THE FOOT LENGTH TO STATURE RATIO: A STUDY OF RACIAL VARIANCE

by

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ABSTRACT

This research investigates the often cited observation that foot length constitutes 15 percent of an individual's stature in all populations. Using the measurements of samples drawn from two distinct populations, this thesis explores the differences in the foot length/stature ratio between populations. African Americans, individuals predominantly of African descent, and Caucasian Americans, individuals predominantly of European descent, are measured for comparison. The subjects of this research were males and females between the ages of 18 and 26. Each individual was measured for stature, sitting height, and foot length. Statistical methods were used to calculate regression formulae and make comparisons. T-test's revealed significant sex and population differences in absolute, as well as relative, measurements. While no such differences were found between the average foot lengths of the left and right feet, significant differences were found in the foot length/stature ratios based on each foot. Regression formulae were

computed for the left and right feet of both populations. The results indicate the foot length/stature ratio of 15 percent is not applicable to all populations. This information is useful to forensic anthropologists for individual identification. Other anthropologists can apply this ratio in the analysis of ancient footprints or skeletal materials. Clothiers can use this ratio to benefit their manufacturing and retail operations.

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CHAPTER I

INTRODUCTION

Early observations of a white, male, European population revealed that a person's overall foot length is approximately 15% of his stature (Topinard, 1895; Martin and Saller, 1957). Further studies of French males confirmed these findings, but the research was limited to a Caucasian population (Pales, 1976). In one recent study, Robbins (1985) measured 500 male and female subjects between the ages of 7 and 80, but did not define the population's race. This study will analyze the differences in the foot length/stature ratio between African Americans and Caucasian Americans in a young, adult population.

This study is using "race" with no implication of subspecific classification, but as a convenient term for a collection of populations that are physically similar to each other and distinct from other such collections. The two groups were identified as African Americans and Caucasian Americans. The African Americans share the common heritage of a predominantly African ancestry. The Caucasian Americans share the common heritage of a predominantly European ancestry.

African Americans are different from Caucasian Americans. One variation common to all African Americans is long extremities (Hrdlička, 1920; Todd and Lindala, 1928; Steggerda, 1940; Steggerda and Petty, 1940; Cureton, 1951; Krogman, 1970; Hamill, Johnson, and Lemeshow, 1973; Malina, Brown, and Zavelta, 1987; Carr, Rempel, and Ross, 1989). This study indicates that the extension of the lower extremities carried over into the bones of the foot, which could explain the differences in the foot length/stature ratio.

There have been numerous anthropometric studies of the physical features of specific populations, such as those by Topinard (1895), Hrdlička (1928), Todd and Lindala (1928), Carter (1932), Steggerda (1932, 1940), and Martin and Saller (1957). However, no significant research, contrasting the variations of the foot length/stature ratio between different populations, has been published. Although Pales (1976) and Robbins (1978, 1985, 1986) have studied the foot length/stature ratio specifically, they did not publish data concerning racial variation (see Tuttle, 1986, for criticism of Robbins' work).

Just as long lower extremities are a common characteristic of African Americans, so too are high foot length/stature ratios. The African Americans have a

higher foot length/stature ratio than the Caucasian Americans. Significant race and sex differences were found between the foot length/stature ratios of both populations.

The information provided by the foot length/stature ratio could be applied in many ways. It has implications in such fields as anthropology, human paleontology, and criminology, and can serve the commercial uses of manufacturers and retailers. The foot length/stature ratio supplies forensic anthropology with an important indicator of variation among populations (Robbins, 1978; Stewart, 1979; Rogers, 1987). Anthropological researchers investigating our ancient ancestors are furnished with a reliable tool for interpreting their findings, especially ancient footprints (Oliver, 1976; Hay and Leakey, 1982). Furthermore, criminal investigators can apply the regression formulae of this study to the footprints of a crime scene to estimate the stature of a suspect (Robbins, 1978, 1985). Finally, clothiers may find practical application for the foot length/stature ratio in sizing garments and shoes, which would be useful for production and inventory.

CHAPTER II

FOOT LENGTH AND STATURE

Neither foot length nor stature is determined from the measurement of a single bone. Both measurements include several types of bones and tissues. Foot length is the maximum horizontal distance of the bones and tissues in the foot. Stature is the maximum vertical distance of an individual's bones and tissues.

Foot Length

The length of the human foot is the measure of three types of bones: tarsals, metatarsals, and phalanges (see Figure 2-1). The seven tarsals form the heel and posterior portion of the sole. While the proximal portion of the five metatarsals forms the anterior portion of the sole, the distal portion forms the ball of the foot. The thirteen to fourteen phalanges form the digits of the foot. Maximum foot length is measured from the posterior surface of the heel, pterion, to the most distal point of the longest toe (Hrdlička, 1920; Harris, Jackson, Paterson, and Scammon, 1930; Davenport, 1932; Lewin, 1954; Martin and Saller, 1957; Robbins, 1985). If measurement is made with bones, Robbins (1985) suggests adding 3 per-

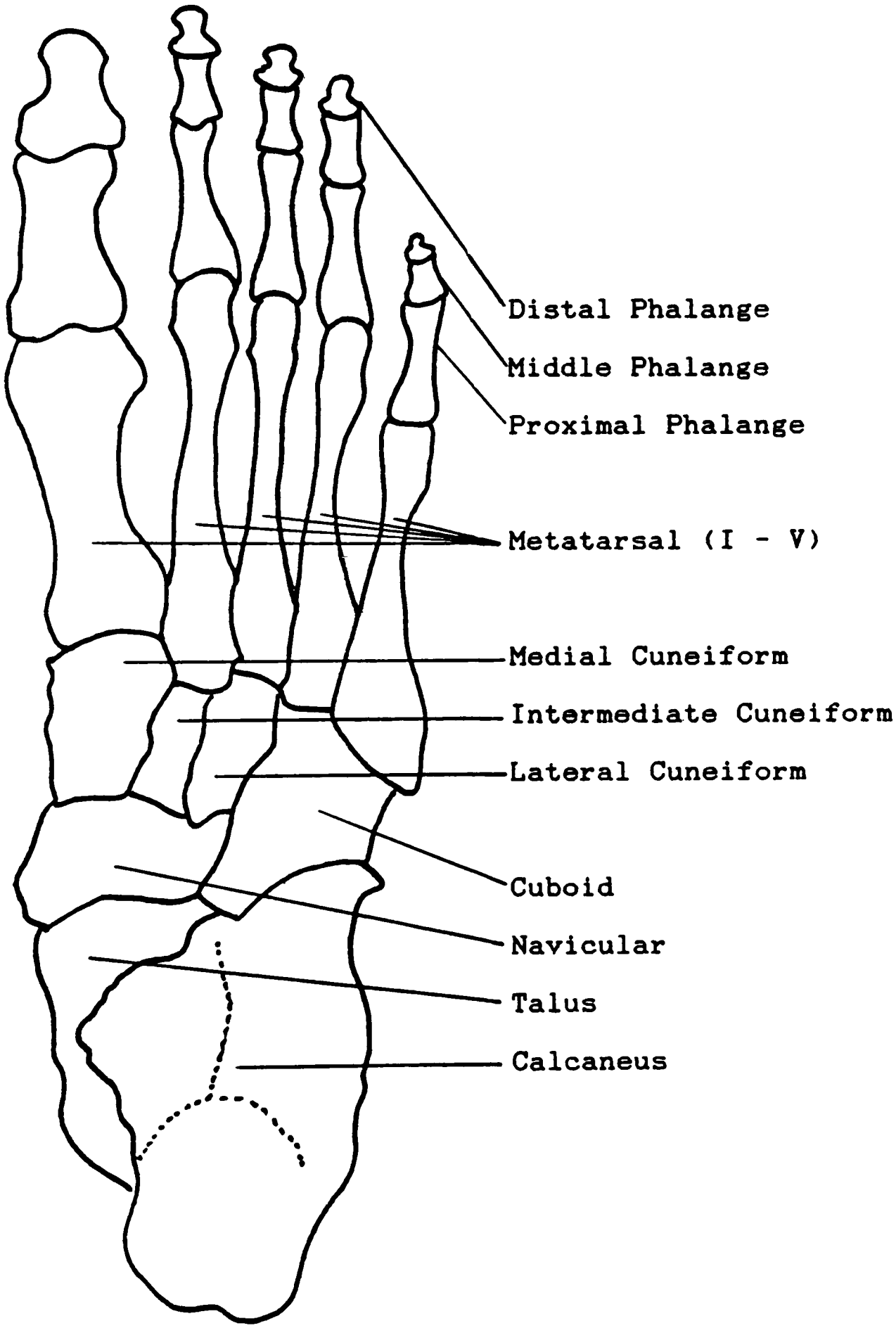

Figure 2-1. Plantar view of skeletal foot (from Robbins, 1985)

cent to the maximum foot length, which accounts for the missing soft tissues (cartilage, ligaments, and skin).

The Tarsal Bones

These bones constitute approximately 50 percent of the overall foot length. The calcaneus, or os calcis, forms the heel, and constitutes over 60 percent of the tarsal foot length. The talus forms the interior of the ankle, and contributes only to stature. The navicular is set within the tarsal bones, and adds approximately 15 percent to tarsal length. The most distal tarsal bones are the cuboid and the three cuneiforms. These bones articulate with the metatarsals and account for the remainder of the tarsal foot length.

The Metatarsals

These bones account for approximately 40 percent of the entire foot's length. The metatarsals are composed of five long bones, each bone containing a head, a body, and a base. The bones are numbered one to five, counting from the medial to the lateral side. The first metatarsal has the shortest length, but is the thickest of all the metatarsals. The head of this bone articulates with the base of the proximal phalange of the great toe. The second metatarsal articulates with the base of the

proximal phalange of the second digit. The point of measurement for maximum foot length is variable among the first three digits, but usually it is taken along the second digit (Robbins, 1985). The third, fourth, and fifth metatarsals articulate with the bases of proximal phalanges.

