153.8	170.1	178.3	184.9	186.4	186.5
P_{50}	138.7	157.3	172.5	178.1	183.2	186.1
P_{25}	125.4	143.6	162.6	172.5	175.5	180.9
Metacarpal II:						
P_{75}	153.2	168.9	180.3	192.8	196.8	204.8
P_{50}	138.7	158.0	172.9	180.5	190.2	196.8
P_{25}	124.1	144.4	163.7	174.3	177.2	190.5
Metacarpal III:						
P_{75}	154.8	170.3	180.3	192.6	197.0	204.1
P_{50}	139.0	159.2	173.8	180.4	190.4	196.4
P_{25}	123.6	144.6	164.2	174.6	177.3	190.0
Metacarpal IV:						
P_{75}	154.5	170.6	180.4	192.6	196.8	200.7
P_{50}	138.8	159.2	174.0	180.5	190.1	196.0
P_{25}	124.2	144.2	164.4	174.7	177.0	188.0
Metacarpal V:						
P_{75}	155.3	170.4	180.8	193.0	198.4	204.5
P_{50}	140.3	160.4	174.2	180.7	191.0	196.8
P_{25}	125.3	144.8	164.6	174.7	180.4	190.6
Pisiform:						
P_{75}	156.3	168.9	178.0	182.4	188.4	192.5
P_{50}	140.6	158.5	168.8	176.2	176.7	192.0
P_{25}	127.0	144.5	160.7	168.3	170.5	180.7

Table 8. Selected percentiles in the distribution of bone-specific skeletal ages for each of the 31 hand-wrist bones of youths, by chronological age in years at last birthday and sex: United States, 1966-70—Con.

Girls-chronological age in years						Girls-chronological age in years					
12	13	14	15	16	17	12	13	14	15	16	17
Bone-specific skeletal age in months—male standard						Bone-specific skeletal age in months—female equivalent					
184.5	194.7	207.8	215.0	223.1	223.2	152.5	164.7	180.8	192.0	200.2	200.4
175.8	186.2	200.1	210.5	216.2	217.9	143.8	154.2	170.1	184.5	193.2	194.9
165.3	178.1	190.0	204.3	211.5	214.0	134.7	146.1	159.0	175.6	186.0	190.0
184.3	196.1	206.1	210.3	210.6	210.7	152.3	166.1	179.1	183.6	184.2	184.4
175.5	185.6	199.1	206.8	210.1	210.3	143.5	153.6	170.1	179.8	183.2	183.6
164.9	177.3	190.3	200.6	206.1	209.8	133.9	145.3	159.6	171.6	179.1	182.8
176.8	183.7	192.0	192.6	192.6	192.7	144.8	151.7	162.0	162.6	162.6	162.7
168.9	177.3	184.8	192.1	192.2	192.4	136.9	145.3	152.8	162.1	162.2	162.4
162.3	168.7	175.4	186.1	186.4	192.1	132.7	136.7	143.4	154.2	154.8	162.1
178.8	184.2	190.9	192.6	192.6	192.7	146.8	152.2	160.8	162.6	162.6	162.7
169.6	178.1	184.7	192.1	192.2	192.4	137.6	146.1	152.7	162.1	162.2	162.4
162.3	169.0	176.3	186.6	186.4	192.1	132.3	137.0	144.3	155.2	155.8	162.1
176.5	182.4	192.0	192.6	192.6	192.7	143.5	150.4	162.0	162.6	162.6	162.7
168.6	176.4	185.2	192.2	192.1	192.4	136.2	143.4	153.2	162.2	162.1	162.4
159.9	168.5	174.8	186.3	184.4	192.1	130.4	136.2	141.8	154.3	152.4	162.1
176.6	181.1	190.6	192.5	192.5	192.7	143.6	149.1	159.6	162.0	162.0	162.4
168.7	176.2	182.4	192.0	192.1	192.4	136.8	143.2	150.4	161.0	161.2	161.8
160.3	168.6	174.6	186.1	190.2	192.1	130.2	136.8	141.6	154.1	159.2	161.2
176.4	182.0	190.9	192.5	192.4	192.7	144.4	150.0	159.9	162.0	161.8	162.4
168.4	175.8	182.9	190.9	190.6	192.3	136.4	143.8	150.9	159.9	159.6	161.6
160.4	168.5	174.6	182.4	188.4	192.0	131.2	136.5	142.6	150.4	157.4	161.0
176.4	181.0	190.9	192.5	192.6	192.8	143.4	149.0	158.9	161.5	161.6	161.8
168.5	176.1	182.0	192.1	192.2	192.5	136.5	143.1	150.0	161.1	161.2	161.5
159.7	168.6	174.6	188.5	188.4	192.2	130.7	136.6	141.6	156.5	156.4	161.2
176.4	181.0	190.9	192.5	192.5	192.8	143.4	149.0	159.8	162.0	162.0	162.6
168.6	176.1	183.3	192.1	190.9	192.5	136.3	143.1	151.3	161.2	159.8	162.0
159.5	168.8	174.8	188.3	188.4	192.2	130.8	136.4	141.8	156.3	156.4	161.4
180.3	186.1	186.5	186.7	186.7	186.7	148.3	155.1	155.5	155.7	155.7	155.7
172.5	180.1	186.0	186.4	186.5	186.5	140.5	148.1	155.0	155.4	155.5	155.5
164.6	172.8	177.6	186.1	186.2	186.2	134.3	140.8	145.6	155.1	155.2	155.2
180.6	194.3	205.1	210.1	210.5	210.5	148.6	164.3	176.2	184.1	184.5	184.5
172.8	181.0	196.1	197.0	206.2	210.1	140.8	149.0	166.1	167.0	178.2	184.1
164.5	174.4	186.9	194.4	198.3	197.4	134.2	142.4	155.8	164.4	168.3	167.4
180.8	194.3	204.2	204.2	204.5	204.6	148.8	163.3	174.2	174.2	174.5	174.6
174.2	181.0	196.1	196.9	204.0	204.2	142.1	149.0	166.1	166.9	174.0	174.2
165.2	174.7	186.6	193.3	197.8	195.9	134.6	142.4	154.6	162.3	167.8	165.8
180.6	194.1	204.1	204.3	204.6	204.6	148.6	164.1	175.1	175.3	175.6	175.6
174.0	180.9	196.0	197.5	204.1	204.2	142.0	148.9	166.0	167.5	175.1	175.2
164.6	174.7	186.4	194.4	197.9	196.9	134.3	142.7	154.8	164.4	167.9	166.9
180.8	194.7	206.0	210.2	210.4	210.6	148.8	163.4	177.0	183.4	183.8	184.2
174.0	182.3	196.2	198.6	204.4	210.2	142.0	150.3	165.2	168.2	175.4	183.4
164.9	174.8	187.2	194.2	198.2	200.3	134.4	142.8	155.2	162.4	167.4	170.3
176.3	180.7	192.1	190.8	192.6	192.8	143.3	148.7	160.1	158.8	160.6	160.8
168.7	176.2	181.0	190.1	192.3	192.5	136.7	143.2	149.0	158.1	160.3	160.5
160.6	168.7	176.6	183.0	184.1	192.2	131.6	136.7	143.6	151.0	152.1	160.2

