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WEIGHT, VOLUME, AND CENTER OF MASS OF SEGMENTS OF THE HUMAN BODY

Charles E. Clauser, et al

Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

August 1969

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WEIGHT, VOLUME, AND CENTER OF MASS OF SEGMENTS OF THE HUMAN BODY

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AUGUST 1969

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13. ABSTRACT

This study was designed to supplement existing knowledge of the weight, volume, and center of mass of segments of the human body and to permit their more accurate estimation on the living from anthropometric dimensions. Weight, volume, and center of mass of 14 segments of the body were determined on 13 male cadavers. Presented are descriptive statistics of these variables as well as a series of regression equations predicting these parameters from anthropometry. Included in the seven supporting appendices are reports of studies of the mid-volume of segments as an approximation of their center of mass, relationships between standing and supine anthropometry, postmortem changes in gross body size, and comparisons between densities of fresh and preserved human tissues.

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AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Summary

Knowledge of the weight, volume, and center of mass of segments of the human body is of significance to research in such diverse fields as physical education, prosthetics, and space technology. While the specific information needed may vary from one specialty to another, common to all is the objective of understanding more fully the biomechanics of man either as an entity or as a component of some complex system.

The engineer or physicist may test a structure or material until it fails to determine designs and conditions appropriate to the physical characteristics of materials. The introduction of man as an integral part of a system, either in a passive or active role, restricts the freedom to test it because of possible injury to the human component. To overcome this restriction, it is common to replace the man with a physical model or, more recently, to use computer simulation. The degree to which a physical or mathematical model can be formulated as an isomorph of the human body thus becomes a crucial factor.

This study was designed to supplement existing knowledge of the weight, volume, and location of the center of mass of segments of the human body and to permit their more accurate estimation on the living from anthropometric dimensions.

Thirteen male cadavers were each dissected into 14 segments. The weight, volume, and center of mass of each segment were determined, and sufficient anthropometry of the cadavers was taken to describe the length, circumference, and breadth or depth of each segment. The relationships between the size of the segments and its weight, volume, and the location of its center of mass form the basis for estimating these parameters of living populations.

Foreword

This study was accomplished under Project 7184, "Human Performance in Advanced Systems"; Task 718408, "Anthropology for Design." It was a joint effort among the Anthropology Branch, Human Engineering Division, Aerospace Medical Research Laboratory (AMRL); the Anthropology Research Project, Antioch College, under contracts AF 33(615)-1101 and F33615-67-C-1310; and the Anthropology Section, Civil Aeromedical Institute (CAMI), Federal Aviation Administration. Significant financial support was provided by the National Aeronautics and Space Administration under contract R-90.

The research reported here could not have been carried out without the complete cooperation of the administrative directors of the several organizations involved. Dr. J. M. Christensen, Director of the Human Engineering Division, H. T. E. Hertzberg, then Chief of the Anthropology Branch, AMRL; Dr. Stanley Mohler, then Director of Research, CAMI; and Professor Edmund Churchill, Director of the Anthropology Research Project, were enthusiastic supporters of the joint undertaking and made every attempt to assure its smooth functioning. The actual data collection was carried out at the CAMI laboratories in Oklahoma City where Mr. John Swearingen, Chief of Protection and Survival Branch, and Dr. R. G. Snyder, then Chief of the Anthropology Section, went to great lengths to assure that proper support in terms of equipment, workspace and personnel was always available.

The efforts and responsibilities were shared equally among the authors, and the study was indeed a joint effort. The names of the many individuals who supported this study at the various laboratories in [illegible] fabrication of equipment and in support activities (administrative, secretarial, photographic, etc.) are too numerous to list individually, yet they often played a significant role in the development of the study. A special acknowledgment is made to Mr. DeWitt Pierce (CAMI) who provided technical advice and assistance in the use of the fluoroscope and X-ray equipment and to Mr. William [illegible]an Flores (CAMI) who prepared the illustrations used in this report. Miss Patricia M[illegible]sh, also of CAMI, acted as a laboratory assistant during the initial data collection phase of the study.

Professor Churchill prepared a number of computer routines and provided extensive guidance and advice in the analysis of the data. Miss Margaret Marshall worked as a laboratory assistant during the data collection phase and as a statistical assistant during the analysis. Her patience and attention to the many details involved in the data processing are gratefully acknowledged.

Most of this study, from the initial plan of research through the interpretation of the data and the preparation of the report, has been discussed in detail with our friends and associates. We particularly wish to acknowledge our gratitude to the late Dr. W. T. Dempster for his detailed explanation of the techniques and procedures he used in his earlier study of a similar nature. Our associates Captain William Bennett and Professor Lloyd L. Laubach each assisted during the data collection on a specimen, and we are grateful for their support.

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This report has been reviewed and is approved by:

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Historical Background

METHODOLOGY AND RESULTS OF PREVIOUS INVESTIGATORS

Active interest in the weight, volume, and center of mass of the human body and its segments has been demonstrated by numerous investigators over the past 200 years. These investigators have developed and used a wide variety of techniques in their studies with varying degrees of success. The following resume of earlier research is certainly neither all-inclusive nor complete; it does, however, provide a background for the present investigation.

The earliest recorded work appears to have been undertaken in the 17th century. Borelli (1679) determined the center of mass of nude men by having them stretch out on a rigid platform supported on a knife edge. By moving the platform until it balanced, an approximation of the subject's center of mass could be obtained.

The Weber brothers (1836) improved this technique. Their platform was supported at its center of mass and the body alone moved until the platform began to tilt. The body was then reversed on the platform and the procedure repeated to obtain a second approximation of the center of mass. The mean position between these points gave a more exact location for the center of mass. This technique would appear more accurate than that used by Borelli, as it was independent of the supporting platform and not dependent upon an exact point of balance.

Harless (1860) repeated the Webers' experiments and extended them to studies of the centers of mass of body segments. In his initial studies, the bodies of two executed criminals were used. Harless's plan was to locate in the long axis the centers of mass for the largest possible number of movable segments. To achieve this, he segmented the cadavers into 18 major segments with the planes of separation passing through the pivotal axis of each of the primary joints. The tissue was severed in a plane that bisected the primary centers of joint rotation and the joints then disarticulated. The segment surfaces were sutured together over the stump to reduce tissue and fluid losses. Sensitive scales and a balance plate were used to determine the weight and center of mass of each segment. The volume of each segment was calculated from its mass, using a postulated total body specific gravity of 1.066. Harless's results (as well as the results obtained by later workers) are shown in tables 1 and 2.

To verify and extend his observations, Harless weighed 44 extremity segments taken from seven corpses. The segments were disarticulated using the same techniques employed for the two whole cadavers. The segment volumes were determined after the principles of Archimedes, by weighing them first in air and then in water. The results of this study are given in table 3. From these data, Harless concluded that age and sex were significant factors in explaining the distribution of values of the specific gravity of segments of the human body.

Von Meyer, beginning in 1863, continued this work and determined the center of mass location along the other two axes of the body as well. An orthogonal axis system is of convenience in locating a point in a three dimensional space. For the human body the convention is to refer to the Z axis as formed at the intersection of the sagittal and coronal planes; the Y axis at the intersection of the coronal and transverse planes; and the X axis at the intersection of the sagittal and transverse planes. By reducing the total body to a series of mathematically descriptive forms (ellipsoids and spheres), Von Meyer was able to estimate the weight and center of mass for each of the major segments of the body. Using these estimates, the shift in the total body's center of

TABLE 1. WEIGHT OF BODY SEGMENTS*

Authors	Harless		Braune and Fischer			Fischer	Dempster							
Cadavar	Graf	Kefer	No. 2	No. 3	No. 4	1906	14815	15059	15062	15095	15097	15168	15250	15251
Entire Body	63970	47087	75100	60750	55700	44057	51364	58409	58403	49886	72500	71364	60455	55909
Head	4555	3747	5350	4040	3930	3880	....	3797	5227	4348	5337	4850	4371	4340
Torso	29608	19847	36020	28850	23780	19910	....	29158	29331	24952	35231	33519	27187	26001
Entire Arm, Right	3770†	2699	4950	3550	3520	2360	2641	3277	2695	2125	3947	3673	3035	2394
Entire Arm, Left	....	2555	4790	3480	3710	2470	2720	2770	2485	2132	3899	3453	3080	2459
Upper Arm, Right	2070†	1485	2580	1990	1730	1243	1212	1920	1528	1123	2171	1970	1614	1372
Upper Arm, Left	....	1411	2560	1880	2020	1252	1157	1541	1373	1133	2199	1909	1663	1315
Forearm + Hand, Rt.	(1700)†	(1214)	2370	1550	1790	1117	1342	1340	1134	1024	1777	1699	1414	1017
Forearm + Hand, Lt.	....	(1144)	2230	1600	1690	1205	1290	1256	1080	1003	1691	1515	1400	1140
Forearm, Right	1160†	821	1700	1050	1300	....	865	995	815	710	1250	1265	1021	713
Forearm, Left	....	770	1600	1120	1240	....	850	934	747	703	1191	1104	1002	780
Hand, Right	540†	393	670	500	490	....	457	352	311	317	517	452	400	295
Hand, Left	....	374	620	470	450	....	445	325	332	317	500	417	390	339
Entire Leg, Right	11135†	9172	12120	10650	10110	7840	6176	9580	8303	7715	11920	11904	11791	8457
Entire Leg, Left	....	9068	11390	10250	10650	7640	6255	9855	8390	8313	11907	11111	11337	8092
Thigh, Right	7165†	5947	7650	6690	6150	4860	3385	6115	5370	4770	7155	6902	7215	4660
Thigh, Left	....	5827	7300	6220	6750	4810	3495	6482	5520	5285	7093	6258	7700	5135
Calf + Foot, Right	(3970)†	(3225)	4470	3950	3930	2980	2613	3472	2907	2878	4825	4765	3955	3322
Calf + Foot, Left	....	(3241)	4500	3980	3900	2800	2602	3384	2835	3041	4846	4812	4045	3432
Calf, Right	2800†	2243	3210	2870	2970	2070	1963	2674	2165	2205	3899	3606	2954	2459
Calf, Left	....	2252	3320	2880	2900	1890	1961	2629	2080	2218	3860	3552	2991	2564
Foot, Right	1170†	982	1100	1060	990	910	655	800	746	767	924	1095	865	808
Foot, Left	....	988	1160	1090	1000	910	725	760	754	814	967	1209	949	796

*All values recorded in grams.
†Average of right plus left.
( ) Indicates calculated value from sum of parts.

TABLE 2. WEIGHT OF BODY SEGMENTS EXPRESSED AS A PERCENT OF TOTAL BODY WEIGHT

Authors	Harless		Braune and Fischer			Fischer	Dempster							
Cadaver	Graf	Kefer	No. 2	No.3	No. 4	1906	14815	15059	15062	15095	15097	15168	15250	15251
Head	7.1	8.0	7.1	6.7	7.1	8.8	......	6.5	8.9	8.7	7.1	6.8	7.2	7.8
Torso	48.3	42.1	48.0	47.5	42.7	45.2	......	49.9	50.2	50.0	48.9	47.0	45.0	46.5
Entire Arm, Right	5.9*	5.7	6.8	5.8	6.3	5.4	5.1	5.6	4.6	4.3	5.4	5.1	5.0	4.3
Entire Arm, Left	......	5.4	6.4	5.7	6.1	5.6	5.3	4.7	4.3	4.3	5.4	4.8	5.1	4.4
Upper Arm, Right	3.2*	3.2	3.4	3.3	3.1	2.8	2.4	3.3	2.6	2.3	3.0	2.8	2.7	2.5
Upper Arm, left	......	3.0	3.4	3.1	3.6	2.8	2.5	2.6	2.4	2.3	3.0	2.7	2.8	2.4
Forearm + Hand, Rt.	2.7*†	2.5†	3.2	2.6	3.2	2.5	2.6	2.3	1.9	2.1	2.5	2.4	2.3	1.8
Forearm + Hand, Lt.	......	2.4†	3.0	2.6	3.0	2.7	2.5	2.2	1.8	2.0	2.3	2.1	2.3	2.0
Forearm, Right	1.8*	1.7	2.3	1.7	2.3	......	1.7	1.7	1.4	1.4	1.7	1.8	1.7	1.3
Forearm, Left	......	1.6	2.1	1.8	2.2	......	1.7	1.6	1.3	1.4	1.6	1.5	1.7	1.4
Hand, Right	0.8*	0.8	0.9	0.8	0.9	......	0.9	0.6	0.5	0.6	0.7	0.6	0.7	0.5
Hand, Left	......	0.8	0.8	0.8	0.8	......	0.9	0.6	0.6	0.6	0.7	0.6	0.6	0.6
Entire Leg, Right	17.4*†	19.5†	16.1	17.5	18.2	17.8	12.0	16.4	14.2	15.5	16.4	16.7	19.5	15.1
Entire Leg, Left	......	19.3†	15.8	16.9	19.1	17.3	12.1	16.9	14.4	16.7	16.4	15.6	18.8	15.0
Thigh, Right	11.2*	12.6	10.2	11.0	11.0	11.0	6.6	10.5	9.2	9.6	9.9	9.7	11.9	9.2
Thigh, Left	......	12.4	9.7	10.2	12.1	10.9	6.8	11.1	9.5	10.5	9.8	8.8	12.7	8.3
Calf + Foot, Right	8.2*†	6.9†	6.0	6.5	7.1	6.8	5.1	5.9	5.0	5.8	6.7	6.7	6.5	5.9
Calf + Foot, Left	......	6.9†	6.0	6.6	7.0	6.4	5.1	5.8	4.9	6.1	6.7	6.7	6.7	6.1
Calf, Right	4.4*	4.8	4.3	4.7	5.3	4.7	3.8	4.6	3.7	4.4	5.4	5.1	4.9	4.4
Calf, Left	......	4.8	4.4	4.7	5.2	4.3	3.8	4.5	3.6	4.4	5.3	5.0	4.9	4.6
Foot, Right	1.8*	2.1	1.5	1.7	1.8	2.1	1.3	1.4	1.3	1.5	1.3	1.5	1.4	1.4
Foot, Left	......	2.1	1.5	1.8	1.8	2.1	1.4	1.3	1.3	1.6	1.3	1.7	1.6	1.4

*Based on average of right plus left.
†Indicates calculated value from sum of parts.

TABLE 3

MASS, VOLUME AND SPECIFIC GRAVITY OF BODY SEGMENTS

(After Harless 1860)

Segment	*Sex*	*Age*	*Weight (gm)*	*Volume (cc)*	*Specific Gravity*
Head	M	30	3747.0	3453.3	1.0851
Head	F	38	4980.0	4407.0	1.1300
Right Upper Arm	F	20	1525.6	1436.2	1.0622
Right Upper Arm	M	40	2560.1	2362.2	1.0838
Right Upper Arm	M	68	1420.7	1302.9	1.0904
Left Upper Arm	M	30	1484.5	1365.4	1.0872
Left Upper Arm	M	30	1411.3	1296.6	1.0884
Left Upper Arm	M	68	1239.1	1133.0	1.0936
Right Forearm	F	20	725.6	671.6	1.0804
Right Forearm	M	40	1389.7	1260.0	1.1030
Right Forearm	M	30	821.0	402.2	1.1034
Right Forearm	M	68	767.2	689.9	1.1119
Left Forearm	M	68	765.3	688.3	1.1117
Left Forearm	M	30	770.1	692.1	1.1127
Right Hand	M	68	447.7	403.5	1.1093
Right Hand	M	40	525.1	471.6	1.1134
Right Hand	F	20	316.8	283.7	1.1163
Right Hand	M	30	393.2	354.3	1.1191
Left Hand	M	68	443.9	402.3	1.1034
Left Hand	M	30	374.0	334.5	1.1178
Right Thigh	F	26	4890.0	4643.0	1.0532
Right Thigh	M	30	5947.0	5637.5	1.0549
Right Thigh	M	40	7567.0	7099.1	1.0659
Right Thigh	M	68	4670.0	4295.8	1.0871
Left Thigh	F	26	4723.0	4492.1	1.0514
Left Thigh	M	30	5827.0	5515.9	1.0564
Left Thigh	M	40	7367.0	6951.4	1.0598
Left Thigh	M	68	4460.4	4102.8	1.0872
Right Calf	F	26	1947.9	1808.1	1.0773
Right Calf	M	40	2760.2	2541.8	1.0859
Right Calf	M	30	2242.6	2064.8	1.0861
Right Calf	M	68	1874.0	1663.5	1.1265
Left Calf	F	26	1863.1	1727.5	1.0785
Left Calf	M	30	2252.5	2073.8	1.0861
Left Calf	M	40	2806.9	2583.6	1.0861
Left Calf	M	68	1811.0	1603.3	1.1295
Right Foot	M	40	1038.8	961.7	1.0802
Right Foot	M	30	982.2	899.1	1.0924
Right Foot	M	68	952.5	869.8	1.0950
Right Foot	F	26	755.0	686.3	1.1017
Left Foot	M	40	1072.3	995.9	1.0767
Left Foot	M	30	988.2	905.2	1.0916
Left Foot	F	26	713.4	648.8	1.0996
Left Foot	M	68	965.5	877.9	1.0998

TABLE 4

LOCATION OF CENTERS OF MASS AS A RATIO OF THE DISTANCE FROM THE PROXIMAL END OR JOINT AXIS AND THE TOTAL SEGMENT LENGTH

	Harless		Braune and Fischer			Fischer	Dempster‡
	Graf	Kefer	No. 2	No. 3	No. 4	1906	
Entire Body	41.4	......	......	......	......	......	......
Head*	36.3	36.1	......	......	......	......	43.3
Torso	......	......	......	......	......	......	......
Entire Arm, Right	......	......	......	......	......	42.7	......
Entire Arm, Left	......	......	......	......	......	46.4	......
Upper Arm, Right	48.4	42.7	......	43.8	50.9	44.6	43.6
Upper Arm, Left	......	43.2	......	45.4	47.8	45.4	......
Forearm + Hand, Right	......	......	......	47.5	47.2	44.4	67.7§
Forearm + Hand, Left	......	......	......	46.3	47.7	47.9	......
Forearm, Right	43.9	41.8	......	41.4	42.2	......	43.0
Forearm, Left	......	40.2	......	40.6	44.1	......	......
Hand, Right	47.4	36.1	......	......	......	......	49.4
Hand, Left	......	35.7	......	......	......	......	......
Entire Leg, Right	......	......	......	......	......	41.5	43.3
Entire Leg, Left	......	......	......	......	......	40.9	......
Thigh, Right	46.8	43.0	43.2	46.9	42.5	43.8	43.3
Thigh, Left	......	57.0	44.6	47.6	38.8	43.4	......
Calf + Foot, Right	......	......	50.0	53.1	52.1	56.4	43.4
Calf + Foot, Left	......	......	51.7	51.4	53.1	50.6	......
Calf, Right	33.0	44.4	42.0	43.5	41.0	42.6	43.3
Calf, Left		49.4	41.6	41.3	42.2	43.9	......
Foot, Right†	46.0	43.6	40.4	43.0	45.3		42.9
Foot, Left†		43.5	42.4	43.9	45.3	......	......

*Measured from crown.
†Measured from heel.
‡Average of eight specimens.
§Distance from elbow to ulnar styloid equals 100%.

mass could be determined from the position and orientation of the trunk and extremities (Von Meyer, 1873).

Braune and Fischer in 1889 published a comprehensive study of weight, volume, and center of mass of the body and its segments. They based their analyses upon the results obtained from a study of three adult male cadavers, all of whom were suicides. The cadavers were of middle-aged individuals of muscular builds and each was about 169 cm in length. To avoid certain problems of earlier workers, Braune and Fischer kept the cadavers frozen solid throughout their investigation. This reduced fluid losses to a minimum, but prohibited dissecting out the joints as Harless had done. Instead, Braune and Fischer sawed directly across the joints through the approximate centers of rotation of each joint.

To obtain a more accurate estimate of the center of mass than was possible with the then current balance plate technique, Braune and Fischer drove strong, thin rods into the frozen tissue and hung each segment from three axes. The intersection of the three planes was marked on the segment and gave an accurate location for the center of mass of each segment. Tables 1 and 2 give the weight of each body segment as determined by Braune and Fischer. Similarly, table 4 gives the center of mass determinations of the body segments.

The data developed by Braune and Fischer have been widely quoted and extensively used, and until very recently, have comprised the most detailed data available.

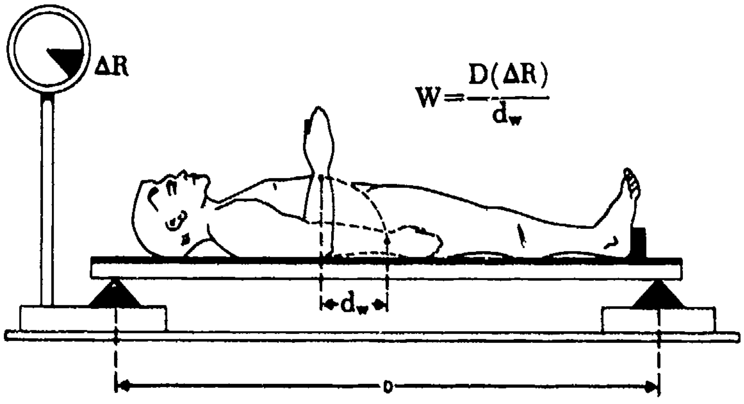
Meeh (1894) pointed out the desirability of supplementing such data with similar information on the volume of segments of the living. To obtain the volume of body segments, Meeh carefully established for each body joint a plane of rotation that could be most easily associated with anatomical reference points. The segments of the individuals were then immersed in water to that plane, with the overflow water being caught and measured. Meeh found this method to be inexact, as considerable variability occurred in repeated trials with the same segment. Therefore, he averaged the results of repeated measurements to reduce his measuring error to a minimum. Because of the difficulties in using this technique on living infants and small children. Meeh duplicated Harless's experiment using four infant cadavers. The relationships between segment weights and volumes obtained from Harless's and his own investigation were then used by Meeh to compute segment weight from the segment volume of his live subjects. From these data, and the data he had experimentally determined on infants and children, Meeh was able to establish a series of graphs to illustrate the growth of the body and its segments with age. Meeh's findings are not reproduced here as they were reported only as percent increments of growth; however, this study was the first serious attempt to understand the changes in the weight of segments during growth and development.

Fischer (1906) reported on a study of the moments of inertia of the human body and its segments. In this study, he included data of the weight and center of mass of body segments from a single cadaver. The procedures used appear to be identical to those he and Braune (1889) had used earlier in their study of segmental parameters. The weight and center of mass data obtained by Fischer are given in tables 1, 2 and 4.

From the turn of the century until the mid-1920's, the interest in segmental parameters seems to have lagged. Indeed, the research that had been carried out in the late 1800's appears to have been received as the definitive work and was widely quoted by those who were working in the area of human mechanics (Fischer, 1906; Amar, 1920).

In 1936, Steinhausen reported on a number of attempts by contemporary researchers to develop segment weight and center of mass data on the living. He particularly cited the work of

Hebestreit (unpublished) who was working with a modified Borelli balance. This device, first attributed to Borelli (1679) and subsequently modified by du Bois-Reymond (1900) and Basler (1931) in their studies of total body center of mass, consists of a rigid board supported by a knife edge at one end and a sensitive dial scale at the other end (figure 1). The subject to be measured stands or lies on the supporting board. Knowing the weight of the subject and the distance between supports, the subject's center of mass can be determined by noting the reaction of the scales to his weight.



Determination of Forearm-Hand Weight
W - Weight of Forearm-Hand
ΔR - Difference Between Scale Readings
D - Distance Between Supports
d_w - Displacement of Center of Mass of Forearm-Hand

Figure 1. Estimation of a Segment's Weight by the Method of Reaction Change.

This technique is quite adequate for center of mass determinations of the total body, but cannot be used for accurate segmental center of mass determinations because the weights of the segments are not known. If one unknown, either the center of mass or the weight of a segment, can be accurately approximated, then the second can be determined using this principle of lever moments.

Bernstein and his co-workers used this approach to determine experimentally on the living, the weight and center of mass of segments of the body. This work, carried out in the late 1920's and reported by Bernstein et al. (1931), is apparently not available in this country and the discussion that follows is based upon the summary statement published later by Bernstein (1967) and others.[1]

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[1] While a number of authors have cited this early work by Bernstein and his associates, none contacted had read the study and all knew of it only through secondary sources. Attempts to obtain copies of Bernstein's works by three libraries were unsuccessful as were personal letters to the scientific attaché of the Russian Embassy in Washington, D. C. and the President of the USSR Academy of Science.

The major problem to be overcome was developing a method to accurately approximate either the weight or the center of mass of the body segments. Using frozen cadaver segments, Bernstein concluded that the center of mass of a segment could be considered coincident, for most practical purposes, with its center of volume. Since the volume and center of volume of a segment can be experimentally determined on the living, the weight of the segment could be determined by the method of reaction change.

The modified Borelli apparatus used by Bernstein is pictured as figure 12 in his 1967 publication, and our line drawing (figure 1) is a simplified version. The subject lies on the platform and two readings of the scale are made, with the segment to be measured held in two different positions. Knowing the reaction of the scale to the changes in segment orientation, as well as the distance the center of mass of the segment has shifted and the distance between the knife edges supporting the platform, the segment weight can be calculated from the following:

$$W = \frac{D(\Delta R)}{d_w}$$

where

W = weight of segment
D = distance between knife edge and scale support edge
d_w = displacement of W (center of mass)
ΔR = difference between scale readings

Bernstein's study was undertaken on a sample of 152 subjects of both sexes, ranging in age from 10 to 75 years. His analysis did not include the center of mass of hands and feet, but did include the weight of all limb segments and all centers of mass with the exception of the above.

Only certain of the summary statistics are available from this study. Those for the male sample are given below. These data are the segment weight as a percent of body weight, and center of mass from the proximal end of the segment as a percent of segment length.

	Segment Weight as Percent of Body Weight		Segment Center of Mass as Percent of Segment Length	
	Mean	SD	Mean	SD
Thigh	12.213%	1.620	38.57%	3.11
Calf	4.655	.507	41.30	1.88
Foot	1.458	.128		
Upper Arm	2.655	.312	46.57	2.63
Forearm	1.818	.184	41.24	2.74
Hand	.703	.084		

Bernstein concluded that the individual variation was so great that, "Either we may resign ourselves to measuring with the complex techniques we have developed every new subject with whom we deal – or we may attempt to find such anthropometric and structural correspondence (correlations) as will enable us to determine with sufficient accuracy the probable radii of our subjects on the basis of their general habits and anthropometric data" (1967, p. 13). If a search for "anthropometric and structural correspondence" was undertaken, it has not been reported by Bernstein or other authors who have described his work.

The accuracy of the estimates of segment weights based on the reaction change technique is largely dependent upon the accuracy of the center of mass estimates. It is unfortunate, therefore, that Bernstein's original work on the basis of which he concluded that the center of mass is, for most practical purpose, coincident with segmental mid-volume, is not available for examination. Our study afforded the opportunity to test this concept, which has been accepted and used by later workers. The results of our investigation are given in Appendix B.

Since the 1930's a number of other researchers have attempted to estimate the weight of body segments of the living. Zook (1932), in a study of human growth, measured in a rather gross way the segment volumes of a large number of boys, ages 5 through 19 years. These data appear to reflect a large experimental error and are believed to be of limited usefulness. In 1943, Cureton reported the specific gravity of the body segments of fifteen male college students. The techniques used by Cureton were not reported, but his results appear to be even more variable than those reported by previous investigators.

Cleveland (1955) determined the weight and center of mass of body segments of 11 male college students. In his study, the volume and mid-volume for the total body and its segments were experimentally determined by hydrostatic weighing. The subject was suspended on a hammock attached to a spring scale above a water-filled tank.

The volume of a segment was determined by weighing a subject in air and then reweighing him with the segment immersed in water (im wt). The loss in weight was considered equivalent to the segment's volume. The mid-volume of a segment was determined by computing the value:

$$CG_{wt} = \frac{\text{air wt} - \text{im wt}}{2} + \text{im wt}$$

This value, CG_{wt}, was the calculated reading of the supporting scale with the segment only immersed to its mid-volume. The segment was then withdrawn from the water until the scale value indicated the CG_{wt} and the center of volume was marked on the segment at the level of the water. The weight of the segments was determined by multiplying the segment volume by the subject's total body density.

Harless's data (table 3) indicate that this procedure for computing weight of segments would lead to significant errors due to the discrepancies between the density of the total body and the density of the various segments. The results of this investigation are therefore believed to be of limited use.

Dempster (1955) reported an intensive study of human biomechanics which included data on the weight, volume, center of mass and moments of inertia of the segments of eight cadavers. The limb segments were separated at each of the primary joints and the trunk divided into a shoulder, neck, thorax, and an abdominopelvis unit. The planes of segmentation were fairly similar to those established by Braune and Fischer, except that before the dismemberment, joints were flexed to mid-range, which Dempster believed would provide a more equitable distribution of tissue mass in each segment. The joints after flexion were frozen before being bisected. Following dismemberment, each segment was put through a series of five steps: (1) the segment was weighed, (2) the center of mass of the straightened part was determined on a balance plate, (3) the period of oscillation (for moment of inertia) was determined, (4) the volume was measured by the Archimedes method and (5) the parts were then refrozen and prepared for further segmentation. The segmental centers of mass were located using a balance plate designed specifically for the study. The results of his analyses are shown in tables 1, 2, and 4.

His study was the most comprehensive study of weight, volume, and center of mass of body segments available. Dempster's sample of eight subjects doubled the number of subjects that had been previously studied and, in addition, provided a wealth of new information on biomechanics not fully reported by earlier investigators. Nevertheless, this investigation was carried out on a sample restricted in terms of age, weight, and physical condition that could significantly hinder the applicability of the data. The cadavers used "represented individuals of the older segment of the population. The specimens were smaller than . . . the average white male population . . . and the weights were below those of average young individuals. Physically, however, the subjects were representative of their age level" (Dempster, p. 47) The composition of the human body changes significantly with age (Behnke, 1961), and the data obtained on an older sample is in all probability not fully representative of a younger population. Despite the possible limitations in application that Dempster cited, these data remain the best available and are widely used by researchers today.

Barter (1957) compiled the data obtained by Braune and Fischer (1889), Fischer (1906), and Dempster (1955) and prepared a series of regression equations for predicting segment weights from body weight. He was fully aware that the differences in technique among the investigators did not make their results fully comparable but felt that these differences were probably not significant when considered in the light of the magnitude of errors introduced by other factors. The errors are those introduced by sampling bias, pre- and post-mortem wasting of the body, fluid and tissue losses during segmentation, etc. Barter believed that the equations would provide a better estimate of segment mass than mean ratio values, and would, through the use of the standard error of estimate, give the range in values that might be expected for a given segment mass. The equations formulated by Barter are:

Head, Neck and Trunk (lb) = .47 x Body Wt. + 12.0 ± 6.4*
Upper Extremities = .13 x Body Wt. — 3.0 ± 2.1
Both Upper Arms = .08 x Body Wt. — 2.9 ± 1.0
Forearms and Hands = .06 x Body Wt. — 1.4 ± 1.2
Forearms = .04 x Body Wt. — 0.5 ± 1.0
Hands = .01 x Body Wt. + 0.7 ± 0.4
Lower Extremities = .31 x Body Wt. + 2.7 ± 4.9
Thighs = .18 x Body Wt. + 3.2 ± 3.6
Calves and Feet = .13 x Body Wt. — 0.5 ± 2.0
Calves = .11 x Body Wt. — 1.9 ± 1.6
Feet = .02 x Body Wt. + 1.5 ± 0.6

*Standard error of estimate

These equations have been used extensively by designers and engineers despite the limitations Barter clearly specified, because they provide a rapid estimation of segment weights.

Goto and Shikko (1956) reviewed the techniques used by previous investigators who had attempted to measure the weight and center of mass of segments on the living and then designed specific equipment for a similar study. They used two methods in their investigation. The first method was that of reaction change using the coefficients Fischer developed for locating the center of mass of limb segments. The second approach was that of determining the moments of inertia of the body with the segments held in different orientations. The results they obtained using the two techniques were found to be unsatisfactory. They concluded that the problem was insoluble unless either a satisfactory approximation were developed for one unknown (segment weight or center of mass) or until a new approach were evolved that would be independent of one of the unknowns. More recently at Kyushu University, Mori and Yamamoto (1959) investigated the weight of the body segments of three male and three female Japanese cadavers. The techniques of this study have not been reported, and one can only assume that they followed those of Braune and Fischer. The results of this study are shown in tables 5 and 6. An additional six cadavers were later studied by Fujikawa (1963) under the direction of Professor Mori. The results of that investigation are also listed in tables 5 and 6.