The Phalanges

The phalanges are the bones of the digits, or "toes," and are the most distal bones of the foot. The phalanges account for only 10 percent of the foot's length. The bones of each digit are referred to as the proximal, the middle, and the distal phalanges. While the four lateral digits usually contain three phalanges, the medial digit, or "great toe," has only two phalanges. In some populations, the fifth digit is composed of only two phalanges.

Stature

Stature is the maximum vertical measurement of an individual as measured from the bottom of the feet to the top of the head. Normally, stature is taken on a standing individual with the head in a Frankfurt plane, using a metric anthropometer (Hrdlička, 1920; Martin and Saller, 1957; Stewart, 1979). This measurement is the composition of several different types of bones.

The Calvarium

The seven bones of the calvarium constitute approximately 10 percent of an individual's stature. The two parietal bones commonly form the apex. Occasionally, the apex is formed by the frontal bone. The occipital bone encloses the base of the calvarium, while the sphenoid and the two temporal bones comprise the anterior and lateral sides. The occipital condyles articulate with the vertebral column.

The Vertebral Column

The spine is the articulation of numerous vertebral bones and intervertebral disks. These bones and tissues comprise 33 percent of an individual's stature. The superior portion of the vertebral column is comprised of seven cervical and twelve thoracic vertebrae. The lower spine is composed of five lumbar vertebrae. The five sacral and three to five coccygeal vertebrae are incorporated into the pelvic region.

The Pelvis

The pelvic region is composed of two innominate bones and the sacrum. The two innominate bones serve to unite the vertebral column with the long bones of the legs. The auricular surface of the innominate bones provides

articulation for the sacrum. The femur articulates with each innominate bone at the acetabulum.

The Lower Extremities

The majority of the lower extremities is composed of the femur and the tibia. These bones account for almost 50 percent of a person's stature. The femur comprises the proximal portion of the lower extremity, while the tibia comprises the distal portion. These bones articulate at the knee joint. Foot height, the product of the height of the talus and the calcaneus, is included in the measurement of the lower extremity.

CHAPTER III

THE FOOT LENGTH TO STATURE RATIO

Early exploration of the foot length/stature ratio was hampered by small samples and inappropriate measuring equipment. As noted in chapter I, the earliest observations of the foot length/stature ratio were recorded by Topinard (1895). He calculated a ratio of 16.95 percent in fifty Caucasian males. Further research by Martin found the current measuring devices inexact, so he invented equipment capable of more precise measurements (Martin and Saller, 1957). Using this new equipment, Martin recorded measurements for over 350 Caucasian males in 1914. From this data Martin concluded the foot length/stature ratio to be approximately 15 percent. Many anthropologists accepted this conclusion, and believed it could apply to all populations.

Historical Research

Early research of young Caucasian American men occurred at Amherst College in Massachusetts (Hitchcock, Seelye, and Phillips, 1900). Over a six-year period, these students of Amherst were measured, weighed, and

tested. Records of 3535 students were collected for evaluation. The mean length of the right foot was 260 mm. The mean stature was recorded at 1725 mm, and the sitting height at 903 mm. Although the foot length/stature ratio was not recorded, a computation of the averages yielded a value of 15.07 percent. A similar study in the United Kingdom yielded different results.

Researchers in the United Kingdom published a study of 3000 criminals. MacDonell (1901) measured criminals from England and Ireland to obtain data on their physical characteristics. MacDonell's measurements revealed the mean stature to be 1664.6 mm. The maximum length of the left foot was recorded as 256.9 mm. These findings yielded a foot length/stature ratio of 15.4 percent. This provided indications of variation among the populations of different environments.

The realization of environmental, and racial, differences started intense research into the physical variations of man. The late 1920's saw the first in-depth research into the morphological differences between the Caucasian American and African American populations in the United States. Using Martin's measurement techniques from Lehrbuch Der Anthropologie, Todd and Lindala (1928) published their findings on both sexes of the Caucasian American and African American populations (see Table

3-1). While the recorded data revealed a difference in the absolute means for foot length and stature, Todd and Lindala insisted these findings were only significant absolutely, and not relatively. While admitting the African American population possessed longer limbs, they stated the "hands and feet are proportionate" (Todd and Lindala, 1928:75). Simple calculations of their findings dispute this claim.

TABLE 3-1

Averages of a Cleveland Population (mm)

No.	Race	Sex	Stature	Sit.	F. L.	Foot/Stat. (%)
100	CC	M	1706	869	244	14.3
100	AA	M	1744	912	256	14.7
36	CC	F	1597	799	215	13.5
35	AA	F	1586	821	231	14.6

Sit. = Sitting Height, F. L. = Foot Length, AA = African American, CC = Caucasian American, M = Male, F = Female

(from Todd and Lindala, 1928)

The implications of the Todd-Lindala study suggested that the foot length was greater in the African Americans than in the Caucasian American population, but more

research was needed to confirm this. Hrdlička's study between sexes in an elderly African American population only confused the issue (Hrdlička, 1928). Since height is reduced with age, the smaller mean stature may have been caused by the use of the elderly population (Stewart, 1979). The large number of older adults in this sample suggests Hrdlička's results were skewed (see Table 3-2). The foot length of Hrdlička's study had a mean value substantially higher than the Todd-Lindala study. When combined with the smaller stature, the results of the foot length/stature ratio were approximately 16 percent. Hrdlička's study did support the conclusion of African Americans possessing long extremities in proportion to trunk length.

TABLE 3-2

Averages of an African American Population (mm)

No.	Race	Sex	Stature	Sit.	F. L.	Foot/Stat. (%)
30	AA	M	1686	872	268	15.9
30	AA	F	1618	819	254	16.1

Sit. = Sitting Height, F. L. = Foot Length, AA = African American, M = Male, F = Female

(from Hrdlička, 1928)

The discrepancy in the data between the Hrdlička and the Todd/Lindala study prompted several researchers to conduct their own research. Davenport and Steggerda (1929) conducted research on 100 Jamaicans of both sexes (see Table 3-3). While the sitting height recorded was unusually high, the foot length/stature ratio was closer to 15 percent for both sexes. Comparative research was conducted on Caucasian American women at Smith College (see Table 3-3). This study concentrated on 100 women of college age, and produced reliable data for comparison with data from other researchers (Steggerda, Crane, and Steele, 1929). Steggerda (1932) continued his investigation into differences in physical characteristics between races by recording the measurements from a population of Dutch descent (see Table 3-4). Carter (1932) made a similar study with Caucasian American women of college age (see Table 3-4). The data from these studies were remarkably similar. This research suggested differences between the sexes, and between races.

More research was needed to recognize and document the types of variation between African American and Caucasian American populations. In 1940, Steggerda published his research comparing African American and Caucasian American women (see Table 3-5). While he stated the mean foot length to be "highly significant," calculation

TABLE 3-3

Averages of Jamaican and College Populations (mm)

No.	Race	Sex	Stature	Sit.	F. L.	Foot/Stat. (%)
50[1]	AA	M	1727	1027	266	15.4
50[1]	AA	F	1605	1011	245	15.2
100[2]	CC	F	1628	868	237	14.5

[1] (from Davenport and Steggerda, 1929)

[2] (from Steggerda, Crane, and Steele, 1929)

TABLE 3-4

Averages of Dutch and College Populations (mm)

No.	Race	Sex	Stature	Sit.	F. L.	Foot/Stat. (%)
70[1]	CC	M	1732	913	266	15.3
60[1]	CC	F	1618	860	242	14.9
109[2]	CC	F	1637	861	241	14.7

Sit. = Sitting Height, F. L. = Foot Length, AA = African American, CC = Caucasian American, M = Male, F = Female

[1] (from Steggerda, 1932; the Dutch population)

[2] (from Carter, 1932; the college population)

TABLE 3-5

Averages of 100 College Women of Both Races (mm)

No.	Race	Sex	Stature	Sit.	F. L.	Foot/Stat. (%)
100	CC	F	1628	868	237	14.5
100	AA	F	1633	837	250	15.3

Sit. = Sitting Height, F. L. = Foot Length, AA = African American, CC = Caucasian American, M = Male, F = Female

(from Steggerda, 1940; Steggerda and Petty, 1940)

of the foot length/stature ratio was not performed (Steggerda, 1940; Steggerda and Petty, 1940). Calculation of the foot length/stature ratio from this data reveals that an absolute difference did exist between the populations. Furthermore, the data indicated the conclusion of a longer leg length in the African American as being a "racial" trait. Further study of the foot length/stature ratio did not occur until the 1970's.

Modern Research

The early 1970's discovery of prehistoric footprints at Laetoli brought renewed interest of the foot length/stature ratio. After researching the available material on the foot length/stature ratio, Mary Leakey concluded

that the foot length/stature ratio was a constant 15 percent for all populations (Oliver, 1976; Hay and Leakey, 1982). Applying these findings to the footprints of the smaller Laetoli hominids, Leakey calculated their stature to be 1200 mm and 1400 mm.

In 1976, a French anthropologist, Pales, published new research on the foot length/stature ratio. This study began as a result of his research in the Ariege caves of France and Italy. Numerous footprints were uncovered, attributable to Neanderthal populations which inhabited the caves during paleolithic times. Pales' research on the foot length/stature ratio utilized male Caucasian subjects of varying ages. Over 100 adult males were found to have a mean foot length/stature ratio of 16 percent. For subjects under 18, the mean foot length/stature ratio was calculated as 17 percent. Statistical analysis of the data provided Pales with regression formulae, which he applied to his cave research. Pales attempted to create reliable formulae for estimating stature from the foot length of children and adults, but he did not make allowance for the children's variable growth rates.

Foot growth studies have shown the proportions of children change drastically in short periods of time (Strauss, 1926; Davenport, 1932; Anderson, Blais, and

Green, 1956; Hill, 1958). The foot's length was shown to increase significantly several weeks before any corresponding growth in stature began. For this reason, any estimation on persons under 18 years of age, the age at which a person's foot attains its full length, is highly unreliable. Although the research was well conducted, earlier studies have shown the differences that can exist between two populations, therefore Pales' material should only be applicable to the adult, Caucasian males of Europe. Clearly, more study is needed in other populations.