Table 8. Selected percentiles in the distribution of bone-specific skeletal ages for each of the 31 hand-wrist bones of youths, by chronological age in years at last birthday and sex: United States, 1966-70—Con.

Hand-wrist bone and percentile	Boys—chronological age in years					
	12	13	14	15	16	17
	Bone-specific skeletal age in months—male standard					
Adductor sesamoid:						
P_{75}	164.3	170.9	178.1	181.5	188.0	192.3
P_{50}	160.0	164.6	170.6	176.2	176.8	186.4
P_{25}	155.8	158.4	164.1	168.6	168.5	176.9
Flexor sesamoid:						
P_{75}	168.7	174.8	178.0	180.9	186.6	192.4
P_{50}	164.6	168.4	172.4	176.1	176.7	190.3
P_{25}	160.6	160.9	166.5	168.9	170.1	180.4
Proximal phalanx I:						
P_{75}	155.8	172.1	180.9	191.5	196.5	210.3
P_{50}	138.7	160.5	174.2	181.1	188.8	200.1
P_{25}	127.0	144.4	164.8	175.1	177.8	192.0
Proximal phalanx II:						
P_{75}	154.8	172.3	182.2	190.7	200.5	204.4
P_{50}	138.9	160.7	174.5	182.2	188.4	198.0
P_{25}	128.0	146.6	164.4	175.0	177.8	190.9
Proximal phalanx III:						
P_{75}	156.0	172.7	182.1	191.2	196.6	204.4
P_{50}	139.6	160.6	174.5	182.5	188.2	198.6
P_{25}	127.9	147.2	164.4	175.5	177.8	190.5
Proximal phalanx IV:						
P_{75}	154.6	172.9	182.1	190.8	200.2	202.3
P_{50}	139.5	160.2	174.8	182.2	188.3	196.7
P_{25}	127.2	144.9	164.3	175.8	178.7	190.1
Proximal phalanx V:						
P_{75}	153.9	172.8	181.9	190.9	204.4	204.4
P_{50}	140.0	160.3	174.7	182.4	188.1	196.9
P_{25}	128.2	146.0	164.4	175.5	178.4	189.4
Middle phalanx II:						
P_{75}	156.3	172.3	182.6	190.0	196.5	204.3
P_{50}	140.2	160.1	174.6	182.5	188.5	196.4
P_{25}	129.8	144.9	164.2	175.0	180.2	188.4
Middle phalanx III:						
P_{75}	156.2	172.2	182.6	191.4	196.3	204.4
P_{50}	140.1	160.2	174.6	182.6	189.4	196.9
P_{25}	129.7	145.0	164.5	176.1	180.4	189.5
Middle phalanx IV:						
P_{75}	154.8	172.5	182.7	190.3	196.0	204.4
P_{50}	138.8	158.9	174.8	182.8	188.9	196.3
P_{25}	128.9	144.5	164.4	176.1	180.5	189.5
Middle phalanx V:						
P_{75}	154.9	172.4	182.5	189.8	196.2	204.3
P_{50}	140.0	159.5	174.6	182.6	188.5	194.9
P_{25}	129.5	144.4	164.4	176.1	180.4	188.5
Distal phalanx I:						
P_{75}	154.7	168.9	177.0	183.7	186.5	186.9
P_{50}	138.8	158.3	170.9	177.0	182.1	186.4
P_{25}	126.4	144.5	162.3	170.1	174.6	184.3
Distal phalanx II:						
P_{75}	155.0	168.9	177.4	182.1	186.3	186.9
P_{50}	138.7	159.8	171.7	177.4	180.5	186.3
P_{25}	126.7	144.9	162.4	170.2	174.7	182.6
Distal phalanx III:						
P_{75}	154.9	169.0	177.2	180.5	186.3	186.9
P_{50}	138.7	159.4	171.5	177.0	179.3	186.4
P_{25}	126.8	144.9	162.4	170.4	174.5	182.5
Distal phalanx IV:						
P_{75}	154.8	170.0	177.7	181.6	186.0	186.6
P_{50}	138.8	159.2	171.9	177.2	180.8	186.2
P_{25}	126.9	144.8	162.4	170.2	174.5	182.2
Distal phalanx V:						
P_{75}	154.7	170.0	177.6	181.0	186.2	186.6
P_{50}	139.3	158.9	171.8	177.3	180.8	186.1
P_{25}	126.7	144.9	162.3	169.8	174.8	182.2

Table 8. Selected percentiles in the distribution of bone-specific skeletal ages for each of the 31 hand-wrist bones of youths, by chronological age in years at last birthday and sex: United States, 1966-70—Con.