TABLE 5

WEIGHT OF BODY SEGMENTS OF JAPANESE (kg)

	Mori and Yamamoto						Fujikawa*
(Cadaver)	I	II	III	IV	V	VI	
(Sex)	M	M	M	F	F	F	
Entire Body	31.7	35.0	28.0	49.4	36.5	26.8	50.30
Head	3.9	4.1	3.9	4.0	4.2	3.7	4.10
Torso	18.6	18.3	14.0	27.2	20.1	13.4	26.95
Entire Arm, Right	1.2	1.7	1.3	2.4	1.6	1.5	2.40†
Entire Arm, Left	1.2	1.6	1.3	2.0	2.0	1.4	2.30†
Upper Arm, Right	0.6	1.0	1.0	1.4	0.8	0.8	1.30
Upper Arm, Left	0.6	1.0	1.0	1.2	1.0	0.7	1.25
Forearm + Hand, Right	0.6	0.7	0.3	1.0	0.8	0.7	1.10†
Forearm + Hand, Left	0.6	0.6	0.3	0.8	1.0	0.7	1.05†
Forearm, Right	0.4	0.5	0.2	0.7	0.5	0.5	0.70
Forearm, Left	0.4	0.4	0.2	0.6	0.6	0.5	0.65
Hand, Right	0.2	0.2	0.1	0.3	0.3	0.2	0.40
Hand, Left	0.2	0.2	0.1	0.2	0.4	0.2	0.40
Entire Leg, Right	3.4	4.7	3.7	7.0	4.3	3.4	7.25†
Entire Leg, Left	3.4	4.4	3.8	6.8	4.3	3.8	7.30†
Thigh, Right	1.9	2.9	2.3	4.3	2.4	2.0	4.75
Thigh, Left	1.9	2.6	2.4	4.1	2.4	2.0	4.80
Calf + Foot, Right	1.5	1.8	1.4	2.7	1.9	1.4	2.50†
Calf + Foot, Left	1.5	1.8	1.4	2.7	1.9	1.4	2.50†
Calf, Right	1.0	1.3	0.9	2.0	1.3	0.9	1.65
Calf, Left	1.0	1.3	0.9	2.0	1.3	0.9	1.65
Foot, Right	0.5	0.5	0.5	0.7	0.6	0.5	0.85
Foot, Left	0.5	0.5	0.5	0.7	0.6	0.5	0.85

*Average of six specimens, male and female.
†Calculated value from sum of parts.

It is unfortunate that neither of the Japanese studies has reported in detail the techniques and procedures used. In any event, the data are of limited use for other than Japanese because of the significant differences in body proportions of the Japanese when compared with a United States population.[1].

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[1] For a brief discussion of the differences in body proportions between Japanese and United States pilots see Alexander, McConville, Kramer and Fritz, (1964)

TABLE 6
WEIGHT OF BODY SEGMENTS OF JAPANESE EXPRESSED AS A PERCENT OF TOTAL BODY WEIGHT

	Mori and Yamamoto						Fujikawa*
(Cadaver)	I	II	III	IV	V	VI	
(Sex)	M	M	M	F	F	F	
Head	12.3	11.7	13.9	8.1	11.5	13.8	8.2
Torso	58.7	52.3	50.0	55.1	55.1	50.0	53.6
Entire Arm, Right	3.8	4.9	4.6	4.9	4.4	5.5	4.8†
Entire Arm, Left	3.8	4.6	4.6	4.1	5.5	5.2	4.6†
Upper Arm, Right	1.9	2.9	3.6	2.8	2.2	3.0	2.6
Upper Arm, Left	1.9	2.9	3.6	2.4	2.7	2.6	2.5
Forearm + Hand,Right	1.9	2.0	1.1	2.0	2.2	2.7	2.2†
Forearm + Hand, Left	1.9	1.7	1.1	1.6	2.7	2.7	2.1†
Forearm, Right	1.3	1.4	0.7	1.4	1.4	1.9	1.4
Forearm, Left	1.3	1.1	0.7	1.2	1.6	1.9	1.3
Hand, Right	0.6	0.6	0.4	0.6	0.8	0.8	0.8
Hand, Left	0.6	0.6	0.4	0.4	1.1	0.8	0.8
Entire Leg, Right	10.7	13.4	13.2	14.2	11.8	12.7	14.4†
Entire Leg, Left	10.7	12.6	13.6	13.8	11.8	13.6	14.5†
Thigh, Right	6.0	8.3	8.2	8.7	6.6	7.5	9.4
Thight, Left	6.0	7.4	8.6	8.3	6.6	7.5	9.5
Calf + Foot, Right	4.8	5.1	5.0	5.5	5.2	5.3	5.0†
Calf + Foot, Left	4.8	5.1	5.0	5.5	5.2	5.3	5.0†
Calf, Right	3.2	3.7	3.2	4.1	3.6	3.4	3.3
Calf, Left	3.2	3.7	3.2	3.1	3.6	3.4	3.3
Foot, Right	1.6	1.4	1.8	1.4	1.6	1.9	1.7
Foot, Left	1.6	1.4	1.8	1.4	1.6	1.9	1.7

*Average of six specimens, male and female.
†Calculated value from sum of parts.

In 1966, Drillis and Contini published a detailed study of characteristic body segments. This investigation, carried out over a number of years, appeared to be extremely thorough[1]. Their initial interest was in the design of improved prosthetic devices, but this necessitated good estimates of the weight, center of mass, and moments of inertia of limb segments. Their dissatisfaction with available segment parameters led them to attempt to develop techniques to provide improved data. The most recent and complete work undertaken by this group included a study of volume, weight, and center of mass of the segments of the living. A sample of 20 young male subjects was studied, and complete data were obtained from 12 (Drillis and Contini, 1966).

Body segment volumes were determined using immersion and segment zone methods. These methods are generally similar; however, the latter is accomplished in small equidistant steps in order that the distribution of volume throughout the length of the segment can be determined. As the center of mass was assumed to be coincident with the mid-volume (following Bernstein), the segment zone method provided an estimate of the center of mass of the segment. These ap-

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[1] See Contini et al., 1959; Contini et al., 1963; Drillis et al, 1964; Duggar, 1962.

proximations were then combined with the previously published center of mass data (table 4) to give an overall average value.

The weight of segments was determined by the method of reaction change, using a highly sensitive apparatus based upon the general principles illustrated in figure 1. The weights of the whole arm and whole leg were first determined, after which the weights of the forearm-hand and calf-foot were determined. The weight of the proximal segment of each extremity was then computed by subtracting the appropriate value. The hand and foot weights were not experimentally determined but were estimated, using proportional values from earlier cadaver studies (table 2). The weights of the forearm and calf were then determined by subtracting the estimated hand and foot values. A summary of their analysis is given in table 7.

TABLE 7
BODY SEGMENT VALUES, NYU SAMPLE (n=12)

	Volume (l)			Weight (kg)		Density	CG
	Mean	SD	% of TB	Mean	% of TB	(g per ml)	Ratio*
Total Body (TB)	....	....	100.0	73.420	100.0	....	....
Head, Neck & Trunk	....	....	....	42.606	58.04	....	....
Total Arm	3.971	.376	5.73	4.384	5.97	....	43.1
Upper Arm	2.412	.334	3.495	2.619	3.57	1.086	44.9
Forearm & Hand	....	....	....	1.765	2.40	....	38.2
Forearm	1.175	.084	1.702	1.324	1.80	1.127	42.3
Hand	.384	.035	.566	.441	0.60	1.148	39.2
Total Leg	10.091	1.758	14.620	11.023	15.01	....	39.7
Thigh	6.378	1.464	9.241	6.946	9.46	1.089	41.0
Calf & Foot	....	....	....	4.077	5.55	....	45.0
Calf	2.818	.399	4.083	3.086	4.20	1.095	39.3
Foot	.895	.175	1.297	.991	1.35	1.107	44.5†

*Location of Mass Centers from proximal joint as a percent of segment length.
†Measured from heel.

This study was well thought out and carefully executed. The authors, fully aware of the many difficulties in determining body segment densities, suggested that the results should be "considered as good first approximations." They do provide, in addition to the results of their study of segment parameters, a detailed procedure for applying their results to orthosis and to the design of prosthesis for specific individuals.

A number of theoretical studies of body segment parameters have been made, beginning with the early model developed by von Meyer (1863), and continuing through the sophisticated computer simulations of today (McHenry and Naab, 1966). An element common to each of these studies is the attempt to represent the irregular shapes of the different body segments with geometric forms which are capable of simple mathematical descriptions.[1] Before developing such a model it is necessary to assume, as did Whitsett (1962, p. 6), essentially that:

a. The human body consists of a limited series of linked masses.

b. The masses are linked at pivotal points (joints) which have a limited number of degrees of freedom.

c. The masses are internally stable, rigid and homogeneous.

d. The masses can be closely approximated by simple geometric forms.

The segments and their most commonly associated geometric forms are:

a. Head – elipsoid or elipsoidal cylinder

b. Trunk – elipsoidal cylinder

c. Arm, Forearm, Thigh and Calf – frustum of a right circular cone.

d. Hand – sphere or elipsoidal cylinder

e. Feet – parallelepipeds

The models are usually based upon data from Braune and Fischer (1889), Fischer (1906), or Dempster (1955). Skerlj (1954) developed a series of formulas for computing the volume and surface area of the body from anthropometric dimensions. His formulas are based upon treating the body segments as a series of simple geometric forms. The general formula for segment volumes suggested by Skerlj is:

Segment volume $= r^2\pi h$

where

r is the average radius of the segment and h is the length of the segment.

As the radius of the segment at specific levels cannot be measured directly, Skerlj modifies the formula for use with body circumference as:

Segment value $= c^2hk$

where

k is a constant 0.79 which approximates $\frac{1}{4}\pi$ and c is the average circumference of the segment. For example, c for trunk is equal to ⅓ of chest plus waist plus hip circumference.

The composite formula for total body volume developed by Skerlj was tested by Bashkirov (1958) who found it offered a good approximation to empirical findings. Bashkirov determined the total body volume for a large sample as 66.69±0.55 liters with a density of 1.0413 where, as with the computed volumes based upon anthropometric dimensions, he obtained values of 66.06 and 1.0514, respectively. This correspondence between the theoretical and empirical total body volume speaks well for the use of models in this type of study. It is unfortunate that the formulas for individual segment volumes have not been compared in a similar manner.

The widespread availability of high speed computers in recent years has intensified the interest in the development of mathematical models of the human body. Whitsett (1962) developed a mathematical model to approximate the mass distribution, center of mass, moments of inertia

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[1] See for example Calvit and Rosenthal, 1964 and Whitsett, 1962.

and mobility of the human body. His primary purpose was to use the model to predict the biodynamic response of the body to specific conditions associated with weightlessness. The basic-parameters of the model were obtained from the data of Dempster (1955) and the regression equations of Barter (1957). Whitsett attempted to validate his model by recording on film a free-floating subject in an airplane flying a Keplerian trajectory. The maximum impact-free periods were found insufficient to demonstrate conclusively the validity of the theoretical formulations.

In 1963, Santschi et al., reported their study of total body moments of inertia and locations of the center of mass of 66 subjects in each of eight body positions (standing, sitting, etc.). Fifty body dimensions were measured on each subject. They found that the moments of inertia of the body in the various positions correlated well with stature and weight (R=.77 to .98). The authors concluded that the location of an individual's center of mass and his moments of inertia can be effectively estimated from easily obtained anthropometric dimensions.

The high degree of relationship between stature and weight and moments of inertia encouraged Gray (1963) to derive from Santschi's anthropometric data three models of differing body size. Gray, as had Whitsett, used Barter's regresssion equations for assigning weight to the segments of the model and Dempster's center of mass data. In comparing the calculated moments of inertia and center of mass values to these experimentally determined parameters of the subjects who served as bases for Gray's models, he found the calculated results differed disappointingly from the experimental values and concluded that the model must be refined to represent the mass distribution of man more precisely.

A more refined mathematical model to predict the inertial properties and the location of the center of mass of the human body was developed by Hanavan (1964). Hanavan restricted the motion of his model to that of the arms and legs. The sizes of the segments of Hanavan's models are based on the individual anthropometry of the 66 subjects used by Santschi. Again the criteria for segment weights were based on the regression equations of Barter (1957), but the center of mass of the segments was dependent solely on the geometry of the segment. The formulated model was then evaluated against the experimental data developed by Santschi for each of his 66 subjects for seven body positions. Hanavan found that the predicted center of mass of the model was fairly comparable to the empirical data and the predicted moments of inertia generally falling within 10% of those experimentally determined.

More recent work with mathematical modeling of the human body is that of McHenry and his associates at Cornell Aeronautical Laboratories. The object of this research has been the approximations of whole-body kinematics and the inertial loading of restraint belts in automotive collision rather than a study of human biomechanical characteristics (McHenry and Naab, 1966). The formulated model was evaluated by comparing the predicted responses with the results obtained in controlled impacts of an instrumented anthropomorphic dummy. The results of the comparison of the theoretical and empiricial data were sufficiently impressive to warrant further developments aimed toward general improvement in the simulation.

From the preceding general outline of research that has been accomplished in determining segment characteristics of body segments, it is apparent that a number of approaches are possible, with each requiring certain explicit or implicit assumptions. It is beyond the scope of this report to discuss in detail each of the above studies or to point out all their merits and weaknesses; rather, a discussion of the classes of studies and a critique of the assumptions which underlie them are presented.

The two most obvious types of studies are those that differentiate between the choice of subject material to be studied. The preference for live subjects as opposed to cadavers is obvious. The use of the live subjects, however, assumes that the weight and center of mass of segments and linked segments can be estimated with the required degree of accuracy. The most critical approach to this with live subjects appears to be that of Bernstein and his associates in Russia during the early 1930's. They were reportedly able to demonstrate that the mid-volume of each segment was coincident with its center of mass. Establishing the center of mass with accuracy is important as it becomes the critical variable for estimating segment weight using the reaction change method. The validity of segment weight determinations is obviously a function of the accuracy of center of mass estimates; but if we accept them as accurate, what errors remain in the actual determinations of weight by the reaction change method? Preliminary work with this method indicated many potential sources of error. If the scales are sensitive enough to detect changes in mass with great accuracy, they respond radically to changes in the body center of mass during respiration. Indeed, the beat of the heart will register on the scales as a slight oscillation. With movement of a segment from one position to another, the muscle masses, which act as the prime movers of the segment, also shift to some extent. For example, in determining the weight of the forearm-hand, the scale is first read with this segment held in a horizontal position (figure 1). The forearm-hand is then moved to a vertical position and the scales read once again to obtain the reaction change. With flexion of the forearm, the belly of the biceps brachii and the underlying brachialis are displaced proximally as much as two to three centimeters during muscle contraction. For composite segments, such as the arm or leg, the proximal shift in the mass of the flexors could introduce a significant bias in determining the segment weights. Moreover, we cannot assume that the proximal shift in the muscle mass of the flexors is necessarily compensated for by a distal movement of the extensors.

The use of cadavers, the second major type of study, while overcoming the above difficulties, requires a new set of assumptions, the foremost being that the relationships found in a cadaver population are equally valid for the living. Changes that take place in the tissues and body fluids at death are not well understood; nor has a serious attempt been made to document the changes that occur or to estimate their significance. The possible sources of error in this type of study are many, a few of which have been cited by Barter (1957). Some of the sources of error, such as gross tissue pathology in general, and the effects of wasting diseases specifically, can be markedly reduced with the careful selection of the cadavers. It does not appear illogical to assume that changes which do occur are nonspecific, that is, they occur throughout the body rather than only in certain portions of segments. If this is true, then the relationships in the cadaver would remain the same as in the living; only the absolute values would change.

The third type of study, that of the mathematical models, has contributed little to our understanding of body segment parameters. Most of the models that have been formulated so far are rather specific in design and have not been fully validated. In addition, with the exception of the work by McHenry and his associates (1966) at the Cornell Aeronautical Laboratories, none of the models were apparently revised on the basis of the information obtained in the validating tests. It should be possible through the use of computer simulations and Monte Carlo techniques to prepare a series of gaming solutions that could be evaluated against the results obtained in limited high stress studies with human subjects. Such an approach would require the development of new and sophisticated simulation techniques and demand a major effort by a number of highly skilled specialists.

There is neither a simple nor easy approach to the study of body segment characteristics. Each type of investigation discussed previously has some definite limitations that reduce confidence in the accuracy of the results obtained. Thus there is a major need for research designed to answer certain pertinent questions. Of primary interest is whether or not body segment parameters can be predicted with any degree of accuracy from anthropometric dimensions. If this can be answered in the affirmative, then it would be important to know if such predictions provide sufficient accuracy for estimating parameters for individuals as well as for the corresponding populations.

We thought an investigation based on the extensive knowledge gained from previous researchers and the results subjected to more elaborate statistical analysis would best answer these questions.

Methods and Techniques

The methods and techniques used in our investigation are similar in many respects to those established by Braune and Fischer (1889) and Dempster (1955) for their studies of the weight, volume, and center of mass of segments of the body. In the earlier investigations, unpreserved cadavers were used, which restricted the selection of subjects to those cadavers that could be brought together in a relatively short period of time. This factor effectively reduced the probability of obtaining a wide range of physical types and ages for inclusion in the sample. In this study preserved specimens were used, which permitted the selection of the sample from a relatively large population of cadavers.[1] The use of preserved specimens is not believed to have introduced a significant bias in the results obtained. In a recent study, Fujikawa (1963, p. 124) reported, "There was little influence of the injected formalin-alcohol about the ratio of weight of each part to the body weight and little individual difference of the physique." Dempster (1955) included one preserved specimen in his sample and did not thereafter differentiate between the preserved and unpreserved specimens in his analysis. This would indicate that he believed, as did Fujikawa, that the data from the two types of specimens were reasonably comparable.[2]

The cadavers used in this study had been treated with a solution containing equal proportions of phenol, glycerine and alcohol. Three gallons of solution were injected by gravity flow through the subclavian and femoral arteries. The cadavers were then stored in tanks containing a 2% solution of phenol. This was the normal technique used by the preparator although there was no attempt at a strict standardization of the procedure. Todd and Lindala (1928) reported that three gallons of preservative would probably be the amount necessary to restore the mean living circumferences on a male white cadaver. Their findings are discussed in more detail in Appendix C.

The effect on the weight of body segments of adding a preservative has not been studied in detail. The density of the preservative used was found to be 1.0615 (25°C)., which closely approximates the average density of healthy young men (1.063) as found by Behnke (Behnke, 1961) and others. If an equal volume of preservative were injected as a replacement for the blood of the body (density 1.056)[*] the differences would be relatively insignificant. If the preservative, however, is an addition to the body fluids then the cadavers should, on the average, gain approximately 20 pounds after treatment. It is fairly obvious that the preservative is not retained in the body tissues for any appreciable length of time in the quantities in which it was injected, rather the tissue appears only to retain the amount of preservative to replace body water, etc., lost through the skin immediately after death. It is our opinion then that the cadavers, if properly treated during storage to retard fluid losses, and if selected for general normal appearances, will be closely comparable in mass distribution and density to living subjects.

The study sample was selected according to the following criteria listed in descending order of importance:

1. Age at death
2. Overall physical appearance, including evidence of pre- or postmortem wasting

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[1] The authors acknowledge their deep gratitude to Dr. K. K. Faulkner and the faculty of the Department of Anatomy, School of Medicine, of the University of Oklahoma, for their wholehearted cooperation and continued support of this investigation.

[2] In a personal communication, Dr. Dempster outlined an experiment he had conducted on limb segments in which he located the center of mass of segments both before and after they were permitted to lose most of their fluids. He found that the loss of tissue fluids did not significantly change the location of the center of mass. He was also of the opinion that preserved specimens which look natural (not excessively puffy or desiccated) have in all probability, a weight and volume similar to that which they had at death.

[*] *Handbook of Biological Data*, 1956, p. 51.

3. Evidence of debilitating diseases or accidents before death, including coroner's statement as to cause of death
4. Body weight
5. Stature

After each cadaver was selected for inclusion in the study it was treated to the following sequence of steps:

1. The cadaver was cleaned and the landmarks to be used in the anthropometry were made. The body measurements were made and somatotype photographs taken.
2. The total body center of mass and volume were measured.
3. The planes of segmentation of the arms and legs were established and the segments severed. The weight, volume, and center of mass for each of the segments were then established. This procedure was continued for the remainder of the cadaver until the data were gathered on each of the major segments of the body.

The specimens selected were photographed by the authors and then somatotyped by Dr. C. W. Dupertuis, Case-Western Reserve School of Medicine. Observations made on each subject are outlined in Appendix A as are the more detailed step-by-step procedures used in the study.

The technique of measuring the cadaver established by Terry (1940) was not used in the study because of the need for a special measuring frame and the necessity for severing the tendons of the ankle to allow proper dorsiflexion of the foot. In this study each cadaver was measured in the supine position with the head oriented in the Frankfort plane (relative) and the trunk and limbs aligned. The inelasticity of cadaver tissue was a constant problem, consequently a rigidly standardized position could not be attained. A headboard, attached perpendicular to the table, provided the base for the anthropometer with all body height measurements being taken from the headboard (figures 2 and 3). A test with live subjects positioned in a similar fashion indicated the correlation coefficient between standing and supine length measurements to be about 0.99. The best approximation of standing stature was found to be the dimension Top-of-Head to Ball-of-Heel with the foot relaxed (see Appendix C).

The body dimensions were measured using primarily the landmarks and techniques of Martin (1928), Stewart (1947), and Hertzberg et al. (1954). Many of the landmarks were difficult to palpate and locate accurately on the cadavers. Therefore, fluoroscopy and X-ray were used to establish the exact position of the landmarks needed for the anthropometry. The layout of the fluoroscopy unit is illustrated in figure 4. Where difficulties were encountered and landmarks could neither be located by fluoroscopy or X-ray, they were established by dissection (e.g. cervicale).

After the anthropometry was completed, the location of the center of mass of the total body and its segments was determined using balance tables developed by Mr. John J. Swearingen (1962). The larger center of mass machine consisted of a table and a series of platforms mounted one above the other with each counterbalanced so that the equipment as a unit remained in perfect balance with the bottom platform regardless of the shifts in position of the upper table on which the subject was positioned. The platforms were mounted to a base by means of a ball and socket joint and four electrical contacts, one at each corner. When the table was not in balance, the upper platforms tilted to the side so that a metal pole touched a contact on the base completing an electric circuit that indicated the direction the table had to be moved to obtain balance. This equipment is illustrated in figure 5. After locating the center of mass in one axis, the table was tilted

Figure 2. Autopsy Table with Headboard in Place.

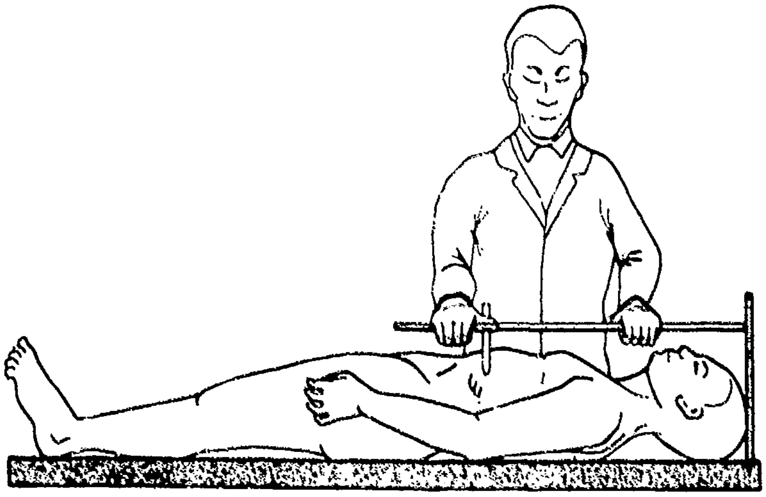

Figure 3. Technique Used in Measuring Vertical Dimensions of the Body.

vertically, approximately 20 degrees, and the center of mass along a second axis was obtained. The center of mass equipment did not provide for a ready determination of the center of mass in the transverse plane, and no further attempt was made to obtain this measurement.[1] For this study, the center of gravity is assumed to lie in the mid-sagittal plane of the body.

A table designed to measure the centers of mass of infants was used for the smaller segments. This equipment was similar in principle to the larger table but not as elaborate, consisting only of an upper platform separated from its base by a ball and socket joint in the center and four electrical contacts. This device is illustrated in figure 6. The center of mass was determined by moving a segment slowly about the surface of the table until both the segment and table remained in balance. A plumb line then indicated the location of the center of mass. Repeated trials with the same segment indicated that the maximum variations in reading were within ±3 mm.

The equipment used in determining the volume of the body and its segments is illustrated in figures 6, 7, and 8. The volume of the body (V_b) and its segments was computed as the difference between the weight in air and the weight in water.

$$V_b = (M_a - M_w)/D_w \qquad (16)$$

where

M_a = weight of the body in air

M_w = weight of the body in water

D_w = density of the water at a specific temperature

With the exception of total body and the trunk and the head-trunk segments, the volume of the segments was also determined by the water displacement method. This method follows closely that outlined by Dempster (1955) for measuring the volume of segments of the body. Each segment was weighed immediately before its volume was determined by either the water displacement or underwater weighing method. The equipment used in measuring volume by water displacement is shown in figures 8 and 9. The water displaced was weighed and corrected for temperature to give the segment volume. Each segment was measured twice by the water displacement method as a check, and the two values were then averaged. If the difference between two trials for the same segment exceeded 1%, the trials continued until successive measurements of volume differed by less than 1% of the total segment volume. In general the differences between two successive measurements of volume were less than 0.5%. Errors caused by changes in the surface tension of the water were reduced and kept to a minimum by flushing the tanks during successive trials, by draining and refilling as needed, and by keeping the tank mouths free of oils and debris. The techniques of volume measurement are illustrated in figures 10 and 11.

Methods of dismemberment of body segments were similar to those used by Braune and Fischer (1892), and Dempster (1955). Ciné- and still-roentgenograms were made of each joint to be studied throughout its range of motion on a series of living subjects. A plane passing through the primary centers of rotation was then established using bony landmarks as reference points. It was hoped that each cadaver joint could be flexed to midrange before freezing and cutting; however, the tissue could not be stretched sufficiently to permit this. The alternative, severing of the tissue to permit flexion to mid-joint range, was not considered as this would have resulted in a significant loss of body fluids before observation. Before dismemberment of the cadavers, each plane of seg-

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[1] Swearingen (1962) reported the lateral displacement of the center of gravity of the total body from the mid-sagittal line to be small for an individual supine with arms and legs adducted. The mean center of gravity for five subjects lay in the mid-sagittal line with all values falling within ±¼ of an inch of this line.

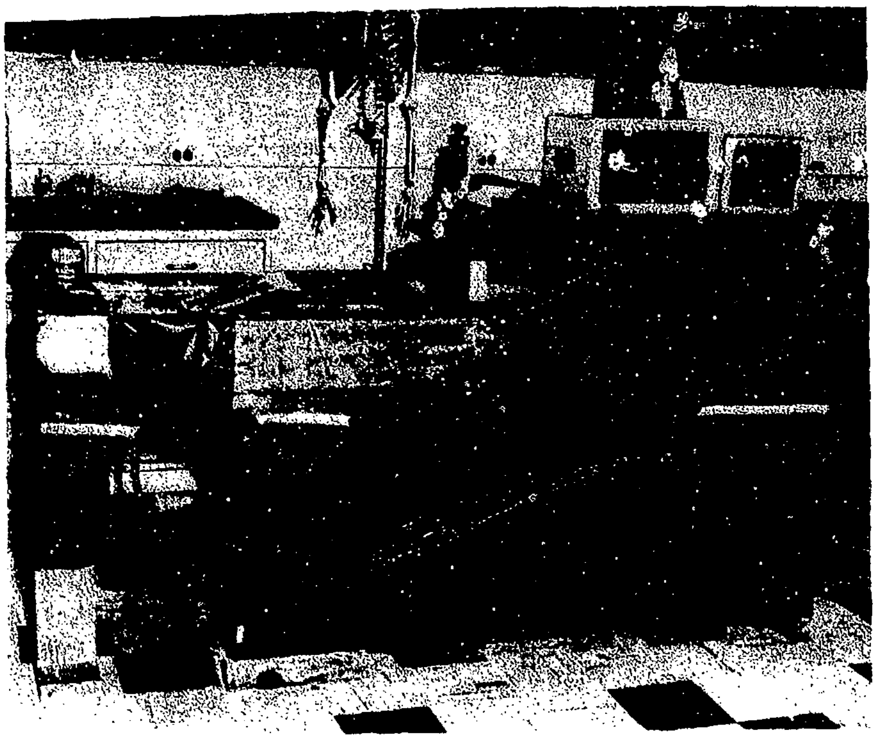

Figure 4. Fluoroscopy Unit Used to Establish Landmarks.

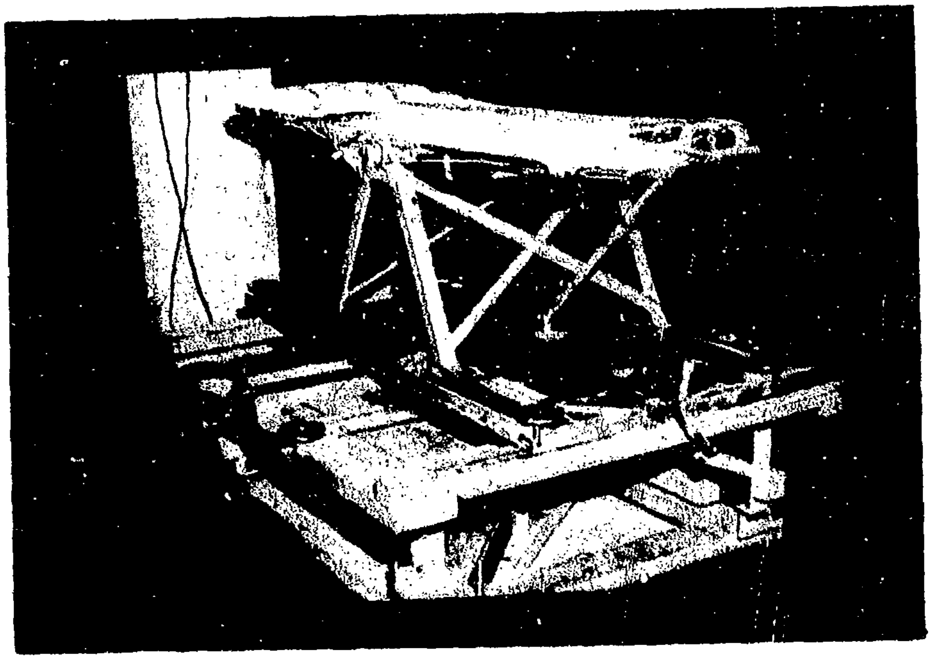

Figure 5. Center of Mass Measuring Table for Total Body and Large Segments.

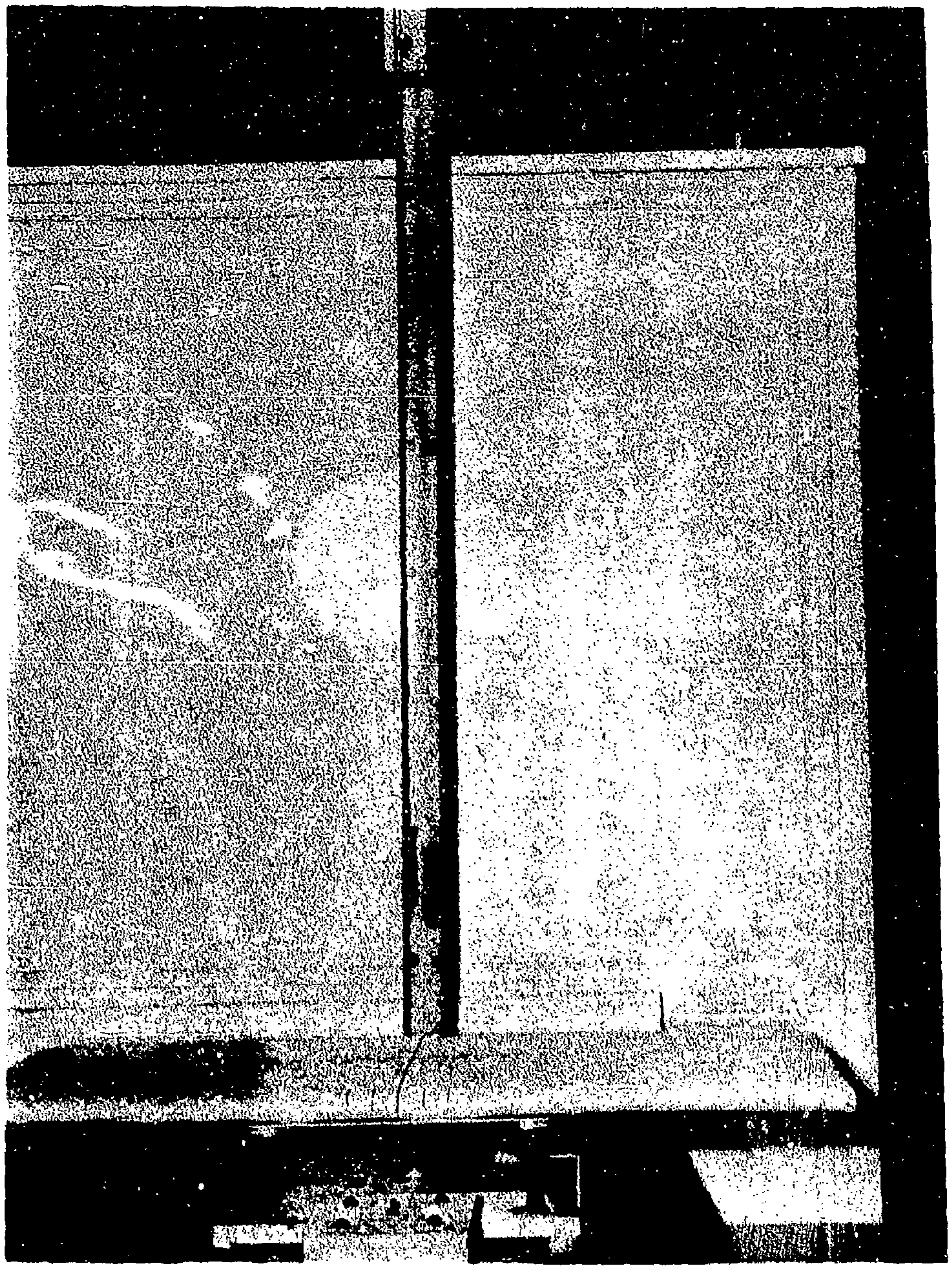

Figure 6. Center of Mass Measuring Table for Small Segments.