Further research was conducted by Robbins in 1985 on a sample population. Robbins' research was aimed at an American population in an attempt to verify the validity of the 15 percent foot length/stature ratio. "All measurements were made using standing height and maximum foot length" (Robbins, 1985:198-201). Her sample of 500 individuals gave a combined foot length/stature ratio of 15 percent for both feet. However, males over the age of 14 were shown to have 15.128 percent for their right foot (S.D. = .951), and 15.199 percent for their left foot (S.D. = .638). Females over the age of 14 were shown to have 14.726 percent for their right foot (S.D. = .636), and 14.750 percent for their left foot (S.D. = .666). No significant differences were found between the right and

left foot of each sex. No allowances were made for differences in sex or race.

While this research was needed, it contained several flaws. Although foot growth occurs up to age 18, over 60 percent of Robbins' subjects were under age 20 (Strauss, 1926; Davenport, 1932; Anderson, Blais, and Green, 1956; Hill, 1958). This error may have skewed her results. Robbins included a scattergram for linear regression manipulation, but failed to discuss or display the calculations (Tuttle, 1986). Additionally, the race and geographical origin of her sample were never documented.

Governmental agencies are a primary source of data (see, for example, Hertzberg, Daniels, and Churchill, 1950; National Aeronautics and Space Administration, 1978; Young, 1983; Najjar and Rowland, 1987). However, these works typically make no note of racial differences.

CHAPTER IV

STUDY OF RACIAL DIFFERENCE

Earlier studies did not recognize the foot length/stature ratio as a distinct characteristic. The results of this study indicate the foot length/stature ratio to have significant differences between races.

Methods and Materials

The sample for this study consisted of 240 Texas Tech University students, between the ages of 18 and 26. Only students identified as African American and Caucasian American were asked to participate. The students were given assurance of strict confidentiality, so their names were kept in a notebook separate from the data.

Four measurements were recorded for each individual: standing stature, sitting height, and the length of the each foot. Stature was measured with an anthropometer, each individual being in stocking feet with the head in the Frankfurt plane. Sitting height was recorded with each individual seated on a flat surface and the head in the Frankfurt plane. Each foot was measured bare for the maximum horizontal length, the maximum length being defined as the longest distance from the middle of the heel

(pterion) to the most distal toe. The foot measurements were made on a flat surface using a metric ruler and a right triangle. All measurements were recorded to the nearest millimeter.

All calculations, regression formulae, and scattergrams were calculated using methods found in An Introduction to Statistical Methods and Data Analysis by Ott (1988).

Results

Table 4-1 lists the mean stature and sitting height from both groups of students. The average stature for the Caucasian American population was 1673 mm, while the average stature for the African American population was 1702 mm. The average sitting height of the Caucasian American population was calculated as 855 mm, which is 51.12 percent of their total stature, 1673 mm. That for the African American population was calculated as 848 mm, which is 49.81 percent of their total stature, 1702 mm.

Sitting height was found to be variable absolutely and relatively in t-test comparisons (see Tables 4-2 and 4-3). Based on a .05 probability level, the absolute sitting height was significant between races for females. There were substantial differences between the males and females of the same race. The relative sitting height

TABLE 4-1

Average Stature and Sitting Height by Race and Sex (mm)

No.	Race	Sex	Stature	SD	Sit.	SD
51	AA	M	1772	62	882	29
63	CC	M	1717	73	872	46
59	AA	F	1641	57	817	25
67	CC	F	1630	56	839	34

TABLE 4-2

Average Sitting Height t-Test Comparisons (mm)

Comparison	No.	Race	Sex	Mean	SD	DF	t-Value
Sit. Height	63	CC	M	872	46	112	1.407
	51	AA	M	883	29		
Sit. Height	67	CC	F	839	35	124	3.885*
	59	AA	F	818	25		
Sit. Height	63	CC	M	872	46	128	4.650*
	67	CC	F	839	35		
Sit. Height	51	AA	M	883	29	108	12.460*
	59	AA	F	818	25		

Sit. = Sitting Height, SD = Standard Deviation, DF = Degrees of Freedom, AA = African American, CC = Caucasian American, M = Male, F = Female, * = $p < .05$

TABLE 4-3

Sitting Height/Stature t-Test Comparisons (%)

Comparison	No.	Race	Sex	Mean	SD	DF	t-Value
Sit. Height	63	CC	M	50.78	1.38	112	4.263*
	51	AA	M	49.83	.88		
Sit. Height	67	CC	F	51.46	1.56	124	7.639*
	59	AA	F	49.81	.60		
Sit. Height	63	CC	M	50.78	1.38	128	2.626*
	67	CC	F	51.46	1.56		
Sit. Height	51	AA	M	49.83	.88	108	.141
	59	AA	F	49.81	.60		

SD = Standard Deviation, DF = Degrees of Freedom, AA = African American, CC = Caucasian American, M = Male, F = Female, * = $p < .05$

produced significant differences between races for males and females each. There were significant differences between African American males and females, but not between Caucasian American males and females.

Table 4-4 lists the measurements recorded for foot length. Based on a .05 probability level, t-test comparisons were made of the mean foot length. Although there were no significant differences between the right and left feet, there were significant differences between sex and race (see Table 4-5).

TABLE 4-4

Average Foot Length by Race and Sex (mm)

No.	Race	Sex	Right	SD	Left	SD
51	AA	M	276	15	277	16
63	CC	M	262	14	262	14
59	AA	F	251	11	251	11
67	CC	F	238	10	237	10

SD = Standard Deviation, AA = African American,
CC = Caucasian American, M = Male, F = Female

The data on foot length and stature were used to calculate the foot length/stature ratio for both races (see Table 4-6). The results of the foot length/stature ratio t-tests were based on a .05 probability level (see Table 4-7). The t-test comparisons between the right and left feet revealed significant differences between Caucasian Americans, but not between African Americans. Accordingly, regression formulae were computed for both feet (see Table 4-8). The t-tests between race and sex were significant in all areas, indicating distinctions between the two populations.

TABLE 4-5

Average Foot Length t-Test Comparisons (mm)

Comparison	No.	Race	Sex	Mean	SD	DF	t-Value
Right Foot	63	CC	M	262	14	124	.258
Left Foot	63	CC	M	261	14		
Right Foot	51	AA	M	276	16	100	.151
Left Foot	51	AA	M	276	16		
Right Foot	67	CC	F	237	10	132	.124
Left Foot	67	CC	F	237	10		
Right Foot	59	AA	F	251	11	116	.030
Left Foot	59	AA	F	251	10		
Right Foot	63	CC	M	262	14	112	4.895*
	51	AA	M	276	16		
Right Foot	67	CC	F	238	10	124	7.069*
	59	AA	F	251	11		
Right Foot	63	CC	M	262	14	128	11.306*
	67	CC	F	238	10		
Right Foot	51	AA	M	276	16	108	9.794*
	59	AA	F	251	11		
Left Foot	63	CC	M	262	14	112	6.212*
	51	AA	M	277	16		

SD = Standard Deviation, DF = Degrees of Freedom, AA = African American, CC = Caucasian American, M = Male, F = Female, * = $p < .05$

TABLE 4-5

Continued

Comparison	No.	Race	Sex	Mean	SD	DF	t-Value
Left Foot	67	CC	F	238	10	124	7.352*
	59	AA	F	251	11		
Left Foot	63	CC	M	262	14	128	11.306*
	67	CC	F	238	10		
Left Foot	51	AA	M	277	16	108	9.944*
	59	AA	F	251	11		

TABLE 4-6

Average Foot Length/Stature Ratio by Race and Sex (%)

No.	Race	Sex	Right	SD	Left	SD
51	AA	M	15.58	.66	15.61	.63
63	CC	M	15.27	.44	15.24	.50
59	AA	F	15.30	.51	15.31	.52
67	CC	F	14.58	.39	14.61	.39

SD = Standard Deviation, DF = Degrees of Freedom, AA = African American, CC = Caucasian American, M = Male, F = Female, * = $p < .05$

TABLE 4-7

Foot Length/Stature t-Test Comparisons (%)

Comparison	No.	Race	Sex	Mean	SD	DF	t-Value
Right Foot	63	CC	M	15.27	.44	124	2.005
Left Foot	63	CC	M	15.24	.50		
Right Foot	51	AA	M	15.58	.66	100	1.185
Left Foot	51	AA	M	15.61	.63		
Right Foot	67	CC	F	14.58	.39	132	2.565*
Left Foot	67	CC	F	14.61	.39		
Right Foot	59	AA	F	15.30	.51	116	.575
Left Foot	59	AA	F	15.31	.52		
Right Foot	63	CC	M	15.27	.44	112	8.737*
	51	AA	M	15.58	.66		
Right Foot	59	AA	F	15.30	.51	124	8.959*
	67	CC	F	14.58	.39		
Right Foot	63	CC	M	15.27	.44	128	9.475*
	67	CC	F	14.58	.39		
Right Foot	51	AA	M	15.58	.66	108	2.507*
	59	AA	F	15.30	.51		
Left Foot	63	CC	M	15.24	.50	112	5.370*
	51	AA	M	15.61	.63		

SD = Standard Deviation, DF = Degrees of Freedom, AA = African American, CC = Caucasian American, M = Male, F = Female, * = $p < .05$

TABLE 4-7

Continued

Comparison	No.	Race	Sex	Mean	SD	DF	t-Value
Left Foot	59	AA	F	15.31	.52	124	8.595*
	67	CC	F	14.61	.39		
Left Foot	63	CC	M	15.24	.50	128	8.934*
	67	CC	F	14.61	.39		
Left Foot	51	AA	M	15.61	.63	108	2.732*
	59	AA	F	15.31	.52		

SD = Standard Deviation, DF = Degrees of Freedom, AA = African American, CC = Caucasian American, M = Male, F = Female, * = $p < .05$

TABLE 4-8

Stature Calculated From Foot Length:
Regression Formulae (cm)

No.	Race	Sex	Foot	Equation	SE
51	AA	M	Right	y = 2.78x + 100.35	±.63
51	AA	M	Left	y = 2.89x + 97.30	±.66
63	CC	M	Right	y = 4.38x + 56.85	±.79
63	CC	M	Left	y = 4.23x + 61.06	±.73
59	AA	F	Right	y = 3.56x + 74.75	±.51
59	AA	F	Left	y = 3.43x + 78.07	±.48
67	CC	F	Right	y = 4.29x + 60.98	±.55
67	CC	F	Left	y = 4.28x + 61.32	±.53

SD = Standard Error, AA = African American, CC = Caucasian American, M = Male, F = Female

CHAPTER V

CONCLUSIONS

This study helps to establish the foot length/stature ratio as a variable characteristic, and one which is distinctive of population groups. Martin's work in 1914 created the impression that the 15 percent foot length/stature ratio was universal (Martin and Saller, 1957). The results of the research presented here contradict Martin's conclusions, and indicate that differences exist between the foot length/stature ratios of Caucasian Americans and of African Americans (see Table 5-1).

