T. D. Stewart,[1] *M.D.*

Responses of the Human Skeleton to Changes in the Quality of Life

REFERENCE: Stewart, T. D., "**Responses of the Human Skeleton to Changes in the Quality of Life,**" *Journal of Forensic Sciences,* JFSCA, Vol. 25, No. 4, Oct. 1980, pp. 912-921.

SYNOPSIS: Americans have been getting taller for more than a century, and within this century their life expectancy has risen markedly. Descendants of some of the immigrants who arrived from Europe early in this century have heads with shapes that differ from those of relatives back in the Old World. Before they were born head shape was assumed to be one of mankind's most stable features. These examples of population change reflect the fact that in America the quality of life has improved more rapidly and widely than elsewhere. Forensic anthropologists have been adjusting their identification techniques to compensate for these population changes. Among other things, they have used data collected in connection with the military programs to repatriate the American dead of World War II and the Korean War.

KEY WORDS: plenary session, physical anthropology, human identification, quality of life, skeletal remains

Participation of physical anthropologists in forensic science activities is limited largely to the identification of the skeletal remains of local suspected victims of recent crimes. This is at variance with the physical anthropologists' traditional activities, which are unlimited chronologically and geographically. In my case, for instance, one of the activities not related to forensic science that I engaged in some years back was the investigation of the physical characteristics of Neanderthal skeletons found in Iraq and dated to between 46 000 and perhaps 60 000 years ago [*1*]. In all such investigations, whether of immediate or historical interest, the remains of unknown individuals are identified by applying knowledge gained from the study of known individuals. The known individuals are mainly whatever documented skeletons can be obtained from the current population. As will be shown, changes in the quality of life have much to do with short-term population change. The latter in turn affects the quality of skeletal identification. (The less obvious causes of population change that geneticists deal with are not considered here.)

Nature of Population Change

Increasingly during the present century physical anthropologists have become aware of the changing character of the American population. By 1900 it had grown in numbers

The opinions or assertions contained herein are the private views of the author and are not to be construed as official or reflecting the views of the American Academy of Forensic Sciences. Presented at the Plenary Session, 32nd Annual Meeting of the American Academy of Forensic Sciences, New Orleans, La., 20-23 Feb. 1980.

[1]Anthropologist emeritus, Department of Anthropology, National Museum of Natural History, Washington, D.C.

fourteenfold since 1800, and yet life expectancy at birth was still very little beyond that of the colonial period, namely, 47.9 years for males and 51.1 years for females [2]. The latter figures have now risen to over 70 and over 75 years, respectively, while in numbers the population is now some fortyfold greater than in 1800. Having been born in 1901, I am one of the fortunate ones who improved on his expectation and thereby contributed to these population statistics.

The rapid rise in life expectancy in America in the 20th century is especially remarkable because it was accompanied by the arrival of European immigrants in unprecedented numbers. This phase of European immigration, which had begun around 1830, reached its climax of well over one million in each of several years between 1909 and 1914 [2]. The majority of the immigrants were fleeing war, famine, poverty, pestilence, or persecution in the Old World and were hoping to make a new life for themselves and their families in the New. They had reason to believe that it would be a better life, but neither they nor anyone else knew how the better life would affect them physically.

It was precisely this problem that led the United States Immigration Commission in 1908 to entrust to anthropologist Franz Boas an investigation of the physical characteristics of immigrants. In his report of the investigation Boas stated the major findings in these words [*3*, p. 5]:

> In most of the European types that have been investigated the head form, which has always been considered one of the most stable and permanent characteristics of human races, undergoes farreaching changes coincident with the transfer of the people from European to American soil. For instance [Fig. 1], the east European Hebrew, who has a very round head, becomes more long-headed; the south Italian, who in Italy has an exceedingly long head, becomes more short-headed; so that in this country both approach a uniform type, as far as the roundness of the head is concerned. . . .
>
> These results are so definite that, while heretofore we had the right to assume that human types are stable, all the evidence is in favor of a great plasticity of human types, and permanence of types in new surroundings appears rather as an exception than as a rule.