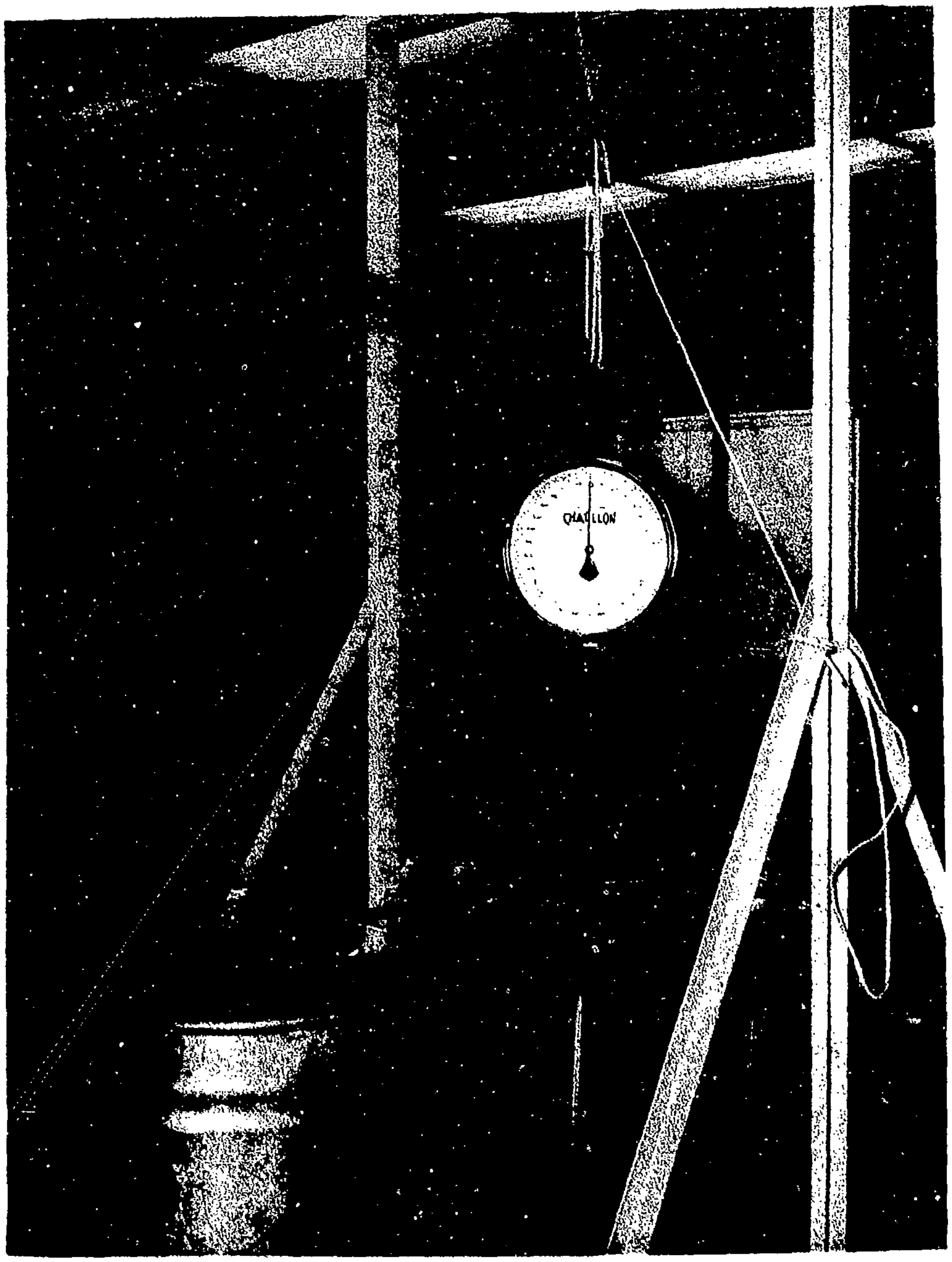

Figure 7. Equipment Used to Determine Segment Volume by Underwater Weighing

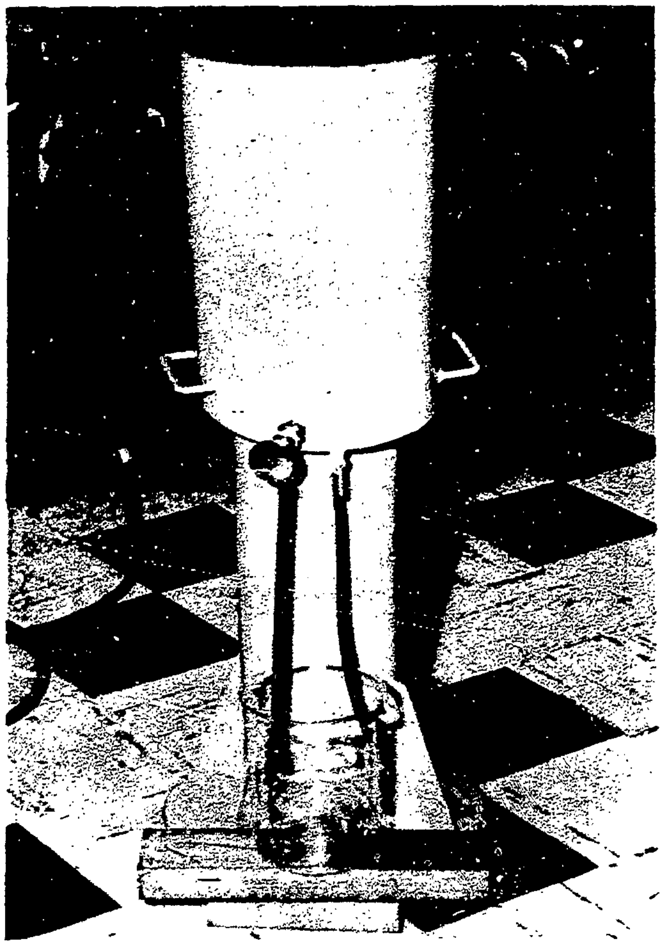

Figure 8. Small Tank Used to Determine Segment Volume by Water Displacement.

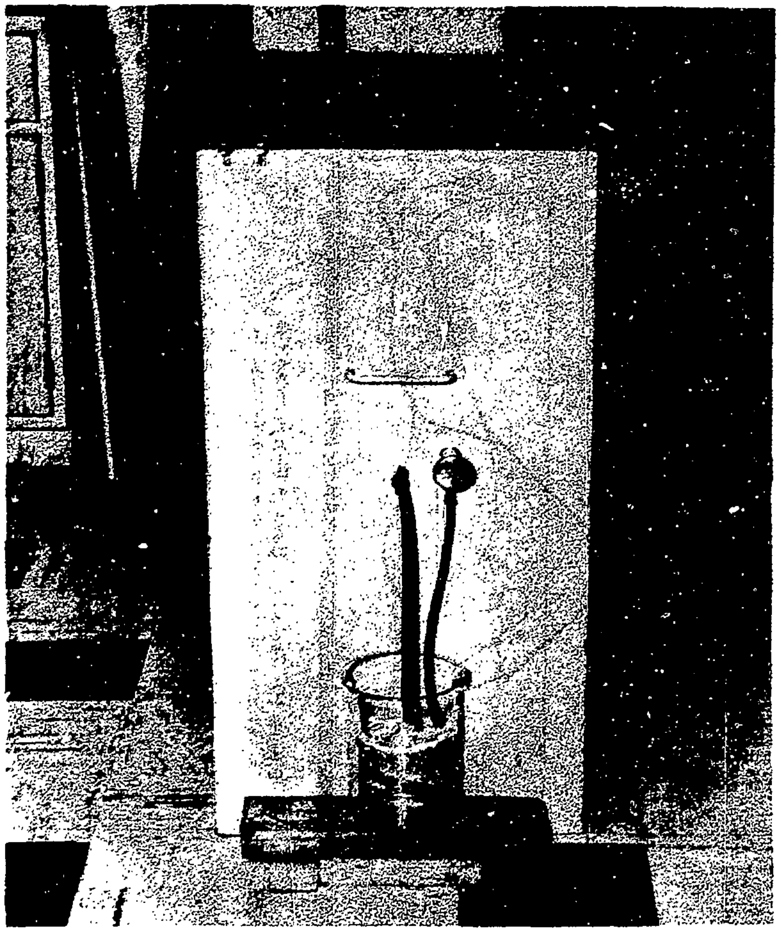

Figure 9. Large Tank Used to Determine Segment Volume by Water Displacement

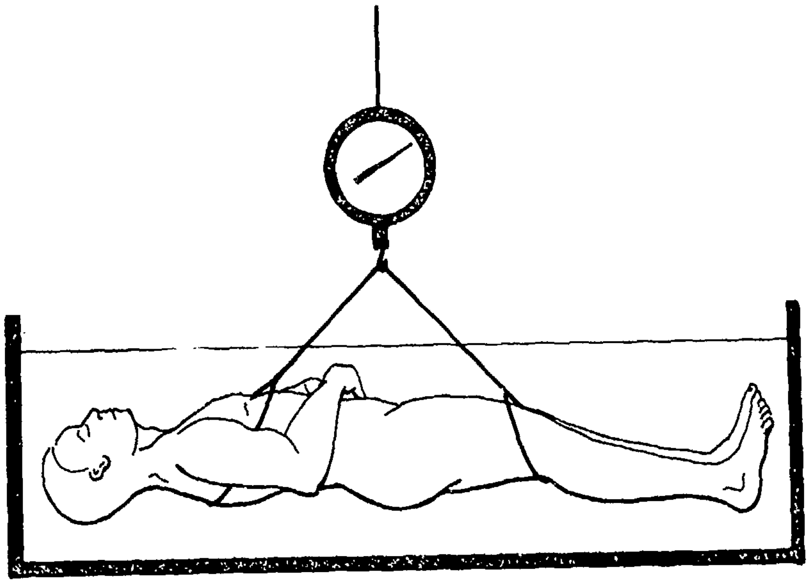

Figure 10. Technique Used in Determining the Volume of the Body and its Segments.

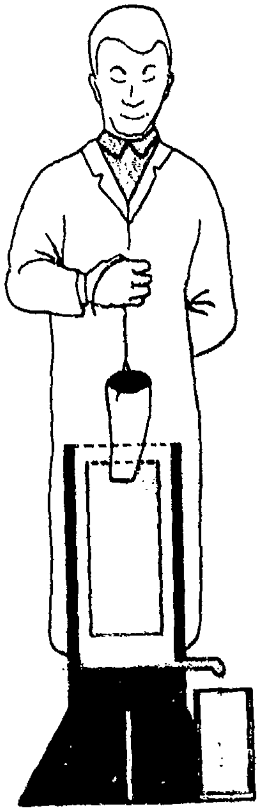

Figure 11. Technique Used in Measuring the Volume of the Small Segments of the Body.

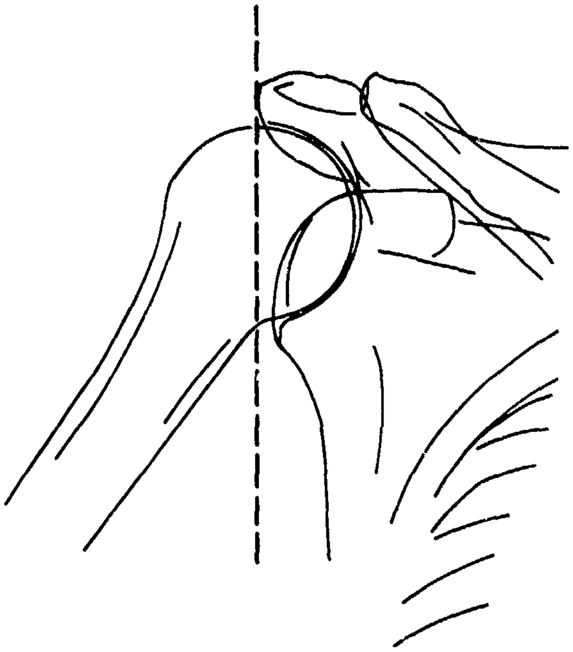

Figure 12a. Tracing of a Roentgenogram of the Shoulder Segmentation.

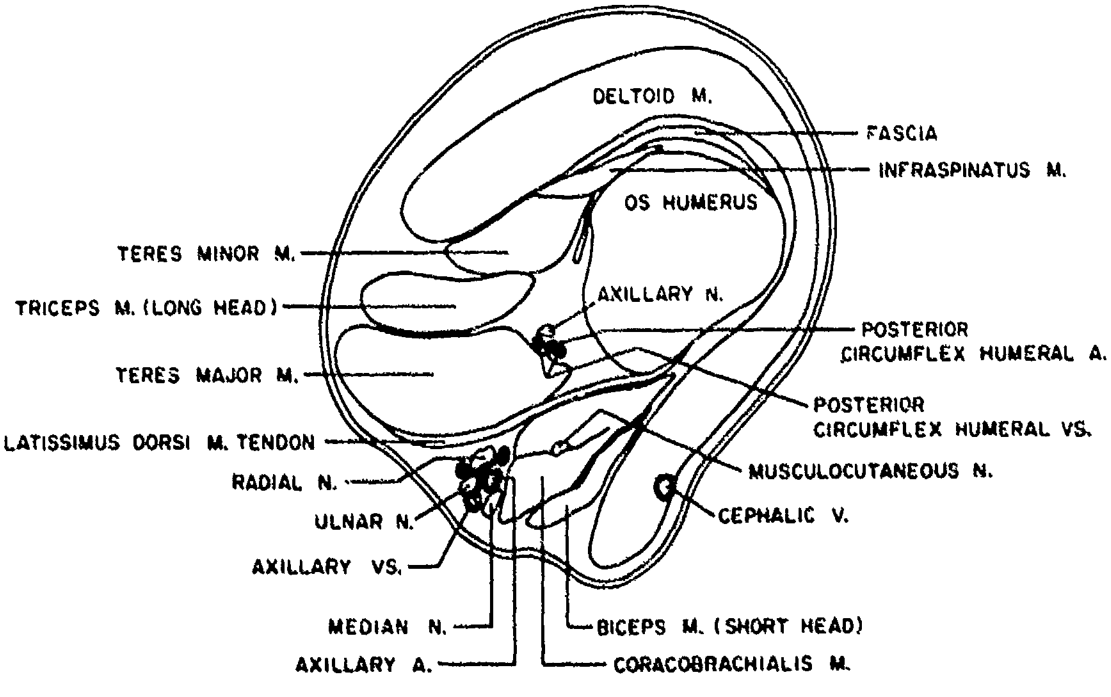

Figure 12b. Cross Section of Shoulder Segmentation

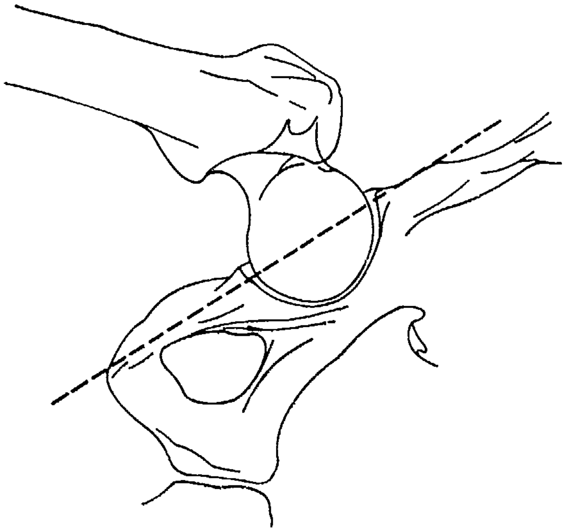

Figure 13a. Tracing of a Roentgenogram of the Hip Segmentation.

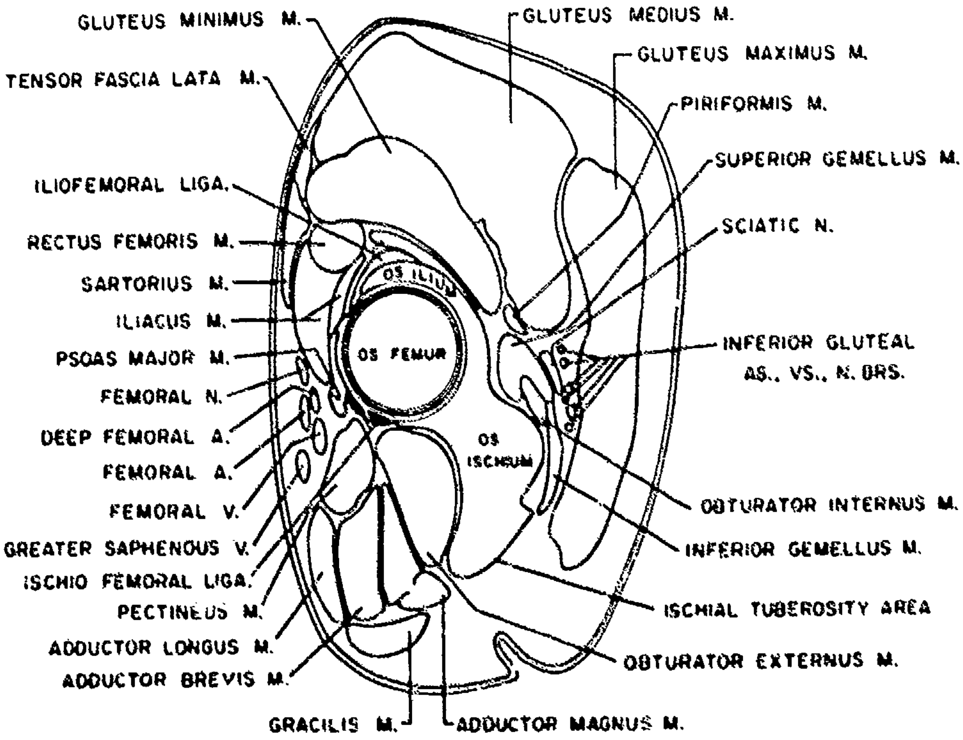

Figure 13b. Cross Section of Hip Segmentation.

mentation was marked with a thin lead strip and studied under a fluoroscope to assure that it would coincide with the desired reference landmarks. The segment to be cut was then frozen. Each segment to be severed was spot frozen along the line of segmentation by packing small pieces of dry ice completely around the segment. Extensive freezing of tissues beyond the plane of segmentation was avoided as much as possible. Immediately before any segmentation was made, the part to be cut was weighed, and immediately upon completion of the dissection, the resulting segments were weighed. All cuts were made with a paper towel under the area being dissected, and the few grams of tissue that fell on the paper or remained on the saw were weighed and one-half the weight was added to each segment.

The shoulder segmentation plane is illustrated in figure 12a. This is a tracing from a roentgenographic plate. As illustrated in the figure, the arm was abducted laterally approximately 15° before freezing. This abduction rotated the shaft of the humerus laterally enough to assure that the cut line would pass from the acromial tip to the anatomical neck of the humerus and into the axillary region without touching the shaft of the humerus or the medial surface of the upper arm. An actual cross section of this shoulder-arm segmentation is illustrated in figure 12b.

The hip plane of segmentation is illustrated in the tracing in figure 13a. The legs were abducted about 20° in order to assure that the plane of segmentation would pass high into the groin. This plane extends from the level of the iliac crest inferiorly along the external shelf of the ilium, cutting the rim of the acetabulum and severing the ischial tuberosity (posteriorly at the level of the attachment of M. Semimembranous anteriorly at the mid-point of the ascending ramus of the ischium). A cross section of this line of dismemberment is shown in figure 13b.

After the appendages were removed, the center of mass of the head-trunk segment was established; and after thawing, the volume of the head-trunk segment was measured using the technique of underwater weighing. The center of mass was then determined for each appendage after which two measurements of volume were made using both the water displacement and the underwater weighing technique. This procedure was repeated for each segment upon dismemberment. In order to reduce fluid losses to a minimum, each cut was sealed with a waterproof plastic film applied by an aerosol spray While the film did not completely prevent the loss of fluids from the severed surface, it did reduce seepage and evaporation.

The head was severed from the trunk along the line illustrated in figure 14a. The head had been positioned in the Frankfort plane. The cut began at the chin-neck juncture, just inferior to the hyoid bone, and was extended through the body of the third cervical vertebra and the spinous tip of the second cervical vertebra. A cross section of this plane is shown in figure 14b.

The thigh was severed at the knee along the plane illustrated in figure 15a. The knee was normally in an extended position and no flexion was attempted. The cut line began near the lower third of the patella and bisected the maximum protrusions of the medial and lateral epicondyles of the femur. The cut passed just above the posterior superior edge of the medial epicondyle and through the posterior superior tip of the lateral epicondyle. A cross section through this plane is illustrated in figure 15b.

The feet of all the specimens were normally plantar extended. The plane of separation for the calf and foot is illustrated in figure 16a. The plane of cut began at the anterior superior edge of the neck of the talus and passed through the posterior superior surface of the calcaneus. A cross section through this plane is shown in figure 16b.

The forearm was normally flexed about 45° and was severed in that position. The plane of separation (figure 17a) began by bisecting the area of insertion of the triceps on the olecranon pro-

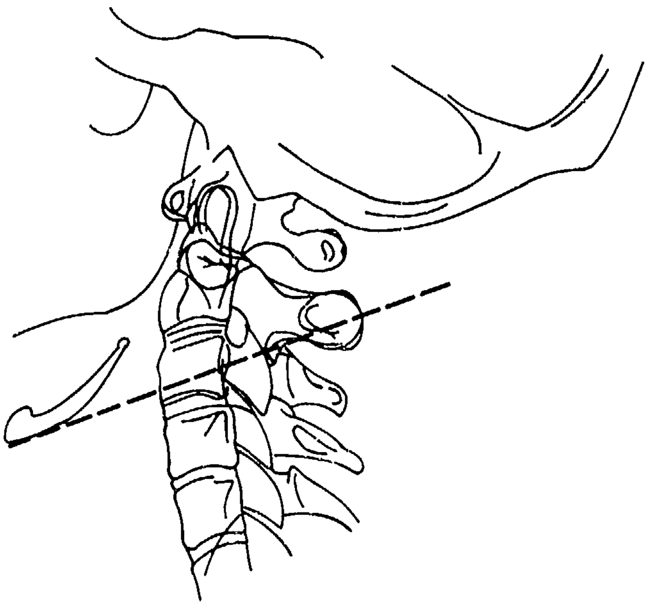

Figure 14a. Tracing of a Roentgenogram of the Neck Segmentation.

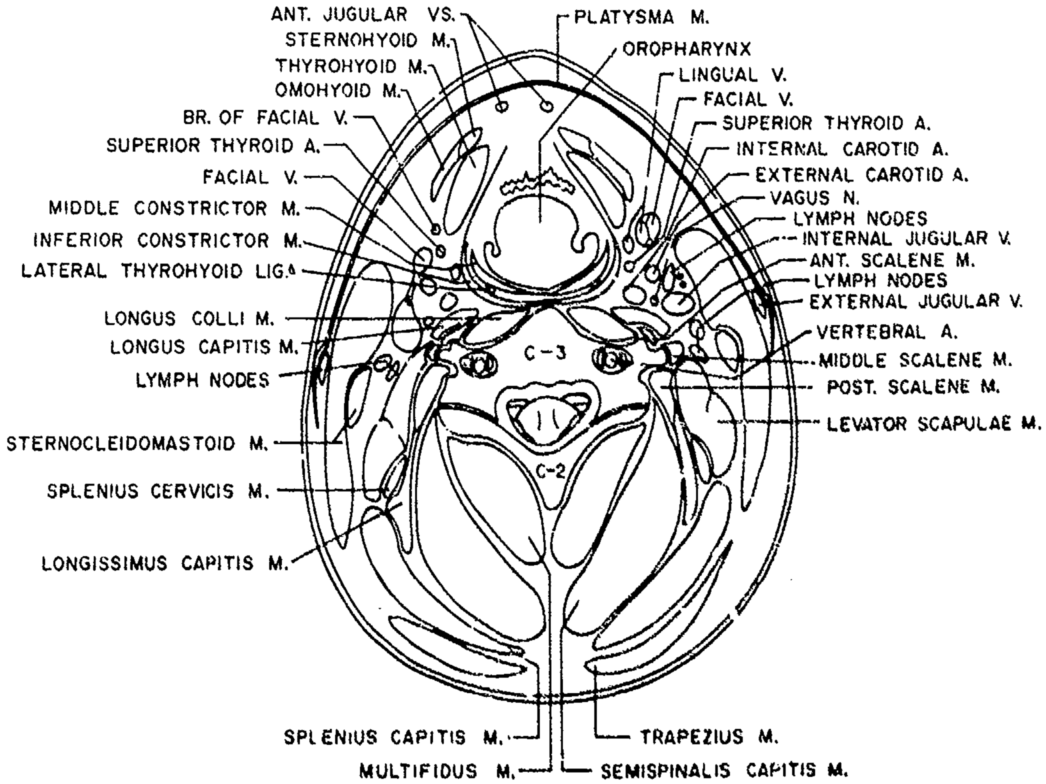

Figure 14b. Cross Section of Neck Segmentation.

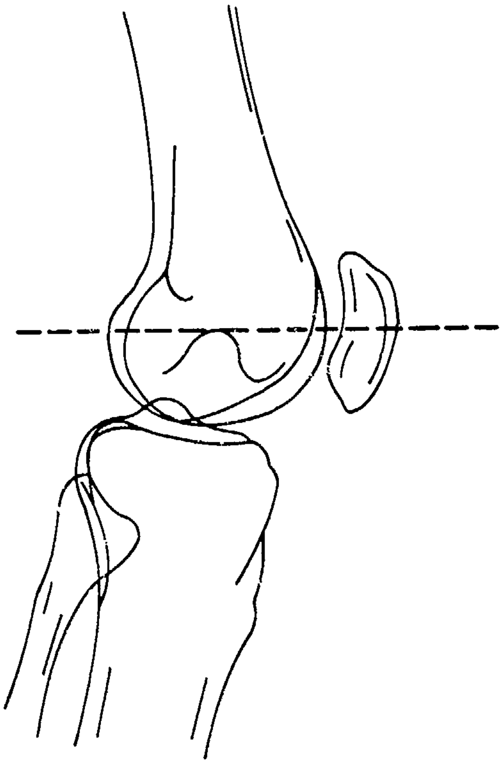

Figure 15a. Tracing of a Roentgenogram of the Knee Segmentation.

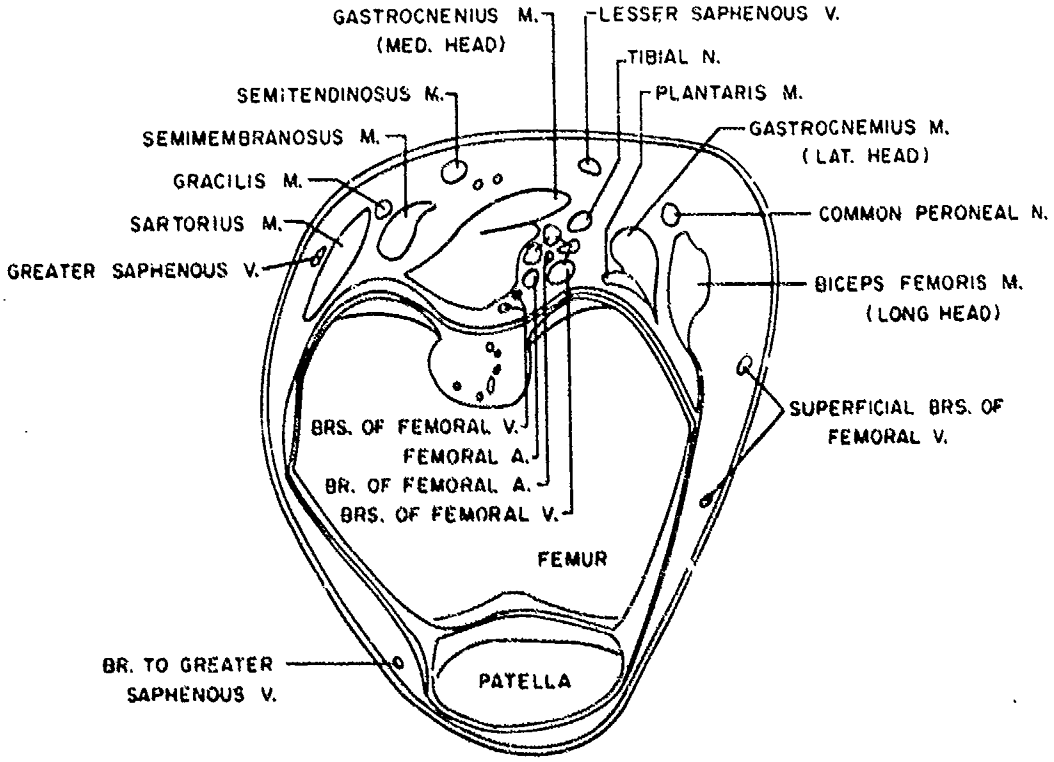

Figure 15b. Cross Section of Knee Segmentation.

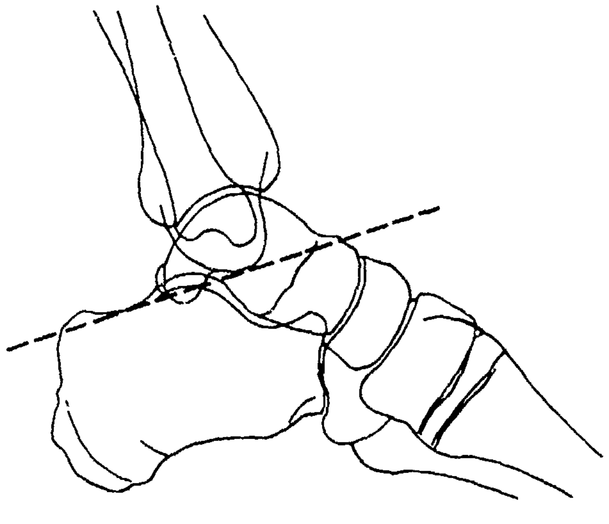

Figure 16a. Tracing of a Roentgenogram of the Ankle Segmentation.

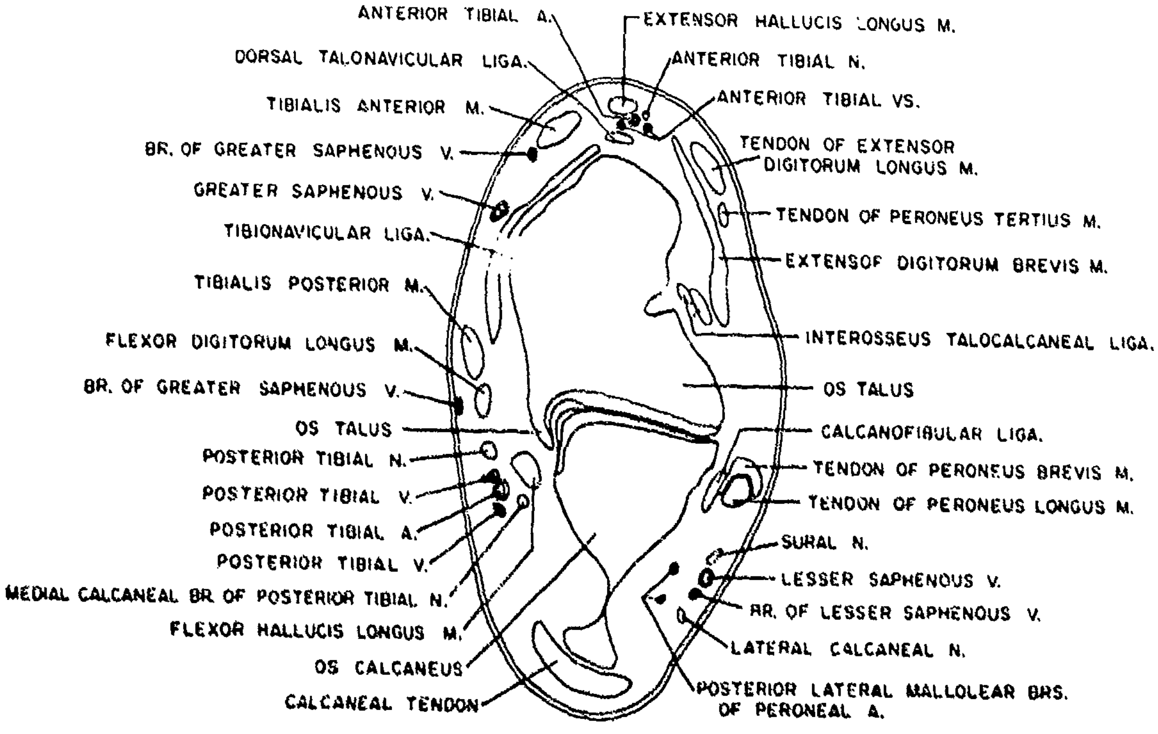

Figure 16b. Cross Section of Ankle Segmentation.