Limb Proportions

Populations can vary in limb proportions. As noted earlier, the African Americans have longer extremities than the Caucasian Americans. The long lower extremities of the African Americans can explain their longer foot length, and suggest an explanation for their larger foot length/stature ratio. The greater limb proportion in the African American can be attributable to two major influences, environment and admixture.

The immigrant ancestors of most of the African American population originated in Western Africa (Montagu, 1960,

TABLE 5-1

Average Foot Length/Stature (%)

No.	Race	Sex	Percent	SD
51	AA	M	15.6	.66
63	CC	M	15.3	.44
59	AA	F	15.3	.51
67	CC	F	14.6	.39

SD = Standard Deviation, AA = African American, CC = Caucasian American, M = Male, F = Female

1964; Allegro, 1982). It has been indicated that the environment of this area selected for the longer limb proportions (Damon, 1975; Coon, 1982). This is an application of Allen's Rule, which states that, within a given species, the warm-blooded mammals have shorter extremities in the colder climates and longer extremities in the warmer climates (Allen, 1877). This variation is a result of natural selection: longer extremities create more surface area, which aids the body's cooling mechanisms against heat stress (Siegel, Doyle, and Kelley, 1923; Coon, Garn, and Birdsell, 1950; Baker and Weiner, 1966; Riesenfeld, 1973; Coon, 1982). Thus, in tropical climates selection would favor the individuals with long limb proportions, which are conducive to effective heat

dissipation; in colder climates, compactly built individuals with short extremities would be favored.

Admixture with other populations may have contributed to the African American's longer extremities by increasing their stature. In North America, intermarriage has occurred between African immigrants and other Americans, including those of European ancestry, and Native American ancestry. In some cases, intermarriage may have contributed to an increase in the stature of African Americans, with a resultant lengthening of the extremities (Trotter and Gleser, 1951). An increase in the length of the lower extremity would increase the overall foot length, suggesting the possibility of a change in the foot length/stature ratio.

Evolutionary Significance

A significant amount of variation exists within our species. Such variation is important when interpreting the fossil remains of morphospecies. In view of the amount of variation existing within our own species, it is dangerous to assume that a general foot length/stature ratio is applicable throughout the species. Each population must be studied for its own foot length/stature ratio, which should be calculated from the complete skeletal remains of that population. A calculation of

stature using the regression formula of this study can provide only an estimate, of course, of the actual stature of any population.

However, researchers studying man's past can benefit from studies of this type. Such analyses can provide a better understanding of an aspect of the morphology of man. With modifications, the foot length/stature ratio should be applicable to the interpretation of the fossil record, providing a more complete reconstruction of early man. Research in this direction would benefit from studies of the foot length/stature ratio of the great apes. A comparative study of the primates could form the basis for tracing the evolution of the foot length/stature ratio from its early beginnings to modern Homo sapiens. We would then be better able to place the early homonids into this framework, and use the variation among early racial divisions as a background to studies of modern, racially mixed, populations. Every piece of evidence is crucial to the understanding of man's early evolution, which adds to the understanding of ourselves.

Uses

Forensic anthropology can benefit from this research. When dealing with the incomplete remains of an individual, every indicator of the individual's identity is

critical. The ability to accurately calculate an individual's stature from the foot length may provide the key to identifying that individual. Since specific ratios are applied to specific populations, an estimation of stature can be used as an indicator of race or sex. The recognition of characteristics common to a particular population are valuable as corroborating evidence for an investigator's conclusions.

An example of a current application for this research is found in the military. The dermatological footprints of pilots in the United States Air Force are recorded and kept on file. In the event of an accident, the records of their footprints may be the only means of identification. For this reason, the pilot's boots are made to withstand the impact and fire of a plane crash (Allison, 1973). If the feet are still intact, but the prints have been burned beyond recognition, application of the regression formulae would provide information on the victim's stature. This method would be especially helpful in the identification of mass disaster victims (Allison, 1973; Stewart, 1979; Rogers, 1987). With a multitude of people to identify, any identifying characteristic can provide the critical piece of information for the proper identification of a victim.

The foot length/stature ratio could assist investigators in some criminal cases. The regression formulae would predict the suspect's stature in a criminal case, but only if a footprint was available for analysis (Robbins, 1985). This method would be helpful for shoe prints, with modifications to adjust for shoe size. In either case, this estimation could be used to corroborate an eyewitness' testimony, or to eliminate suspects.

Finally, the foot length/stature ratio can have several practical applications in commercial fields, such as manufacturing and retailing. For example, clothing manufacturers could apply this ratio in the production of military or retail shoe sizes. If manufacturers have a target population group, the mean stature of individuals in that group would be useful in predicting the range and distribution of shoe sizes to be produced. Similarly, retail clothing stores could use the ratio to estimate the number, and size, of shoes needed for reorder, based on the demographic characteristics of their clientele.

BIBLIOGRAPHY

Allegro JM (1982) All Manner of Men. Springfield, IL: Charles C. Thomas Publisher.

Allen JA (1877) "The Influence of Physical Conditions in the Genesis of Species," Radical Review 1:108-140.

Allison HC (1973) Personal Identification. Boston, MA: Holbrook Press.

Anderson M, Blais M, and Green WT (1956) "Growth of the Normal Foot During Childhood and Adolescence," American Journal of Physical Anthropology 14:2:287-308.

Baker PT, and Weiner JS (1966) The Biology of Human Adaptability. Oxford, UK: Clarendon Press.

Carr RV, Rempel RD, and Ross WD (1989) "Sitting Height: An Analysis of Five Measurement Techniques," American Journal of Physical Anthropology 79:339-344.

Carter IG (1932) "Physical Measurements of 'Old American' College Women," American Journal of Physical Anthropology 16:4:497-514.

Coon CS (1982) Racial Adaptations. Chicago, IL: Nelson-Hall Inc.

Coon CS, Garn SM, and Birdsell JB (1950) Races...A Study of the Problems of Race Formation in Man. Springfield, IL: Charles C. Thomas Publisher.

Cureton TK (1951) Physical Fitness of Champion Athletes. Urbana, IL: The University of Illinois Press.

Damon A (1975) Physiological Anthropology. New York: Oxford University Press.

Davenport CB (1932) "The Growth of the Human Foot," American Journal of Physical Anthropology 17:2: 167-211.

Davenport CB, and Steggerda M (1929) "Race Crossing in Jamaica," Carnegie Institution of Washington, Pub. 395.

Hamill PVV, Johnson FE, and Lemeshow S (1973) "Body Weight, Stature, and Sitting Height: White and Negro Youths 12-17 Years, United States." Vital and Health Statistics, Series 11, No. 126 (DHEW Publication No. (HRA) 74-1608).

Harris JA, Jackson CM, Paterson DG, and Scammon RE (1930) The Measurement of Man. Minneapolis, MN: The University of Minnesota Press.

Hay RL, and Leakey MD (1982) "The Fossil Footprints of Laetoli," Scientific American 246:2:50-57.

Hertzberg HTE, Daniels GS, and Churchill E (1954) Anthropometry of Flying Personnel - 1950. Wright-Patterson Air Force Base, OH: Wright Air Force Development Center. (AF Publication No. (WADC) 52-321).

Hill LM (1958) "Changes in the Proportions of the Female Foot During Growth," American Jouranl of Physical Anthropology 16:3:349-366.

Hitchcock E, Seelye HH, and Phillips PC (1900) An Anthropometric Manual Giving Physical Measurements and Tests of Amherst College Students. Amherst, MA: Press of Carpenter and Morehouse.

Hrdlička A (1920) Anthropometry. Philadelphia, PA: The Wistar Institute of Anatomy and Biology.

Hrdlička A (1928) "The Full-Blood American Negro," American Journal of Physical Anthropology 12:1:15-35.

Krogman WM (1970) "Growth of the Head, Face, Trunk, and Limbs in Philadelphia White and Negro Children of Elementary and High School Age," Monographs of the Society for Research in Child Development, Serial No. 136, 35:3:1-77.

Lewin P (1954) The Foot and Ankle. Philadelphia, PA: Lea and Febiger. 4th Edition.

MacDonell WR (1901) "On Criminal Anthropometry and the Identification of Criminals," Biometrika 1:177-227.

Malina RM, Brown KH, and Zavelta AN (1987) "Relative Lower Extremity Length in Mexican American and in American Black and White Youths," American Journal of Physical Anthropology 72:89-94.

Martin R, and Saller K (1957) Lehrbuch der Anthropologie. Stuttgart: Gustav Fischer. 3rd Edition.

Montagu MFA (1960) An Introduction to Physical Anthropology. Springfield, IL: Charles C. Thomas Publisher. 3rd Edition.

Montagu MFA (1964) The Concept of Race. London, UK: Collier-MacMillan Limited.

National Aeronautics and Space Administration (1978) Anthropometric Source Book. Scientific and Technical Information Office, Washington, D.C.: Webb Associates. (NASA Publication No. 1024).

Najjar MF, and Rowland M (1987) Anthropometric Reference Data and Prevalence of Overweight Persons in the United States, 1976-80. Hyattsville, MD: U. S. Department of Health and Human Services. (DHHS Publication No. (PHS) 87-1688).

Oliver G (1976) "The Stature of Australopithecines," Journal of Human Evolution 5:529-534.