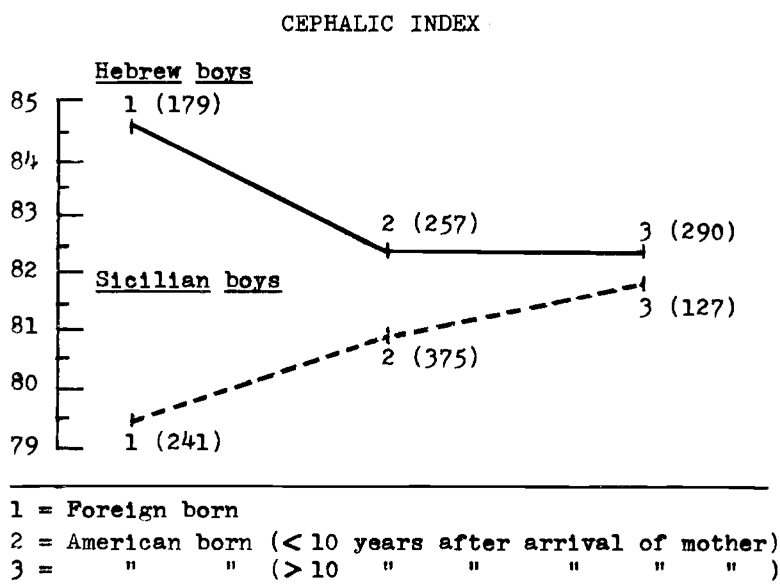

FIG. 1—*Change in the cephalic index (head breadth in percent of head length) of descendants of immigrants relative to time of mother's arrival in the United States* [3, Table 2].

Immigrants into America from other parts of the world besides Europe also have produced offspring that differ physically from their stay-at-home populations—the latter often referred to as *sedentes*. The Japanese are a good example of this, as Greulich showed in studies carried out in California in 1956 and 1957 [*4*]. In this case the change in stature rather than in head form (the latter not having been studied) provides the best illustration (Fig. 2). The California Japanese, while taller than sedentes of the same age, are well below the American standard, which, because of genetic restraints, they are not likely ever to reach.

In this connection it is noteworthy that some of the young Mexican Indians who crossed the international border a few years back in search of work in the United States achieved a different physique simply through exposure to the American environment for a limited time. According to Lasker [*5*], who in 1948 studied the Tarascan Indians of the town of Paracho in Michoacán, the degree of physical change depends on the age of the migrants and the duration of their stay in the United States, the greatest change in stature being found in those who were under 17 years of age when they left Mexico and who remained away over two years.

Early in this century Aleš Hrdlička, my predecessor in the curatorship of the Division of Physical Anthropology in the National Museum, and a 19th-century immigrant, undertook an anthropometric study of the American whites who had been longest in this country [*6*]. He called them "Old Americans" to distinguish them from the newer immigrants. More specifically, Hrdlička limited the Old Americans of his day to those "whose ancestors on each side of the family were born in the United States for at least two generations; in other words, all those whose parents as well as four grandparents were born in this country" [*6*, pp. 4–5].

In his analysis of the stature of his Old Americans, Hrdlička reviewed records going back through the Civil and Revolutionary Wars into the colonial period. Although he hesitated to draw firm conclusions from these data because of the variant and uncertain

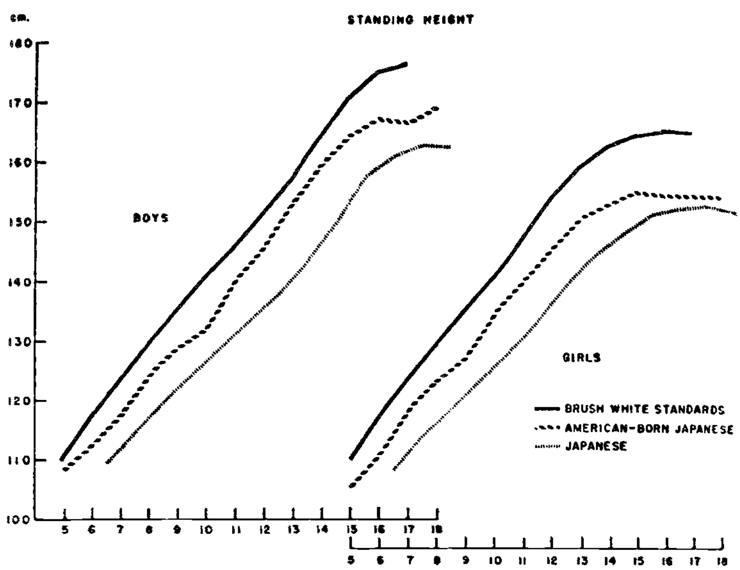

FIG. 2—*Average stature of American-born Japanese, Japanese sedentes, and Cleveland white children at successive chronological ages* [4, Fig. 2].