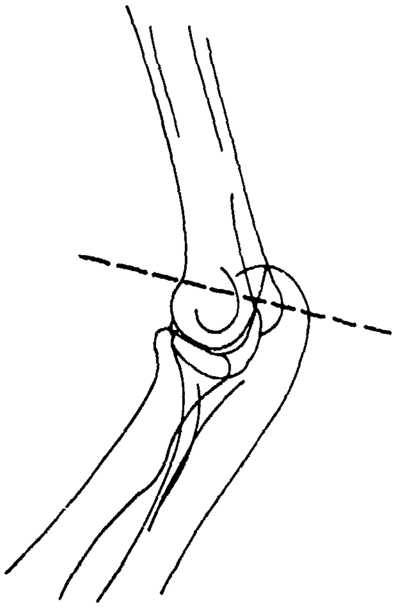

Figure 17a. Tracing of a Roentgenogram of the Elbow Segmentation.

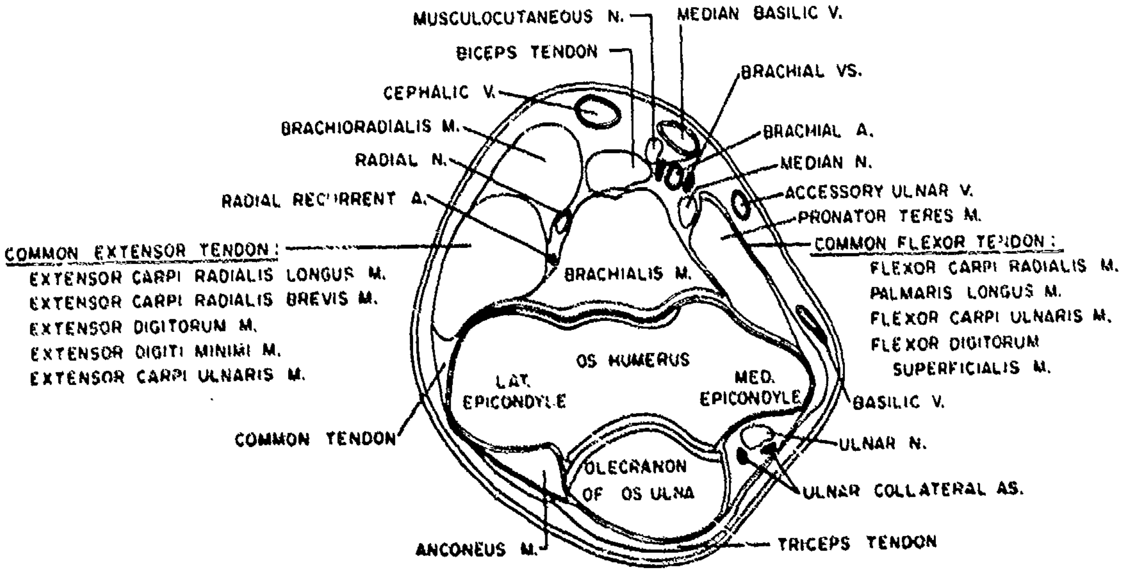

Figure 17b. Cross Section of Elbow Segmentation.

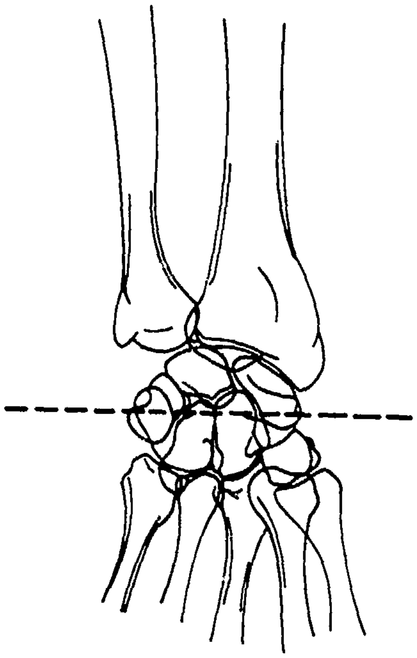

Figure 18a. Tracing of a Roentgenogram of the Wrist Segmentation.

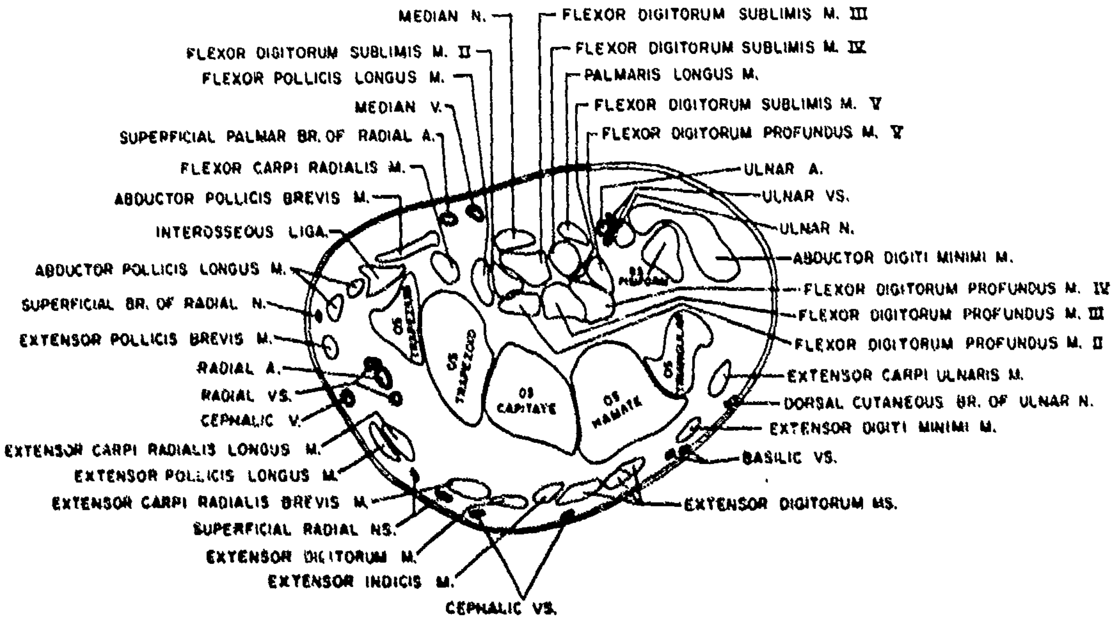

Figure 18b. Cross Section of Wrist Segmentation.

cess, crossed the greatest projection of the medial epicondyle of the humerus and ended at the skin crease of the anterior surface of the elbow. A cross section of the plane of segmentation is shown in figure 17b.

The hands of the cadavers were flexed to approximately 30° with the fingers slightly curled in the relaxed position. This was not a desired orientation for measuring the center of mass of the hand; however, the inelasticity of the tissues prevented the straightening of the fingers.[1] The plane of cut for the wrist began at the palpable groove between the lunate and capitate bone, bisected the volar surface of the pisiform and ended at the distal wrist crease. The plane of separation and a cross section of this cut is illustrated in figure 18.

In all, the body was divided into 14 segments. Fourteen cadavers were used in this study and data were gathered fully on 13. The first cadaver was used as a test specimen to evaluate the techniques to be used; therefore data on this cadaver are not included in the analyses that follow.

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[1] Dempster found that the location of the center of gravity of the hand is not significantly affected by the flattening or loose cupping of the hand (1955, p. 125).

Summary Statistics and Predictive Equations

As previously pointed out, no attempt was made to select a fractional or stratified sample. In choosing the sample of cadavers, a list of all the available adult males was ordered according to age. Starting with the youngest (age 28), each was examined for condition of preservation, evidence of debilitating or wasting disease, deformities, etc. Every specimen that met the requirements previously set was included in the study. Though the cadaver population from which the sample was drawn was large, there was a paucity of specimens that met the stringent requirements for this study. The final sample consisted of 13 specimens on which the data were complete for all variables studied.

The physical evidence for emaciation, debilitating diseases, etc. was determined by visual inspection. An attempt was made to select only those specimens that appeared physically "normal." This could have biased the sampling process if the subjective criteria used were invalid. There is no absolute method to determine if a sampling bias existed. However, no consistent bias is believed to have existed in the method of selection that would invalidate the assumptions necessary for normal statistical analysis.

The summary statistics for the variables of stature, weight, and age of the sample are listed below. In comparison, the same variables for a USAF personnel sample (Hertzberg et al., 1954) and a male civilian work force sample (Damon and McFarland, 1955) are also listed.

	Cadavers		*USAF Personnel*		*Civilian Workers*	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD*
1. Stature (cm)	172.72	5.94	175.54	6.19	173.6	6.5
2. Weight (kg)	66.52	8.70	74.24	9.46	75.75	13.15
3. Age (yr)	49.31	13.69	27.87	4.22	37.0	8.2

*SD estimated from s.e.

The cadaver sample was shorter, lighter and older in terms of mean values than either the military or civilian sample. The differences in stature among the three samples is relatively small, but the differences in weight are larger than were desired. The standard deviations for both height and weight are reasonably comparable except for the civilian sample. It is unfortunate that a closer approximation to the adult male population in respect to body size was not achieved. A comparison of the anthropometry of living samples and the cadaver sample is discussed in some detail in Appendix C. It was from this comparison that we concluded that the anthropometric dimensions of the cadavers are reasonable approximations to those obtained on the living and can be used within the framework of this study. Also of interest is the effect of the preservatives used on the densities of cadaver tissues. This is discussed in Appendix G.

The descriptive statistics for the anthropometry of the cadaver sample are given in table 8. These statistics include the range, mean, standard error of the mean, standard deviation, standard error of the standard deviation, and coefficient of variation. As these statistics are meant to describe only the sample and not a population, none of the conventional techniques for providing an unbiased estimate of the population variance has been used. A brief outline of the statistical formulas used in this study is given in appendix E. The coefficients of variation indicate that these data reflect the level of relative variability common for anthropometric data on the living. Exceptions to this are restricted primarily to the dimensions of the abdomen where greater relative variability

TABLE 8

ANTHROPOMETRY OF STUDY SAMPLE*

	VARIABLE NAME (N=13)	RANGE	MEAN (SE)		S.D. (SE)		CV
1.	AGE	28.0 – 74.0	49.31	(3.80)	13.69	(2.68)	27.76
2.	ENDOMORPHY	3.0 – 5.5	4.04	(0.16)	0.57	(0.11)	14.13
3.	MESOMORPHY	3.0 – 5.0	4.31	(0.18)	0.64	(0.12)	14.78
4.	ECTOMORPHY	1.0 – 5.0	2.38	(0.29)	1.04	(0.20)	43.64
5.	WEIGHT	54.0 – 87.9	66.52	(2.41)	8.70	(1.71)	13.07
6.	ESTIMATED STATURE	162.5 – 184.9	172.72	(1.65)	5.94	(1.16)	3.44
7.	TRAGION HT	151.2 – 172.8	160.45	(1.57)	5.67	(1.11)	3.53
8.	MASTOID HT	147.4 – 169.4	157.18	(1.59)	5.72	(1.12)	3.64
9.	NECK/CHIN INTER HT	139.3 – 161.1	148.70	(1.54)	5.55	(1.09)	3.73
10.	CERVICALE HT	140.1 – 160.6	148.98	(1.42)	5.11	(1.00)	3.43
11.	SUPRASTERNALE HT	131.8 – 151.8	141.05	(1.38)	4.98	(0.98)	3.53
12.	SUBSTERNALE HT	105.9 – 134.2	120.72	(1.84)	6.62	(1.30)	5.49
13.	THELION HT	119.9 – 138.1	128.91	(1.36)	4.92	(0.96)	3.81
14.	TENTH RIB HT	103.6 – 120.8	110.91	(1.31)	4.71	(0.92)	4.24
15.	OMPHALION HT	96.7 – 114.0	105.50	(1.25)	4.49	(0.88)	4.26
16.	PENALE HT	78.7 – 95.4	85.99	(1.23)	4.43	(0.87)	5.15
17.	SYMPHYSION HT	81.6 – 98.5	89.60	(1.10)	3.98	(0.78)	4.44
18.	ANT SUP SPINE HT	88.7 – 107.1	96.59	(1.23)	4.43	(0.87)	4.59
19.	ILIAC CREST HT	95.9 – 116.9	104.27	(1.42)	5.12	(1.00)	4.91
20.	TROCHANTERIC HT	83.0 – 99.7	90.81	(1.13)	4.08	(0.80)	4.49
21.	TIBIALE HT	40.9 – 50.9	45.68	(0.65)	2.34	(0.46)	5.12
22.	LAT-L MALLEOLUS HT	6.4 – 7.9	7.13	(0.11)	0.41	(0.08)	5.73
23.	SPHYRION HT	5.8 – 8.8	7.05	(0.23)	0.83	(0.16)	11.84
24.	HEAD BREADTH	15.3 – 16.6	15.75	(0.11)	0.38	(0.07)	2.41
25.	HEAD LENGTH	18.6 – 21.2	19.98	(0.20)	0.73	(0.14)	3.65
26.	NECK BREADTH	11.0 – 14.6	12.45	(0.27)	0.96	(0.19)	7.75
27.	NECK DEPTH	12.3 – 15.3	13.53	(0.29)	1.03	(0.20)	7.61
28.	CHEST BREADTH	29.1 – 39.4	33.23	(0.70)	2.53	(0.50)	7.62
29.	CHEST BREADTH/BONE	26.7 – 33.9	29.99	(0.51)	1.85	(0.36)	6.17
30.	CHEST DEPTH	17.7 – 24.6	21.06	(0.52)	1.88	(0.37)	8.93
31.	WAIST BREADTH/OMPH	25.8 – 38.8	30.59	(0.90)	3.26	(0.64)	10.65
32.	WAIST DEPTH/OMPH	15.1 – 23.5	18.17	(0.71)	2.56	(0.50)	14.10
33.	BICRISTAL BREADTH	23.5 – 34.0	29.08	(0.75)	2.72	(0.53)	9.35
34.	BI-SPINOUS BREADTH	20.6 – 27.5	24.08	(0.58)	2.09	(0.41)	8.68
35.	HIP BREADTH	29.6 – 40.8	34.62	(0.75)	2.69	(0.53)	7.76
36.	BI-TROCH BR/BONE	28.5 – 36.7	32.51	(0.58)	2.10	(0.41)	6.47
37.	KNEE BREADTH/BONE	9.1 – 11.1	10.01	(0.14)	0.52	(0.10)	5.21
38.	ELBOW BREADTH/BONE	6.6 – 8.0	7.27	(0.12)	0.43	(0.08)	5.94
39.	WRIST BREADTH/BONE	5.2 – 6.1	5.72	(0.08)	0.30	(0.06)	5.22
40.	HAND BREADTH	7.4 – 9.5	8.50	(0.15)	0.54	(0.11)	6.31
41.	HEAD CIRC	53.9 – 60.0	57.06	(0.49)	1.78	(0.35)	3.12
42.	NECK CIRC	36.6 – 45.0	40.43	(0.71)	2.56	(0.50)	6.34
43.	CHEST CIRC	84.5 – 103.8	93.39	(1.59)	5.74	(1.13)	6.15
44.	WAIST CIRC	70.3 – 103.4	80.65	(2.15)	7.74	(1.52)	9.60
45.	BUTTOCK CIRC	80.4 – 102.2	89.87	(1.53)	5.51	(1.08)	6.13
46.	UPPER THIGH CIRC	41.4 – 53.7	47.36	(1.01)	3.64	(0.71)	7.69
47.	LOWER THIGH CIRC	30.3 – 41.4	35.55	(0.74)	2.65	(0.52)	7.47
48.	CALF CIRC	26.8 – 35.1	30.82	(0.69)	2.50	(0.49)	8.12
49.	ANKLE CIRC	18.6 – 22.4	20.05	(0.34)	1.24	(0.24)	6.17
50.	ARCH CIRC	23.4 – 27.5	25.80	(0.35)	1.28	(0.25)	4.95

*UNITS OF MEASURE –
Age in years, somatotype in half units (0-7), weight in kilograms, body fat in millimeters, all other dimensions in centimeters.

TABLE 8 (Cont.)

ANTHROPOMETRY*

VARIABLE NAME (N=13)	RANGE	MEAN	(SE)	S.D.	(SE)	CV
51. ARM CIRC (AXILLA)	26.1 – 33.0	29.38	(0.58)	2.08	(0.41)	7.07
52. BICEPS CIRC	24.9 – 32.2	28.05	(0.61)	2.19	(0.43)	7.79
53. ELBOW CIRC	24.1 – 31.3	27.85	(0.56)	2.01	(0.39)	7.22
54. FOREARM CIRC	24.3 – 29.7	26.27	(0.39)	1.41	(0.28)	5.36
55. WRIST CIRC	14.8 – 18.6	16.54	(0.29)	1.05	(0.21)	6.38
56. HAND CIRC	19.0 – 22.6	21.06	(0.25)	0.90	(0.18)	4.28
57. HEAD + TRUNK LENGTH	76.2 – 87.1	81.92	(0.84)	3.02	(0.59)	3.68
58. HEIGHT OF HEAD	22.4 – 26.6	24.02	(0.30)	1.06	(0.21)	4.43
59. TRUNK LENGTH	53.2 – 62.1	57.89	(0.73)	2.65	(0.52)	4.58
60. THIGH LENGTH	42.1 – 48.8	45.14	(0.51)	1.84	(0.36)	4.08
61. CALF LENGTH	35.1 – 42.9	38.65	(0.56)	2.00	(0.39)	5.19
62. FOOT LENGTH	23.0 – 26.8	24.78	(0.28)	1.00	(0.20)	4.05
63. ARM LENGTH (EST)	72.3 – 84.2	77.45	(0.90)	3.24	(0.64)	4.18
64. ACROM-RADIALE LGTH	30.2 – 37.4	33.35	(0.56)	2.01	(0.39)	6.03
65. BALL HUM-RAD LGTH	27.8 – 33.6	30.68	(0.43)	1.56	(0.31)	5.07
66. RAD-STYLION LENGTH	23.5 – 28.0	25.90	(0.34)	1.22	(0.24)	4.70
67. STYLION-MET 3 LGTH	7.6 – 10.5	9.05	(0.20)	0.71	(0.14)	7.79
68. META 3-DACTYLION L	9.7 – 11.1	10.43	(0.12)	0.44	(0.09)	4.23
69. JUXTA NIPPLE (FAT)	0.5 – 25.0	8.85	(2.00)	7.21	(1.41)	81.53
70. MAL XIPHOID (FAT)	0.1 – 15.0	5.70	(1.17)	4.23	(0.83)	74.22
71. TRICEPS (FAT)	1.0 – 23.0	8.23	(1.45)	5.22	(1.02)	63.43
72. ILIAC CREST (FAT)	1.0 – 27.0	10.58	(1.87)	6.72	(1.32)	63.58
73. MEAN FAT THICKNESS	0.9 – 22.5	8.33	(1.48)	5.35	(1.05)	64.23

*UNITS OF MEASURE –
Age in years, somatotype in half units (0-7), weight in kilograms, body fat in millimeters, all other dimensions in centimeters.

occurs than is normal, and we believe this reflects the wide range of age and age-related changes in the physique of the abdomen associated with the cadaver sample.

The 73 variables listed here are considerably less than the total number collected (99). A number of dimensions such as Top-of-Head to Heel, Top-of-Head to Ball-of-Foot, etc., were all estimates of stature and therefore were eliminated in the final analyses (Appendix C). Early during the collection of data, it became apparent that the shoulders could not be measured in any standard way; therefore, Acromial Height and Biacromial Breadth were both deleted from the analyses. In addition, a number of body dimensions were measured on both the right and left side of the body. These measurements were then averaged to give a single value to be used in further analysis. The right and left side measurements of these body dimensions were found generally to agree within measuring error; therefore, averaging did not result in a significant numerical change. Several circumferences measured on the right and left sides did show some differences, primarily for those measurements of major active muscle masses, such as over the biceps, forearm, and upper thigh. Before the right and left values could be averaged, it was necessary to determine if the relationships between these and all the other variables were essentially the same for the right and the left side. This was accomplished by computing the correlation coefficients for the right and left measurements with all other variables used in the study. The right coefficients were then used as ordinate or X coordinates with the left coefficients being used as abscissa or Y coordinates for plotting as rectangular coordinates. If a perfect relationship existed between the right and left measurements, the points on the graph would fall along a line that passed through the origin of the graph and bisected the first and third quadrant. The variables treated in this manner indicated that the relationship of other variables with the measurements made on the right and left sides was high, with most of the points being rather tightly clustered along the line that would indicate a perfect relationship. It is believed on this basis that the measured values of the right and left sides could be averaged without a significant loss in information.[1].

In addition to deleting or combining anthropometric variables, there were a number of additional variables calculated from other data. The computed variables are numbered 57 through 61 and are all concerned with segment length. These variables are largely simple subtractions of measured anthropometry and are described in appendix D. Arm length (variable 63), however, could not be measured directly on the cadavers owing to the flexion of the elbow, wrist and digits. A summation of the lengths of the individual segments normally gives an excessive value for arm length. In the 1967 Air Force anthropometric survey,[2] for example, arm length measured as Acromial Height less Dactylion Height is one centimeter less than the sum of Acromion-Radiale Length plus Radiale-Stylion Length plus Hand Length. In order to estimate arm length more effectively on the cadaver population, a series of regression equations was prepared, using Air Force data, to predict arm length from measured values of Acromion-Radiale Length and Radiale-Stylion Length. These two dimensions were measured in the same manner in both the Air Force survey and in the cadaver series. The multiple correlation coefficient obtained was 0.892 and the regression equation:

> Arm Length (estimated) = 1.126 Acromion-Radiale Length + 1.057 Radiale-Stylion Length + 12.52 (±1.58).*
>
> *(All variables used in the equation are in centimeters)

This equation estimates an average arm length, which was about a centimeter less than the sum of parts for the arm in the cadaver sample. This variable is used only in the descriptive statistics and the segmental ratios that follow (tables 9-22) and not in any other analysis of the data as it is considered an approximation and not a measured variable.

A comment is appropriate at this point about the statistical analysis presented in the remainder of this study. In previous studies of segmental parameters, the statistics presented in the analysis were, in general, limited to simple ratios and averages. The reasons for this are understandable, as either the statistical techniques had not been developed or the samples were extremely small. Sample size can be considered as an effective limiting factor on the degree and sophistication of the statistical analysis. The sample size in this study is significantly larger than in previous studies of this nature, but is still extremely small for the type of analysis that is desired. The small sample size does not, of course, invalidate the statistical analysis, but does demand more caution in the interpretation of the results. In this study we have two levels of data interpretation. The first level of interpretation is associated with the descriptive statistics. Random experimental errors associated with data collection are magnified, in a sense, because of the small number of observations made for each variable. They affect the descriptive statistics to a greater extent than an error of a similar magnitude affects the descriptive statistics for a large sample. Care in collecting and editing the data helps reduce such errors but does not assure that the data are error free. A brief summary of the editing procedure used is given in appendix E.

A second level of interpretation is involved when the statistics are used to establish population parameters from the sample or when the results are applied to a different population. Here

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[1] Correspondence in anthropometric measurements made on the right and left sides of the body has been studied for a number of body dimensions on the living with essentially similar findings to those reported above. (See, for example, Laubach and McConville, 1967.)

[2] Unpublished data, Anthropology Branch, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio.

again, the sample size is a limiting factor, as the precision of an estimate is a function of the sample size. The first factor is of less moment in this study, because an attempt is made only to relate segmental characteristics to body size characteristics of the sample rather than established population parameters. The difficulties in application may not be so lightly dismissed, however, since the ultimate goal of this investigation is to transfer the findings of the interrelationships of the cadaver population to the living, as a first approximation for determining segmental parameters from body size characteristics.

An approach that strengthens the confidence in the interpretation of the statistical data from a practical, but not a statistical point, is to examine the data for patterns of values rather than for individual values. In table 8, for example, we find the relative variability, as expressed by the coefficients of variation, to be that normally associated with anthropometric data. In a similar fashion, the interrelationship of these variables may be listed. The intensity of association among body size dimensions is best expressed by the product-moment correlation coefficient (r). This statistic is a numeric measure of the degree to which variables change together. The correlation coefficient measures the degree of linear relationship. Since most pairs of body dimensions exhibit an essentially linear relationship, its use here seems appropriate. The total intercorrelation matrix has been computed but is not presented here because of its excessive length (6,903 individual values for the 118 variables used in this study). A partial correlation matrix is given in appendix F, which illustrates only the relationship of the anthropometry with the segmental parameters.

The interrelationships among human body dimensions are relatively well understood but less well documented. A number of correlation matrices of anthropometry have been prepared from military anthropometric survey data, but these have not been fully published or widely circulated. These matrices show a common series of patterns of relationships between body dimensions which have practical applications in many design problems.[1] A comparison of the cadaver correlation coefficients with the 1967 Air Force correlation coefficients indicates that the two samples exhibit a similar series of relationships and that the individual coefficients are alike in magnitude despite the great differences in the sizes of the two samples. This suggests that the body dimensions of the cadaver sample exhibit essentially the same type and degree of interrelation as are found in the living.

Despite these findings, the analysis presented below is based upon a very small sample and considerable caution in interpretation is warranted.

The descriptive statistics for the weight, volume, and center of mass of the body and its segments are given as variables 74 through 132 in tables 9-22. A single table is devoted to each of the body segments as well as to the total body. Each table is divided into three parts with the upper section containing descriptive statistics, the center section predictive equations, and the lower section simple ratios.

Each of the body segments is described by a weight, a volume, and a center of mass location. For the smaller segments, the center of mass is located in the X as well as the Z plane with the anteroposterior depth of the segments at the center of mass (AP at CM) also being given. The location of the center of mass in the Y plane was not measured on the body segments and is assumed to lie in the mid-line of the segment in each instance.

The results obtained in measuring both the right and left sides for segmental variables have been averaged in a manner similar to that carried out for the anthropometric data. The rationale

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[1] In general, body lengths correspond most highly with stature and body girths with weight, with only a moderate relationship being found between stature and weight. For a practical application of these relationships see Emanuel *et al.*, 1959, or McConville and Alexander, 1963.

for this is the same as was used in averaging the anthropometric data and involved an identical type of evaluation. The average weight of segments from the right side was found in each instance to be greater than the averages for the left, with the difference being 1% or less of the total segment weight for the leg and leg segments. The difference in right and left average arm segment weight was found to be proportionally greater with the largest difference, 4.8% (81 g), being associated with the weight of the upper arm. This difference is assumed to be due to muscle development related to use and handedness. The combining of the data from the right and left sides is not believed to have resulted in a significant decrease in information and greatly simplifies the presentation of the analysis that follows.

The total body weight given in table 9 (variable 74) differs from that given in table 8 (variable 5). This difference reflects the body fluids lost during the course of the work. The body weight given in table 9 is the one used in the following analysis and is the value that reflects more closely the actual sum of the weight of segments. Despite numerous precautions to retard fluid losses and prevent evaporation of body fluids through the epidermis, the segments lost weight during the various steps of the study. For example, the sum of the weight and volume for the foot plus calf plus thigh was always less than the measured weight and volume of the total leg. To prevent carrying this type of discrepancy into the analysis, an adjustment was made to the values for the segments so that the sum of parts and the total segment values would be equal. Thus, if the sum of the parts was 50 grams less, for example, than the total segment's original weight, then the weight of each part was adjusted upward by that amount of the difference so that each part was as a ratio of its mass to that of the total segment. The volume was then adjusted upward to maintain the density of the segment at its original level.

The descriptive statistics are followed by a series of equations that permit the prediction of a segment variable from anthropometric dimensions. The multi-step regression equations were obtained by using a step-wise regression computer program. This program selected body dimensions (variables 1-73) having the maximum power to predict a given segment variable. The initial anthropometric variable was selected on the basis of the largest correlation coefficient, and then partial correlation coefficients were computed from which the next variable having the greatest predictive power was selected. The process was then repeated to obtain the third prediction variable.

The predictive equations were restricted to three or less steps because of the small sample size. There is, also, a decreasing efficiency (in terms of predictive power) in the addition of steps in the regression equation after a certain level is reached. Here again, the small sample size is a limiting factor, as one degree of freedom is lost for each added step in the regression equation.

Body size variables used in each equation were restricted to those measured directly on the segment involved and body weight. If, for example, the weight of the arm were to be predicted, the only variables that could be selected are measurements of arm size or total body weight. The latter was included as it often provided a better prediction of segment weight than any other single variable. In addition, when two anthropometric variables had essentially the same level of predictive power, the one that we believed would be the easiest to measure with the greatest accuracy was selected. This selection was made possible by weighting certain variables so they would appear first in the equation. The cut-off point in terms of the number of steps in any equation was based upon the rate of decrease in the standard error of estimate (Se_{est}). For most variables, a three step equation is given, although the Se_{est} may not show a marked decrease in the third step. In a few instances, the second and third steps are not given, indicating that the Se_{est} shown is the lowest that could be obtained by using the available predictive variables.

TABLE 9

TOTAL BODY

DESCRIPTIVE STATISTICS

	RANGE	MEAN	(SE)	S.D.	(SE)	CV
74 WEIGHT*	53.240 - 86.819	65.606	(2.40)	8.640	(1.69)	13.17
75 VOLUME	51.740 - 83.721	62.989	(2.34)	8.451	(1.66)	13.42
76 CM-TOP OF HEAD	65.2 - 74.4	71.11	(0.66)	2.39	(0.47)	3.36

PREDICTIVE EQUATIONS

	WEIGHT 74	CHEST CIRC 43	WAIST BREADTH 31	CONSTANT	R	SE EST
75 VOLUME	0.970			- 0.650	.992	1.13
	0.802	+ 0.288		- 16.525	.996	0.79
	0.703	+ 0.299	+ 0.305	- 20.388	.999	0.49

	WEIGHT 74	EST STATURE 6	CHEST CIRC 43	CONSTANT	R	SE EST
76 CM-TOP OF HEAD	0.199			+ 58.052	.720	1.73
	0.139	+ 0.147		+ 36.598	.777	1.63
	0.357	+ 0.239	- 0.441	+ 47.591	.914	1.11

LOCATION OF CENTER OF MASS AS A RATIO OF SEGMENT SIZE

	RANGE	MEAN (SE)	S.D. (SE)	CV
133 CM-TOP OF HEAD/STATURE	39.4 - 43.1	41.19 (0.32)	1.14 (0.22)	2.78

Weight in kilograms, volume in liters, body fat in millimeters, and all other dimensions in centimeters.
*See page 41.

TABLE 10

HEAD AND TRUNK

DESCRIPTIVE STATISTICS

	RANGE	MEAN	(SE)	S.D.	(SE)	CV
77 WEIGHT	30.237 - 50.542	38.061	(1.44)	5.180	(1.02)	13.61
78 VOLUME	30.080 - 49.085	37.123	(1.42)	5.115	(1.00)	13.78
79 CM-TOP OF HEAD	43.0 - 53.7	48.52	(0.72)	2.60	(0.51)	5.37

PREDICTIVE EQUATIONS

				CONSTANT	R	SE EST
	WEIGHT 74	TRUNK LENGTH 59	CHEST DEPTH 30			
77 WEIGHT	0.580			+ 0.009	.968	1.36
	0.521	+ 0.362		- 17.077	.980	1.11
	0.491	+ 0.504	+ 0.370	- 31.122	.987	0.93
	WEIGHT 74	CHEST CIRC 43	TRUNK LENGTH 59			
78 VOLUME	0.563			+ 0.137	.951	1.65
	0.358	+ 0.355		- 19.331	.970	1.35
	0.228	+ 0.450	+ 0.448	- 45.797	.988	0.90
	BICRISTAL BR 33	HEAD-TRK LTH 57	EST STATURE 6			
79 CM-TOP OF HEAD	0.839			+ 23.539	.897	1.20
	0.491	+ 0.402		+ 1.313	.935	1.01
	0.421	+ 0.582	- 0.181	+ 14.050	.968	0.75

LOCATION OF CENTER OF MASS AS A RATIO OF SEGMENT SIZE

	RANGE	MEAN (SE)	S.D. (SE)	CV
134 CM-TOP OF HEAD/H+TRUNK LTH	56.4 - 62.6	59.21 (0.44)	1.60 (0.31)	2.70

RATIO OF THE WEIGHT OF A SEGMENT AS A PERCENT OF TOTAL BODY WEIGHT

	RANGE	MEAN (SE)	S.D. (SE)	CV
137 HEAD+TRUNK WT/BODY WT	54.4 - 61.3	58.01 (0.36)	2.00 (0.39)	3.45

Weight in kilograms, volume in liters, body fat in millimeters, and all other dimensions in centimeters.