Ott L (1988) An Introduction to Statistical Methods and Data Analysis. Boston, MA: PWS-Kent Publishing.

Pales L (1976) Les Emprientes de Pieds Humains dans les Cavernes. Memoir 36. Masson: Archives de L'Institut de Paleoontologie Humaine.

Riesenfeld A (1973) "The Effects of Extreme Temperature and Starvation on the Body Proportions of Rats," American Journal of Physical Anthropology 39:426-460.

Robbins LM (1978) "Individuality of Human Footprints," Journal of Forensic Science 23:3:778-785.

Robbins LM (1985) Footprints: Collection, Analysis, and Interpretation. Springfield, IL: Charles C. Thomas Publisher.

Robbins LM (1986) "Estimating Height and Weight from Size of Footprints," Journal of Forensic Science 31:1:143-152.

Rogers SL (1987) Personal Identification from Human Remains. Springfield, IL: Charles C. Thomas Publisher.

Siegel ML, Doyle WT, and Kelley C (1923) "Heat Stress, Fluctuating Assymetry and Prenatal Selection in the Lab Rat," American Journal of Physical Anthropology 6:121-126.

Steggerda M, Crane J, and Steele MD (1929) "One Hundred Measurements and Observations on One Hundred Smith College Students," American Journal of Physical Anthropology 13:2:189-254.

Steggerda M (1932) "Physical Measurements on Dutch Men and Women," American Journal of Physical Anthropology 16:3:309-337.

Steggerda M (1940) "Physical Measurements of Negro, Navaho and White Girls of College Age," American Journal of Physical Anthropology 49:15-22.

Steggerda M, and Petty CE (1940) "An Anthropometric Study of Negro and White College Women," The Research Quarterly 11:3:110-118.

Steegman AT, and Planter WS (1968) "Experimental Cold Modification of Craniofacial Morphology," American Journal of Physical Anthropology 28:17-30.

Stewart TD (1979) The Essentials of Physical Anthropology. Springfield, IL: Charles C. Thomas Publisher.

Strauss WL (1926) "The Development of the Human Foot and its Phylogenetic Significance," American Journal of Physical Anthropology 9:4:427-438.

Todd TW, and Lindala A (1928) "Dimensions of the Body: Whites and American Negroes of Both Sexes," American Journal of Physical Anthropology 12:1:35-113.

Topinard P (1895) L'Anthropologie. Paris: C. Reinwald & Cie, Libraires-Editeurs.

Trotter ML, and Gleser GC (1951) "Trends in the Stature of American Whites and Negroes Born Between 1840 and 1924," American Journal of Physical Anthropology 9: 427-440.

Tuttle RH (1986) "Review: L.M. Robbins' Footprints: Collection, Analysis, and Interpretation," American Anthropologist 88:4:1000-1002.

Young JW (1983) Anthropometric and Mass Distribution Characteristics of the Adult Female. Springfield, VA: National Technical Information Service.

APPENDIX A

SCATTERGRAMS

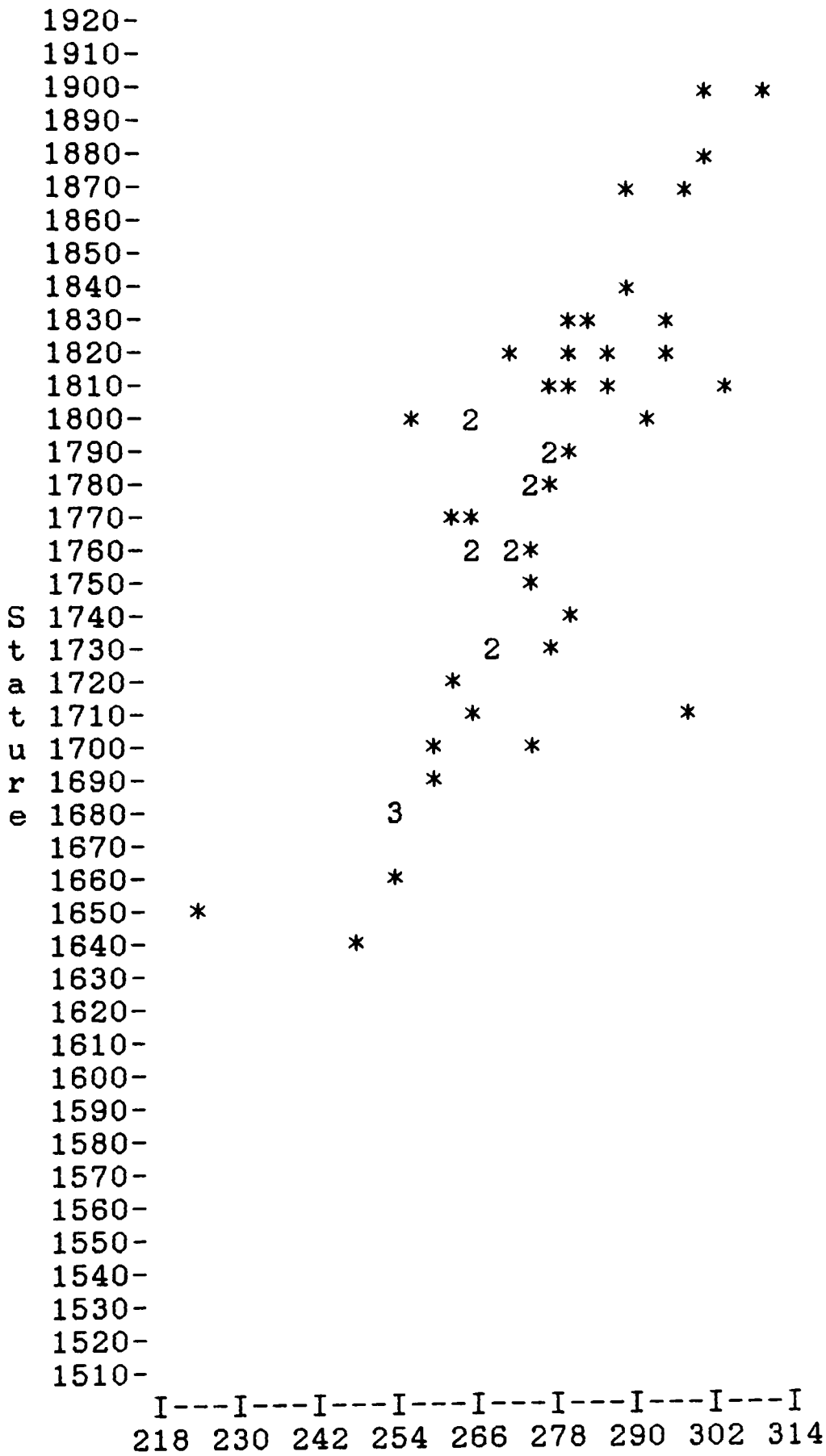

Figure A-1. African American male right foot (51).

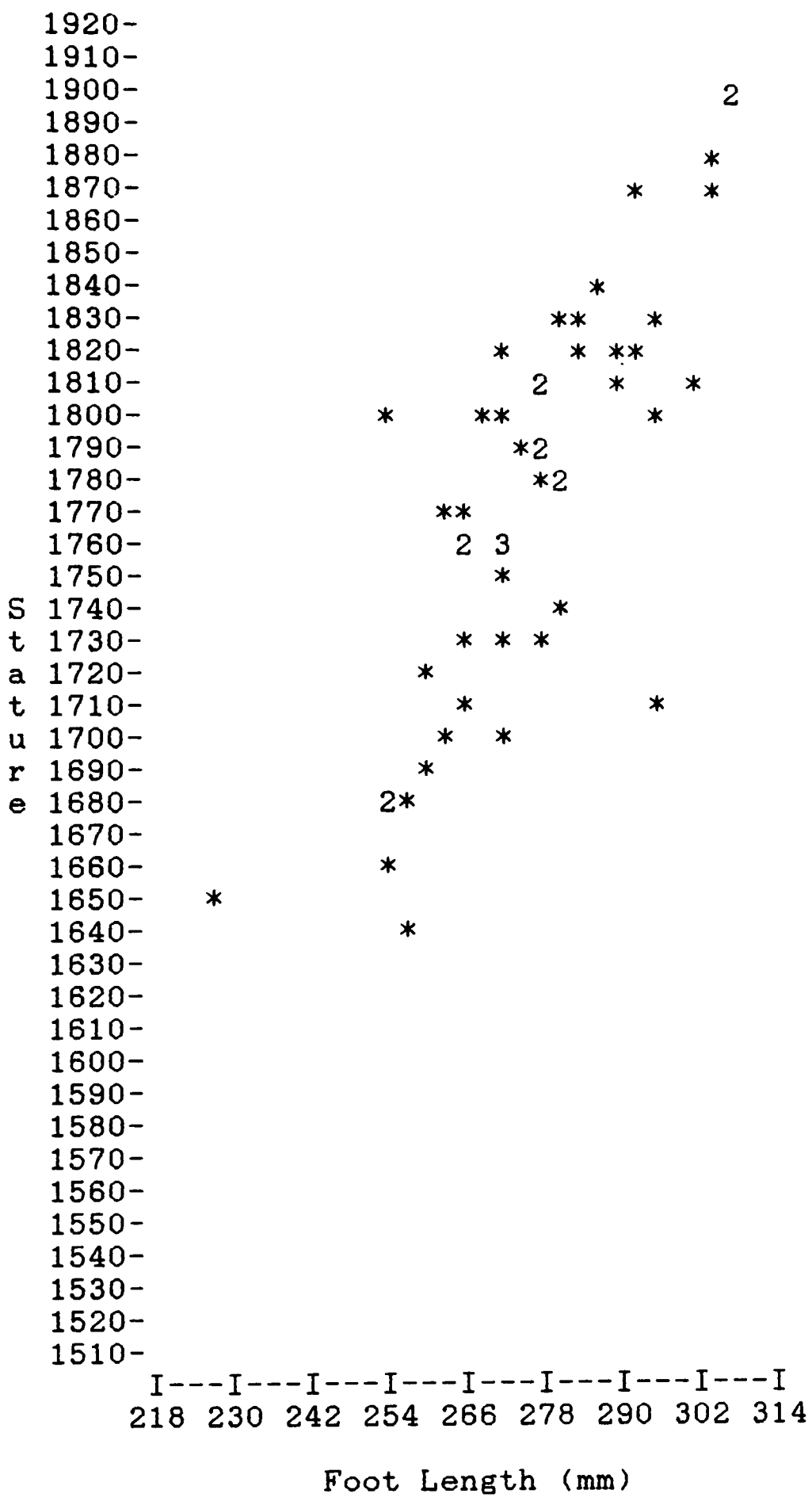

Figure A-2. African American male left foot (51).