Girls—chronological age in years						Girls—chronological age in years					
12	13	14	15	16	17	12	13	14	15	16	17
Bone-specific skeletal age in months—male standard						Bone-specific skeletal age in months—female equivalent					
176.6	180.8	186.7	186.7	190.2	192.4	144.6	148.8	154.7	154.7	159.2	161.8
168.9	174.8	180.5	180.7	180.8	189.4	136.9	142.8	148.5	148.7	148.8	158.4
163.1	166.9	171.7	174.7	176.2	180.5	133.0	134.9	139.7	142.7	144.2	148.5
178.2	180.8	186.9	186.3	192.1	192.6	146.2	148.8	154.9	154.3	161.2	162.2
170.6	176.0	180.5	180.7	186.1	192.2	138.6	144.0	148.5	148.7	154.1	161.4
166.6	170.4	174.5	180.1	180.2	180.7	134.8	138.4	142.5	148.1	148.2	148.0
182.3	194.2	210.2	210.5	210.6	210.7	150.3	164.2	183.4	184.0	184.2	184.4
175.5	183.9	196.1	210.1	210.2	210.3	142.5	151.9	166.1	183.2	183.4	183.6
168.7	175.9	184.7	196.9	204.8	210.0	136.4	142.9	152.7	166.9	176.6	183.0
183.3	193.5	204.4	204.6	204.7	204.7	150.6	163.2	174.4	174.6	174.7	174.7
176.3	182.8	196.5	204.2	204.4	204.5	143.3	150.4	166.0	174.2	174.4	174.5
168.2	176.1	184.1	194.5	204.0	204.2	136.2	143.1	151.1	163.8	174.0	174.2
184.0	193.0	204.4	204.6	204.7	204.7	152.0	163.0	176.4	176.6	176.7	176.7
176.6	183.0	197.3	204.2	204.2	204.5	144.8	151.0	167.3	176.2	176.2	176.5
168.3	176.2	184.8	196.6	204.1	204.2	136.6	144.6	152.8	166.6	176.1	176.2
184.2	194.1	204.4	204.6	204.7	204.7	152.2	164.1	176.4	176.6	176.7	176.7
177.2	183.9	196.7	204.2	204.4	204.5	145.2	151.9	166.7	176.2	176.4	176.5
168.4	176.4	184.8	196.4	204.1	204.2	136.7	144.7	152.8	166.4	176.1	176.2
183.6	193.7	204.4	204.6	204.7	204.7	151.6	162.7	174.8	175.2	175.4	175.4
177.3	183.4	197.4	204.3	204.4	204.5	145.3	151.4	166.4	174.6	174.8	175.0
168.4	176.4	184.5	196.9	204.1	204.2	136.4	144.4	152.5	165.9	174.2	174.4
184.9	193.3	204.3	204.6	204.7	204.7	152.9	163.3	175.3	175.6	175.7	175.7
176.9	184.2	194.6	204.1	204.4	204.5	144.9	152.2	164.6	175.1	175.4	175.5
167.9	176.3	184.7	195.5	204.1	204.2	135.9	144.3	152.7	165.5	175.1	175.2
184.8	194.2	204.3	204.5	204.7	204.7	152.8	163.2	175.3	175.5	175.7	175.7
176.9	184.5	195.0	204.1	204.4	204.5	144.9	152.5	164.0	175.1	175.4	175.5
168.1	176.7	186.3	194.9	204.0	204.2	136.0	144.7	154.3	163.9	175.0	175.2
186.1	194.1	204.3	204.5	204.7	204.7	154.1	163.1	175.3	175.5	175.7	175.7
177.1	186.0	195.2	204.1	204.4	204.5	145.1	154.0	164.4	175.1	175.4	175.5
167.4	176.8	186.9	194.6	204.1	204.2	135.4	144.8	154.9	163.6	175.1	175.2
185.9	192.7	204.3	204.5	204.7	204.7	153.9	162.4	174.6	175.0	175.4	175.4
177.0	184.4	194.3	204.1	204.4	204.5	145.0	152.4	164.3	174.1	174.8	175.0
168.0	176.6	184.8	192.3	204.1	204.2	136.5	144.6	152.8	161.6	174.2	174.4
178.5	186.4	186.8	204.1	186.9	186.8	146.5	153.4	153.8	-	153.9	153.8
173.3	177.9	186.2	186.7	186.6	186.5	141.3	145.9	153.2	153.7	153.6	153.5
164.7	172.0	177.0	186.3	186.3	186.3	134.4	140.0	145.0	153.3	153.3	153.3
180.2	186.3	186.8	204.2	186.9	186.8	148.2	154.3	154.8	-	154.9	154.8
173.2	180.2	186.3	186.7	186.6	186.5	141.2	148.2	154.3	154.7	154.6	154.5
164.5	172.6	180.1	186.3	186.3	186.3	133.5	140.6	148.1	154.3	154.3	154.3
178.3	186.1	186.8	204.2	187.0	186.8	146.3	153.2	154.6	-	155.0	154.6
174.0	178.0	186.2	186.7	186.6	186.5	142.0	146.0	153.4	154.4	154.2	154.0
164.5	172.9	177.8	186.3	186.3	186.3	134.2	140.9	145.8	153.6	153.6	153.6
180.2	183.3	186.5	186.7	186.8	186.7	148.2	151.3	154.0	154.4	154.6	154.4
174.1	178.7	186.0	186.4	186.5	186.5	142.1	146.7	153.0	153.8	154.0	154.0
164.2	172.6	177.2	186.2	186.2	186.2	134.1	140.6	145.2	153.4	153.4	153.4
180.3	184.3	186.5	186.7	186.8	186.7	148.3	152.3	154.5	154.7	154.8	154.7
174.2	178.2	186.0	186.4	186.5	186.5	142.1	145.2	154.0	154.4	154.5	154.5
164.2	172.5	177.7	186.2	186.2	186.2	134.1	139.8	144.7	154.2	154.2	154.2

Table 9. Selected percentiles, mean and standard deviations (s_x) in the distribution of the individual youth's range in bone-specific skeletal ages for the radio-opaque (not adult) bones in the hand-wrist for youth's, by chronological age in years at last birthday and sex: United States, 1966-70