TABLE 11

TOTAL LEG

DESCRIPTIVE STATISTICS

	RANGE	MEAN	(SE)	S.D.	(SE)	CV
80 WEIGHT	8.672 - 13.935	10.563	(0.42)	1.516	(0.30)	14.35
81 VOLUME	8.254 - 13.362	9.955	(0.41)	1.468	(0.29)	14.74
82 CM-TROCHANTERION	31.6 - 39.3	34.68	(0.53)	1.90	(0.37)	5.48
83 AP AT CM	10.2 - 13.9	12.04	(0.30)	1.09	(0.21)	9.09
84 CM-ANT ASPECT	5.9 - 9.1	7.59	(0.23)	0.83	(0.16)	10.99

PREDICTIVE EQUATIONS

				CONSTANT	R	SE EST
	WEIGHT 74	CALF CIRC 48	UPPER THIGH C 46			
80 WEIGHT	0.161			- 0.000	.919	0.62
	0.115	+ 0.221		- 3.792	.954	0.50
	0.094	+ 0.146	+ 0.113	- 5.455	.964	0.46
	WEIGHT 74	UPPER THIGH C 46				
81 VOLUME *	0.157			- 0.345	.924	0.58
	0.105	+ 0.157		- 4.370	.955	0.47
	TIBIALE HT 21	CALF CIRC 48	UPPER THIGH C 46			
82 CM-TROCH	0.518			+ 11.016	.638	1.52
	0.534	+ 0.099		+ 7.235	.650	1.57
	0.562	+ 0.404	- 0.264	+ 9.061	.721	1.50
	AP AT CM 83	WEIGHT 74	ILIAC CR FAT 72			
84 CM-ANT ASPECT	0.530			+ 1.212	.695	0.62
	0.795	- 0.053		+ 1.499	.817	0.52
	0.935	- 0.054	- 0.050	+ 0.408	.894	0.43

LOCATION OF CENTER OF MASS AS A RATIO OF SEGMENT SIZE

	RANGE	MEAN (SE)	S.D. (SE)	CV
135 CM-TROCH/TROCHANTERIC HT	34.5 - 40.6	38.21 (0.46)	1.67 (0.33)	4.38
136 CM-ANT ASPECT/AP AT CM	55.7 - 74.0	63.13 (1.41)	5.07 (0.99)	8.03

RATIO OF THE WEIGHT OF A SEGMENT AS A PERCENT OF TOTAL BODY WEIGHT

	RANGE	MEAN (SE)	S.D. (SE)	CV
158 LEG WEIGHT/BODY WEIGHT	14.3 - 17.5	16.10 (0.26)	0.94 (0.18)	5.84

Weight in kilograms, volume in liters, body fat in millimeters, and all other dimensions in centimeters.
*Additional steps do not improve the effectiveness of prediction.

TABLE 12

TOTAL ARM

DESCRIPTIVE STATISTICS

	RANGE	MEAN	(SE)	S.D.	(SE)	CV
85 WEIGHT	2.647 - 4.177	3.216	(0.13)	0.464	(0.09)	14.44
86 VOLUME	2.383 - 3.956	2.978	(0.12)	0.445	(0.09)	14.96
87 CM-ACROMION	29.2 - 37.7	31.98	(0.61)	2.20	(0.43)	6.87

PREDICTIVE EQUATIONS

				CONSTANT	R	SE EST
	WEIGHT 74	WRIST CIRC 55	BICEPS CIRC 52			
85 WEIGHT	0.047			+ 0.132	.883	0.23
	0.031	+ 0.186		- 1.894	.929	0.19
	0.014	+ 0.182	+ 0.083	- 3.041	.952	0.16
	WEIGHT 74	WRIST CIRC 55	BICEPS CIRC 52			
86 VOLUME	0.047			- 0.106	.907	0.20
	0.032	+ 0.165		- 1.850	.945	0.16
	0.015	+ 0.161	+ 0.080	- 2.913	.968	0.13
	B HUM-RAD LTH 65	FOREARM CIRC 54	ARM CIRC(AX) 51			
87 CM-ACROMION	0.966			+ 2.336	.684	1.67
	0.947	+ 0.391		- 7.353	.729	1.64
	0.963	+ 0.918	- 0.571	- 4.909	.842	1.35

LOCATION OF CENTER OF MASS AS A RATIO OF SEGMENT SIZE

	RANGE	MEAN (SE)	S.D. (SE)	CV
137 CM-ACROMION/ARM LENGTH	39.3 - 44.8	41.26 (0.44)	1.59 (0.31)	3.86

RATIO OF THE WEIGHT OF A SEGMENT AS A PERCENT OF TOTAL BODY WEIGHT

	RANGE	MEAN (SE)	S.D. (SE)	CV
139 ARM WEIGHT/BODY WEIGHT	4.4 - 5.4	4.90 (0.09)	0.34 (0.07)	6.85

Weight in kilograms, volume in liters, body fat in millimeters, and all other dimensions in centimeters.

TABLE 13

HEAD

DESCRIPTIVE STATISTICS

	RANGE	MEAN	(SE)	S.D.	(SE)	CV
88 WEIGHT	4.333 - 5.307	4.729	(0.09)	0.324	(0.06)	6.86
89 VOLUME	3.929 - 4.925	4.418	(0.10)	0.350	(0.07)	7.92
90 CM-TOP OF HEAD	10.0 - 12.6	11.15	(0.21)	0.74	(0.15)	6.65
91 CM-BACK OF HEAD	7.0 - 9.0	7.98	(0.17)	0.60	(0.12)	7.54

PREDICTIVE EQUATIONS

			CONSTANT	R	SE EST
	HEAD CIRC 41	WEIGHT 74			
88 WEIGHT *	0.148		- 3.716	.814	0.20
	0.104	+ 0.015	- 2.189	.875	0.17
	HEAD CIRC 41	WEIGHT 74			
89 VOLUME *	0.173		- 5.453	.883	0.17
	0.139	+ 0.012	- 4.301	.912	0.16
	HEAD CIRC 41	HT OF HEAD 58			
90 CM-TOP OF HEAD *	0.293		- 5.573	.704	0.55
	0.246	+ 0.159	- 6.711	.731	0.55
	HEAD CIRC 41	HEAD BREADTH 24			
91 CM-BACK OF HEAD *	0.158		- 1.039	.468	0.55
	0.238	- 0.570	+ 3.376	.541	0.55

LOCATION OF CENTER OF MASS AS A RATIO OF SEGMENT SIZE

	RANGE	MEAN (SE)	S.D. (SE)	CV
138 CM-TOP OF HEAD/HT OF HEAD	42.2 - 50.4	46.42 (0.73)	2.63 (0.52)	5.66
139 CM-BACK OF HEAD/HEAD LGTH	35.0 - 44.7	39.96 (0.82)	2.97 (0.58)	7.44

RATIO OF THE WEIGHT OF A SEGMENT AS A PERCENT OF TOTAL BODY WEIGHT

	RANGE	MEAN (SE)	S.D. (SE)	CV
160 HEAD WEIGHT/BODY WEIGHT	5.9 - 8.2	7.28 (0.16)	0.59 (0.12)	8.16

Weight in kilograms, volume in liters, body fat in millimeters, and all other dimensions in centimeters.
*Additional steps do [illegible] improve the effectiveness of prediction.

TABLE 14

TRUNK

DESCRIPTIVE STATISTICS

	RANGE	MEAN	(SE)	S.D.	(SE)	CV
92 WEIGHT	25.809 - 45.337	33.312	(1.37)	4.931	(0.97)	14.80
93 VOLUME	26.127 - 44.386	32.691	(1.35)	4.860	(0.95)	14.87
94 CM-SUPRASTERNALE	19.8 - 24.2	22.02	(0.40)	1.43	(0.28)	6.48

PREDICTIVE EQUATIONS

				CONSTANT	R	SE EST
	WEIGHT 74	TRUNK LENGTH 59	CHEST CIRC 43			
92 WEIGHT	0.551			- 2.837	.966	1.33
	0.494	+ 0.347		- 19.186	.979	1.11
	0.349	+ 0.423	+ 0.229	- 35.460	.986	0.92
	WEIGHT 74	WAIST BREADTH 31	CHEST CIRC 43			
93 VOLUME	0.534			- 2.343	.949	1.59
	0.389	+ 0.476		- 7.392	.968	1.33
	0.179	+ 0.502	+ 0.347	- 26.817	.988	0.86
	BI-SPINOUS BR 34	ILIAC CR FAT 72	TRUNK LENGTH 59			
94 CM-SUPRASTERN	0.578			+ 8.102	.846	0.79
	0.622	- 0.066		+ 7.741	.900	0.68
	0.471	- 0.058	+ 0.166	+ 1.683	.926	0.61

LOCATION OF CENTER OF MASS AS A RATIO OF SEGMENT SIZE

	RANGE	MEAN (SE)	S.D. (SE)	CV
140 CM-SUPRASTERN/TRUNK LGTH	35.6 - 41.1	38.03 (0.43)	1.55 (0.30)	4.08

RATIO OF THE WEIGHT OF A SEGMENT AS A PERCENT OF TOTAL BODY WEIGHT

	RANGE	MEAN (SE)	S.D. (SE)	CV
161 TRUNK WEIGHT/BODY WEIGHT	46.7 - 53.7	30.70 (0.57)	2.06 (0.40)	4.07

Weight in kilograms, volume in liters, body fat in millimeters, and all other dimensions in centimeters.

TABLE 15

THIGH

DESCRIPTIVE STATISTICS

	RANGE	MEAN	(SE)	S.D.	(SE)	CV
95 WEIGHT	5.414 - 9.437	6.749	(0.32)	1.158	(0.23)	17.16
96 VOLUME	5.331 - 9.119	6.462	(0.31)	1.129	(0.22)	17.47
97 CM-TROCHANTERION	14.9 - 19.0	16.80	(0.34)	1.21	(0.24)	7.21
98 AP AT CM	13.0 - 17.8	15.78	(0.48)	1.72	(0.34)	10.90
99 CM-ANT ASPECT	6.4 - 10.9	8.43	(0.34)	1.22	(0.24)	14.49

PREDICTIVE EQUATIONS

	WEIGHT 74	UPPER THIGH C 46	ILIAC CR FAT 72	CONSTANT	R	SE EST
95 WEIGHT	0.120			- 1.123	.893	0.54
	0.074	+ 0.138		- 4.641	.933	0.45
	0.074	+ 0.123	+ 0.027	- 4.216	.944	0.43

	WEIGHT 74	UPPER THIGH C 46	ILIAC CR FAT 72	CONSTANT	R	SE EST
96 VOLUME	0.116			- 1.149	.888	0.54
	0.073	+ 0.128		- 4.390	.924	0.47
	0.073	+ 0.106	+ 0.039	- 3.760	.950	0.40

	TROCH HT 20	KNEE BR/BONE 37	ILIAC CR FAT 72	CONSTANT	R	SE EST
97 CM-TROCH	0.250			- 5.902	.841	0.68
	0.214	+ 0.902		- 11.660	.918	0.52
	0.227	+ 0.989	- 0.033	- 13.362	.934	0.49

	AP AT CM 98	CONSTANT	R	SE EST
99 CM-ANT ASPECT *	0.595	- 0.956	.838	0.69

LOCATION OF CENTER OF MASS AS A RATIO OF SEGMENT SIZE

	RANGE	MEAN	(SE)	S.D.	(SE)	CV
141 CM-TROCHANTERION/THIGH LGTH	34.4 - 39.6	37.19	(0.47)	1.69	(0.33)	4.55
142 CM-ANT ASPECT/AP AT CM	48.2 - 62.3	53.35	(1.15)	4.16	(0.82)	7.79

RATIO OF THE WEIGHT OF A SEGMENT AS A PERCENT OF TOTAL BODY WEIGHT

	RANGE	MEAN	(SE)	S.D.	(SE)	CV
162 THIGH WEIGHT/BODY WEIGHT	8.9 - 11.4	10.27	(0.23)	0.82	(0.16)	8.00

Weight in kilograms, volume in liters, body fat in millimeters, and all other dimensions in centimeters.
*Additional steps do not improve the effectiveness of prediction.

TABLE 16

CALF AND FOOT

DESCRIPTIVE STATISTICS

	RANGE	MEAN	(SE)	S.D.	(SE)	CV
100 WEIGHT	2.913 - 4.518	3.805	(0.12)	0.442	(0.09)	11.61
101 VOLUME	2.691 - 4.166	3.505	(0.11)	0.406	(0.08)	11.59
102 CM-TIBIALE	19.7 - 24.4	21.67	(0.30)	1.07	(0.21)	4.93
103 AP AT CM	7.1 - 9.9	8.48	(0.25)	0.90	(0.18)	10.60
104 CM-ANT ASPECT	1.7 - 3.9	2.84	(0.17)	0.62	(0.12)	21.83

PREDICTIVE EQUATIONS

	CALF CIRC 48	TIBIALE HT 21	ANKLE CIRC 49	CONSTANT	R	SE EST
100 WEIGHT	0.165			- 1.279	.934	0.16
	0.172	+ 0.051		- 3.824	.971	0.11
	0.130	+ 0.058	+ 0.103	- 4.915	.982	0.09

	CALF CIRC 48	TIBIALE HT 21	ANKLE CIRC 49	CONSTANT	R	SE EST
101 VOLUME	0.148			- 1.056	.911	0.17
	0.155	+ 0.050		- 3.555	.955	0.13
	0.103	+ 0.059	+ 0.127	- 4.910	.975	0.10

	TIBIALE HT 21	CALF CIRC 48	CONSTANT	R	SE EST
102 CM-TIBIALE *	0.360		+ 5.226	.789	0.68
	0.335	- 0.159	+ 11.267	.871	0.57

	AP AT CM 103	CALF LENGTH 61	CONSTANT	R	SE EST
104 CM-ANT ASPECT *	0.539		- 1.731	.782	0.40
	0.646	+ 0.114	- 7.044	.850	0.35

LOCATION OF CENTER OF MASS AS A RATIO OF SEGMENT SIZE

	RANGE	MEAN (SE)	S.D. (SE)	CV
143 CM-TIBIALE/TIBIALE HT	44.7 - 50.7	47.47 (0.43)	1.54 (0.30)	3.25
144 CM-ANT ASPECT/AP AT CM	23.1 - 40.6	33.25 (1.46)	5.26 (1.03)	15.81

RATIO OF THE WEIGHT OF A SEGMENT AS A PERCENT OF TOTAL BODY WEIGHT

	RANGE	MEAN (SE)	S.D. (SE)	CV
165 CALF+FOOT WEIGHT/BODY WT	5.2 - 6.7	5.92 (0.12)	0.44 (0.09)	7.53

Weight in kilograms, volume in liters, body fat in millimeters, and all other dimensions in centimeters.
*Additional steps do not improve the effectiveness of prediction.

TABLE 17

CALF

DESCRIPTIVE STATISTICS

	RANGE	MEAN	(SE)	S.D.	(SE)	CV
105 WEIGHT	2.125 - 3.419	2.842	(0.10)	0.363	(0.07)	12.77
106 VOLUME	1.950 - 3.194	2.620	(0.09)	0.340	(0.07)	12.99
107 CM-TIBIALE	12.9 - 16.5	14.32	(0.22)	0.81	(0.16)	5.63
108 AP AT CM	8.5 - 11.7	10.06	(0.28)	1.00	(0.20)	9.93
109 CM-ANT ASPECT	2.9 - 5.7	4.28	(0.19)	0.68	(0.13)	15.97

PREDICTIVE EQUATIONS

	CALF CIRC 48	TIBIALE HT 21	ANKLE CIRC 49	CONSTANT	R	SE EST
105 WEIGHT	0.135			- 1.318	.933	0.14
	0.141	+ 0.042		- 3.421	.971	0.09
	0.111	+ 0.047	+ 0.074	- 4.208	.979	0.08

	CALF CIRC 48	TIBIALE HT 21	ANKLE CIRC 49	CONSTANT	R	SE EST
106 VOLUME	0.123			- 1.170	.908	0.15
	0.130	+ 0.044		- 3.396	.956	0.11
	0.090	+ 0.051	+ 0.097	- 4.427	.973	0.09

	TIBIALE HT 21	KNEE BR/BONE 37	CONSTANT	R	SE EST
107 CM-TIBIALE *	0.276		+ 1.709	.800	0.50
	0.309	- 0.558	+ 5.786	.872	0.43

	AP AT CM 108	CALF LENGTH 61	CONSTANT	R	SE EST
109 CM-ANT ASPECT *	0.455		- 0.301	.665	0.53
	0.503	+ 0.101	- 4.688	.725	0.51

LOCATION OF CENTER OF MASS AS A RATIO OF SEGMENT SIZE

	RANGE	MEAN	(SE)	S.D.	(SE)	CV
145 CM-TIBIALE/CALF LENGTH	34.7 - 38.6	37.05	(0.36)	1.30	(0.26)	3.52
146 CM-ANT ASPECT/AP AT CM	34.1 - 49.6	42.47	(1.42)	5.12	(1.00)	12.05

RATIO OF THE WEIGHT OF A SEGMENT AS A PERCENT OF TOTAL BODY WEIGHT

	RANGE	MEAN	(SE)	S.D.	(SE)	CV
164 CALF WEIGHT/BODY WEIGHT	3.9 - 5.1	4.35	(0.10)	0.36	(0.07)	8.38

Weight in kilograms, volume in liters, body fat in millimeters, and all other dimensions in centimeters.
*Additional steps do not improve the effectiveness of prediction.

TABLE 18

FOOT

DESCRIPTIVE STATISTICS

	RANGE	MEAN	(SE)	S.D.	(SE)	CV
110 WEIGHT	0.760 - 1.159	0.959	(0.03)	0.091	(0.02)	9.49
111 VOLUME	0.699 - 1.048	0.885	(0.02)	0.083	(0.02)	9.38
112 CM-HEEL	10.3 - 11.6	11.11	(0.11)	0.39	(0.08)	3.47
113 CM-SOLE	2.5 - 5.0	3.75	(0.17)	0.62	(0.12)	16.44

PREDICTIVE EQUATIONS

				CONSTANT	R	SE EST
	WEIGHT 74	ANKLE CIRC 49	FOOT LENGTH 62			
110 WEIGHT	0.009			+ 0.369	.810	0.06
	0.005	+ 0.033		- 0.030	.882	0.05
	0.003	+ 0.048	+ 0.027	- 0.869	.907	0.04
	WEIGHT 74	ANKLE CIRC 49	FOOT LENGTH 62			
111 VOLUME	0.008			+ 0.360	.810	0.05
	0.005	+ 0.029		- 0.025	.875	0.04
	0.003	+ 0.043	+ 0.025	- 0.794	.901	0.04
	FOOT LENGTH 62	ANKLE CIRC 49	LAT MALL HT 22			
112 CM-HEEL	0.217		-	+ 5.729	.566	0.33
	0.233	+ 0.135		+ 2.627	.712	0.29
	0.153	+ 0.137	+ 0.444	+ 1.403	.827	0.25
	ARCH CIRC 50					
113 CM-SOLE *	0.325			- 4.639	.672	0.47

LOCATION OF CENTER OF MASS AS A RATIO OF SEGMENT SIZE

	RANGE	MEAN (SE)	S.D. (SE)	CV
147 CM-HEEL/FOOT LENGTH	43.1 - 47.7	44.85 (0.44)	1.59 (0.31)	3.55
148 CM-SOLE/SPHYRION HEIGHT	33.3 - 73.5	53.78 (2.80)	10.09 (1.98)	18.76

RATIO OF THE WEIGHT OF A SEGMENT AS A PERCENT OF TOTAL BODY WEIGHT

	RANGE	MEAN (SE)	S.D. (SE)	CV
165 FOOT WEIGHT/BODY WEIGHT	1.2 - 1.6	1.47 (0.03)	0.10 (0.02)	6.92

Weight in kilograms, volume in liters, body fat in millimeters, and all other dimensions in centimeters.
*Additional steps do not improve the effectiveness of prediction.

TABLE 19

UPPER ARM

DESCRIPTIVE STATISTICS

	RANGE	MEAN	(SE)	S.D.	(SE)	CV
114 WEIGHT	1.365 - 2.305	1.730	(0.08)	0.290	(0.06)	16.78
115 VOLUME	1.243 - 2.250	1.638	(0.08)	0.293	(0.06)	17.91
116 CM-ACROMION	14.2 - 20.3	17.13	(0.44)	1.60	(0.31)	9.33
117 AP AT CM	8.9 - 11.8	10.16	(0.25)	0.90	(0.18)	8.90
118 CM-ANT ASPECT	4.5 - 5.9	5.18	(0.13)	0.46	(0.09)	8.87

PREDICTIVE EQUATIONS

	WEIGHT 74	ARM CIRC(AX) 51	ACROM-RAD LTH 64	CONSTANT	R	SE EST
114 WEIGHT	0.030			- 0.238	.879	0.14
	0.019	+ 0.060		- 1.280	.931	0.12
	0.007	+ 0.092	+ 0.050	- 3.101	.961	0.09

	WEIGHT 74	ARM CIRC(AX) 51	ACROM-RAD LTH 64	CONSTANT	R	SE EST
115 VOLUME	0.030			- 0.330	.886	0.14
	0.018	+ 0.070		- 1.600	.953	0.10
	0.008	+ 0.098	+ 0.044	- 3.234	.976	0.07

	B HUM-RAD LTH 65	ARM CIRC(AX) 51	ELBOW BR/BONE 38	CONSTANT	R	SE EST
116 CM-ACROMION	0.707			- 4.563	.689	1.21
	0.710	- 0.045		- 3.333	.691	1.26
	0.329	- 0.250	+ 2.827	- 6.168	.918	0.72

	AP AT CM 117	CONSTANT	R	SE EST
118 CM-ANT ASPECT *	0.444	+ 0.665	.874	0.23

LOCATION OF CENTER OF MASS AS A RATIO OF SEGMENT SIZE

	RANGE	MEAN	(SE)	S.D.	(SE)	CV
149 CM-ACROM/ACROM-RAD LGTH	46.2 - 55.6	51.30	(0.75)	2.72	(0.53)	5.30
150 CM-ANT ASPECT/AP AT CM	46.4 - 56.3	51.00	(0.64)	2.29	(0.45)	4.50

RATIO OF THE WEIGHT OF A SEGMENT AS A PERCENT OF TOTAL BODY WEIGHT

	RANGE	MEAN	(SE)	S.D.	(SE)	CV
166 UPPER ARM WEIGHT/BODY WT	2.2 - 3.1	2.63	(0.06)	0.22	(0.04)	8.38

Weight in kilograms, volume in liters, body fat in millimeters, and all other dimensions in centimeters.
*Additional steps do not improve the effectiveness of prediction.

TABLE 20

FOREARM AND HAND

DESCRIPTIVE STATISTICS

	RANGE	MEAN	(SE)	S.D.	(SE)	CV
119 WEIGHT	1.263 - 1.926	1.483	(0.06)	0.203	(0.04)	13.69
120 VOLUME	1.138 - 1.716	1.349	(0.05)	0.181	(0.04)	13.39
121 CM-RADIALE	14.6 - 18.5	16.21	(0.30)	1.08	(0.21)	6.66
122 AP AT CM	5.7 - 8.0	6.49	(0.17)	0.61	(0.12)	9.45
123 CM-ANT ASPECT	2.6 - 4.5	3.42	(0.17)	0.60	(0.12)	17.46

PREDICTIVE EQUATIONS

	WRIST CIRC 55	FOREARM CIRC 54	RAD-STYL LTH 66	CONSTANT	R	SE EST
119 WEIGHT	0.168			- 1.295	.874	0.10
	0.132	+ 0.049		- 1.987	.919	0.09
	0.103	+ 0.046	+ 0.043	- 2.543	.940	0.08

	WRIST CIRC 55	FOREARM CIRC 54	RAD-STYL LTH 66	CONSTANT	R	SE EST
120 VOLUME	0.153			- 1.181	.890	0.09
	0.117	+ 0.048		- 1.847	.943	0.07
	0.093	+ 0.045	+ 0.035	- 2.278	.960	0.06

	WRIST BR/BONE 39	RAD-STYL LTH 66	FOREARM CIRC 54	CONSTANT	R	SE EST
121 CM-RADIALE	2.765			+ 0.405	.764	0.72
	1.962	+ 0.379		- 4.822	.847	0.62
	1.617	+ 0.585	- 0.331	+ 0.510	.929	0.46

	AP AT CM 122	ELBOW BR/BONE 38	STYL-META 3 67	CONSTANT	R	SE EST
123 CM-ANT ASPECT	0.890			- 2.355	.913	0.25
	0.900	- 0.280		- 0.385	.936	0.23
	0.890	- 0.313	- 0.229	- 2.153	.974	0.16

LOCATION OF CENTER OF MASS AS A RATIO OF SEGMENT SIZE

	RANGE	MEAN (SE)	S.D. (SE)	CV
151 CM-RADIALE/RAD-STYL LGTH	58.5 - 67.7	62.58 (0.81)	2.91 (0.57)	4.64
152 CM-ANT ASPECT/AP AT CM	45.6 - 60.6	52.40 (1.40)	5.04 (0.99)	9.62

RATIO OF THE WEIGHT OF A SEGMENT AS A PERCENT OF TOTAL BODY WEIGHT

	RANGE	MEAN (SE)	S.D. (SE)	CV
167 FOREARM+HAND WT/BODY WT	1.9 - 2.6	2.27 (0.06)	0.20 (0.04)	8.98

Weight in kilograms, volume in liters, body fat in millimeters, and all other dimensions in centimeters.

TABLE 21

FOREARM

DESCRIPTIVE STATISTICS

	RANGE	MEAN	(SE)	S.D.	(SE)	CV
124 WEIGHT	0.850 - 1.380	1.055	(0.04)	0.152	(0.03)	14.41
125 VOLUME	0.781 - 1.250	0.961	(0.04)	0.138	(0.03)	14.40
126 CM-RADIALE	8.1 - 11.6	10.10	(0.23)	0.83	(0.16)	8.22
127 AP AT CM	6.6 - 9.3	7.61	(0.18)	0.66	(0.13)	8.68
128 CM-ANT ASPECT	2.4 - 5.1	3.72	(0.17)	0.62	(0.12)	16.65

PREDICTIVE EQUATIONS

			CONSTANT	R	SE EST
	WRIST CIRC 55	FOREARM CIRC 54			
124 WEIGHT *	0.119		- 0.913	.827	0.09
	0.081	+ 0.052	- 1.650	.920	0.06
	WRIST CIRC 55	FOREARM CIRC 54			
125 VOLUME *	0.111		- 0.875	.842	0.08
	0.072	+ 0.053	- 1.622	.954	0.05
	RAD-STYL LGTH 66	WRIST BR/BONE 39			
126 CM-RADIALE *	0.537		- 3.808	.788	0.53
	0.440	+ 0.761	- 5.645	.821	0.51
	AP AT CM 127				
128 CM-ANT ASPECT *	0.790		- 2.295	.843	0.35

LOCATION OF CENTER OF MASS AS A RATIO OF SEGMENT SIZE

	RANGE	MEAN (SE)	S.D. (SE)	CV
153 CM-RADIALE/RAD-STYL LGTH	34.5 - 42.0	38.96 (0.59)	2.11 (0.41)	5.42
154 CM-ANT ASPECT/AP AT CM	33.8 - 54.8	48.63 (1.44)	5.18 (1.02)	10.66

RATIO OF THE WEIGHT OF A SEGMENT AS A PERCENT OF TOTAL BODY WEIGHT

	RANGE	MEAN (SE)	S.D. (SE)	CV
168 FOREARM WEIGHT/BODY WT	1.4 - 1.9	1.61 (0.04)	0.15 (0.03)	9.60

Weight in kilograms, volume in liters, body fat in millimeters, and all other dimensions in centimeters.
*Additional steps do not improve the effectiveness of prediction.

TABLE 22

HAND

DESCRIPTIVE STATISTICS

	RANGE	MEAN	(SE)	S.D.	(SE)	CV
129 WEIGHT	0.334 - 0.540	0.426	(0.02)	0.063	(0.01)	14.72
130 VOLUME	0.302 - 0.480	0.384	(0.02)	0.057	(0.01)	14.73
131 CM-META 3	1.1 - 2.3	1.63	(0.11)	0.39	(0.08)	24.10
132 CM-MED ASPECT	3.7 - 5.5	4.77	(0.13)	0.47	(0.09)	9.95

PREDICTIVE EQUATIONS

	WRIST CIRC 55	WRIST BR/BONE 39	HAND BRDTH 40	CONSTANT	R	SE EST
129 WEIGHT	0.051			- 0.418	.863	0.03
	0.038	+ 0.080		- 0.660	.917	0.03
	0.029	+ 0.075	+ 0.031	- 0.746	.942	0.02

	WRIST CIRC 55	WRIST BR/BONE 39	HAND BRDTH 40	CONSTANT	R	SE EST
130 VOLUME	0.048			- 0.410	.885	0.03
	0.036	+ 0.071		- 0.617	.935	0.02
	0.028	+ 0.066	+ 0.027	- 0.686	.958	0.02

	WRIST BR/BONE 39	HAND CIRC 56	CONSTANT	R	SE EST
131 CM-META 3 *	0.358		- 0.415	.272	0.39
	0.657	- 0.202	+ 2.130	.486	0.37

	WRIST BR/BONE 39	HAND BRDTH 40	CONSTANT	R	SE EST
132 CM-MED ASPECT *	1.224		- 2.226	.769	0.32
	1.038	+ 0.248	- 3.271	.810	0.30

LOCATION OF CENTER OF MASS AS A RATIO OF SEGMENT SIZE

	RANGE	MEAN	(SE)	S.D.	(SE)	CV
155 CM-META 3/STYL-META 3 LGTH	13.0 - 24.7	18.02	(1.16)	4.17	(0.82)	23.13
156 CM-MED ASPECT/HAND BRDTH	45.7 - 67.1	56.13	(1.33)	4.80	(0.94)	8.55

RATIO OF THE WEIGHT OF A SEGMENT AS A PERCENT OF TOTAL BODY WEIGHT

	RANGE	MEAN	(SE)	S.D.	(SE)	CV
169 HAND WEIGHT/BODY WT	0.5 - 0.8	0.65	(0.02)	0.08	(0.01)	11.64

Weight in kilograms, volume in liters, body fat in millimeters, and all other dimensions in centimeters.
*Additional steps do not improve the effectiveness of prediction.

The regression equations presented in these tables are relatively simple to use. For example, in table 16, the weight of the Calf and Foot (variable 100) is given with relation to one, two, and three anthropometric variables. The dimension of Calf Circ (variable 48) gave the highest correlation coefficient with Calf and Foot weight ($r = .932$). The regression equation is: Weight of Calf and Foot (kg) = 0.165 Calf Circ (cm) − 1.279 (±0.16 kg).

If the average values for the cadaver sample (table 8) are used for the independent variable, the three step equation becomes: Weight of Calf plus Foot = 0.130 x 30.82 (Calf Circ.) + 0.058 x 45.68 (Tibiale Ht.) + 0.103 x 20.05 (Ankle Circ.) − 4.915 = 3.806 kg ± 0.090 kg.

The predicted value of the Calf plus Foot weight for the sample is 3.806 kg with the true value for such a sample falling between 3.716 kg and 3.896 kg (3.806 ± .090) in two out of three such samples.

Simple ratios for predicting weight and location of the center of mass as a function of body weight, segment length, and the anteroposterior depth of the segment at its center of mass are given at the bottom of each table. The ratio of segment weight to total body weight and center of mass from proximal end as a ratio of segment length have been the most widely used methods of reporting segment data and are given here to facilitate comparison with previous studies (tables 2 and 4). Such comparisons are necessarily gross because of the variation in methods of dismemberment used by different authors. In this study, the length of a segment is defined as the distance between specific bony landmarks that approximate, but are not necessarily coincident with, the ends of the segment. Trochanterion, radiale, and tibiale are traditional anthropometric approximations for the "hinge points" at the hip, elbow, and knee but are all somewhat distal to the actual plane of segmentation used in this study. The ratios for the center of mass often, therefore, are not precisely comparable to the ratios obtained by other investigators who may have used only approximately the same plane of segmentation for that particular segment.

There are a number of patterns that become apparent when the predictive equations are viewed together. Total body weight appears as one of the best anthropometric variables for predicting the weight and volume of segments, occurring more often than any other single variable. The body circumferences are also often selected to predict segment weight, whereas segment lengths most often occur in the prediction of the location of center of mass of segments.

A number of methods for estimating weight and center of mass have been given in the preceding discussion. It is a natural desire, when alternative methods of making an approximation are given, to know which method is the most accurate or appropriate for a given problem. The regression equations were used to predict the weight and the location of the center of mass for each segment of each cadaver. The various ratios were also computed and the resulting values compared to the actual weight and location of center of mass of each segment. These comparisons show that the three step regression equations, without exception, provide the smallest average error for predicting the unknown variables on the cadavers. In fact, the three step equations generally reduce the average error (actual-predicted) to one half, or less, of the average error obtained by using the ratios or single step equations. Without exception, the simple ratios provided the poorest average estimate, with improvement found with the addition of each step of the equation.[1] This is not to say that the multi-step equations always provided a better estimate for a single segmental value than did the simple ratio; in a few instances, the simple ratio provided the best estimate for a single segment from a single cadaver. In terms of all the segments from all of the cadavers, the multi-step equations were clearly more effective in providing an estimate closer to the mea-

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[1] When the single step equation to predict segment weight uses body weight as the predicting variable, the results are identical to those obtained using the simple ratio.

sured value. The multiple step equations, however, necessitate the maximum amount of information concerning the anthropometry of the sample. On the other hand, the simple ratios can be used when the minimum anthropometric data are available, and provide the first but least accurate prediction. For these reasons, the alternate methods of computing unknowns have been provided in order that the techniques of computation can be tailored to the availability of body-size information.