techniques used earlier in stature determinations, he made one very significant statement: "[The records] all show plainly ... that the stature does not tend to decrease with time notwithstanding the influx of shorter Europeans, *but rather the reverse*" [*6*, p. 60, italics added].

So far as I am aware, this was the first time that an authority had presented suggestive evidence of a secular increase in stature in long-time Americans. (The word *secular* is used here to designate changes over time.) In any event, convincing proof of the truth of this suggestion did not come along until seven years later. In 1932 Earnest Hooton, professor of physical anthropology at Harvard, wrote a foreword to a little book by Gordon Bowles, one of his graduate students, in which he said [*7*, p. v]:

> Harvard University is sufficiently old so that membership in it has become traditional for many sons of New England families. Dr. William T. Brigham and Dr. Dudley A. Sargent, early directors of the Hemenway Gymnasium, were so enlightened as to record and file the physical measurements of Harvard men from the late [eighteen-] sixties on. Hence there has existed for many years, in dead storage, an invaluable mass of data on the bodily characteristics of Harvard sons, fathers, and grandfathers, which is virtually unique. The analysis of such material [carried out by Bowles] should afford a brief glimpse of the most recent phases of physical evolution in males of Old American stock.

Two of Bowles' findings that warranted him entitling his book *New Types of Old Americans at Harvard* are pertinent here: (1) the mean stature of Harvard sons exceeded that of their fathers at the same age by 3.5 cm (Fig. 3); and (2) a pronounced secular increase in stature characterized the Old American population (as well as certain Old World populations) over the century beginning in 1830 (Fig. 4). More recent studies of this subject at Harvard [*8*] and elsewhere [*9*] have shown that the secular increase in stature has now run its course, at least among economically favored men. However, it is still true that the Old Americans are among the world's tallest peoples.

Mechanism of Population Change

Growth, as represented by stature, is the summation, so to speak, of many changes, labeled developmental, taking place at ossification centers throughout the skeleton. Radiographs enable one to rate the progress of ossification, or degree of maturation, at the separate centers. By this means individuals are revealed to vary in their speed of skeletal maturation, some showing acceleration, others retardation. Recognition of this variability led to the need for radiological standards for normal maturation of readily viewable parts of the skeleton, especially the hand. The first set of these standards for Americans was that published by Todd in 1937 [*10*]. However, his standards suffered from the fact that the study series upon which they were based included a high proportion of children regarded as economically underprivileged. Greulich and Pyle [*11*] remedied this deficiency in 1950.

The lack in America before 1937 of reliable population data on skeletal aging makes it impossible to calculate with certainty the maximum amount of developmental retardation by modern standards that may have existed here at any earlier time. Perhaps it was not far different from that reported by Greulich [*12*] for the children of Guam. There, for example (Fig. 5), a native boy with a chronological age of ten years had a skeletal age of a little over seven years by the American standard, while a native girl of the same chronological age had a skeletal age of eight years.

Things Affecting the Quality of Life

In this review of a few of the more striking things learned in this century about the plasticity of the human skeleton, the most noteworthy is that the physical alterations