Chronological age and sex	Percentile point						
	P_{95}	P_{75}	P_{50}	P_{25}	P_5	Mean	s_x
Boys	Bone-specific skeletal age range in months—male standard						
12 years	30.2	20.4	15.8	12.3	7.1	16.3	6.83
13 years	27.5	18.7	14.5	10.9	6.3	15.0	7.00
14 years	26.6	16.9	12.4	8.9	4.7	13.1	6.77
15 years	24.8	15.6	10.8	6.7	1.8	11.5	7.34
16 years	28.0	15.0	8.8	3.8	0.4	10.3	8.94
17 years	25.4	12.4	5.4	0.9	0.2	7.7	8.76
Girls							
12 years	26.9	18.8	14.1	10.5	5.0	14.8	7.42
13 years	30.1	18.9	12.8	8.7	2.6	14.1	8.90
14 years	30.8	18.5	10.7	4.9	0.6	12.4	10.22
15 years	34.2	16.5	6.7	1.4	0.2	10.3	11.39
16 years	34.8	10.7	2.3	0.5	0.1	7.6	12.25
17 years	34.5	14.3	2.0	0.5	0.1	8.3	11.86

Table 10. Median age in months at epiphyseal fusion for selected hand-wrist bones of youths 12-17 years chronological age at last birthday by sex: United States, 1966-70

Hand-wrist bone	Median chronological age in months for:	
	Boys	Girls
Radius	*	*
Ulna	*	194
Metacarpal I	190	166
Metacarpal II	199	178
Metacarpal III	199	177
Metacarpal IV	198	178
Metacarpal V	199	179
Proximal phalanx I	196	168
Proximal phalanx II	191	168
Proximal phalanx III	193	169
Proximal phalanx IV	193	169
Proximal phalanx V	191	168
Middle phalanx II	194	168
Middle phalanx III	197	169
Middle phalanx IV	197	169
Middle phalanx V	196	168
Distal phalanx I	188	161
Distal phalanx II	188	161
Distal phalanx III	189	161
Distal phalanx IV	187	161
Distal phalanx V	188	161

*Estimates of median age not possible or not sufficiently reliable for publication. The radius had reached the "adult" stage for only 26 percent of boys and 53 percent of girls and the ulna in only 51 percent of boys by 17.9 years.

Table 11. Selected skeletal maturity findings for children age 6-11 years in 1963-65 who were again examined as youths age 12-17 years in 1966-70 (32 percent of the youth examinees): United States, 1963-70

Skeletal maturity	Boys—chronological age in 1966-1970						Girls—chronological age in 1966-1970					
	12 years	13 years	14 years	15 years	16 years	17 years	12 years	13 years	14 years	15 years	16 years	17 years
Skeletal age in months												
As children 6-11 years in 1963-1965:												
Mean	98.7	107.5	118.7	125.0	130.4	-	115.5	130.1	145.0	156.9	159.3	-
$s_{\bar{x}}$	1.68	2.00	1.19	1.48	30.22	-	1.54	2.40	2.32	1.76	36.48	-
As youths 12-17 years in 1966-1970:												
Mean	139.7	158.2	173.0	187.2	193.3	-	174.7	187.1	197.8	206.3	207.0	-
$s_{\bar{x}}$	0.93	0.90	0.96	1.90	43.67	-	1.02	0.81	0.68	0.72	46.62	-
Number of bones ossifying (not adult)												
As children 6-11 years in 1963-1965:												
Mean	27.8	28.3	28.6	28.8	28.8	-	28.6	29.2	29.5	29.2	27.0	-
$s_{\bar{x}}$	0.06	0.04	0.03	0.06	6.45	-	0.09	0.07	0.10	0.13	6.35	-
As youths 12-17 years in 1966-1970:												
Mean	29.2	28.9	26.3	17.5	12.0	-	25.6	19.2	11.6	5.2	5.8	-
$s_{\bar{x}}$	0.06	0.23	0.44	1.07	7.97	-	0.57	0.58	0.61	0.36	4.60	-
Number of adult bones												
As children 6-11 years in 1963-65:												
Mean	-	-	-	-	-	-	-	0.1	0.2	0.7	2.5	-
$s_{\bar{x}}$	-	-	-	-	-	-	-	0.02	0.06	0.14	2.00	-
As youths 12-17 years in 1966-1970:												
Mean	4.3	7.7	10.8	18.0	23.4	-	12.5	15.7	21.2	26.3	26.0	-
$s_{\bar{x}}$	1.84	0.83	0.58	1.12	8.98	-	0.96	0.41	0.53	0.28	7.39	-
Bone-specific skeletal age range												
As children 6-11 years in 1963-1965:												
Mean	23.9	21.0	20.6	21.6	16.8	-	22.3	22.9	24.5	24.0	27.4	-
$s_{\bar{x}}$	0.73	0.58	0.68	0.94	6.33	-	0.55	0.52	0.65	1.15	7.35	-
As youths 12-17 years in 1966-1970:												
Mean	16.8	15.7	13.2	10.5	9.2	-	14.4	14.0	12.5	10.3	6.2	-
$s_{\bar{x}}$	0.43	0.59	0.35	0.64	2.80	-	0.52	0.62	0.68	0.65	4.13	-
Radius-skeletal age												
As children 6-11 years in 1963-1965:												
Mean	101.9	110.5	119.6	124.6	130.6	-	113.8	128.4	146.1	156.2	166.0	-
$s_{\bar{x}}$	1.29	0.93	1.23	1.33	30.39	-	1.33	1.94	1.43	0.87	38.02	-
As youths 12-17 years in 1966-1970:												
Mean	139.3	157.8	172.7	187.9	192.8	-	173.4	185.9	197.7	210.4	208.0	-
$s_{\bar{x}}$	1.01	0.82	0.94	1.87	43.60	-	1.09	0.91	0.65	0.73	46.83	-
Ulna-skeletal age												
As children 6-11 years in 1963-1965:												
Mean	103.0	110.8	118.4	124.0	130.4	-	113.6	128.3	143.6	154.1	155.4	-
$s_{\bar{x}}$	1.07	0.85	1.25	1.24	30.03	-	1.42	1.93	1.39	1.03	36.65	-
As youths 12-17 years in 1966-1970:												
Mean	139.5	157.6	172.3	186.7	194.5	-	173.1	185.4	196.2	204.6	204.4	-
$s_{\bar{x}}$	0.96	0.88	0.88	1.82	44.11	-	1.10	0.93	0.70	0.55	64.67	-
Scaphoid-skeletal age												
As children 6-11 years in 1963-1965:												
Mean	103.8	111.6	119.6	125.3	132.4	-	117.2	129.0	143.0	148.2	100.2	-
$s_{\bar{x}}$	1.23	0.79	1.14	0.97	30.62	-	1.19	1.72	1.92	2.39	37.68	-
As youths 12-17 years in 1966-1970:												
Mean	138.7	154.6	166.9	171.2	177.5	-	166.7	174.8	179.3	177.6	-	-
$s_{\bar{x}}$	0.96	0.96	1.06	2.39	88.86	-	0.83	1.14	1.87	88.83	-	-