It is also pertinent to determine the appropriateness of these equations for the living. The ability to transfer the equations formulated on a cadaver population to a live population is not without danger because of the numerous uncertainties that have previously been cited. A validation of the predictive equations developed in this study is clearly desirable.

In working with many biological populations, the general validating procedure would be to select a representative sample from the population, make the necessary measurements, and then compute the values for the unknown variables. Animals could then be sacrificed and the unknown values measured. If the values computed should provide a sufficiently accurate estimate of the true values, the equations would be considered to have been validated for the represented population. In working with human populations, the validation procedure is indirect and may not be fully satisfactory as rigorous proof.

If the volume of body segments could be measured accurately on the living, then it would be possible to validate the predictive equation for the segment volume and indirectly validate the approach that was used. In obtaining the volume of the cadaver segments, we found that repeated measurements of a segment could be held within a range of ±0.5% or less of the segment's average volume. The experimental error has been found to be much larger than ±0.5%, however, when segmental volumes of the living were determined using the same equipment and landmarks as had been used for the cadavers. For major segments such as the arm or leg, the range of repeated observations became as high as 3 to 5% of the total average volume. The higher error was related to the difficulties encountered in maintaining a subject's body segment relatively motionless at a specific depth in the tank for the period of time necessary to allow runoff of the displaced water. Contini indicated that his group has been able to obtain the volume of the more distal segments on the living with a small error, using specially developed equipment.[1] This equipment does not, however, appear to be usable for the larger segments of the body. Until new techniques of measuring segmental volumes accurately on the living can be developed, this approach to the validation of the predictive equations does not appear to be satisfactory.

As it is not possible to validate satisfactorily the predictive equation on the living, an attempt was made to determine the reasonableness and consistency of predicted segment variables for the living. Three individuals were selected that represented a wide range of adult male body types. The subjects were measured for the body dimensions needed, and the weight for each segment was computed, using the three step equations given in tables 9-22. The results obtained for the segment weights are given in table 23.

The column to the left for each subject gives the predicted values for the weight of each segment, and the column on the right (values in parentheses) gives the sum of the component segments. In general, the internal consistency, that is, the sum of the small component segments equaling the value of a total segment, is remarkably good. This, of course, should be true when the same anthropometric dimensions are used to predict the segmental parameter for both the total segment and the segment's parts. Where this is not true, the values of the total and sum of parts

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[1] Personal communication with R. Contini. For details of the technique and equipment see: Drillis and Contini (1966).

appear to be very comparable. The greatest discrepancy in values is in the difference between Head-Trunk weight and the sum Head weight and Trunk weight for subjects A and B. This difference is larger than expected, and the reason for it is not understood.

TABLE 23

PREDICTED WEIGHT OF BODY SEGMENTS OF THE LIVING (kg)

Subject	*A*	*B*	*C*
Stature (cm)	161.5	178.3	175.5
Weight	58.523(57.937)	71.200(73.210)	84.350(84.333)
Weight of:			
Head-Trunk	32.368(30.737)	41.575(40.030)	48.931(48.905)
Leg	10.320(10.430)	12.574(12.716)	13.580(13.572)
Arm	3.103(2.900)	3.440(3.874)	4.142(4.124)
Head	4.357	4.976	6.140
Trunk	26.380	35.054	42.765
Thigh	6.298	8.394	8.663
Calf and Foot	4.173(4.133)	4.322(4.322)	4.909(4.909)
Calf	3.144	3.279	3.669
Foot	.989	1.043	1.240
Upper Arm	1.425	2.114	2.218
Forearm and Hand	1.455(1.425)	1.741(1.760)	1.915(1.906)
Forearm	1.045	1.314	1.358
Hand	.380	.446	.548

A second area of discrepancy is in the sum of parts not equaling the total body weight. For subject A, the sum of parts is less than the total body weight; for subject B, the sum of parts exceeds the total; and for subject C the sum and the total body weight are essentially equal. Initially we believed that the sum of the predicted weights of segments would always give an overestimate of the actual total body weight on the living. The logic involved was that the cadavers had certainly lost body fluid after death that would effectively reduce the body circumferences on which the predictive equations were based. The use of the body cricumferences of the living would, therefore, tend to overestimate the weight of each segment so that the sum of the weight of segments would exceed the actual live weight. If it can be assumed that the fluid losses are equal throughout the body, then when the sum of parts needs to be equated to the body weight, the adjustment should be proportional for all segments. For example, for subject B, live body weight is equal to 97.25% of the estimated sum of component weights. In order to adjust the sum of parts to the observed body weight, each of the smaller segments must be multiplied by the constant 97.25% to arrive at the adjusted weight for each of the component parts. This process will preserve the relationships of the weights of the various segments, while making the sum of parts equal to the observed total body weight.

The methods of predicting the weight and the location of the center of mass of body segments presented are believed to represent a marked improvement over the methods used in the past, but must still be considered as approximations for the unknown quantities. They do, however, permit the estimates of the weight and the location of the center of mass of the segments to be based upon the individual variability in body size, which until this time, had not been adequately considered.

Summary and Conclusions

It is desirable to determine how the results obtained in this study compare with the results obtained by earlier workers. As previously pointed out, differences in the techniques of dismemberment, etc., are such that any comparisons are necessarily gross and only indicative of similarities and/or differences between results or both.

The comparisons of primary interest are those of (1) the segmental weight as a ratio of total body weight and (2) the location of the center of mass from the proximal end of the segment as a ratio of segment length. These two comparisons are shown in tables 24 and 25.

TABLE 24

SEGMENTAL WEIGHT/BODY WEIGHT RATIOS FROM SEVERAL CADAVER STUDIES*

Source	Harless (1860)	Braune and Fischer (1889)	Fischer (1906)	Dempster (1955)	Dempster† (1955)	This Study
Sample Size	2	3	1	8	8	13
Head	7.6%	7.0%	8.8%	7.9%	(8.1)%	7.3
Trunk	44.2	46.1	45.2	48.6	(49.7)	50.7
Total Arm	5.7	6.2	5.4	4.9	(5.0)	4.9
Upper Arm	3.2	3.3	2.8	2.7	(2.8)	2.6
Foreram & Hand	2.6	2.9	2.6	2.2	(2.2)	2.3
Forearm	1.7	2.1	.....	1.6	(1.6)	1.6
Hand	0.9	0.8	.....	0.6	(0.6)	0.7
Total Leg	18.4	17.2	17.6	15.7	(16.1)	16.1
Thigh	11.9	10.7	11.0	9.7	(9.9)	10.3
Calf & Foot	6.6	6.5	6.6	6.0	(6.1)	5.8
Calf	4.6	4.8	4.5	4.5	(4.6)	4.3
Foot	2.0	1.7	2.1	1.4	(1.4)	1.5
Sum‡	100.0	100.0	100.0	97.7	100.0	100.0

*(Studies of Japanese populations by Mori and Yamamoto (1959) and Fujikawa (1963) are not included in this comparison.)
†Adjusted values. Explanation in text.
‡The sum is calculated as Head + Trunk + 2 (Total Arm + Total Leg.)

Table 24 indicates that the results of this study are most similar, in terms of the simple segmental ratio, to the results obtained by Dempster. This finding is not completely unexpected as the techniques of this investigation were based on those Dempster had used in his work. Note that Dempster's sum of the ratio of parts is 97.7% rather than 100%. It is assumed that this discrepancy reflects fluid and tissue losses during segmentation although this is not explained in his text. If the loss is added proportionately to each segment, the values given in parentheses (column, Dempster 1955, adjusted values) will be obtained. The data from Dempster's and this study thus appear to be very comparable.

If the center of mass determinations from the various investigators are compared in a similar manner, the results are as given in table 25.

TABLE 25

CENTER OF MASS/SEGMENT LENGTH RATIOS FROM SEVERAL CADAVER STUDIES

Source	Harless (1860)	Braune and Fischer (1889)	Fischer (1906)	Dempster (1955)	This Study
Total Body	41.4%	......	......	......	41.2%
Head	36.2	......	......	43.3%	46.6
Trunk	44.8	......	......	......	38.0*
Total Arm	......	......	44.6%	......	41.3
Upper Arm	......	47.0%	45.0	43.6	51.3
Forearm & Hand	......	47.2	46.2	67.7*	62.6*
Forearm	42.0	42.1	...	43.0	3.90
Hand	39.7	......	...	49.4	18.0*
Total Leg	......	......	41.2	43.3	38.2*
Thigh	48.9	44.0	43.6	43.3	37.2*
Calf & Foot	......	52.4	53.7	43.7	47.5
Calf	43.3	42.0	43.3	43.3	37-1
Foot	44.4	44.4	..	42.9	44.9

*These values are not directly comparable due to variations in the definition of segment length used by the different investigators.

This comparison is less helpful than the previous one for segment weights as so many of the values can not be equated. In our study, as we have pointed out above, segment lengths were determined from readily identifiable bony landmarks and not from the actual overall length of the segment. A major criticism of the earlier work has been with the inability to determine accurately the length of body segments of the living based upon the planes of segmentation used by different workers. The use of bony landmarks to approximate segment lengths eliminates this difficulty, but at the same time almost entirely precludes meaningful comparisons. The data in table 25 do, however, illustrate the wide range of ratios that have been obtained for the center of mass of body segments. From the above comparisons, particularly the first, we may conclude that the results obtained in this investigation are not grossly different from the results of earlier investigations and that the ratios are approximately the same magnitude.

The specific goals of this study were to investigate two basic questions concerning the estimation of body segment parameters:

1. Can body segment parameters be predicted from one or more anthropometric dimensions with the needed degree of accuracy?

2. Can predictive equations for estimating the weight and the location of the center of mass of body segments provide accurate estimates for individuals as well as for populations?

To answer the questions satisfactorily, it was necessary to undertake a basic study of the relationships of anthropometry to the weight and center of mass of body segments. The approach to this study was neither new nor unique but followed closely the guidelines of the classic studies undertaken by Braune and Fischer (1889) and Dempster (1955). A major difference between this investigation and those previously undertaken was in the choice of study specimens. In this study preserved specimens were used so that the selection of subjects would more closely approximate the wide range of physical body sizes found in normal populations.

Data developed in this investigation indicate that the anthropometry of the body can be used effectively to predict weight and location of the center of mass of body segments. In earlier investigations, the simple ratio of segment weight as a percent of body weight and the distance of the center of mass from the proximal end as a percent of segment length were the primary methods for prediction of these variables on the living. This study indicates that these predictive variables were well chosen in that they occurred more often in the predictive equations developed in this study than any other single variable.[1] The fact remains, however, that in using the ratios, the assumption is made that all individuals have essentially the same body proportions, with the variance from the group "average" being disregarded. This should lead to major errors in estimates made for those individuals and groups that differ in any significant way in body size from the average of the group from which the ratios were calculated. This was indeed found to be so with the ratios having a greater average error in estimating segment unknowns than the one, two, or three step predictive equations based upon body size variability. One may draw from this the possibly self-evident conclusion that the greater the amount of information available concerning the individual's body size, the more accurate becomes the prediction of the segment weight and its center of mass location.

It would appear, therefore, that the two questions can be answered in the affirmative. A key word, accuracy, in each question has not been adequately dealt with in this study owing to the inability of validating the findings of this study on the living. As with any statistical prediction, accuracy must be thought of in terms of probability, with the standard error of the estimate providing a measure of the accuracy of a predictive equation. As the standard error of the estimate is reduced through the use of the multi-step equations, one may assume that the relative accuracy of the predictions is also improved.

The predictive equations developed in this study are believed to provide a better estimate of weight and location of the center of mass of segments of the body for individuals and populations than were previously available. They should not, however, be considered as other than good first approximations until they can be adequately validated on live populations.

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[1] There is an element of bias here in that variables that could be selected in this study were limited to those anthropometric dimensions of the segment involved and body weight. Even with the bias, the statement is largely true.

Appendix A

OUTLINE OF PROCEDURES AND DATA FORM

The general step-by-step procedures followed in this study are outlined below. Detailed descriptions of the procedures are in the text.

1st Day

Step. 1. The cadaver was cleaned, examined, and its condition noted. It was weighed, and landmarks required for the anthropometry and the planes of segmentation for the arms and legs were established.

Step 2. The cadaver was weighed in air and weighed under water.

2nd Day

Step 3. The cadaver was measured.

Step 4. The total body center of mass was located, and its distance from selected landmarks was measured.

Step 5. Somatotype photographs of the cadaver were taken.

Step 6. The areas of segmentation of the arms and legs were packed in dry ice.

3rd Day

Step 7. The cadaver was weighed, and the arm and leg segments were removed.

Step 8. The arm, leg, and head-trunk segments were weighed.

Step 9. Photographs of the planes of segmentation were taken, and the cut ends of the segments were sealed.

Step 10. The center of mass of the leg and head-trunk segments were located, and their distances from selected landmarks were measured.

Step 11. After complete thawing, the arm and leg segments were weighed and their volumes measured by the water displacement method.

Step 12. The arm, leg, and head-trunk segments were weighed in air and weighed under water.

Step 13. The planes of segmentation of the head, forearm-hand, and calf-foot segments were determined.

Step 14. The areas of segmentation of the head, forearm-hand, and calf-foot segments were packed in dry ice.

4th Day

Step 15. The head-trunk segment was weighed, and the head was separated from the trunk.

Step 16. The head and trunk segments were weighed.

Step 17. The plane of segmentation was photographed, and the cut surfaces were sealed.

Step 18. The leg segments were weighed, and the thigh segments were separated from the calf-foot segments.

Step 19. The thigh and calf-foot segments were weighed.

Step 20. The planes of segmentation were photographed, and the cuts ends were sealed.

Step 21. The arm segments were weighed, and the upper arm segments were separated from the forearm-hand segments.

Step 22. The upper arm and forearm-hand segments were weighed.

Step 23. The planes of segmentation were photographed, and the cut surfaces were sealed.

Step 24. The center of mass of the head, trunk, thigh, calf-foot, upper arm, and forearm-hand segments were located, and their distances from selected landmarks were measured.

Step 25. After complete thawing, the head, thigh, calf-foot, upper arm, and forearm-hand segments were weighed and their volumes measured by the water displacement method.

Step 25a. OPTIONAL. The volumes of selected segments proximal to their centers of mass were determined.

Step 26. The head, trunk, thigh, calf-foot, upper arm, and forearm-hand segments were weighed in air and weighed under water.

Step 27. The planes of segmentation of the hands and feet were determined.

Step 28. The areas of segmentation of the hands and feet were packed in dry ice.

5th Day

Step 29. The calf-foot segments were weighed.

Step 30. The feet were separated from the calves.

Step 31. The calf and foot segments were weighed.

Step 32. The planes of segmentation were photographed, and the cut surfaces of the segments were sealed.

Step 33. The forearm-hand segments were weighed.

Step 34. The hands were separated from the forearms.

Step 35. The hand and forearm segments were weighed.

Step 36. The planes of segmentation were photographed, and the cut surfaces of the segments were sealed.

Step 37. The center of mass of the segments were located, and their distances from selected landmarks were measured.

Step 38. After complete thawing, the feet, calf, forearm, and hand segments were weighed and their volumes were measured by the water displacement method.

Step 38a. OPTIONAL. The volumes of selected segments proximal to their center of mass were determined.

Step 39. The foot, calf, forearm, and hand segments were weighed in air and weighed under water.

Step 40. Small areas of the upper arm, chest, and hip were dissected and the thicknesses of the skin and panniculus adiposus were measured.

Step 41. OPTIONAL. Samples of skin, fat, muscle, and bone tissue were dissected for density determinations.

DATE ________

BODY SEGMENTS—WEIGHT, VOLUME, C. M. DATA SHEET

SUBJECT NO. ________ AGE ________ RACE ________

CONDITION OF SPECIMEN ________

CAUSE OF DEATH ________ DATE OF DEATH ________

DEGREE OF WASTING, MALNUTRITION ________

DEGREE OF DESICCATION ________

EVIDENCE OF PREVIOUS DEBILITATION ________

SOMATOTYPE ________ d ________ PRESERVATION DATA ________

ANTHROPOMETRY

Weight ________

Approx. Stature r.[1] ________ l.[2] ________

TOP OF HEAD TO:

Tragion ________

Mastoid ________

Neck/Chin Intersect ________

Cervicale ________

Acromion r. ________ l. ________

Suprasternale ________

Substernale ________

Thelion ________

10th Rib ________

Omphalion ________

Penale ________

Symphysion ________

Iliospinale r. ________ l. ________

Iliocristale r. ________ l. ________

Trochanterion r. ________ l. ________

Tibiale r. ________ l. ________

Med. Malleolus r. ________ l. ________

Lat. Malleolus r. ________ l. ________

Sphyrion r. ________ l. ________

Ball of Foot r. ________ l. ________

Ball of Heel r. ________ l. ________

BREADTHS AND DEPTHS:

Head Breadth ________

Head Length ________

Neck Breadth ________

Neck Depth ________

Biacromial Breadth ________

Chest Breadth ________

Chest Breadth (Bone) ________

Chest Depth ________

Waist (O)[3] Breadth ________

[1] r. - Right
[2] l. - Left
[3] Omphalion

BODY SEGMENTS—WEIGHT, VOLUME, C. M. DATA SHEET (Cont'd)

Page 2

SUBJECT NO. ________

BREADTHS AND DEPTHS (Cont'd)

Waist (O) Depth ________

Bicristal Breadth ________

Bispinal Breadth ________

Hip Breadth ________

Bitrochanteric Breadth (Bone) ________

Knee Breadth (Bone) ________

Elbow Breadth (Bone) ________

Wrist Breadth (Bone) ________

Hand Breadth ________

CIRCUMFERENCES:

Head ________

Neck ________

Chest ________

Waist (O) ________

Buttock ________

U. Thigh r. ________ l. ________

L. Thigh r. ________ l. ________

Calf r. ________ l. ________

Ankle r. ________ l. ________

Arch of Foot r. ________ l. ________

Axillary Arm r. ________ l. ________

Biceps r. ________ l. ________

Elbow r. ________ l. ________

Forearm r. ________ l. ________

Wrist r. ________ l. ________

Hand r. ________ l. ________

LENGTHS:

Acromion-Radiale r. ________ l. ________

G. T.[1]-Radiale r. ________ l. ________

Radiale-Stylion r. ________ l. ________

Stylion-Meta III r. ________ l. ________

Meta III-Dactylion r. ________ l. ________

FAT THICKNESS:

Direct Measurement

	Fat	Skin	Total
JN[2]			
MALx[3]			
Triceps			
Iliac Crest			

DENSITY OF BODY TISSUE

Fat ________

____

____

Muscle ________

____

____

Bone ________

____

____

[1] Greater Tubercle of Humerus
[2] JN - Juxta Nipple
[3] MALx - Mid-Axillary Line at Xyphoid

BODY SEGMENTS—WEIGHT, VOLUME, C. M. DATA SHEET (Cont'd)

Page 3

SUBJECT NO. ________

DENSITY OF BODY TISSUE (Cont'd)

Other ________

____

____

TOTAL BODY:

Initial Wt. in Air ________ date ________ time ________

Weight in H_2O ________ date ________ time ________ temp ________ °

Pre-cut Wt. in Air ________ date ________ time ________

C. m.[1] from Top of Head ________

C. m. from Suprasternale ________

C. m. from Symphysion ________

C. m. from Penale ________

C. m. from Table ________

S. g.[2] ________

HEAD, NECK, TRUNK:

Initial Wt. in Air ________ +[3] ____ + ____ + ____ + ____ + ____ date ________ time ________

Wt. in Air Pre H_2O Wt. ________ date ________ time ________

Weight in H_2O ________ date ________ time ________ temp ________ °

Pre-cut Wt. in Air ________ date ________ time ________

Added Weight ________

C. m. from Top of Head ________

C. m. from Suprasternale ________

C. m. from Symphysion ________

C. m. from Penale ________

C. m. from Table ________

S. g. ________

[1] C. m. - Center of mass
[2] S. g. - Specific gravity
[3] Weight of tissue lost during segmentation

BODY SEGMENTS—WEIGHT, VOLUME, C. M. DATA SHEET (Cont'd)

Page 4

SUBJECT NO. ________

TOTAL LEGS:

R. Initial Wt. in Air ________ + ________ date ________ time ________

R. Wt. in Air Pre H_2O Wt. ________ date ________ time ________

R. Weight in H_2O ________ date ________ time ________ temp ________ °

R. Pre-cut Wt. in Air ________ date ________ time ________

R. C. m. from Trochanterion ________

R. C. m. from Tibiale ________

R. C. m. from L. Malleolus ________

R. C. m. above Table ________

R. A-P* Depth at C. m. ________

R. C. m. from anterior surface ________

R. S. g. ________

L. Initial Wt. in Air ________ + ________ date ________ time ________

L. Wt. in Air Pre H_2O Wt. ________ date ________ time ________

L. Weight in H_2O ________ date ________ time ________ temp ________ °

L. Pre-cut Wt. in Air ________ date ________ time ________

L. C. m. from Trochanterion ________

L. C. m. from Tibiale ________

L. C. m. from L. Malleolus ________

L. C. m. from Table ________

L. A-P Depth at C. m. ________

L. C. m. from anterior surface ________

L. S. g. ________

*Anteroposterior

BODY SEGMENTS—WEIGHT, VOLUME, C. M. DATA SHEET (Cont'd)

Page 5

SUBJECT NO.________

TOTAL ARMS:

R. Initial Wt. in Air____________+___ date__________ time__________
R. Wt. in Air Pre H_2O Wt.__________ date__________ time__________
R. Weight in H_2O______________ date________ time______ temp____ °
R. Pre-cut Wt. in Air______________ date__________ time__________
R. C. m. from Radiale*______________
R. S. g.______________
R. ∠ of Elbow______________
R. ∠ of Wrist______________

L. Initial Wt. in Air____________+___ date__________ time__________
L. Wt. in Air Pre H_2O Wt.__________ date__________ time__________
L. Weight in H_2O______________ date________ time______ temp____ °
L. Pre-cut Wt. in Air______________ date__________ time__________
L. C. m. from Radiale*______________
L. S. g.______________
L. ∠ of Elbow______________
L. ∠ of Wrist______________

HEAD AND NECK:

Initial Wt. in Air____________+___ date__________ time__________
Wt. in Air Pre H_2O Wt.__________ date__________ time__________
Weight in H_2O______________ date________ time______ temp____ °
C. m. from Top of Head______________
C. m.__________Tragion______________
C. m.__________Tragion______________
C. m. from Back of Head______________
S. g.______________

*Computed Value

BODY SEGMENTS—WEIGHT, VOLUME, C. M. DATA SHEET (Cont'd)

Page 6

SUBJECT NO.________

TRUNK:

Initial Weight______________+___ date__________ time__________
Wt. in Air Pre H_2O Wt.__________ date__________ time__________
Weight in H_2O______________ date________ time______ temp____ °
C. m. from Symphysion______________
C. m. from Suprasternale______________
C. m. from Penale______________ Added Weight__________
C. m. above Table______________
S. g.______________

THIGH:

R. Initial Wt. in Air____________+___ date__________ time__________
R. Wt. in Air Pre H_2O Wt.__________ date__________ time__________
R. Wt. in H_2O______________ date________ time______ temp____ °
R. C. m. from Trochanterion__________
R. A-P Depth at C. m.______________
R. C. m. from anterior surface________
R. S. g.______________

L. Initial Wt. in Air____________+___ date__________ time__________
L. Wt. in Air Pre H_2O Wt.__________ date__________ time__________
L. Weight in H_2O______________ date________ time______ temp____ °
L. C. m. from Trochanterion__________
L. A-P Depth at C. m.______________
L. C. m. from anterior surface________
L. S. g.______________

BODY SEGMENTS—WEIGHT, VOLUME, C. M. DATA SHEET (Cont'd)

Page 7

SUBJECT NO.________

CALF AND FOOT:

R. Initial Wt. in Air____________+___ date__________ time__________
R. Wt. in Air Pre H_2O Wt.__________ date__________ time__________
R. Weight in H_2O______________ date________ time______ temp____ °
R. Pre-cut Wt. in Air______________ date__________ time__________
R. C. m. from Tibiale______________
R. A-P Depth at C. m.______________
R. C. m. from anterior surface________
R. S. g.______________
R. ∠ of Foot______________

L. Initial Wt. in Air____________+___ date__________ time__________
L. Wt. in Air Pre H_2O Wt.__________ date__________ time__________
L. Weight in H_2O______________ date________ time______ temp____ °
L. Pre-cut Wt. in Air______________ date__________ time__________
L. C. m. from Tibiale______________
L. A-P Depth at C. m.______________
L. C. m. from anterior surface________
L. S. g.______________
L. ∠ of Foot______________

CALF:

R. Initial Wt. in Air____________+___ date__________ time__________
R. Wt. in Air Pre H_2O Wt.__________ date__________ time__________
R. Weight in H_2O______________ date________ time______ temp____ °
R. C. m. from Tibiale______________
R. A-P Depth at C. m.______________
R. C. m. from anterior surface________
R. S. g.______________

BODY SEGMENTS—WEIGHT, VOLUME, C. M. DATA SHEET (Cont'd)

Pa

SUBJECT NO.______

CALF (Cont'd):

L. Initial Wt. in Air____________+___ date__________ time__________
L. Wt. in Air Pre H_2O Wt.__________ date__________ time__________
L. Weight in H_2O______________ date________ time______ temp____
L. C. m. from Tibiale______________
L. A-P Depth at C. m.______________
L. C. m. from anterior surface________
L. S. g.______________

FOOT:

R. Wt. in Air______________+___ date__________ time__________
R. Wt. in Air Pre H_2O Wt.__________ date__________ time__________
R. Weight in H_2O______________ date________ time______ temp____ °
R. Foot Length______________
R. C. m. from gt. toe______________
R. C. m. from heel______________
R. C. m. from table______________
R. S. g.______________

L. Wt. in Air______________+___ date__________ time__________
L. Wt. in Air Pre H_2O Wt.__________ date__________ time__________
L. Weight in H_2O______________ date________ time______ temp____ °
L. Foot Length______________
L. C. m. from gt. toe______________
L. C. m. from heel______________
L. C. m. from table______________
L. S. g.______________

BODY SEGMENTS—WEIGHT, VOLUME, C. M. DATA SHEET (Cont'd) Page 9

SUBJECT NO.________

UPPER ARM:

R. Initial Wt. in Air____________+___ date__________ time____________

R. Wt. in Air Pre H_2O Wt.__________ date__________ time____________

R. Weight in H_2O________________ date________ time______ temp____°

R. C. m. from G. T.______________

R. C. m. from mid-olecranon________

R. A-P Depth at C. m.______________

R. C. m. from anterior surface_______

R. S. g.__________________

L. Initial Wt. in Air____________+___ date__________ time____________

L. Wt. in Air Pre H_2O Wt.__________ date__________ time____________

L. Weight in H_2O________________ date________ time______ temp____°

L. C. m. from G. T.______________

L. C. m. from mid-olecranon________

L. A-P Depth at C. m.______________

L. C. m. from anterior surface_______

L. S. g.__________________

BODY SEGMENTS—WEIGHT, VOLUME, C. M. DATA SHEET (Cont'd) Page 10

SUBJECT NO.________

FOREARM-HAND*:

R. Initial Wt. in Air____________+___ date__________ time____________

R. Wt. in Air Pre H_2O Wt.__________ date__________ time____________

R. Weight in H_2O________________ date________ time______ temp____°

R. Pre-cut Wt. in Air______________ date__________ time____________

R. C. m. from Radiale______________

R. A-P Depth at C. m.______________

R. C. m. from anterior surface_______

R. S. g.__________________

L. Initial Wt. in Air____________+___ date__________ time____________

L. Wt. in Air Pre H_2O Wt.__________ date__________ time____________

L. Weight in H_2O________________ date________ time______ temp____°

L. Pre-cut Wt. in Air______________

L. C. m. from Radiale______________

L. A-P Depth at C. m.______________

L. C. m. from anterior surface_______

L. S. g.__________________

FOREARM*:

R. Initial Wt. in Air____________+___ date__________ time____________

R. Wt. in Air Pre H_2O Wt.__________ date__________ time____________

R. Weight in H_2O________________ date________ time______ temp____°

R. C. m. from Radiale______________

R. C. m. from olecranon____________

R. A-P Depth at C. m.______________

R. C. m. from anterior surface_______

R. S. g.__________________

*When applicable, anterior is thumb side.

BODY SEGMENTS—WEIGHT, VOLUME, C. M. DATA SHEET (Cont'd) Page 11

SUBJECT NO.________

FOREARM* (Cont'd):

L. Initial Wt. in Air____________+___ date__________ time____________

L. Wt. in Air Pre H_2O Wt.__________ date__________ time____________

L. Weight in H_2O________________ date________ time______ temp____°

L. C. m. from Radiale______________

L. C. m. from Olecranon____________

L. A-P Depth at C. m.______________

L. C. m. from anterior surface_______

L. S. g.__________________

HAND:

R. Initial Wt. in Air____________+___ date__________ time____________

R. Wt. in Air pre H_2O Wt.__________ date__________ time____________

R. Weight in H_2O________________ date________ time______ temp____°

R. C. m. from Meta III______________

R. C. m. from Medial (little finger) Aspect__________

R. S. g.__________________

L. Initial Wt. in Air____________+___ date__________ time____________

L. Wt. in Air Pre H_2O Wt.__________ date__________ time____________

L. Weight in H_2O________________

L. C. m. from Meta III______________

L. C. m. from Medial (little finger) Aspect__________

L. S. g.__________________

DEGREE OF WASTING - MALNUTRITION: DESICCATION

- 0 None
- 1 Slight
- 2 Moderate
- 3 Marked

*When applicable, anterior is thumb side.

BODY SEGMENTS—WEIGHT, VOLUME, C. M. DATA SHEET (Cont'd) Page 12

SUBJECT NO.________

VOLUMES

LEGS

R. Wt. in Air_______date_______time_______

R. Wt. of H_2O Displaced_______temp_______°

Trial
1________
2________
3________

L. Wt. in Air_______date_______time_______

L. Wt. of H_2O Displaced_______temp_______°

Trial
1________
2________
3________

ARMS

R. Wt. in Air_______date_______time_______

R. Wt. of H_2O Displaced_______temp_______°

Trial
1________
2________
3________

L. Wt. in Air_______date_______time_______

L. Wt. of H_2O Displaced_______temp_______°

Trial
1________
2________
3________

HEAD AND NECK

Wt. in Air_______date_______time_______

Wt. of H_2O Displaced_______temp_______°

Trial
1________
2________
3________
4________

BODY SEGMENTS—WEIGHT, VOLUME, C.M. DATA SHEET (Cont'd) Page 13

SUBJECT NO._______

VOLUMES (Cont'd)

THIGHS

R. Wt. in Air_______date_______time_______
R. Wt. of H_2O Displaced_______temp_______°

Trial
1_______
2_______
3_______

L. Wt. in Air_______date_______time_______
L. Wt. of H_2O Displaced_______temp_______°

Trial
1_______
2_______
3_______

CALVES AND FEET

R. Wt. in Air_______date_______time_______
R. Wt. of H_2O Displaced_______temp_______°

Trial
1_______
2_______
3_______

L. Wt. in Air_______date_______time_______
L. Wt. of H_2O Displaced_______temp_______°

Trial
1_______
2_______
3_______

UPPER ARMS

R. Wt. in Air_______date_______time_______
R. Wt. of H_2O Displaced_______temp_______°

Trial
1_______
2_______
3_______

BODY SEGMENTS—WEIGHT, VOLUME, C.M. DATA SHEET (Cont'd) Page 14

SUBJECT NO._______

VOLUMES (Cont'd)

UPPER ARMS (Cont'd)

L. Wt. in Air_______date_______time_______
L. Wt. of H_2O Displaced_______temp_______°

Trial
1_______
2_______
3_______

FOREARMS-HANDS

R. Wt. in Air_______date_______time_______
R. Wt. of H_2O Displaced_______temp_______°

Trial
1_______
2_______
3_______

L. Wt. in Air_______date_______time_______
L. Wt. of H_2O Displaced_______temp_______°

Trial
1_______
2_______
3_______

CALVES

R. Wt. in Air_______date_______time_______
R. Wt. of H_2O Displaced_______temp_______°

Trial
1_______
2_______
3_______

L. Wt. in Air_______date_______time_______
L. Wt. of H_2O Displaced_______temp_______°

Trial
1_______
2_______
3_______

BODY SEGMENTS—WEIGHT, VOLUME, C.M. DATA SHEET (Cont'd) Page 15

SUBJECT NO._______

VOLUMES (Cont'd)

FEET

R. Wt. in Air_______date_______time_______
R. Wt. of H_2O Displaced_______temp_______°

Trial
1_______
2_______
3_______

L. Wt. in Air_______date_______time_______
L. Wt. of H_2O Displaced_______temp_______°

Trial
1_______
2_______
3_______

FOREARMS

R. Wt. in Air_______date_______time_______
R. Wt. of H_2O Displaced_______temp_______°

Trial
1_______
2_______
3_______

L. Wt. in Air_______date_______time_______
L. Wt. of H_2O Displaced_______temp_______°

Trial
1_______
2_______
3_______

HANDS

R. Wt. in Air_______date_______time_______
R. Wt. of H_2O Displaced_______temp_______°

Trial
1_______
2_______
3_______

BODY SEGMENTS—WEIGHT, VOLUME, C.M. DATA SHEET (Cont'd) Page 16

SUBJECT NO._______

VOLUMES (Cont'd)

HANDS (Cont'd)

L. Wt. in Air_______date_______time_______
L. Wt. of H_2O Displaced_______temp_______°

Trial
1_______
2_______
3_______

Appendix B

MID-VOLUME OF SEGMENTS AS AN APPROXIMATION OF A SEGMENT'S CENTER OF MASS

A few investigators, notably Bernstein, *et al.*, (1931), Cleveland (1955), and Drillis and Contini (1966), have assumed that for the required accuracy the center of mass of a body segment can be considered coincident with its center of volume. Salzgeber (1947), using this assumption, treated the body segments as a series of geometric forms from which he developed mathematical formulas to predict the weight and the location of the center of mass of body segments of the living.