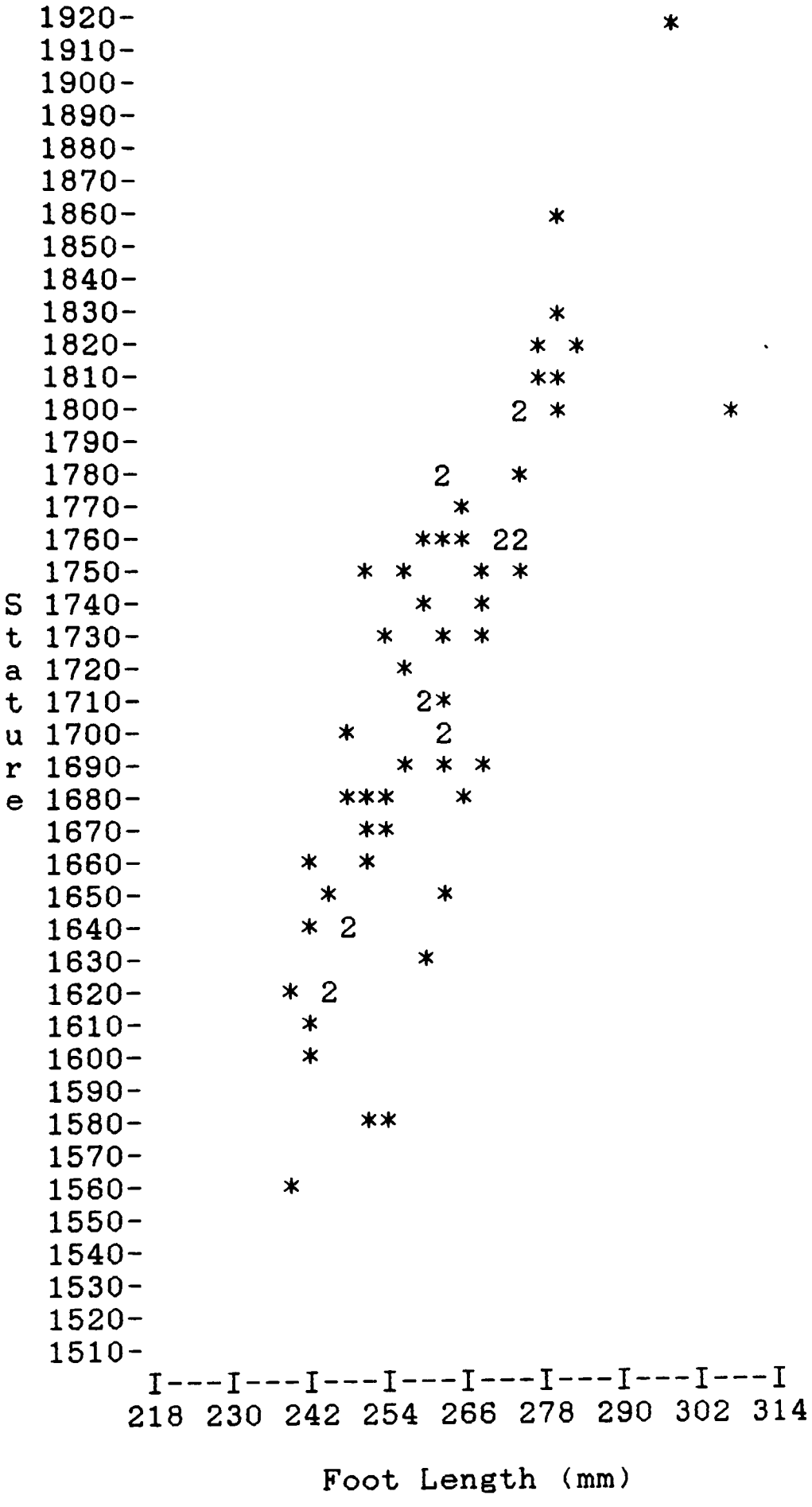

Figure A-3. Caucasian American male right foot (63).

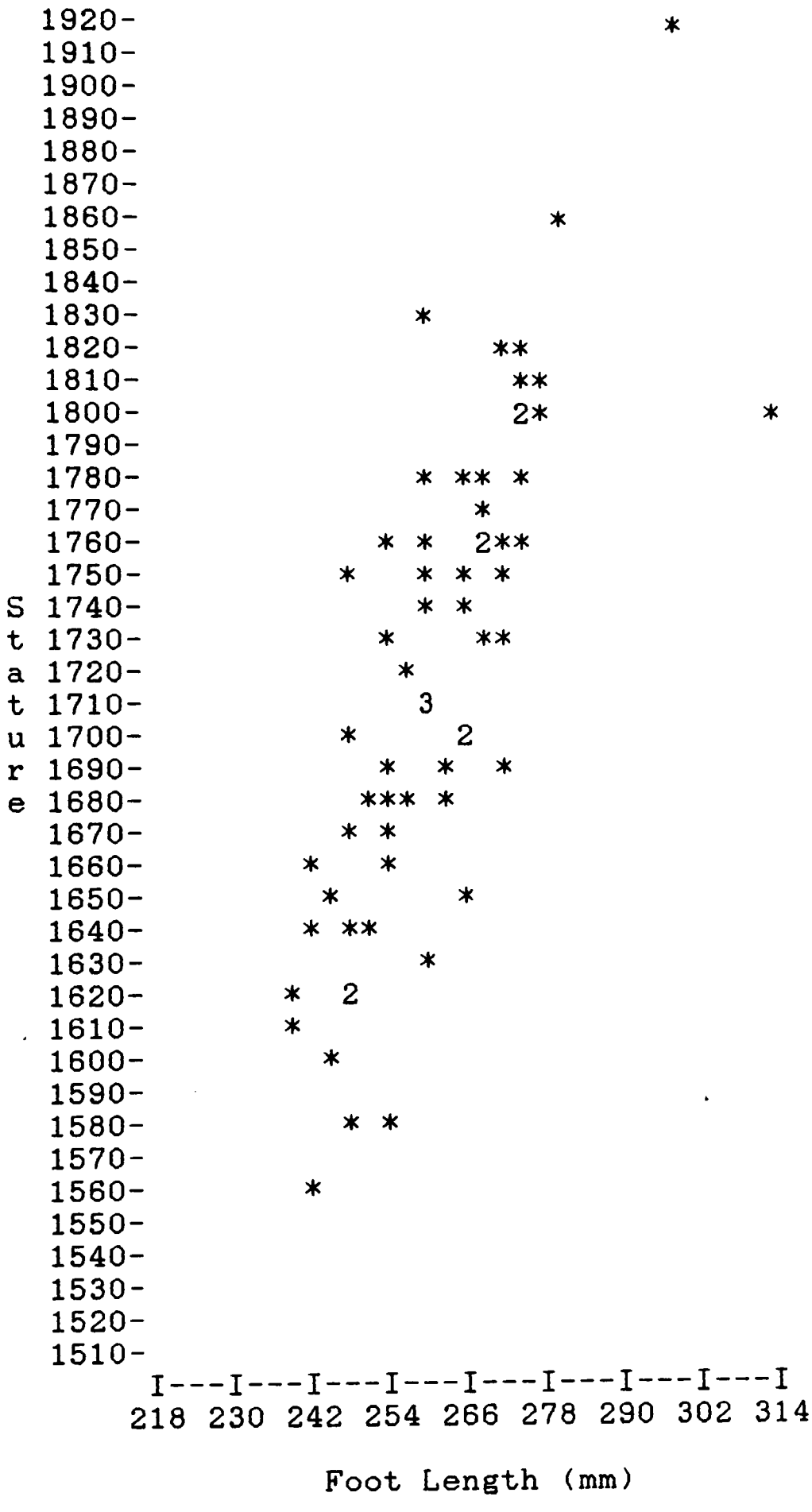

Figure A-4. Caucasian American male left foot (63).