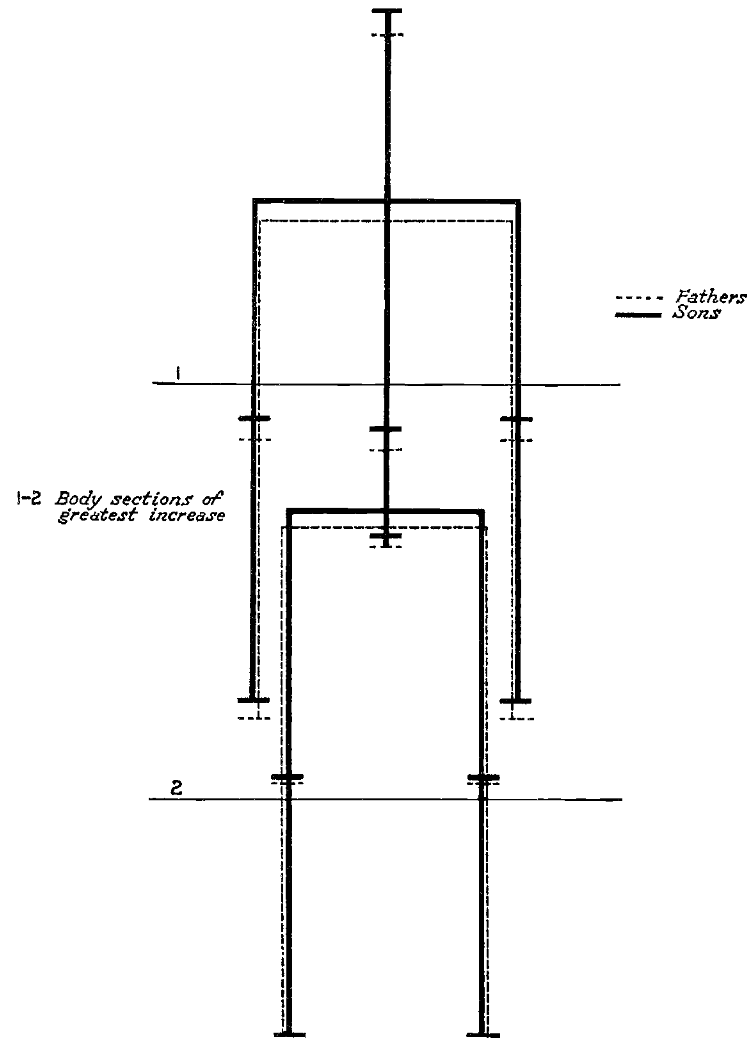

FIG. 3—*Increases of various body parts of sons over fathers among Old Americans at Harvard University* [7, Fig. 6].

involved, whether attributed to growth or development, have resulted from something that amounts to change in the quality of life. Investigators have been both cautious and vague about the nature of the change in the quality of life. One could hardly be more cautious than Boas [*3*] in explaining the physical changes in the descendants of immigrants when he said (in the quotation given above) that these changes appeared "coincident with the transfer of people from Europe to American soil." He seems to imply by this statement that the physical changes had resulted from something in the American environment to which the immigrants had not been exposed in the Old World. Everyone writing on this subject since the date of Boas' publication have identified this "something in the environment" as a better way of life.

The better way of life that attracted foreigners to American shores, especially at the beginning of this century, did not remain static. When I was a boy in Pennsylvania,