This study offered an excellent opportunity to ascertain the correspondence between the plane of mid-volume and the plane of the center of mass of segments by using a number of segments from a series of cadavers all being treated under the same experimental conditions. Twenty-four body segments were selected on a random basis for use in this test. The center of mass was first established for each segment on the medial and lateral surfaces by an observer, using the small electric balance plate described previously. A second observer then independently redetermined the center of mass after reversing the position of the segment on the balance plate. A line drawn around the circumference of the segment perpendicular to its long axis then joined the center of mass points established by the two observers. The total volume of each segment was measured using the water displacement technique. This was done twice with the average total volume being recorded. The difference between successive trials was small and generally ran to 0.5% or less of the total volume of the segment. The volume of the proximal end of the segment (measured to the circumferential line at the center of mass) was then measured in a similar manner. The data from this investigation are given in Table 26. The last column represents the percent of the segment volume that is proximal to its center of mass.

TABLE 26

VOLUME OF SEGMENT PROXIMAL TO ITS CENTER OF MASS AS A PERCENT OF TOTAL SEGMENT VOLUME

Segment	Total Segment Volume	Volume Proximal to Center of Mass	% of Volume to Center of Mass
Right Leg	9499 ml	5525 ml	58.2%
Left Leg	9788	5544	56.6
Right Thigh	6281	3374	53.7
Left Thigh	6262	3419	54.6
Right Thigh	4264	2304	54.0
Left Thigh	8029	4152	51.7
Right Calf and Foot	3080	1655	53.7
Left Calf and Foot	3423	1827	53.4
Right Calf	2250	1224	54.4
Left Calf	2383	1325	55.6
Calf	1814	1012	55.8
Calf	1964	1084	55.2
Calf	2094	1160	55.4

TABLE 26 – (Cont.)

Calf	1819	967	53.2
Calf	2037	1120	55.0
Right Upper Arm	1642	882	53.7
Left Upper Arm	1784	943	52.9
Left Upper Arm	1613	913	56.6
Right Forearm and Hand	1360	751	55.2
Left Forearm and Hand	1370	744	54.3
Right Forearm	869	489	56.1
Right Forearm	977	562	57.5
Left Forearm	937	518	55.3
Left Forearm	865	485	56.1

These data are summarized in table 27 with the minimum, maximum, and average ratio for each group of segments being given as well as the mean ratio for all segments. From this summary, it is apparent that segment mid-volume is not coincident with segment center of mass; in each instance, the volume of the segment proximal to its center of mass exceeds one-half the total segment volume.

TABLE 27

SUMMARY OF MID-VOLUME AS PREDICTOR OF CENTER OF MASS

Segment	N	Percent of Volume Proximal to Center of Mass		
		Minimum	Maximum	Mean
Leg	2	56.6%	58.2%	57.4%
Thigh	4	51.7	54.6	53.5
Calf and Foot	2	53.4	53.7	53.6
Calf	7	53.2	55.8	54.9
Upper Arm	3	53.7	56.6	54.4
Forearm and Hand	2	54.3	55.2	54.8
Forearm	4	55.3	57.5	56.3
Mean of All Segments				54.9%

If the mid-volume were to be used to approximate the location of the center of mass of segments, the estimated center of mass would be proximal to its true location. The actual error involved in using this assumption is difficult to determine for the irregular-shaped segments of the human body. It is believed, however, that the mid-volume of the segment will be, at most, some two to three centimeters proximal to the actual segment center of mass. No attempt was made to establish the plane of the actual mid-volume of segments in order that the distance between the center of mass as measured and as approximated by its mid-volume could be determined. In retrospect, it is unfortunate that this was not done. The error involved in using mid-volume to locate the center of mass of body segments may not be so great as to invalidate this approach for some problems, but it is important to understand that an error of constant direction is imparted with its use.

Appendix C

STANDING AND SUPINE ANTHOROPOMETRY AND POSTMORTEM CHANGES IN BODY SIZE

Considerable attention has been given to the standardization and replicability of anthropometry on the living with the subject in the standing and seated positions (Randall *et al*, 1946; Stewart, 1947). The anthropometry of a supine subject has received little attention, with the exception of workspace anthropometry to determine supine clearance dimensions (Alexander and Clauser, 1965) and a comparative study by Terry (1940) of supine and erect anthropometry.

In the present study, it is necessary to understand the relationships of anthropometry as traditionally taken on the living to the anthropometry of the cadaver measured in the supine position. Terry (1940) made a detailed study of measuring and photographing cadavers and, in addition, compared the standing and supine anthropometry of live subjects. His analysis was primarily concerned with the changes in body length, with the exception of a single dimension of body breadth. A summary of his results is presented in table 28A. In an extension of his study, using a specially designed measuring panel that vertically supported the body, Terry measured ten cadavers in a supine and an erect position. He found that by careful positioning of the cadaver on the panel, characteristic features of the standing posture could be reproduced. A summary of the results obtained in this test is given in table 28B. From his analysis of the two studies, Terry (1940, p 438) concluded that, "... measurements made on the supine body should not generally be accepted as equivalent to those taken with the body erect." His findings on the living series showed that the differences were relatively constant in direction; that is, in all but a few instances, the supine value exceeded the standing value for the same measurement. This finding was not as well substantiated in the measurement of the cadavers, which indicates that a greater measuring error is associated with this series.

Todd and Lindala (1928), using a selected series of cadavers, made an intensive study of the postmortem changes in the thickness of body tissue and their consequent effect on the anthropometry of the cadaver. They observed that the weight of cadavers was almost always less than might be expected. This weight loss did not fully result from emaciation associated with a lingering illness, but persisted after death, with a cadaver losing a pound and a half for the first and second days after death and thereafter progressively smaller amounts. They attributed the weight lost primarily to tissue dehydration of fluids through the epidermis. We observed a similar weight loss when dealing with preserved cadavers. However, an effective reduction in the weight losses can be achieved by keeping the room temperature low and by covering the cadaver with moist sheets whenever possible.

Todd and Lindala designed an experiment in which a series of cadavers were measured before and after the injection of a known quantity of embalming fluid. Sufficient fluid was injected in each instance to restore the tissue to a "normal" appearance. In general, approximately two or three gallons of fluid were required for a satisfactory restoration of the appearance of the tissue. This amount of fluid was found to increase the radius of the head, chest and appendages of adult white male cadavers by an average of 6.2 mm, ranging from 16.0 mm at the level of thigh circumference to 2.3 mm at wrist circumference. This difference, while not large, will increase the circumference at thigh and wrist respectively by 10.0 and 1.4 cm. Todd concluded from this experiment that the results obtained on different cadavers were highly variable and quite unsatisfactory for predicting accurately the living body size from measurements of the cadaver. As Todd pointed out, the fault lies not so much with the technique he used as with the problem under consideration.

TABLE 28

COMPARISON OF ANTHROPOMETRY:
STANDING AND SUPINE*
(All Values in Millimeters)

A. LIVING

Subject	Stature	Acro Height	Sternal Height	Xiphoid Height	Umbil. Height	Pubic Height	Biacromial Breadth
1	7	91	–7	24	20	5	2
2	2	51	6	18	10	14	–7
3	13	41	11	12	15	12	–1
4	5	27	12	5	25	17	2
5	24	39	21	24	22	5	0
6	23	61	27	36	....	19	–2
7	8	41	11	29	28	3	–6
8	7	26	8	4	8	11	1
9	11	19	15	14	6	3	15
10	28	61	30	39	16	22	–1
Mean	12.8	45.7	13.4	20.5	17.6	11.1	.03
SD	8.55	20.22	10.17	11.46	7.43	6.56	5.69

B. CADAVERS

Subject							
734	1	46	–5	–19	30	10	–34
792	7	20	14	–7	29	12	7
797	6	24	3	–7	28	3	–3
837	–14	20	–16	–20	1	–3	3
883	5	41	6	11	41	31	9
899	1	23	7	–7	2	2	–2
904	1	23	1	1	30	40	1
945	1	50	10	13	...	16	10
1101	–14	29	–2	–6	...	4	–22
1029	12	63	–15	–15	.	5	–27
Mean	0.6	33.0	0.3	–5.6	23.0	12.0	–5.8
SD	8.04	14.31	9.53	10.71	14.16	12.98	15.12

*Summarized from Terry(1940). The values shown in this table are differences in body dimensions obtained when standing measurements are subtracted from supine measurements on the same subject.

In table 29 are summarized Todd's recommended increments in radii necessary to approximate living dimensions on the male. The variability of the data from which these recommendations are derived is high, their coefficients of variation averaging about 50%.

TABLE 29

AVERAGE INCREASE IN RADIUS OF CADAVER DIMENSIONS TO APPROXIMATE LIVING DIMENSIONS (in mm)*

Circumferences	Male Caucasian	Male Negro
Head	3.5	3.9
Chest	7.7	7.8
Upper Arm	5.2	5.6
Forearm	3.4	3.9
Wrist	2.3	2.8
Thigh	16.0	17.0
Calf	9.9	14.5
Ankle	7.6	6.0

*After Todd and Lindala (1928) table 14, page 194.

From their analysis,it appears that any attempt to obtain living dimensions of the body from cadaver measurements, even when the tissues are returned by injection of a fluid to a normal appearance, must be acknowledged as approximate. A significant finding by Todd and Lindala (1928, p. 177) stated that "... sudden death brings in its train no marked changes of radii from those characteristic of the living body and therefore calls for no correction of (body) dimensions. In the lingering deaths accompanied by emaciation, however, the subcutaneous tissues are dehydrated and one is fairly safe in correcting the several dimensions."

On the basis of Todd and Lindala's research, we decided to select for our study only those cadavers having a medical history that indicated "sudden death" and those having postmortem appearances that showed signs of minimal desiccation. Because of the limited number of cadavers in our study, it was possible to be highly selective, using only very well preserved specimens. This does not imply that the cadavers can be assumed to be fully representative in all their body dimensions to those of the living. However, because it was possible to be highly critical in selecting the sample, the anthropometry taken on the cadavers is believed to be a "reasonable approximation" to that of the living.

Terry's study (1940) indicated that the measurement of stature in the supine position is significantly different from the in normal standing position. In order to understand these differences more fully, a brief study of certain measurements with subjects in a supine and a standing position was carried out.[1] The supine position was one similar to that observed in the cadavers, the body being fully relaxed with the feet in plantar flexion and rolled slightly laterally. Table 30 gives the statistics for the variables considered in the 30 subjects studied. The correlation coefficients between paired variables are quite high for the dimensions of length and somewhat lower for the dimensions of girth. Estimates of stature were computed for the cadavers based upon the simple and multiple regression equations using variables 2, 3, and 4. The estimates of stature predicted from these variables appeared excessively large. The possibility that the factors involved in diurnal variation in stature may affect estimates of stature in the cadaver cannot be overlooked.

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[1] The authors wish to express their appreciation to Capt. W. Bennett, Mr. D. Walk and Capt. J. Henniger, then of the Anthropology Branch, Aerospace Medical Research Laboratory, Wright-Patterson AFB, Ohio, for their work in obtaining the data used in this section.

TABLE 30

COMPARISON OF ANTHROPOMETRY OF SUBJECTS IN STANDING AND SUPINE POSITION (N=30)

Linear Dimensions Correlation Coefficients	1	2	3	4	Mean*	SD
1. Stature	------				177.98	8.23
2. Vertex to Ball Foot	.986	------			186.77	8.98
3. Vertex to Ball Heel	.989	.988	------		179.42	8.32
4. Vertex to Arch Foot	.990	.990	.996	------	182.23	8.22

Dimensions of Weight and Girth Correlation Coefficients	1	2	3	4	5	6	7	Mean	SD
5. Weight	------							79.21	11.49
6. Stand. Chest Circ. Exp.	.883	------						96.20	7.06
7. Stand. Chest Circ. Nor.	.897	.978	------					98.62	6.91
8. Stand. Buttock Circ.	.937	.881	.889	------				98.98	6.35
9. Supine Chest Circ. Exp.	.902	.936	.926	.923	------			96.26	6.67
10. Supine Chest Circ. Nor.	.875	.939	.925	.886	.982	------		98.72	6.78
11. Supine Buttock Circ.	.897	.857	.870	.980	.907	.863	------	97.46	5.95

*Weight in kilograms; all other dimensions in centimeters.

Estimates of diurnal variation are given as averaging 0.5 inches in children (Kelly *et al*, 1943) and 0.95 inches in adult males (Backman, 1924). This type of variation could be expected in a cadaver population in which the muscles and ligaments are without tension, giving a body stature in excess of that for the same individual during life. A more refined estimate of stature was therefore believed necessary.

If samples of live subjects could be matched to the cadaver sample on the basis of certain critical body dimensions, then the live samples should serve as a basis of validating estimates of body dimensions in the cadaver series. Body stature and weight, for example, are relatively sensitive indicators of many other body dimensions (McConville and Alexander, 1963). Three samples from live populations were therefore matched to the cadaver sample on the basis of weight and various estimates of cadaver stature.[1] The most reasonable estimate of stature proved to be the dimension, Top-of-Head to Ball-of-Heel. The results of this comparison are given in table 31. The comparisons are surprisingly close considering the inability to match the samples on the basis of age. Differences in technique and in the interpretation of landmarks are apparent in those instances where the comparisons show gross differences. The factor of age, which could not be controlled in matching the samples, is undoubtedly also responsible for some of the variations seen in the comparison.

It was on this basis then that the dimension, Estimated Stature, was determined. In order to make the anthropometric data of the cadaver sample more readily usable by others, the vertical distances on the body (that is, the heights) were determined by subtracting the Top-of-Head to, etc., distance from the estimates of body stature. This means that errors associated with estimated stature are also reflected in these height dimensions This propagation of possible error in stature determination is unfortunate but is unavoidable if the data are to be presented in the simplest and most usable form.

Referring to table 30, note that the correlation coefficients for paired dimensions of girth, standing versus supine, are somewhat lower than those for the linear dimensions but are still quite high. Of importance here, are the means and standard deviations of the measurements. In the first two cases, the means between the standing and supine measurements are nearly identical and the SD's are reasonably close. The third dimension, Buttock Circumference, is significantly different between the two measurements, with a marked tissue compression occurring in the supine position. The difference is about 1.5% of the standing value. The weight of the cadavers rested on the heels, occipital area of the head, the scapula, and the buttocks. Of these, the buttocks are obviously deformed by flattening; but the others, because of the bony structures just beneath the subcutaneous tissue, exhibited only minor distortion and flattening. The buttocks may therefore have the maximum compression of tissue, which is approximately 1.5% of the standing dimension.

In summary, while no attempt is made to suggest the anthropometry of the cadavers is identical to that of the living, the assumption is made that their anthropometric data are a reasonable approximation of those obtained on the living and can be used within the framework of this study.

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[1] It is unfortunate that extensive anthropometric data are available for rather few populations. The matched samples used here were selected from: the USAF flying population survey of 1950; Hertzberg *et al*., 1954; the USAF military population survey in 1957, using a photometric technique to supplement the traditional form of measurements, unpublished MS, Anthropology Branch, Aerospace Medical Research Laboratory, Wright-Patterson AFB, Ohio; and an older civilian population survey made up of Spanish-American veterans residing in the Boston area, Damon and Stoudt, 1963. The military samples are composed largely of men younger, and the civilian sample men older than those in the cadaver series.

TABLE 31

ANTHROPOMETRY OF MATCHED SAMPLES

Variables*	Cadaver		1950 USAF		1957 USAF		Spanish War Vet.	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1. Age	49.3	13.7	27.4	4.4	28.4	5.6	82.2	3.2
2. Endomorphy	4.0	0.6	2.8	0.8	----	----	4.0	1.2
3. Mesomorphy	4.3	0.6	4.5	0.7	----	----	4.1	1.2
4. Ectomorphy	2.4	1.0	3.2	0.9	----	----	2.3	0.7
5. Weight	66.5	8.7	66.6	8.7	66.5	5.6	66.8	9.2
6. Stature	172.7	5.9	172.8	5.9	173.0	6.3	171.6	4.8
7. Tragion Ht.	160.4	5.7	159.7	6.0	----	----	----	----
10. Cervicale Ht.	149.0	5.1	147.9	5.9	148.7	6.2	----	----
11. Suprasternale Ht.	141.0	5.0	140.5	5.3	142.2	5.2	----	----
12. Substernale Ht.	120.7	6.6	121.7	4.8	----	----	----	----
13. Thelion Ht.	128.9	4.9	125.8	5.4	----	----	----	----
15. Ophalion Ht.	105.5	4.5	----	----	105.2	4.5	----	----
16. Penale Ht.	86.0	4.4	67.1	3.8	----	----	----	----
19. Iliac Crest Ht.	104.3	5.1	105.0	4.2	----	----	----	----
22. Lat. Malleolus Ht.	7.1	0.4	6.8	0.5	----	----	----	----
24. Head Br.	15.8	0.4	15.1	0.5	----	----	15.4	0.4
25. Head Lgth.	20.0	0.7	19.6	0.6	----	----	19.5	0.4
28. Chest Br.	33.2	2.5	28.9	1.6	32.4	1.8	29.2	1.6
30. Chest Depth	21.1	1.9	21.6	1.4	----	----	23.6	2.5
31. Waist Br.	30.6	3.3	25.1	1.5	29.1	2.2	30.9	1.9
32. Waist Depth	18.2	2.6	18.4	1.9	----	----	25.4	2.8
35. Hip Br.	34.6	2.7	32.4	1.4	33.4	2.2	36.7	2.4
41. Head Circ.	57.1	1.8	56.2	1.6	56.8	1.1	55.7	3.0
42. Neck Circ.	40.4	2.6	37.1	1.8	36.3	1.5	----	----
43. Chest Circ.	93.4	5.7	95.2	5.5	90.6	4.1	92.9	6.3
44. Waist Circ.	80.6	7.7	75.6	5.7	78.2	6.5	85.6	7.0
45. Buttock Circ.	89.9	5.5	92.2	4.2	91.4	6.3	----	----
46. Up. Thigh Circ.	47.4	3.6	53.8	3.3	52.7	4.8	----	----
47. Lower Thigh Circ.	35.5	2.6	41.4	3.3	37.4	3.0	----	----
48. Calf Circ.	30.8	2.5	35.0	2.0	35.0	2.3	33.4	2.3
49. Ankle Circ.	20.0	1.2	21.5	1.0	21.5	1.2	----	----
51. Arm Circ. (Ax.)	29.4	2.1	30.7	2.4	29.2	2.1	28.1	2.9
54. Forearm Circ.	26.3	1.4	----	----	26.2	1.1	----	----
55. Wrist Circ.	16.5	1.0	16.9	1.0	16.6	0.8	----	----

*Age in years, somatotype in half units (0-7), weight in kilograms, and all other body dimensions in centimeters.

Appendix D

DESCRIPTIONS OF ANTHROPOMETRIC DIMENSIONS

1. Age: As recorded on the coroner's report.

2.* *Endomorphy:* The relative predominance of soft-roundness throughout the various regions of the body. An expression of the relative amount of body fat.

3.* *Mesomorphy:* The relative predominance of muscle, bone, and connective tissue.

4.* *Ectomorphy:* The relative predominance of linearity and fragility. This is, in part, expressed by $Ht/\sqrt[3]{wt.}$

5. *Weight:* Body weighed with scales read to the nearest gram.

6. *Approximate Stature:* Cadaver supine with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. Using an anthropometer, measure the horizontal distance from the headboard to the most distal portion of the heel. The distance to both the right and left heels is measured and the two values averaged. Note: All anthropometry which follows was measured to the nearest millimeter.

7. *Top-of-Head to Tragion Length:* Cadaver supine with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. Using an anthropometer, measure the horizontal distance from the headboard to the right tragion.

8. *Top-of-Head to Mastoid Length:* Cadaver supine, with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. Using an anthropometer, measure the horizontal distance from the headboard to the apex of the right mastoid (or to the mastoid landmark).

9. *Top-of-Head to Chin/Neck Intersect Length:* Cadaver supine with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. Using an anthropometer, measure the horizontal distance from the headboard to the anterior intersection of the chin and neck (or to the chin/neck landmarks).

10. *Top-of-Head to Cervicale Length:* The horizontal distance between the headboard and cervicale. This dimension is computed from the difference between top of head to thelion and the horizontal distance between thelion and cervicale.

11. *Top-of-Head to Suprasternale Length:* Cadaver supine with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. Using an anthropometer, measure the horizontal distance between the headboard and suprasternale.

12. *Top-of-Head to Substernale Length:* Cadaver supine with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. Using an anthropometer, measure the horizontal distance between the headboard and substernale.

13. *Top-of-Head to Thelion Length:* Cadaver supine with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. Using an anthropometer, measure the horizontal distance between the headboard and thelion.

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*Somatotype Components: An anthroposcopic method of classifying the configuration of the human form according to an established typology. The somatotype of an individual is the numerical expression of the strength of three body components based on a seven point scale; 1 is the least expression, 7 the maximum expression of the component. The first number of a somatotype rating is the strength of the endomorphic component, the second is the strength of the mesomorphic component, and the third is the strength of the ectomorphic component.

14. *Top-of-Head to 10th Rib Length:* Cadaver supine with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. Using an anthropometer, measure the horizontal distance between the headboard and the most inferior point on the margin of the 10th rib.

15. *Top-of-Head to Omphalion Length:* Cadaver supine with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. Using an anthropometer, measure the horizontal distance between the headboard and omphalion.

16. *Top-of-Head to Penale Length:* Cadaver supine with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. Using an anthropometer, measure the horizontal distance between the headboard and penale.

17. *Top-of-Head to Symphysion Length:* Cadaver supine with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. Using an anthropometer, measure the horizontal distance between the headboard and symphysion.

18. *Top-of-Head to Anterior-Superior Iliac Spine Length:* Cadaver supine with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. Using an anthropometer, measure the horizontal distance between the headboard and the anterior-superior iliac spine.

19. *Top-of-Head to Iliac Crest Length:* Cadaver supine with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. Using an anthropometer, measure the horizontal distance between the headboard and the iliac crest.

20. *Top-of-Head to Trochanterion Length:* Cadaver supine with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. Using an anthropometer, measure the horizontal distance between the headboard and trochanterion.

21. *Top-of-Head to Tibiale Length:* Cadaver supine with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. Using an anthropometer, measure the horizontal distance between the headboard and tibiale.

22. *Top-of-Head to Lateral Malleolus Length:* Cadaver supine with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. Using an anthropometer, measure the horizontal distance between the headboard and lateral malleolus.

23. *Top-of-Head to Sphyrion Length:* Cadaver supine with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. Using an anthropometer, measure the horizontal distance between the headboard and sphyrion.

24. *Head Breadth:* Using spreading calipers, measure the maximum horizontal breadth of the head.

25. *Head Length:* Using spreading calipers, measure the maximum length of the head between the glabella and the occiput.

26. *Neck Breadth:* Using the beam caliper, measure the maximum horizontal breadth of the neck.

27. *Neck Depth:* Using a beam caliper, measure the maximum depth of the neck perpendicular to the long axis of the neck.

28. *Chest Breadth:* Using a beam caliper, measure the horizontal breadth of the chest at the level of thelion.

29. *Chest Breadth (Bone):* Using a body caliper, measure the horizontal breadth of the chest at the level of thelion exerting sufficient pressure to compress the tissue overlying the rib cage.

30. *Chest Depth:* Using an anthropometer, measure the vertical distance from the measuring table to the anterior surface of the body at the level of thelion.

31. *Waist Breadth:* Using a beam caliper, measure the horizontal breadth of the body at the level of the omphalion.

32. *Waist Depth:* Using an anthropometer, measure the vertical distance between the measuring table and the anterior surface of the body at the level of the omphalion.

33. *Bicristal Breadth (Bone):* Using a body caliper, measure the horizontal distance between the right and left ilia exerting sufficient pressure to compress the tissue overlying the bone.

34. *Bispinous Breadth:* Using a beam caliper, measure the horizontal distance between the right and left anterior-superior iliac spines.

35. *Hip Breadth:* Using a beam caliper, measure the horizontal distance across the greatest lateral protrusion of the hips.

36. *Bitrochanteric Breadth (Bone):* Using a body caliper, measure the horizontal distance between the maximum protrusion of the right and left greater trochantor exerting sufficient pressure to compress the tissue overlying the femurs.

37. *Knee Breadth (Bone):* Using a beam caliper, measure the maximum distance between the right femoral epicondyles exerting sufficient pressure to compress the tissue overlying the femur.

38. *Elbow Breadth (Bone):* With a spreading caliper, measure the maximum distance between the humeral epicondyles exerting sufficient pressure to compress the tissue overlying the humerus.

39. *Wrist Breadth (Bone):* With a spreading caliper, measure the maximum distance between the radical and ulnar styloid processes exerting sufficient pressure to compress the tissue overlying the radius and ulna.

40. *Hand Breadth:* With a sliding caliper, measure the maximum breadth across the distal ends of metacarpal II and V.

41. *Head Circumference:* With the tape passing above the brow ridges and parallel to the Frankfort plane (relative), measure the maximum circumference of the head.

42. *Neck Circumference:* With a tape in a plane perpendicular to the axis of the neck and passing over the laryngeal prominance (Adam's Apple), measure the circumference of the neck.

43. *Chest Circumference:* With a tape passing over the nipples and perpendicular to the long axis of the trunk, measure the circumference of the chest.

44. *Waist Circumference:* With a tape passing over the umbilicus and perpendicular to the long axis of the trunk, measure the circumference of the waist.

45. *Buttock Circumference:* With a tape passing over the greatest lateral protrusion of the hips, and in a plane perpendicular to the long axis of the trunk, measure the circumference of the hips.

46. *Upper Thigh Circumference:* With a tape perdendicular to the long axis of the leg and passing just below the lowest point of the gluteal furrow, measure the circumference of the thigh.

47. *Lower Thigh Circumference:* With a tape passing just superior to the patella and perpendicular to the long axis of the leg, measure the circumference of the lower thigh.

48. *Calf Circumference:* With a tape perpendicular to the long axis of the lower leg, measure the maximum circumference of the calf.

49. *Ankle Circumference:* With a tape perpendicular to the long axis of the lower leg, measure the minimum circumference of the ankle.

50. *Arch Circumference:* With a tape perpendicular to the long axis of the foot and passing over the highest point in the arch, measure the circumference of the arch.

51. *Arm Circumference, Axillary:* With a tape perpendicular to the long axis of the upper arm and passing just below the lowest point of the axilla, measure the circumference of the upper arm.

52. *Biceps Circumference:* With a tape perpendicular to the long axis of the upper arm, measure the circumference of the upper arm at the level of the maximum anterior prominence of the biceps brachii.

53. *Elbow Circumference:* The elbows of the cadaver were flexed to about 125° ($\bar{X}=125°$; S.D. $=16°$). With a tape passing over the olecranon process of the ulna and into the crease of the elbow, measure the circumference of the elbow.

54. *Forearm Circumference:* With a tape perpendicular to the long axis of the forearm, measure the maximum circumference of the forearm.

55. *Wrist Circumference:* With a tape perpendicular to the long axis of the forearm, measure the minimum circumference of the wrist proximal to the radial and ulnar styloid processes.

56. *Hand Circumference:* With a tape passing around the metacarpal-phalangeal joints, measure the circumference of the hand.

57. *Head-Trunk Length:* A derived dimension calculated by subtracting Trochanteric Height from Stature.

58. *Height of Head:* A derived dimension calculated by subtracting Chin/Neck Intersect Height from Stature.

59. *Trunk Length:* A derived dimension calculated by subtracting Trochanteric Height from Chin/Neck Intersect Height.

60. *Thigh Length:* A derived dimension calculated by subtracting Tibiale Height from Trochanteric Height.

61. *Calf Length:* A derived dimension calculated by subtracting Sphyrion Height from Tibiale Height.

62. *Foot Length:* Using a beam caliper, measure the distance from the dorsal surface of the heel to the tip of the longest toe.

63. *Arm Length, Estimated:* A derived dimension calculated by the following: Arm Length (Est.) $=1.126$ Acrom-Radiale Length $+$ 1.057 Radiale-Stylion Length $+$ 12.52 (± 1.58) (in centimeters).

64. *Acromion-Radiale Length:* Using a beam caliper, measure the distance along the long axis of the upper arm between acromion and radiale.

65. *Ball of Humerous-Radiale Length:* Using a beam caliper, measure the distance along the axis of the upper arm between the superior portion of the intertubercular sulcus of the humerous and radiale.

66. *Radiale-Stylion Length:* Using a beam caliper, measure the distance along the long axis of the forearm from radiale to stylion.

67. *Stylion-Meta III Length:* With a sliding caliper parallel to the forearm-hand axis, measure the distance between stylion and metacarpale III.

68. *Metacarpale III-Dactylion Length:* Holding digit III as straight as possible and using a sliding caliper, measure the distance between metacarpale III and dactylion.

69. *Juxta Nipple (Fat):* The thickness of the panniculus adiposus dissected from a site approximately one centimeter lateral to the right areola.

70. *MAL X (Fat)*:* The thickness of the panniculus adiposus dissected from a site on the mid-axillary line at the level of the distal end of the xiphoid process.

71. *Triceps (Fat)*:* The thickness of the panniculus adiposus dissected from a site on the posterior aspect of the upper arm midway between acromion and olecranon.

72. *Iliac Crest (Fat)*:* The thickness of the panniculus adiposus dissected from a site in the mid-axillary line, just superior to the crest of the right ilium.

73. *Mean Fat Thickness:* A derived dimension calculated as the arithmetic mean of the values obtained in variables 69-72.

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*These dimensions (in millimeters) can be approximated on the living from skinfold measurements through the use of the regression equations developed by Lee and Ng (1965) where:

MAL X (Fat) = 0.66 Skinfold MAL X − 0.94 (±1.55)
Triceps (Fat) = 0.89 Skinfold Triceps − 0.44 (±1.78)
Iliac Crest (Fat) = 0.78 Skinfold Iliac Crest − 0.27 (±2.01)

Appendix E

STATISTICAL TECHNIQUES

The statistical techniques used in this study are those most commonly used for a random sample. In selecting the sample there was no attempt made to select a stratified or fractional sample.

Prior to preparation of descriptive and analytical statistical analyses, the data were treated to an extensive set of editing routines. Any large body of data is likely to contain errors of observation and transcription. While the number of subjects in this sample was small ($n=13$), the number of observations per sampling unit was large (approximately 510). A number of these observations, however, were redundant in that they were duplicate estimations of the same variable. The volume of segments, for example, was measured by both under-water weighing and by water displacement.

Despite the rigorous checking of observations, which normally consisted of independent checks by two observers, the probability is high that errors exist in the more than sixty-six hundred observations made, recorded, and transcribed to punch cards. In order to determine if and where errors in these data might occur, a series of test or editorial routines were used. These routines have been developed by Professor Edmund Churchill, and while rather widely used, have never been adequately described in the literature. The simplest and least expensive routine is that which he terms the "X-VAL" routine. This is a computer program that orders each variable from its smallest to the largest value and then prints out the ten lowest and ten largest values with the $\bar{x}$, SD and CV of the total sample. In addition, this routine deletes the top and bottom values and recomputes the $\bar{x}$ and SD. This allows a close look at the two tails of the distribution of values and often permits the pinpointing of values obviously out of range as a result of transposition or dropping of digits.

A second editing routine that we used extensively (termed EDIT) is more expensive and time consuming but is correspondingly more sensitive in error detection. This routine requires that all values of a variable be tested against values predicted from one or more multiple regression equations. The multiple regression equation contains independent variables that have a high correlation with the variable being tested. If the predicted values are greater than a specified number of Se_{est} units away from the actual recorded value, the information is printed.[1] While the X-VAL routine treats only the ends of the distribution, the EDIT routine examines each value against the values of two or more closely related variables. The use of a sufficient number of combinations of the variables in various regressions permits the pinpointing of possible errors. It is important to stress that the editing routines cannot offer a "correct" value for an "incorrect" observed value but can only furnish a value in line with those observed in the rest of the sample. It rests with the investigator to determine in the final stage where possible errors exist and how the data should be treated when such questions arise.