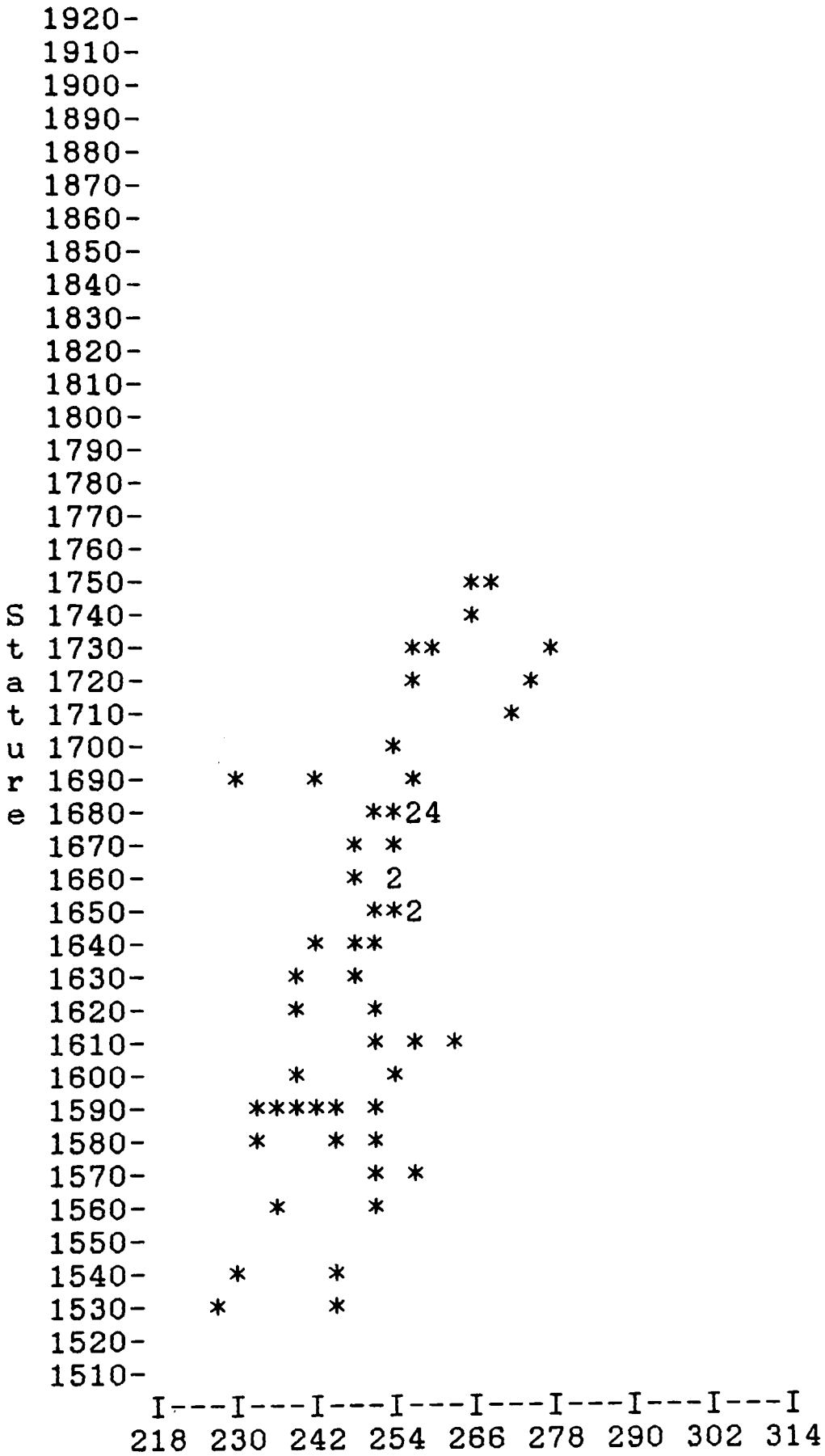

Figure A-5. African American female right foot (59).

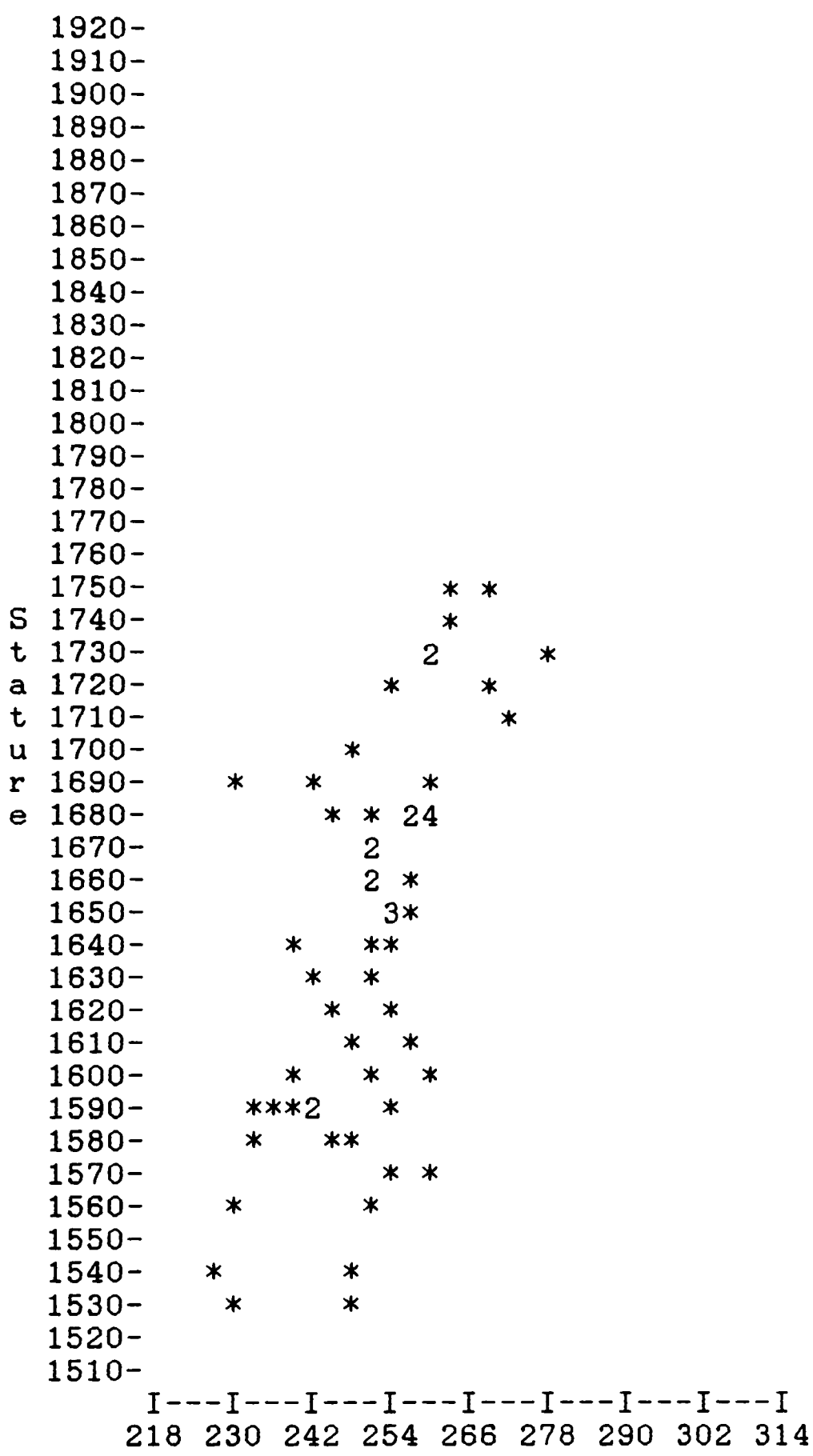

Figure A-6. African American female left foot (59).

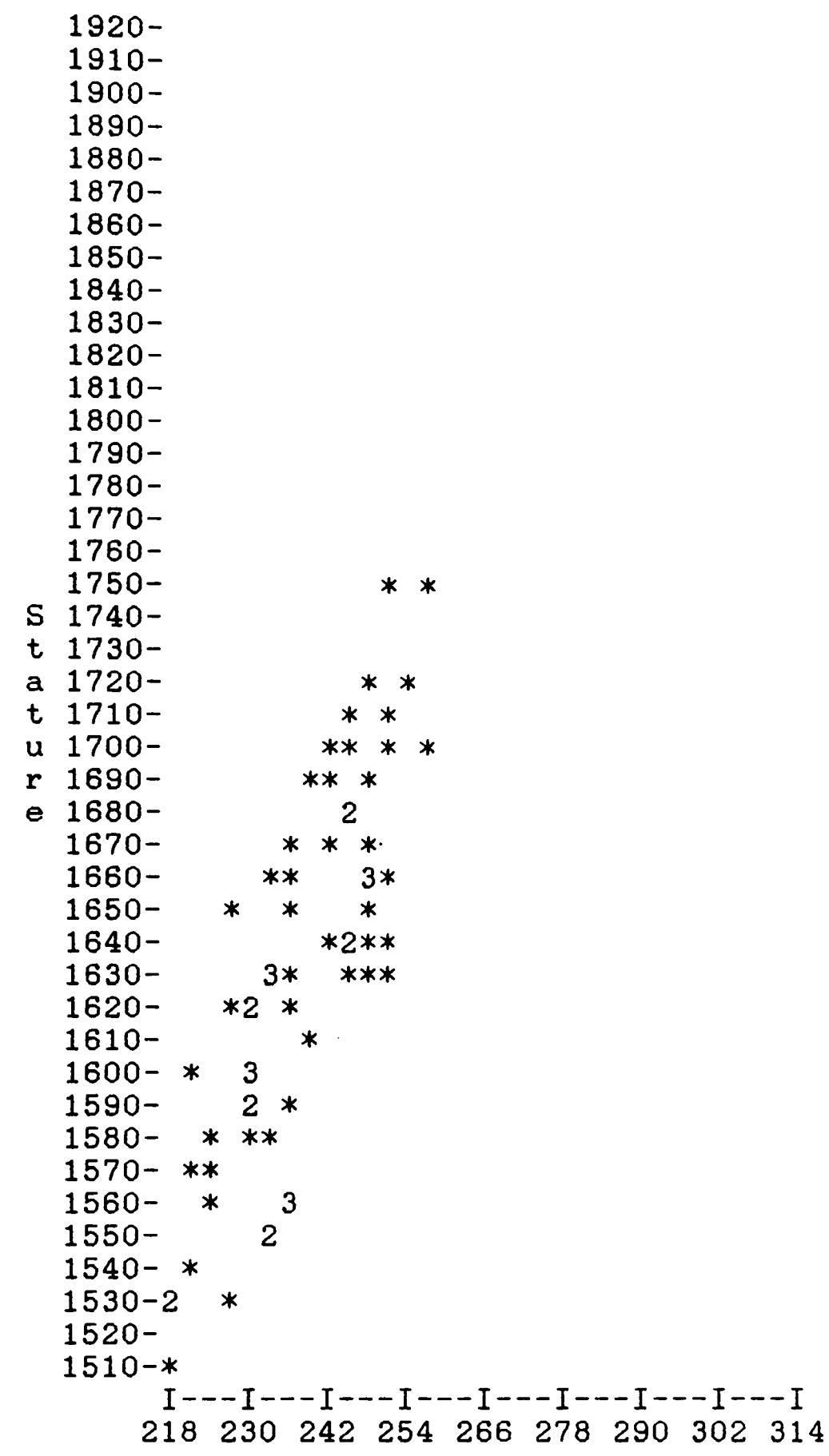

Figure A-7. Caucasian American female right foot (67).