Table 11. Selected skeletal maturity findings for children age 6-11 years in 1963-65 who were again examined as youths age 12-17 years in 1966-70 (32 percent of the youth examinees): United States, 1963-70—Con.

Skeletal maturity	Boys—chronological age in 1966-1970						Girls—chronological age in 1966-1970					
	12 years	13 years	14 years	15 years	16 years	17 years	12 years	13 years	14 years	15 years	16 years	17 years
Metacarpal I-skeletal age (months)												
As children 6-11 years in 1963-1965:												
Mean	100.3	109.4	118.0	125.0	129.3	-	117.4	131.7	147.8	156.6	156.0	-
$s_{\bar{x}}$	1.32	0.76	1.21	1.65	29.92	-	1.43	1.86	1.53	1.07	35.78	-
As youths 12-17 years in 1966-1970:												
Mean	137.8	156.2	169.1	175.0	177.2	-	169.9	177.8	180.3	184.9	-	-
$s_{\bar{x}}$	0.95	0.84	0.94	1.66	68.84	-	0.85	0.59	0.83	0.56	-	-
Pisiform-skeletal age												
As children 6-11 years in 1963-1965:												
Mean	116.0	118.6	124.8	129.6	132.5	-	124.6	134.7	148.4	156.4	152.5	-
$s_{\bar{x}}$	0.81	0.80	1.40	1.60	42.68	-	1.03	1.97	1.57	1.17	35.27	-
As youths 12-17 years in 1966-1970:												
Mean	140.8	156.0	166.8	171.2	169.5	-	167.2	174.8	181.4	184.0	-	-
$s_{\bar{x}}$	0.99	0.75	1.24	2.17	119.85	-	0.75	0.79	1.62	58.28	-	-
Adductor sesamoid-skeletal age												
As children 6-11 years in 1963-1965:												
Mean	-	159.0	155.8	156.4	-	-	155.8	158.9	161.2	164.6	168.4	-
$s_{\bar{x}}$	-	79.61	1.35	1.15	-	-	0.98	0.75	0.51	0.77	65.65	-
As youths 12-17 years in 1966-1970:												
Mean	159.2	165.8	171.1	174.7	176.7	-	169.3	174.4	179.3	183.0	-	-
$s_{\bar{x}}$	0.54	0.64	0.71	1.12	68.53	-	0.83	0.61	1.34	2.66	-	-
Flexor sesamoid-skeletal age												
As children 6-11 years in 1963-1965:												
Mean	-	-	158.5	160.6	-	-	161.7	162.2	165.3	167.4	166.0	-
$s_{\bar{x}}$	-	-	50.13	1.31	-	-	1.05	0.80	0.77	0.99	117.37	-
As youths 12-17 years in 1966-1970:												
Mean	165.0	169.0	172.1	174.9	176.2	-	171.1	175.7	181.1	181.8	-	-
$s_{\bar{x}}$	1.22	0.95	0.68	1.20	68.36	-	0.77	0.66	1.01	40.78	-	-
Proximal phalanx II-skeletal age												
As children 6-11 years in 1963-1965:												
Mean	103.7	112.0	120.2	126.6	131.0	-	120.7	135.9	152.8	162.0	161.2	-
$s_{\bar{x}}$	1.03	0.72	1.14	1.79	30.23	-	1.65	1.79	1.51	0.94	36.73	-
As youths 12-17 years in 1966-1970:												
Mean	139.9	158.8	171.9	180.2	181.7	-	174.7	184.1	193.1	199.7	200.0	-
$s_{\bar{x}}$	0.94	0.95	1.03	1.81	70.51	-	0.88	0.95	0.96	1.42	141.42	-
Middle phalanx II-skeletal age												
As children 6-11 years in 1963-1965:												
Mean	105.1	113.2	121.6	128.0	132.9	-	120.9	136.1	152.6	162.0	161.8	-
$s_{\bar{x}}$	1.07	0.89	1.19	1.42	30.56	-	1.39	1.80	1.44	1.02	37.19	-
As youths 12-17 years in 1966-1970:												
Mean	141.1	159.1	171.8	181.2	180.3	-	175.0	184.7	193.1	199.9	200.0	-
$s_{\bar{x}}$	0.95	0.99	1.03	2.08	69.89	-	0.95	1.00	0.95	1.40	141.42	-
Distal phalanx II-skeletal age												
As children 6-11 years in 1963-1965:												
Mean	105.5	112.2	121.1	127.1	130.0	-	118.8	133.1	149.4	158.8	155.9	-
$s_{\bar{x}}$	1.09	0.69	0.90	1.69	30.27	-	1.23	1.79	1.36	1.34	36.14	-
As youths 12-17 years in 1966-1970:												
Mean	139.2	157.0	168.3	173.8	177.4	-	170.6	179.6	183.9	186.8	186.0	-
$s_{\bar{x}}$	1.02	1.02	0.90	1.33	88.79	-	1.00	1.17	1.24	1.31	131.52	-