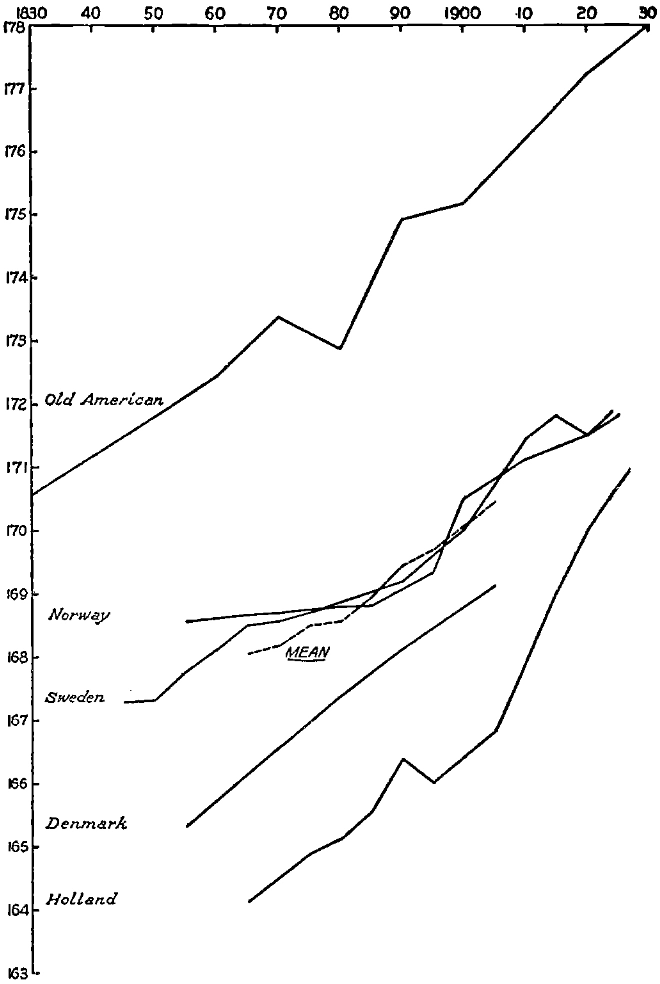

FIG. 4—*Stature increases by decades for Europeans and Old Americans* [7, Fig. 4].

citrus fruits were not available year-round, milk was not widely pasteurized, and refrigeration depended largely on the supply of pond or river ice. Many homes lacked interior toilets. Smallpox vaccination was the only required immunization. Children inevitably contracted chicken pox, measles, mumps, and whooping cough. A few contracted "strep throat," diphtheria, or scarlet fever. Routine dental examinations were still to come. The tremendous changes along these lines that have taken place during the succeeding decades are too well known to require enumeration. In essence, from the standpoint of stimulation of growth and development, the better way of life became better and better.

Now, however, we have about run out of new means for stimulating growth and development. There is even some backtracking because of the possibility that some of the artificial food additives may be carcinogenic. And our automobiles and other labor-saving devices have lured us so far from exercising that we have had to make a fetish of jogging in an effort to maintain our exalted life expectancy.

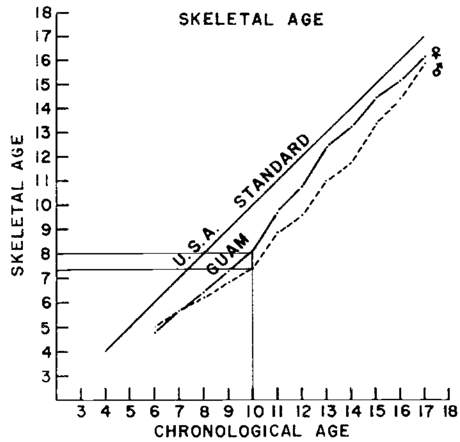

FIG. 5—*Skeletal versus chronological age in Guamanian children showing retardation by the American standard* [12, Fig. 4].

Implications for Forensic Science of Changing Life-Styles

Anatomists were slow in following up the changing character of American life-styles. Through the first two decades of the 20th century textbook writers continued to copy the same general statements about such things as the ages of epiphyseal union given unchanged over and over again in earlier editions. Also, they said nothing about the range of variation of the developmental processes. Then in the 1930s T. Wingate Todd and his associates at Western Reserve Medical School began to report their anatomical findings on documented skeletons from the dissecting rooms of that university and on their radiological findings on Cleveland's living population [*13*]. From then on more exact statements about the process of skeletal maturation began to appear in the textbooks.

Forensic anthropologists got their first inkling of the new findings at Western Reserve University from Krogman's "Guide to the Identification of Human Skeletal Material" published by the FBI [*14*]. Krogman had been associated with Todd when the latter's skeletal collection began yielding its information about developmental rates, and he stressed these findings in his "Guide."

On the other hand, Krogman's "Guide" contained nothing new on methods of stature estimation. Because no one had adapted existing methods to the American population of that day, Krogman fell back on the general regression equations for deriving stature from long-bone lengths developed in 1899 by Karl Pearson, the English biometrician [*15*]. These equations were based on the measurements of 50 male and 50 female French cadavers made in 1888 by Étienne Rollet [*16*]. Although in 1929 Paul Stevenson [*17*] reported from China that the Pearson equations were not generally applicable, American anthropologists, ignoring the evidence that our population had changed, continued to use them until after World War II.

The need to identify the American dead from the Pacific theater of World War II for repatriation provided an opportunity to develop stature-estimation equations based on skeletal remains of our current population. Mildred Trotter, professor of gross anatomy at Washington University School of Medicine in St. Louis, collected the data for this purpose in 1948 and 1949 while serving in Hawaii at the Identification Laboratory of the army's Graves Registration Service [*18*].