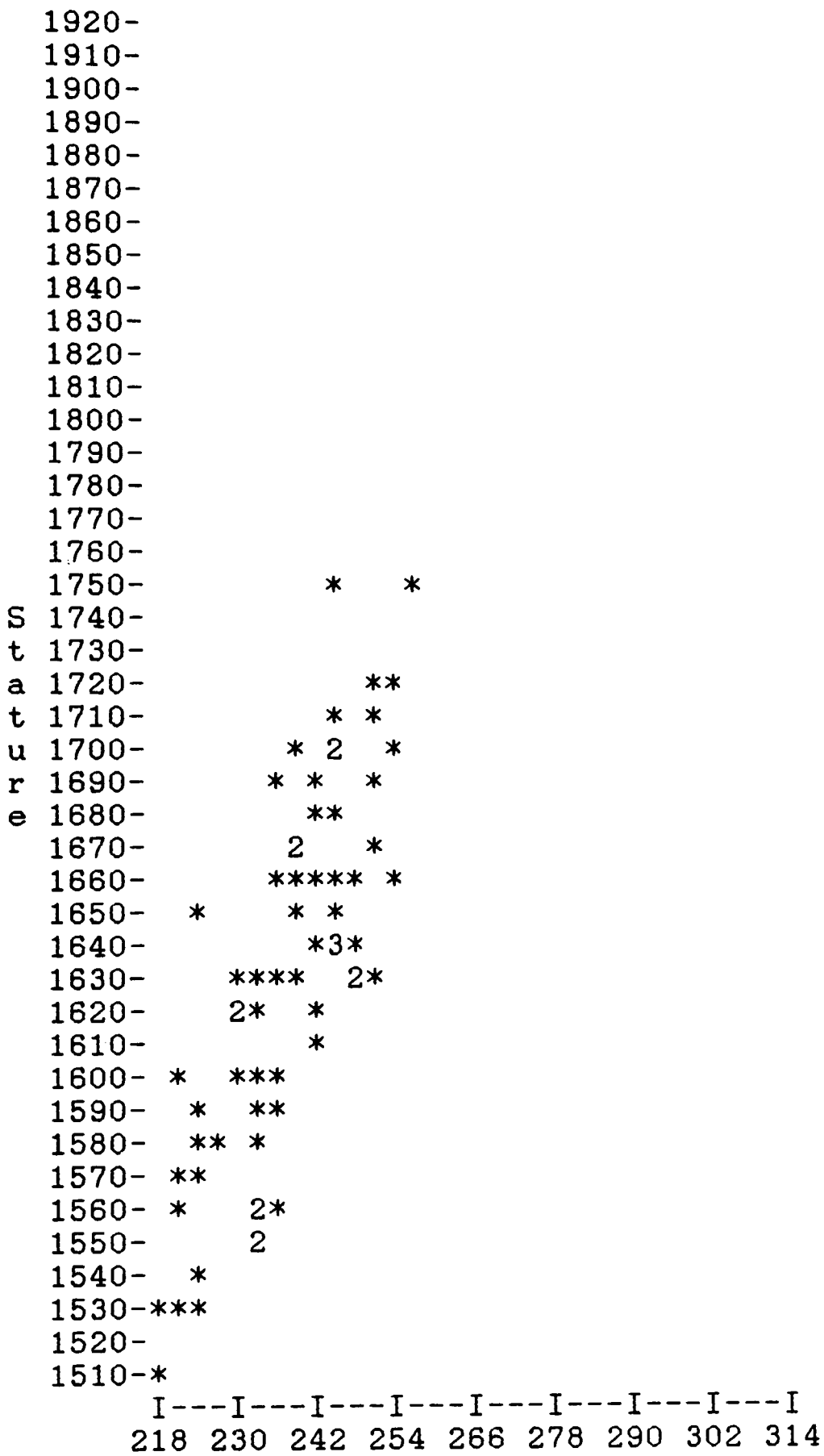

Figure A-8. Caucasian American female left foot (67).

APPENDIX B

DATA TABLES

TABLE B-2

63 Caucasian American Males (mm)

Stat.	Sit.	R	L	Stat.	Sit.	R	L
1814	952	282	278	1759	883	273	271
1749	918	270	265	1648	831	263	265
1758	928	264	255	1633	829	259	261
1820	937	283	275	1583	795	251	249
1830	937	281	260	1615	821	245	249
1920	1030	300	300	1784	895	276	275
1755	922	259	259	1689	857	263	262
1737	948	268	267	1576	802	253	255
1725	886	255	253	1734	869	269	271
1677	872	254	258	1803	910	309	313
1686	886	258	255	1710	872	260	259
1819	952	279	273	1715	873	257	258
1745	917	275	272	1673	852	255	253
1687	898	270	271	1783	885	264	266
1743	880	260	259	1564	797	239	241
1855	992	281	280	1683	855	249	254
1773	879	267	270	1664	845	251	253
1697	837	249	247	1712	874	259	264
1753	863	258	260	1674	851	252	249
1764	864	272	268	1651	838	245	244
1656	872	241	242	1639	825	242	241
1758	891	275	270	1683	837	251	252
1813	918	278	275	1711	851	263	261
1803	834	274	274	1705	861	264	266
1755	868	265	268	1596	805	243	245
1682	839	265	264	1763	892	274	276
1748	867	250	249	1643	841	249	252
1699	842	264	267	1621	820	245	247
1775	850	262	260	1609	815	241	240
1801	875	275	274	1624	817	239	238
1734	862	264	269	1643	835	247	249
1799	910	281	277				

Stat. = Stature, Sit. = Sitting Height,
R = Right Foot Length, L = Left Foot Length

TABLE B-1

51 African American Males (mm)

Stat.	Sit.	R	L	Stat.	Sit.	R	L
1819	906	280	284	1779	870	276	280
1835	907	291	287	1768	861	264	262
1796	901	267	270	1663	830	253	255
1826	910	296	297	1679	890	254	254
1775	879	275	278	1683	837	255	257
1767	856	267	266	1690	842	261	259
1654	822	224	226	1703	849	275	273
1899	935	310	308	1638	875	281	277
1867	949	299	305	1711	854	301	297
1902	940	303	307	1725	861	277	279
1789	895	280	277	1736	864	281	282
1831	903	283	284	1785	879	277	276
1821	892	287	290	1790	883	279	278
1806	897	279	277	1763	875	272	274
1756	869	265	265	1734	862	271	273
1797	901	267	270	1716	851	263	259
1831	907	280	281	1781	888	279	280
1805	893	287	291	1810	901	305	303
1875	927	302	305	1802	895	294	297
1711	863	270	267	1683	840	253	255
1812	903	281	279	1695	849	260	264
1867	924	289	293	1751	871	274	272
1815	947	295	292	1763	879	265	267
1821	892	271	273	1762	862	274	273
1803	903	257	255	1734	865	269	267
1757	873	271	273				

Stat. = Stature, Sit. = Sitting Height,
R = Right Foot Length, L = Left Foot Length

TABLE B-3

59 African American Females (mm)

Stat.	Sit.	R	L	Stat.	Sit.	R	L
1748	863	268	270	1686	842	242	241
1675	823	257	256	1692	840	231	230
1634	812	249	251	1631	830	240	242
1683	840	259	260	1746	860	265	264
1594	779	240	240	1584	801	232	232
1717	857	257	255	1622	804	240	244
1532	767	227	229	1689	833	257	260
1663	822	253	251	1593	790	234	233
1654	814	255	257	1646	819	252	255
1679	830	259	258	1683	839	252	251
1539	791	230	228	1741	859	265	263
1712	831	271	272	1725	860	257	259
1734	852	279	277	1673	842	249	251
1669	827	254	252	1703	841	253	250
1658	819	255	256	1585	791	251	255
1661	820	247	251	1543	803	247	249
1719	849	275	270	1645	829	258	254
1681	837	261	259	1573	785	258	260
1635	805	241	240	1563	780	251	250
1590	803	235	237	1605	803	263	261
1643	815	249	250	1601	793	254	251
1563	782	235	231	1582	777	250	249
1678	824	259	260	1593	802	241	243
1675	837	256	258	1531	765	245	247
1598	787	238	240	1617	820	251	254
1573	782	251	253	1653	821	256	255
1611	803	257	258	1642	823	251	253
1732	857	259	261	1584	804	244	246
1593	801	245	241	1682	849	253	244
1612	810	251	250				

Stat. = Stature, Sit. = Sitting Height,
R = Right Foot Length, L = Left Foot Length

TABLE B-4

67 Caucasian American Females (mm)

Stat.	Sit.	R	L	Stat.	Sit.	R	L
1663	881	235	238	1593	804	229	233
1662	899	247	248	1582	797	234	232
1581	830	230	227	1613	831	239	241
1604	866	221	220	1537	792	221	224
1621	821	228	233	1631	831	232	230
1533	787	218	220	1622	827	237	241
1512	765	219	215	1676	878	244	242
1597	819	231	236	1662	861	233	237
1643	872	244	246	1594	811	235	237
1656	873	251	253	1701	893	243	245
1687	852	242	238	1684	860	245	244
1525	811	216	219	1674	889	241	238
1709	843	251	245	1692	859	239	236
1560	790	235	232	1648	841	237	238
1597	843	229	233	1656	831	249	245
1629	840	251	249	1640	829	251	248
1669	829	249	250	1583	795	225	227
1653	886	226	224	1572	789	224	223
1554	809	233	233	1602	813	229	231
1563	783	235	234	1634	827	234	235
1526	805	226	225	1592	852	230	223
1701	804	258	254	1633	859	248	250
1554	768	234	232	1753	905	250	244
1717	836	248	250	1625	892	236	240
1656	793	248	243	1641	879	248	245
1697	842	244	238	1630	871	246	248
1712	842	246	250	1643	878	245	242
1621	829	229	230	1569	834	222	220
1669	812	237	240	1646	859	248	245
1631	842	233	233	1562	826	235	236
1693	889	249	252	1745	911	258	258
1699	897	250	246	1559	821	223	220
1621	829	229	230	1639	835	242	244
1715	851	254	255				

Stat. = Stature, Sit. = Sitting Height,
R = Right Foot Length, L = Left Foot Length

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Date	Date