Table 12. Percent distribution of increase in skeletal maturation (hand-wrist) between first and second examination within designated time intervals between the two examinations for boys and girls in both the Health Examination Surveys of 1963-65 and 1966-70

Increase in skeletal age between first and second examination	Increase in chronological age between first and second examination: Total	Under 30 months	30-35 months	36-41 months	42-47 months	48 months or more	Skeletal age increase from first to second examination
	Percent distribution						
Boys							
Total[1]	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Under 30 months	1.9	38.0	25.9	20.9	8.0	5.4	14.3
30-35 months	18.4	28.6	15.7	10.6	14.1	5.2	10.6
36-41 months	25.5	14.3	14.7	10.6	11.1	10.5	11.5
42-47 months	18.0	-	14.7	18.2	13.6	12.5	14.2
48 months or more	36.2	19.1	29.0	39.7	53.2	66.4	49.4
Girls							
Total[2]	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Under 30 months	1.7	29.4	9.4	4.5	3.1	1.2	4.3
30-35 months	16.9	11.8	21.3	10.3	2.1	2.3	7.8
36-41 months	27.1	29.3	21.9	18.1	7.7	2.3	11.4
42-47 months	19.4	11.8	25.5	21.3	7.7	8.0	14.6
48 months or more	34.9	17.7	21.9	45.8	79.4	86.2	61.9

[1]Excludes 32 boys without usable radiographs in both surveys.
[2]Excludes 39 girls without usable radiographs in both surveys.

Table 13. Percent distribution of the lag of skeletal age (hand-wrist) behind chronological age at the time of the first and second examination for boys and girls in both the Health Examination Surveys of 1963-65 and 1966-70

Skeletal age less chronological age at second examination	Skeletal age less chronological age at first examination					
	Total	Less than -24 months	-13 through -24 months	-1 through -12 months	0 through 11 months	12 months or more
Boys						
Total[1]	100.0	11.7	32.9	35.6	15.7	4.1
Less than -24 months	13.7	4.0	6.8	2.4	0.5	-
-13 thru -24 months	16.3	2.1	6.5	6.4	1.1	0.2
-1 thru -12 months	26.2	3.3	9.5	10.2	2.9	0.3
0 thru 11 months	26.4	1.8	6.4	10.8	6.4	1.0
12 months or more	17.4	0.5	3.7	5.8	4.8	2.6

	Skeletal age less chronological age at first examination						
	Total	Less than -12 months	-1 through -12 months	0 through 11 months	12 through 23 months	24 through 35 months	36 months or more
Girls							
Total[2]	100.0	3.7	13.0	29.6	26.0	21.6	6.1
Less than 12 months	0.6	0.3	0.2	-	0.1	-	-
-1 thru -12 months	2.4	0.7	1.2	0.5	-	-	-
0 thru 11 months	10.7	1.7	3.4	4.0	1.2	0.3	0.1
12 thru 23 months	31.3	0.8	5.0	12.8	9.6	2.8	0.3
24 thru 35 months	37.5	0.1	2.6	9.3	11.4	12.3	1.8
36 months or more	17.5	0.1	0.6	3.0	3.7	6.2	3.9

[1]Excludes 32 boys without usable radiographs in both surveys.
[2]Excludes 39 girls without usable radiographs in both surveys.

APPENDIX I

STATISTICAL NOTES

The Survey Design

The sample design for the first three programs or Cycles I-III of the Health Examination Survey has been essentially similar in that each has been a multi-stage, stratified probability sample of clusters of households in land-based segments. The successive elements for this sample design are primary sampling units, census enumeration district, segment (a cluster of households), eligible persons, and finally, the sample person.

The 40 sample areas and the segments utilized in the design of Cycle III were the same as those in Cycle II. Previous reports describe in detail the sample design used for Cycle II and in addition discuss the problems and considerations given to other types of sampling frames, cluster versus random sampling, and whether or not to control the selection of siblings.[6,7]

Requirements and limitations placed on the design for Cycle III, similar to those for children in Cycle II, were that:

1. The target population be defined as the civilian noninstitutionalized population of the United States, including Alaska and Hawaii, between the ages of 12 and 17 years for Cycle III, with the special exclusion of children residing on reservation lands of the American Indians. The latter exclusion was due to operational problems encountered on those lands in Cycle I.
2. The time period of data collection be limited to about 3 years for each cycle and the length of the individual examination within the specially constructed mobile examination center be between 2 and 3 hours.
3. Ancillary data be collected on specially designed household, medical history and school questionnaires, and from birth certificate copies.
4. Examination objectives be primarily related to factors of physical and intellectual growth and development.
5. The sample be sufficiently large to yield reliable findings within broad geographic regions and population density groups as well as age, sex, and limited socioeconomic groups for the total sample.

The sample was drawn jointly with the Bureau of the Census starting with the 1960 decennial census list of addresses and the nearly 1,900 primary sampling units (PSU's) into which the entire United States was divided. Each PSU is either a standard metropolitan statistical area (SMSA), a county, or a group of two or three contigious counties. These PSU's were grouped into 40 strata, so that each stratum having an average size of about 4.5 million persons, in such a manner as to maximize the degree of homogeneity within strata with regard to the population size of the PSU's, degree of urbanization, geographic proximity, and degree of industrialization. The 40 strata were then classified into 4 broad geographic regions of 10 strata each and then within each region, cross-classified by four population density classes and classes of rate of population change from 1950 to 1960. Using a modified Goodman-Kish controlled-selection technique, one PSU was drawn from each of the 40 strata.

Further stages of sampling within PSU's required first the selection of census enumeration districts (ED's). The ED's are small well-defined areas of about 250 housing units into which the entire Nation was divided for the 1960 population census. Each ED was assigned a "measure of size" equal to the rounded whole number resulting from a "division by nine" of the number of children, aged 5-9, in the ED at the time of the 1960 census. A sample of 20 ED's in the sample PSU were selected by systematic sampling with each ED having a probability of selection proportional to the population of children 5-9 years at the time of the 1960 census date. A further random selection by size of segments (smaller clusters of housing units) within each ED was then made.