To show how the new American equations compare with Pearson's, Trotter used those based on the femur and humerus for testing purposes (Table 1). She found the mean

TABLE 1—*Reduction of mean error of estimate (cm) of stature in 100 white males by improvement in regression formulae based on humerus and femur* [18, Table 15].

Author	Standard Error of Estimate	Errors of Estimate	
		Range	Mean
	Humerus		
Pearson (1899) [*15*]	7.15	−15 to +3	−6.22
Trotter and Gleser (1952) [*18*]	3.66	−9 to +9	−0.12
	Femur		
Pearson (1899) [*15*]	5.02	−11 to +4	−3.67
Trotter and Gleser (1952) [*18*]	3.22	−6 to +9	−0.02

error of estimate to be only −0.02 and −0.12 cm, respectively, for her equations, but −3.67 and −6.22 cm, respectively, for Pearson's equations. The poorer showing for the humerus is expectable because that bone is not a component of stature. These findings confirmed the suspicion arising out of the demonstrated changes in the American population, that, if the Pearson equations served to correctly estimate American stature early in this century, which is unlikely, certainly they would no longer do so in the 1950s. Trotter's concern for the effect of changes in the quality of life on the human skeleton had paid off.

The demonstration that a method for estimating stature from long bones, specifically designed for the American population, was an improvement over the general method in use convinced the American military authorities of the need to update another important identification procedure, namely, skeletal aging. Although in males skeletal maturation is nearing completion at 17 or 18 years of age—the bottom years of the military age range—the metamorphic and degenerative changes that follow provide a means for estimating the time elapsed since the cessation of growth. By the 1950s the limited observations along this line by Todd and his associates in Cleveland, made some 30 years earlier as noted above, were no longer fully acceptable. It was high time, in other words, that new and more detailed observations on age changes be made on the skeletons of a current sample of the American population.

The opportunity to obtain new data on skeletal aging presented itself when the time came to identify the American dead from the Korean War, and I was the one selected by the Graves Registration Service to make the observations [*19*]. Although this operation represents tragic loss of life, there are at least three advantages to using a military population instead of a dissecting-room population for the study of skeletal aging: (1) the military population is far younger; (2) it is far healthier; and (3) it is far more representative of the American population at large.

Typical of the results I obtained in this second study of war dead are the ages of union of the ring epiphyses of the vertebral centra (Table 2). Whereas the textbook of human anatomy that I used in medical school [*20*] simply gives 25 years as the age of complete union of these rings, I found some cases of complete union at age 18, about 50% of cases united at age 21, and the last cases united before age 24. In addition, I found that the union of these rings begins at the extremities of the vertebral column and simultaneously progresses craniad and caudad. More importantly, as Table 3 shows, the last signs of nonunion tend to be located in the vicinity of the fourth thoracic segment.

In conclusion, I see in these examples of additions to our knowledge of skeletal plasticity gained during this second half of the 20th century an admonition against allowing the concern of forensic scientists for the quality of life to abate.

TABLE 2—*Percentages of four stages of union of ring ephiphyses in presacral vertebrae by age in males* [19, Table 31].

		Superior Surface Stages					Inferior Surface Stages				
Age	No.	0	1	2	3	4	0	1	2	3	4
17-18	54	5	22	37	23	13	2	24	37	23	13
19	50	...	10	30	36	24	...	8	32	48	14
20	43	...	7	14	33	46	...	7	14	37	42
21	35	...	...	20	27	63	...	...	20	36	44
22	24	...	...	4	8	88	...	...	4	8	88
23	26	...	...	...	7	93	...	...	...	11	89
24-25	27	...	...	...	...	100	...	...	...	...	100
Total	259	...	...	...	...	...	...	...	...	...	...

TABLE 3—*Percentages of complete union of ring epiphyses of first eight thoracic vertebrae by age in males* [19, Table 32].

		Thoracic Vertebrae							
Age	No.	1	2	3	4	5	6	7	8
17-18	54	13	13	13	8	4	4	8	13
19	50	24	22	14	6	8	8	22	24
20	43	100	86	77	70	68	77	96	100
21	35	100	92	83	86	89	89	95	100
22	24	100	96	84	67	71	91	96	100
23	26	100	97	93	81	85	97	100	100
24-25	27	100	100	100	100	100	100	100	100
Total	259	...	...	...	...	...	...	...	...