Because of the 3-year time interval between Cycle II and Cycle III, the Cycle III frame had to be supplemented for new construction and to compensate for segments where housing was partially or totally demolished to make room for highway construction or urban redevelopment.

Advanced planning for the examinations at the various locations or stands provided for about 17 days of examinations which limited the number of examinees per location to approximately 200. When the number of eligible youths in the sample drawn for a particular location exceeded this number, subsampling was done by deleting from the master list of eligible youths (ordered by segment, household order within segment, and age within household) every nth name on the list starting with the yth name, y being a number between l and n selected randomly and n being the extent of oversampling in the original draw.

In Cycle III, as in Cycle II, twins who were deleted in the sample selection, were also scheduled for examination, time permitting, as were youths deleted from the Cycle III sample who had been examined in Cycle II. The sample was selected in Cycle III, as it had been for the children in Cycle II, so as to contain the correct proportion of youths from families having only one eligible youth, two eligible youths, and so on to be representative of the total target population. However, since households were one of the elements in the sample frame, the number of related youths in the resultant sample is greater than would come from a design which sampled youths 12-17 years without regard to household. The resultant estimated mean measurements or rates should be unbiased but their sampling variability will be sonewhat greater than those from more costly, time-consuming systematic sample design in which every kth youth would be selected.

The total probability sample for Cycle III included 7,514 youths representative of the approximately 22.7 million noninstitutionalized United States youths of 12-17 years. The sample contained youths from 25 different States and approximately 1,000 in each single year of age.

The response rate in Cycle III was 90 percent, with 6,768 youths examined out of the total sample. These examinees were closely representative of those in the samples as well as the population from which the samples were drawn with respect to age, sex, race, region, population density, and population growth in area of residence. Hence it appears unlikely that nonresponse could bias the findings appreciably.

Measures used to control the quality of the data from these surveys have been cited previously;[6,7,118] those additional measures specifically related to skeletal age are outlined earlier in this report.

Reliability

While measurement processes in the surveys were carefully standardized and closely controlled; the correspondence between the real world and survey results cannot be expected to be exact. Survey data 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 processes themselves are inexact even though standardized and controlled.

The first report on Cycle III[7] describes in detail the faithfulness with which the sampling design was carried out.

Data recorded for each sample youth are inflated in the estimation process to characterize the larger universe of which the sample youth is representative. The weights used in this inflation process are a product of the reciprocal of the probability of selecting the youth, 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 12 through 17 for the youth's survey.

In the third cycle of the Health Examination Survey (as for the children in Cycle II) the samples were the result of three prinicipal stages of selection—the single PSU from each stratum, the 20 segments from each sample PSU, and the sample youth from the eligible persons.[119] The probability of selecting an individual youth 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 youths were examined in each of the sample PSU's, the sample design is essentially self-weighting with respect to the target population; that is, each youth 12 through 17 years had about the same probability of being drawn into the respective samples.

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 youths in a sample PSU having the same age (in years) and sex as youths not examined in that sample PSU.

The poststratified ratio adjustment used in the third cycle achieved most of the gains in precision which would have been attained if the sample had been drawn from a population stratified by age, color, and sex and makes the final sample estimates of population agree exactly with independent controls prepared by the Bureau of the Census for the United States noninstitutionalized population as of March 9, 1968, (approximate midsurvey point for Cycle III) by color and sex for each single year of age 12-17. The weights of every responding sample youth in each of the 24 age, color, and sex classes is adjusted upwards or downwards so that the weighted total within the class equals the independent population control for each survey.

In addition to youths not examined at all, there were 32 for whom there was no radiograph or else the radiograph could not be assessed. The age and sex distribution for these 32 youths as well as for the 6,736 for whom assessments were made is shown in table I. The skeletal ages for these youths without useable radiographs were not estimated. It is assumed that the distribution of their skeletal ages is similar to that for the remaining 6,736. In other words they were treated as nonresponders.

Table I. The number of youths whose radiographs were assessed; the number not assessed refers to youths who were examined but whose radiographs were missing or of poor quality: Health Examination Survey, 1966-70

Age	Assessed (6,736)		Not assessed (32)	
	Boys	Girls	Boys	Girls
Total--------	3,534	3,202	11	21
12 years-----------	640	543	3	4
13 years-----------	625	582	1	-
14 years-----------	617	584	1	2
15 years-----------	610	503	3	-
16 years-----------	555	528	1	8
17 years-----------	487	462	2	7

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 completely 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) from the survey are coming thousands of statistics, many for subclasses of the population for which there are a small number of 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 even occasionally when the number of cases is substantial.

Estimates of approximate sampling variability for selected statistics used in this report are included in the detailed tables. These estimates have been prepared by a replication technique which 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 $S_d = \left(S_x^2 + S_y^2\right)^{1/2}$ where S_x and S_y are the sampling errors, respectively, of x and y. Of course, where the two groups or measures are positively or negatively correlated, this will give an overestimate or underestimate, respectively, of the actual standard error.

Small Numbers

In some tables magnitudes are shown for cells for which the sample size is so small that the sampling error

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, 1966-70

Bone	Radio-opaque, not adult		Adult	
	Boys	Girls	Boys	Girls
Radius-------------	3,445	2,977	11	5
Ulna---------------	3,286	2,407	11	4
Capitate-----------	2,011	759	1	1
Hamate-------------	1,986	741	1	1
Triquetral---------	2,007	752	2	1
Lunate-------------	2,000	756	3	1
Scaphoid-----------	2,017	776	1	1
Trapezium----------	2,007	780	2	1
Trapezoid----------	1,995	768	2	1
Metacarpal I-------	2,448	1,128	1	1
Metacarpal II------	2,759	1,590	1	1
Metacarpal III-----	2,738	1,560	1	1
Metacarpal IV------	2,729	1,577	1	1
Metacarpal V-------	2,799	1,701	2	1
Proximal phalanx I-	2,638	1,398	2	3
Proximal phalanx II---------------	2,588	1,319	1	1
Proximal phalanx III--------------	2,591	1,346	1	1
Proximal phalanx IV---------------	2,584	1,350	1	1
Proximal phalanx V-	2,576	1,327	1	1
Middle phalanx II--	2,618	1,316	1	1
Middle phalanx III-	2,651	1,372	1	1
Middle phalanx IV--	2,648	1,377	1	1
Middle phalanx V---	2,625	1,292	1	2
Distal phalanx I---	2,296	968	1	3
Distal phalanx II--	2,339	982	2	1
Distal phalanx III-	2,335	974	2	2
Distal phalanx IV--	2,298	893	1	1
Distal phalanx V---	2,307	893	2	1
Pisiform-----------	1,773	744	166	10
Adductor sesamoid--	1,511	908	574	25
Flexor sesamoid----	1,095	746	1,052	264

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.

Among the 6,736 children with useable radiographs, there were a few of inadequate quality to permit assessment of all bones. In general, these would have been bones that became radio-opaque recently or bones near the margin of the radiographic field. The number of youths for whom bone-specific skeletal ages were assigned and the numbers in which particular bones were adult are shown in table II.

APPENDIX II

RELIABILITY OF ASSESSMENTS

To provide the basis for determining the level of reliability of the bone-specific skeletal age assessments made by the nine medical students at Case Western University from hand-wrist radiographs of the 12-17 year old youths examined in the Health Examination Survey of 1966-70, a randomly selected sample of one in 23 radiographs was reassessed by the same reader and approximately one in 20 independently randomly selected radiographs were reassessed by another reader, as described previously. All nine readers, before starting these final assessments, had been trained by Dr. Pyle in the Greulich-Pyle method using the HES Standard to the point that their assessments were in close agreement with hers. In all, 351 self-replicate assessments and 301 cross-replicate assessments were made. Each reader made approximately the same number of self-replicate and cross-replicate assessments.

All nine readers maintained a high level of consistency in their own assessments throughout all 40 examination stands of the survey. The mean difference in self-replicate assessments for all nine readers was 0.1 month for all 31 bones as well as for the 28 bones from which those that were late to ossify (the pisiform, adductor sesamoid, and flexor sesamoid) were excluded. Considering data for all 31 bones the mean difference per reader between his original and self-replicate assessments ranged from 0.2 to 1.7 months combining data from both sexes. For the 28 bones that ossify relatively early, the mean differences range from 0.2 to 1.6 months among the nine readers (table III).

A consistently high level of agreement in bone-specific skeletal age assessments was maintained among the nine readers but the level was, as expected, somewhat lower than that for the individual readers with themselves. The mean cross-replicate difference for all 31 hand-wrist bones was 0.2 month. It ranged between 0.7 and 2.6 months for the readers. When only the 28 centers that are relatively early to ossify were considered, the overall mean difference was substantially slightly less—0.1 month—and ranged from 0.8 to 2.4 months among the individual readers.

The aspects considered include consistency within observers (intraobserver differences), comparability between observers (interobserver differences), and differences resulting from variations in the way the

Table III. Mean difference in cross- and self-replicate assessments of bone-specific skeletal ages from hand-wrist radiographs of examinees 12-17 years old at last birthday, by reader: Health Examination Survey, 1966-70

Reader	Self-replicates		Cross-replicates		Number of films replicated	
	31 bones	28 bones	31 bones	28 bones	Self-	Cross-
All readers	-0.1	-0.1	-0.2	-0.1	351	301
Reader 21	1.6	1.6	0.7	0.8	36	32
Reader 22	-1.2	-1.4	-2.3	-2.1	36	30
Reader 24	-1.7	-1.6	-1.7	-1.6	21	20
Reader 25	0.5	0.4	2.6	2.4	66	56
Reader 26	-0.2	-0.2	-0.8	-0.5	44	32
Reader 27	-0.3	-0.3	-1.5	-1.7	44	43
Reader 28	0.3	0.2	1.0	1.3	44	33
Reader 29	0.2	0.3	-1.0	-0.8	30	27
Reader 30	-1.0	-1.0	-1.3	-1.0	30	28

Greulich-Pyle Atlas has been used. This review is restricted to reports based on samples of at least 10 radiographs and to the chronological age range 12 to 17 years.

Although it is impossible at present to determine the true maturity level of the bones visualized in a radiograph, it is necessary to define the reliability of assessments both within and between observers. As stated by Greulich and Pyle:[27] "Through the ability to duplicate assessments 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[120] that sets of duplicate radiographs that 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 analyzed their data in different ways. For intraobserver differences, 95-percent confidence limits of 7.2 months[121] and mean differences ranging from 1.2 to 6.6 months have been reported,[117,122-125] in addition to variable errors of 1.4 to 4.2 months.[126,127] The median intraobserver differences range from zero to 4 months.[128,129] A report of zero median differences seems surprising but it is possible because Moed and his coworkers made overall assessments to the nearest atlas standard.

Todd's[34] claim that interobserver differences less than 6 months could be achieved readily appears justified. Reported mean interobserver differences range from 1.3 to 4.2 months.[124,130,131] In addition, a root mean square of 6.2 months and confidence limits of 7.4 months have been reported.[121,125] Reported incidence of particular interobserver differences indicate that the medians were less than 3 months for the study by Hansman and Maresh[132] and less than 6 months for the study by Moed et al.[128]

Bone-Specific Skeletal Ages

Moore[120] 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 differences between chronological and skeletal ages.[123,126] However, the range of maturity between the bones of hand-wrist influences the replicability of overall but not bone-specific assessments.[123,124] The quality of radiographs (exposure, positioning) has no effect on replicability within the range that is common in research studies,[124] but unusually poor radiographic quality does reduce replicability.[126] The method by which the Greulich-Pyle Atlas is used has an effect. Maresh[65] reported a technical error of 3.0 months between overall assessments and those obtained as the means of bone-specific skeletal ages.

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