References

[*1*] Stewart, T. D., "The Neanderthal Skeletal Remains from Shanidar Cave, Iraq: A Summary to Date," *Proceedings of the American Philosophical Society*, Vol. 121, April 1977, pp. 121-165.
[*2*] Stewart, T. D., "Anthropology and the Melting Pot," *Smithsonian Report for 1946*, Smithsonian Institution, Washington, D.C., 1947, pp. 315-344.
[*3*] Boas, F., *Changes in Bodily Form of Descendants of Immigrants*, Columbia University Press, New York, 1912.
[*4*] Greulich, W. W., "A Comparison of the Physical Growth and Development of American-Born and Native Japanese Children," *American Journal of Physical Anthropology*, Vol. 15, Dec. 1957, pp. 489-515.
[*5*] Lasker, G. W., "An Anthropometric Study of Returned Mexican Emigrants," in *Indian Tribes of Aboriginal America: Selected Papers of the XXIXth International Congress of Americanists*, S. Tax, Ed., University of Chicago Press, Chicago, 1952, pp. 242-246.
[*6*] Hrdlička, A., *The Old Americans*, Williams and Wilkins, Baltimore, 1925.
[*7*] Bowles, G. T., *New Types of Old Americans at Harvard*, Harvard University Press, Cambridge, Mass., 1932.
[*8*] Damon, A., "Secular Trend in Height and Weight Within Old American Families at Harvard, 1870-1965. I. Within Twelve Four-Generation Families," *American Journal of Physical Anthropology*, Vol. 29, July 1968, pp. 45-50.
[*9*] Bakwin, H. and McLaughlin, S. M., "Secular Increase in Height. Is the End in Sight?" *Lancet*, Vol. 2, Dec. 1964, pp. 1195-1196.
[*10*] Todd, T. W., *Atlas of Skeletal Maturation (Hand)*, C. V. Mosby, St. Louis, 1937.
[*11*] Greulich, W. W. and Pyle, S. I., *Radiographic Atlas of Skeletal Development of the Hand and Wrist*, Stanford University Press, Stanford, Calif., 1950.

[12] Greulich, W. W., "The Growth and Development Status of Guamanian School Children in 1947," *American Journal of Physical Anthropology*, Vol. 9, March 1951, pp. 55-70.
[13] Krogman, W. M., "Contributions of T. Wingate Todd to Anatomy and Physical Anthropology," *American Journal of Physical Anthropology*, Vol. 25, July-Sept. 1939, pp. 145-186.
[14] Krogman, W. M., "Guide to the Identification of Human Skeletal Material," *FBI Law Enforcement Bulletin*, Vol. 8, Aug. 1939, pp. 3-31.
[15] Pearson, K., "IV. Mathematical Contributions to the Theory of Evolution. V. On the Reconstruction of the Stature of Prehistoric Races," *Philosophical Transactions of the Royal Society*, Series A, Vol. 192, 1899, pp. 169-244.
[16] Rollet, E., *De la Mensuration des Os Longs des Membres dans ses Rapports Avec l'Anthropologie, la Clinique et la Médecine Judiciaire*, Lyon, France, 1889.
[17] Stevenson, P. H., "On Racial Differences in Stature Long Bone Regression Formulae, with Special Reconstruction Formulae for the Chinese,"*Biometrika*, Vol. 21, Dec. 1929, pp. 303-321.
[18] Trotter, M. and Gleser, G. C., "Estimation of Stature from Long Bones of the American Whites and Negroes," *American Journal of Physical Anthropology*, Vol. 10, Dec. 1952, pp. 463-514.
[19] McKern, T. W. and Stewart, T. D., "Skeletal Age Changes in Young American Males," Technical Report EP-45, Research Division, Quartermaster Research and Development Center, Natick, Mass., 1957.
[20] Terry, R. J., "Osteology," in *Morris' Human Anatomy*, C. M. Jackson, Ed., 8th ed., P. Blakiston's Son and Co., Philadelphia, 1925, pp. 81-253.

Address requests for reprints or additional information to
T. Dale Stewart, M.D.
National Museum of Natural History
Washington, D.C. 20560