In this study many observations were made using two independent techniques so that suspected values could be checked against their companion values as well as the values suggested by the editing routine. Values for any variable were not changed except in those instances where the burden of proof was overwhelming and consistent that a change was necessary to correct some form of error.

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[1] A simplified version of this type of editing routine is outlined by Yates (1960, pp. 392-394).

The general formulas for statistics used in this study are as follows:

$$\bar{x} = \frac{\Sigma X}{n}$$

$$SD^2 = \frac{N\Sigma X - \Sigma X^2}{N^2}$$

$$CV = \frac{SD}{\bar{x}} \text{ X } 100$$

$$Se_{\bar{x}} = \frac{SD}{\sqrt{N}}$$

$$Se_{SD} = \frac{SD}{\sqrt{2N}}$$

$$r = \frac{N\Sigma XY - \Sigma X\Sigma Y}{\sqrt{[N(\Sigma X^2) - (\Sigma X)^2][N(\Sigma Y^2) - (\Sigma Y)^2]}}$$

The stepwise regression program used in this study is a modified form of the computer program prepared at the School of Medicine, University of California. The program was extensively modified to expand the number of variables to be considered in the analysis but otherwise remains similar to the form described by Dixon (1964). The program computes a sequence of multiple linear regression equations with an independent variable being added at each step. The first independent variable to be added has the highest correlation coefficient with the dependent variable. The remaining independent variables are then selected from the highest partial correlation coefficients, partialed on the variables already in the equation.

The program permits the weighting of the independent variables so that they can be forced into the equation at any step in the sequence. The general background for this type of computer program has been well described by Efroymson (1960).

Appendix F

CORRELATION MATRIX OF SEGMENTAL VARIABLES

LIST OF ANTHROPOMETRIC VARIABLES

1. Age
2. Endomorphy
3. Mesomorphy
4. Ectomorphy
5. Weight
6. Estimated Stature
7. Tragion Height
8. Mastoid Height
9. Neck/Chin Intersect Height
10. Cervicale Height
11. Suprasternale Height
12. Substernale Height
13. Thelion Height
14. Tenth Rib Height
15. Omphalion Height
16. Penale Height
17. Symphysion Height
18. Anterior Superior Spine Height
19. Iliac Crest Height
20. Trochanteric Height
21. Tibiale Height
22. Lateral Malleolus Height
23. Sphyrion Height
24. Head Breadth
25. Head Length
26. Neck Breadth
27. Neck Depth
28. Chest Breadth
29. Chest Breadth/Bone
30. Chest Depth
31. Waist Breadth/Omphalion
32. Waist Depth/Omphalion
33. Bicristal Breadth
34. Bispinous Breadth
35. Hip Breadth
36. Bitroch Breadth/Bone
37. Knee Breadth/Bone
38. Elbow Breadth/Bone
39. Wrist Breadth/Bone
40. Hand Breadth
41. Head Circumference
42. Neck Circumference
43. Chest Circumference
44. Waist Circumference
45. Buttock Circumference
46. Upper Thigh Circumference
47. Lower Thigh Circumference
48. Calf Circumference
49. Ankle Circumference
50. Arch Circumference
51. Arm Circumference (Axilla)
52. Biceps Circumference
53. Elbow Circumference
54. Forearm Circumference
55. Wrist Circumference
56. Hand Circumference
57. Head and Trunk Length
58. Height of Head
59. Trunk Length
60. Thigh Length
61. Calf Length
62. Foot Length
63. Arm Length (Estimated)
64. Acromion-Radiale Length
65. Ball Humerous-Radiale Length
66. Radiale-Stylion Length
67. Stylion-Meta 3 Length
68. Meta 3-Dactylion Length
69. Juxta Nipple (Fat)
70. Mal Xiphoid (Fat)
71. Triceps (Fat)
72. Iliac Crest (Fat)
73. Mean Fat Thickness

83\. AP at Cm* (Leg)
98\. AP at Cm* (Thigh)
103\. AP at Cm* (Calf and Foot)
108\. AP at Cm* (Calf)
117\. AP at Cm* (Upper Arm)
122\. AP at Cm* (Forearm and Hand)
127\. AP at Cm* (Forearm)

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*Anteroposterior depth at the level of the center of mass.

CORRELATION COEFFICIENTS OF SEGMENTAL VARIABLES WITH ANTHROPOMETRY

```
74      WEIGHT OF TOTAL BODY

 1) .074 .838 .099 .105 .999   6) .599 .561 .538 .493 .408
11) .540 .654 .526 .501 .323  16) .039 .246 .198 .251 .325
21) .288 .207 .038 .539 .558  26) .598 .746 .859 .907 .085
31) .807 .436 .772 .297 .906  36) .902 .821 .568 .262 .596
41) .605 .676 .875 .813 .953  46) .785 .814 .716 .641 .518
51) .705 .843 .756 .737 .733  56) .306 .741 .770 .534 .364
61) .315 .469 .568 .551 .385  66) .474 .381 .515 .269 .600
71) .481 .257 .408

75      VOLUME OF TOTAL BODY

 1) .100 .838 .108 .121 .992   6) .642 .600 .582 .543 .466
11) .590 .719 .584 .580 .403  16) .114 .313 .266 .313 .397
21) .360 .261 .076 .489 .541  26) .599 .729 .877 .904 .130
31) .838 .444 .784 .332 .923  36) .926 .840 .586 .254 .547
41) .570 .663 .914 .837 .968  46) .754 .823 .662 .602 .522
51) .709 .828 .774 .731 .714  56) .281 .728 .750 .527 .433
61) .382 .529 .541 .529 .360  66) .446 .407 .481 .321 .646
71) .537 .321 .469

76      CM-TOP OF HEAD (TOTAL BODY)

 1) .369 .671 .026 .220 .720   6) .665 .615 .599 .593 .517
11) .573 .489 .582 .467 .406  16) .119 .287 .272 .361 .398
21) .376 .373 .545 .491 .544  26) .135 .442 .559 .604 -044
31) .735 .285 .894 .594 .791  36) .802 .692 .515 .465 .431
41) .592 .148 .463 .624 .745  46) .635 .713 .635 .548 .569
51) .293 .370 .320 .191 .414  56) .434 .773 .620 .631 .408
61) .216 .282 .687 .782 .771  66) .368 .356 .494 .206 .369
71) .241 -076 .177

77      WEIGHT OF HEAD AND TRUNK

 1) .198 .778 .035 .187 .968   6) .673 .635 .622 .597 .522
11) .631 .713 .619 .573 .419  16) .102 .311 .280 .322 .391
21) .369 .330 .141 .559 .614  26) .538 .683 .890 .898 .116
31) .860 .444 .823 .395 .921  36) .912 .781 .551 .350 .574
41) .615 .610 .878 .855 .917  46) .679 .759 .582 .536 .401
51) .645 .743 .686 .642 .755  56) .228 .796 .641 .649 .409
61) .367 .540 .571 .539 .383  66) .501 .432 .519 .310 .588
71) .476 .215 .405

78      VOLUME OF HEAD AND TRUNK

 1) .218 .762 .024 .232 .951   6) .722 .680 .671 .650 .586
11) .690 .785 .682 .657 .517  16) .199 .400 .368 .405 .484
21) .459 .384 .183 .491 .587  26) .524 .630 .887 .879 .196
31) .872 .452 .822 .410 .923  36) .929 .788 .565 .330 .515
41) .565 .594 .925 .861 .929  46) .631 .752 .529 .493 .424
51) .631 .721 .699 .636 .723  56) .197 .767 .636 .618 .499
61) .453 .621 .550 .522 .360  66) .479 .478 .481 .349 .614
71) .521 .273 .452
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CORRELATION COEFFICIENTS OF SEGMENTAL VARIABLES WITH ANTHROPOMETRY

```
79      CM-TOP OF HEAD (HEAD AND TRUNK)

 1) .482 .683 .130 .079 .712    6) .591 .552 .552 .555 .477
11) .503 .426 .544 .397 .290   16) -085 .117 .103 .173 .204
21) .236 .459 .519 .565 .557   26) .216 .308 .702 .662 -215
31) .856 .336 .897 .734 .780   36) .756 .711 .331 .674 .481
41) .473 .150 .431 .795 .714   46) .489 .680 .520 .614 .411
51) .359 .363 .283 .200 .628   56) .337 .889 .406 .849 .161
61) .063 .206 .542 .546 .548   66) .417 .362 .454 .181 .385
71) .214 -080 .163

80      WEIGHT OF LEG

 1) -087 .839 .180 -055 .919    6) .420 .380 .344 .286 .204
11) .346 .497 .340 .378 .182   16) -034 .131 .072 .133 .213
21) .150 -011 -098 .415 .417   26) .594 .774 .707 .812 .033
31) .654 .365 .642 .159 .796   36) .793 .786 .524 .046 .523
41) .523 .695 .772 .659 .909   46) .879 .842 .836 .701 .668
51) .673 .856 .746 .754 .532   56) .334 .540 .852 .272 .291
61) .212 .300 .451 .487 .319   66) .289 .234 .398 .189 .572
71) .472 .300 .388

81      VOLUME OF LEG

 1) -066 .857 .214 -082 .924    6) .438 .393 .366 .311 .234
11) .366 .535 .371 .427 .215   16) -013 .150 .089 .146 .235
21) .176 .031 -082 .401 .413   26) .618 .777 .747 .829 .025
31) .700 .378 .661 .204 .822   36) .818 .813 .535 .053 .498
41) .509 .690 .794 .701 .925   46) .875 .868 .793 .682 .650
51) .705 .861 .768 .756 .538   56) .321 .545 .821 .290 .307
61) .235 .317 .417 .455 .287   66) .261 .234 .370 .248 .637
71) .530 .365 .455

82      CM-TROCHANTERION (LEG)

 1) .349 .065 -347 .567 .101    6) .665 .649 .647 .703 .701
11) .651 .367 .638 .497 .643   16) .492 .570 .592 .636 .610
21) .638 .628 .813 .058 .229   26) -264 -117 .050 .031 .159
31) .336 .034 .574 .612 .295   36) .321 .177 .262 .544 -070
41) .138 -320 .028 .203 .174   46) -125 .056 .030 -019 .245
51) -362 -353 -192 -308 -006   56) .109 .486 .048 .534 .540
61) .410 .259 .646 .711 .773   66) .385 .301 .286 -120 -142
71) -195 -340 -224

84      CM-ANT ASPECT (LEG)

 1) -113 .219 .359 -369 .106    6) -157 -213 -218 -226 -220
11) -253 -190 -164 -127 -231   16) -342 -360 -346 -274 -218
21) -255 -130 .049 -079 -120   26) -147 -002 .033 .025 -303
31) .126 .130 .230 .101 .165   36) .181 .090 -122 -188 -014
41) .033 -125 -078 .078 .187   46) .437 .448 .393 .419 .504
51) -015 .004 -227 -203 -189   56) .104 -015 .301 -138 -159
61) -305 -279 -210 -026 -010   66) -476 .073 -148 .115 .219
71) .113 -014 .107             83) .695
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CORRELATION COEFFICIENTS OF SEGMENTAL VARIABLES WITH ANTHROPOMETRY

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85      WEIGHT OF ARM

 1) -099 .704 .145 .112 .883   6) .458 .451 .420 .340 .234
11) .384 .477 .342 .239 .088  16) -070 .138 .069 .123 .160
21) .145 .124 -079 .525 .400  26) .586 .710 .697 .755 .037
31) .570 .377 .499 .063 .697  36) .709 .714 .512 .352 .628
41) .489 .586 .692 .631 .762  46) .633 .579 .662 .657 .390
51) .728 .861 .750 .779 .843  56) .500 .686 .783 .466 .179
61) .193 .367 .633 .541 .434  66) .653 .343 .597 .151 .411
71) .265 .181 .255

86      VOLUME OF ARM

 1) -086 .745 .178 .089 .907   6) .501 .490 .467 .390 .288
11) .431 .546 .402 .326 .152  16) -018 .185 .115 .165 .211
21) .197 .172 -064 .500 .400  26) .640 .742 .765 .802 .023
31) .636 .371 .540 .123 .752  36) .700 .763 .550 .339 .593
41) .490 .611 .741 .685 .804  46) .651 .632 .624 [illegible] .375
51) .780 .882 .800 .796 .845  56) .478 .702 .761 .493 .226
61) .248 .406 .602 .517 .406  66) .619 .340 .583 .226 .504
71) .360 .278 .352

87      CM-ACROMION (ARM)

 1) .190 .096 -314 .709 .406   6) .624 .645 .593 .580 .518
11) .625 .411 .488 .360 .450  16) .440 .569 .567 .623 .571
21) .520 .253 .220 .128 .186  26) .011 .300 .146 .222 .541
31) .162 .238 .306 -083 .357  36) .399 .211 .524 .427 .594
41) .178 .207 .407 .155 .287  46) .013 .001 .228 .077 .156
51) -135 .116 .201 .287 .403  56) .287 .458 .456 .338 .605
61) .508 .527 .848 .814 .684  66) .709 .371 .522 -291 -304
71) -298 -429 -365

88      WEIGHY OF HEAD

 1) .058 .573 -435 .308 .748   6) .528 .501 .484 .476 .452
11) .519 .572 .492 .377 .364  16) .104 .289 .251 .257 .333
21) .354 .345 .217 .668 .711  26) .425 .524 .568 .680 .030
31) .387 .257 .734 .414 .625  36) .611 .486 .313 .143 .241
41) .814 .435 .575 .583 .694  46) .549 .492 .628 .416 .479
51) .477 .550 .469 .423 .402  56) .035 .609 .518 .485 .295
61) .321 .267 .687 .660 .580  66) .576 .331 .481 .156 .478
71) .288 .171 .270

89      VOLUME OF HEAD

 1) -017 .578 -473 .389 .716   6) .624 .585 .571 .564 .555
11) .627 .719 .620 .540 .564  16) .309 .442 .432 .419 .500
21) .498 .315 .235 .527 .729  26) .410 .520 .604 .738 .069
31) .571 .042 .755 .411 .665  36) .676 .470 .359 -113 .136
41) .883 .508 .708 .496 .758  46) .672 .571 .350 .263 .458
51) .536 .563 .532 .354 .256  56) -097 .553 .539 .413 .478
61) .480 .509 .511 .519 .466  66) .381 .395 .519 .364 .584
71) .565 .352 .485
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CORRELATION COEFFICIENTS OF SEGMENTAL VARIABLES WITH ANTHROPOMETRY

```
90      CM-TOP OF HEAD (HEAD)

 1) -129 .687 -022 .027 .851   6) .434 .396 .399 .365 .328
11) .434 .679 .431 .488 .306  16) .095 .226 .193 .184 .283
21) .250 .120 -194 .491 .570  26) .688 .753 .833 .874 .067
31) .660 .276 .578 .167 .762  36) .741 .606 .468 -125 .371
41) .704 .757 .877 .671 .804  46) .757 .692 .450 .304 .215
51) .822 .846 .792 .698 .539  56) .003 .474 .522 .329 .317
61) .365 .489 .261 .232 .066  66) .256 .248 .374 .507 .785
71) .726 .561 .679

91      CM-BACK OF HEAD (HEAD)

 1) -426 -087 -353 .457 .102   6) .155 .187 .164 .117 .120
11) .194 .275 .167 -005 .171  16) .186 .171 .222 .172 .158
21) .159 -069 -111 .103 .242  26) -001 .021 .127 .229 .076
31) -177 -397 -039 -296 .016  36) .100 -186 -041 -435 .017
41) .468 .249 .343 -225 .115  46) .065 -047 -006 -146 -194
51) .329 .261 .149 -032 .121  56) -189 .092 .255 .002 .143
61) .222 .609 -091 -181 -095  66) .088 .465 .467 .584 .080
71) .365 .185 .291

92      WEIGHT OF TRUNK

 1) .205 .781 .065 .174 .966   6) .669 .632 .620 .594 .517
11) .627 .710 .616 .577 .415  16) .099 .306 .276 .319 .308
21) .352 .322 .134 .543 .600  26) .537 .661 .897 .899 .116
31) .865 .446 .817 .390 .926  36) .917 .788 .557 .356 .546
41) .594 .611 .883 .859 .913  46) .672 .767 .870 .535 .389
51) .647 .743 .689 .644 .762  56) .235 .795 .637 .649 .408
61) .362 .548 .552 .521 .363  66) .484 .429 .512 .317 .588
71) .484 .216 .409

93      VOLUME OF TRUNK

 1) .229 .763 .063 .209 .949   6) .709 .668 .658 .637 .570
11) .674 .771 .668 .648 .498  16) .181 .382 .349 .389 .467
21) .441 .377 .173 .482 .567  26) .523 .626 .890 .872 .199
31) .877 .473 .809 .402 .922  36) .927 .797 .566 .352 .534
41) .533 .589 .922 .871 .924  46) .620 .753 .521 .503 .416
51) .630 .723 .700 .645 .741  56) .215 .765 .631 .617 .485
61) .436 .613 .536 .506 .340  66) .472 .472 .465 .344 .608
71) .511 .266 .445

94      CM-SUPRASTERNALE (TRUNK)

 1) .536 .471 -050 -073 .366   6) .331 .287 .318 .361 .346
11) .280 .190 .369 .191 .150  16) -233 -087 -069 -049 -015
21) .071 .483 .542 .483 .554  26) .067 -055 .455 .380 -370
31) .676 .213 .728 .846 .454  36) .398 .388 -082 .599 .198
41) .366 -105 .081 .644 .403  46) .239 .416 .289 .408 .246
51) .125 .050 -030 -080 .328  56) -014 .673 -033 .779 -116
61) -136 -082 .271 .249 .331  66) .248 .151 .227 .088 .268
71) .079 -120 .062
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CORRELATION COEFFICIENTS OF SEGMENTAL VARIABLES WITH ANTHROPOMETRY

```
 95      WEIGHT OF THIGH

  1) -165 .821 .211 -117 .893    6) .381 .338 .315 .257 .188
 11) .322 .521 .320 .406 .175   16) -000 .142 .082 .130 .221
 21) .152 -024 -211 .331 .354   26) .673 .822 .717 .798 .057
 31) .624 .371 .562 .090 .777   36) .767 .750 .541 -044 .464
 41) .482 .737 .792 .645 .875   46) .868 .820 .737 .599 .577
 51) .716 .879 .799 .811 .499   56) .273 .452 .790 .197 .306
 61) .260 .307 .374 .409 .219   66) .232 .160 .340 .247 .644
 71) .539 .422 .477

 96      VOLUME OF THIGH

  1) -153 .830 .244 -138 .888    6) .396 .350 .335 .278 .214
 11) .339 .555 .347 .448 .205   16) .025 .161 .101 .145 .242
 21) .177 .012 -194 .313 .345   26) .690 .819 .748 .808 .046
 31) .656 .368 .569 .126 .793   36) .784 .770 .551 -042 .436
 41) .468 .725 .807 .672 .881   46) .856 .836 .687 .572 .548
 51) .748 .880 .819 .804 .502   56) .266 .453 .758 .211 .321
 61) .282 .330 .335 .370 .187   66) .202 .162 .319 .310 .701
 71) .597 .486 .544

 97      CM-TROCHANTERION (THIGH)

  1) .465 .390 .015 .473 .466    6) .887 .856 .869 .888 .845
 11) .860 .758 .853 .861 .837   16) .691 .783 .765 .821 .841
 21) .820 .652 .680 .104 .255   26) .102 .350 .492 .421 .255
 31) .665 .161 .715 .592 .701   36) .743 .611 .726 .479 .111
 41) .257 .015 .506 .503 .545   46) .186 .444 .042 .028 .217
 51) .168 .114 .355 .090 .295   56) .364 .611 .318 .568 .823
 61) .673 .611 .631 .717 .700   66) .344 .382 .357 .357 .373
 71) .344 .158 .328

 99      CM-ANT ASPECT (THIGH)

  1) -143 .412 .072 -164 .557    6) -112 -170 -214 -252 -284
 11) -162 .074 -174 -154 -216   16) -387 -294 -331 -296 -184
 21) -263 -346 -222 .534 .434   26) .088 .337 .240 .369 .186
 31) .237 .474 .252 -191 .313   36) .353 .310 .043 -286 .449
 41) .510 .368 .468 .303 .512   46) .745 .515 .752 .610 .635
 51) .414 .618 .297 .389 .197   56) .158 .028 .689 -248 -071
 61) -213 .040 .039 .101 -047   66) -078 .268 -026 .229 .362
 71) .278 .080 .243             98) .838

100      WEIGHT OF CALF AND FOOT

  1) .126 .725 .059 .125 .814    6) .448 .423 .362 .316 .214
 11) .351 .344 .332 .237 .170   16) -112 .084 .036 .117 .155
 21) .122 .033 .215 .557 .498   26) .284 .504 .553 .699 -044
 31) .609 .275 .733 .311 .696   36) .713 .730 .380 .272 .570
 41) .534 .459 .575 .570 .829   46) .739 .740 .934 .838 .779
 51) .440 .637 .466 .463 .523   56) .425 .673 .854 .423 .196
 61) .054 .225 .574 .604 .524   66) .395 .391 .479 .000 .281
 71) .209 -069 .086
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CORRELATION COEFFICIENTS OF SEGMENTAL VARIABLES WITH ANTHROPOMETRY

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101      VOLUME OF CALF AND FOOT

  1) .165 .749 .119 .092 .817    6) .467 .439 .382 .339 .236
 11) .367 .370 .359 .289 .204   16) -089 .105 .052 .135 .179
 21) .145 .060 .249 .539 .479   26) .294 .507 .587 .715 -058
 31) .659 .281 .761 .366 .727   36) .744 .780 .406 .289 .553
 41) .501 .449 .590 .608 .851   46) .740 .782 .911 .841 .789
 51) .460 .634 .484 .457 .522   56) .442 .679 .839 .436 .218
 61) .067 .231 .543 .583 .504   66) .353 .389 .442 .043 .333
 71) .260 -020 .138

102      CM-TIBIALE (CALF AND FOOT)

  1) .109 -339 -365 .776 -047    6) .580 .612 .610 .633 .665
 11) .655 .552 .571 .564 .715   16) .801 .820 .808 .786 .767
 21) .789 .597 .336 -250 -180   26) -059 -070 .023 -078 .575
 31) .009 .032 .017 -001 .043   36) .122 -080 .308 .212 -290
 41) -189 -092 .273 -020 -065   46) -508 -362 -484 -432 -183
 51) -180 -240 .023 -055 .130   56) -052 .106 -062 .145 .695
 61) .772 .642 .420 .349 .290   66) .454 .479 .138 .025 -100
 71) -081 .057 -012

104      CM-ANT ASPECT (CALF AND FOOT)

  1) -184 .431 -137 -083 .393    6) .090 .105 .049 .023 -020
 11) .046 .016 .035 .055 -027   16) -160 -039 -107 -088 -087
 21) -072 -141 -134 .197 .126   26) .468 .379 .274 .462 -364
 31) .219 -131 .374 .203 .272   36) .202 .340 .050 -082 .072
 41) .219 .540 .175 .210 .432   46) .478 .400 .706 .548 .561
 51) .201 .341 .256 .360 .101   56) -041 .295 .385 .181 -096
 61) -026 -223 .283 .282 .201   66) .217 -066 .246 -423 .085
 71) .015 .022 -114            103) .782

105      WEIGHT OF CALF

  1) .102 .732 .026 .109 .793    6) .446 .422 .363 .320 .225
 11) .350 .334 .339 .238 .171   16) -111 .082 .037 .113 .149
 21) .125 .053 .211 .519 .482   26) .316 .495 .544 .692 -094
 31) .598 .293 .736 .342 .680   36) .688 .709 .348 .264 .518
 41) .521 .461 .540 .560 .817   46) .728 .729 .933 .827 .782
 51) .421 .613 .452 .458 .489   56) .376 .676 .820 .440 .178
 61) .059 .187 .576 .602 .532   66) .402 .350 .491 -043 .273
 71) .193 -057 .070

106      VOLUME OF CALF

  1) .136 .766 .079 .084 .808    6) .479 .451 .399 .357 .262
 11) .380 .375 .380 .299 .213   16) -081 .112 .063 .141 .182
 21) .160 .094 .246 .503 .471   26) .339 .508 .590 .718 -108
 31) .656 .240 .771 .401 .723   36) .730 .763 .381 .287 .504
 41) .501 .456 .565 .608 .848   46) .733 .774 .908 .828 .785
 51) .454 .621 .482 .461 .502   56) .394 .697 .810 .468 .208
 61) .085 .207 .558 .591 .523   66) .377 .353 .473 .009 .335
 71) .251 .001 .132
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CORRELATION COEFFICIENTS OF SEGMENTAL VARIABLES WITH ANTHROPOMETRY

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107      CM-TIBIALE (CALF)

  1) .080 -336 -436 .822 -041    6) .598 .627 .623 .645 .685
 11) .672 .554 .591 .539 .719   16) .793 .816 .816 .795 .777
 21) .800 .613 .351 -267 -150   26) -091 -104 -004 -092 .589
 31) -017 .026 .032 -013 .035   36) .122 -127 .262 .200 -292
 41) -153 -109 .270 -040 -059   46) -503 -374 -444 -419 -144
 51) -218 -253 -017 -075 .113   56) -092 .128 -026 .156 .701
 61) .778 .666 .453 .378 .331   66) .483 .516 .195 -004 -142
 71) -118 .008 -055

109      CM-ANT ASPECT (CALF)

  1) .191 .506 -037 -090 .513    6) .278 .288 .226 .241 .211
 11) .239 .207 .235 .334 .180   16) -050 .101 .031 .069 .115
 21) .128 .174 .077 .230 .155   26) .465 .382 .415 .472 -126
 31) .538 .300 .573 .455 .465   36) .384 .526 .190 .258 .109
 41) .074 .431 .299 .560 .529   46) .417 .478 .602 .561 .648
 51) .110 .263 .265 .424 .226   56) .004 .392 .295 .328 .100
 61) .122 -189 .440 .463 .280   66) .300 -009 .041 -396 .215
 71) -028 .012 -092            108) .665

110      WEIGHT OF FOOT

  1) .212 .638 .189 .172 .810    6) .423 .395 .329 .279 .156
 11) .325 .346 .282 .207 .152   16) -100 .083 .036 .130 .168
 21) .098 -057 .232 .649 .527   26) .111 .493 .529 .657 .134
 31) .588 .375 .663 .171 .698   36) .749 .741 .483 .279 .729
 41) .556 .391 .640 .533 .796   46) .724 .726 .853 .786 .677
 51) .466 .660 .469 .415 .587   56) .590 .607 .906 .327 .252
 61) .019 .355 .512 .562 .471   66) .312 .496 .415 .186 .278
 71) .262 -121 .145

111      VOLUME OF FOOT

  1) .292 .666 .249 .133 .810    6) .448 .414 .354 .313 .190
 11) .350 .379 .319 .280 .207   16) -065 .113 .063 .158 .203
 21) .131 -027 .288 .640 .529   26) .108 .491 .564 .671 .131
 31) .657 .388 .707 .254 .738   36) .786 .802 .518 .302 .715
 41) .528 .373 .657 .584 .822   46) .725 .773 .820 .774 .683
 51) .474 .644 .485 .397 .569   56) .600 .609 .871 .343 .288
 61) .035 .362 .471 .540 .447   66) .250 .460 .356 .242 .338
 71) .327 -072 .206

112      CM-HEEL (FOOT)

  1) .134 .506 -370 .530 .629    6) .773 .742 .730 .718 .703
 11) .746 .784 .758 .615 .703   16) .437 .600 .553 .561 .639
 21) .686 .624 .602 .460 .562   26) .256 .300 .546 .594 .099
 31) .629 .095 .775 .596 .617   36) .688 .571 .348 .220 .007
 41) .638 .188 .614 .542 .720   46) .419 .474 .491 .377 .581
 51) .485 .426 .447 .212 .365   56) .154 .659 .568 .522 .546
 61) .547 .566 .642 .620 .655   66) .542 .644 .497 .380 .548
 71) .450 .352 .455
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CORRELATION COEFFICIENTS OF SEGMENTAL VARIABLES WITH ANTHROPOMETRY

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113     CM-SOLE (FOOT)

  1) -048 -104 -321 .320 .190    6) -018 -019 -100 -105 -110
 11) -037 -001 -106 -133 .014   16) -112 -014 -082 -065 -010
 21) -003 -058 .151 .450 .158   26) -198 -077 -065 .075 .188
 31) -001 .215 .176 -057 -029   36) .039 .035 -162 -146 -014
 41) .225 .076 .166 .015 .176   46) .208 .040 .530 .487 .672
 51) -013 .096 -145 -061 .038   56) .042 -021 .451 -205 -021
 61) -061 -030 .222 .232 .140   66) .158 .557 -110 -169 -031
 71) -147 -175 -153

114     WEIGHT OF UPPER ARM

  1) -127 .789 .172 .009 .879    6) .461 .440 .425 .348 .253
 11) .381 .523 .374 .306 .129   16) -036 .147 .075 .121 .178
 21) .168 .149 -030 .534 .446   26) .645 .766 .741 .801 -095
 31) .631 .283 .567 .194 .743   36) .746 .773 .538 .245 .516
 41) .591 .569 .674 .651 .809   46) .750 .689 .662 .625 .408
 51) .837 .893 .808 .739 .730   56) .485 .666 .755 .455 .189
 61) .203 .320 .558 .507 .442   66) .526 .262 .568 .319 .604
 71) .456 .376 .457

115     VOLUME OF UPPER ARM

  1) -115 .822 .180 -017 .886    6) .495 .468 .464 .393 .308
 11) .422 .586 .432 .385 .192   16) .010 .185 .116 .154 .222
 21) .218 .206 -012 .502 .455   26) .691 .775 .796 .834 -116
 31) .688 .268 .606 .265 .782   36) .780 .798 .546 .222 .440
 41) .596 .579 .708 .698 .839   46) .757 .730 .613 .583 .388
 51) .874 .896 .839 .739 .711   56) .429 .674 .709 .482 .225
 61) .252 .350 .513 .467 .405   66) .484 .249 .549 .391 .694
 71) .547 .472 .551

116     CM-ACROMION (UPPER ARM)

  1) .390 .273 -153 .543 .480    6) .702 .691 .653 .667 .596
 11) .701 .549 .588 .648 .648   16) .605 .692 .677 .741 .723
 21) .625 .203 .340 .203 .309   26) .058 .511 .281 .370 .509
 31) .398 .209 .524 .164 .576   36) .591 .471 .805 .283 .370
 41) .325 .272 .516 .276 .457   46) .278 .318 .246 -001 .214
 51) -020 .166 .363 .265 .204   56) .351 .405 .439 .285 .809
 61) .586 .518 .742 .845 .689   66) .389 .193 .359 -003 .028
 71) .077 -183 -034

118     CM-ANT ASPECT (UPPER ARM)

  1) -228 .458 .103 -199 .630    6) -049 -062 -108 -159 -223
 11) -059 .175 -137 .040 -153   16) -189 -087 -177 -167 -095
 21) -174 -398 -533 .475 .283   26) .572 .728 .898 .547 .177
 31) .257 .379 .133 -281 .369   36) .331 .470 .365 -239 .459
 41) .370 .762 .571 .352 .511   46) .488 .444 .617 .438 .357
 51) .580 .788 .681 .806 .359   56) .189 .032 .556 -187 .017
 61) .015 .014 .197 .185 -075   66) .169 -083 .019 .024 .390
 71) .289 .281 .246            117) .874
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CORRELATION COEFFICIENTS OF SEGMENTAL VARIABLES WITH ANTHROPOMETRY

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119      WEIGHT OF FOREARM AND HAND

  1) -049 .477 .083 .239 .758   6) .383 .397 .347 .278 .170
 11) .327 .338 .244 .106 .013  16) -108 .102 .049 .106 .107
 21) .087 .069 -140 .433 .275  26) .419 .825 .529 .576 .214
 31) .396 .451 .325 -134 .526  36) .545 .520 .395 .447 .689
 41) .272 .525 .611 .507 .578  46) .373 .332 .565 .604 .304
 51) .466 .688 .555 .720 .874  56) .444 .609 .702 .410 .135
 61) .150 .373 .644 .508 .356  66) .735 .405 .549 -112 .075
 71) -046 -120 -070

120      VOLUME OF FOREARM AND HAND

  1) -034 .517 .099 .240 .787   6) .438 .449 .405 .335 .233
 11) .386 .412 .310 .188 .080  16) -050 .161 .105 .160 .170
 21) .150 .125 -119 .414 .282  26) .464 .589 .584 .614 .230
 31) .454 .465 .362 -090 .579  36) .599 .567 .442 .456 .672
 41) .277 .542 .664 .559 .621  46) .385 .371 .537 .583 .299
 51) .508 .713 .608 .751 .890  56) .439 .633 .700 .439 .195
 61) .215 .425 .650 .517 .359  66) .737 .412 .553 -053 .146
 71) .022 -046 .004

121      CM-RADIALE (FOREARM AND HAND)

  1) .349 -025 -127 .679 .211   6) .620 .646 .623 .612 .557
 11) .576 .366 .526 .270 .424  16) .320 .467 .440 .491 .448
 21) .515 .638 .686 .237 .100  26) -212 -130 .174 .095 .194
 31) .281 .157 .354 .313 .240  36) .332 .243 .238 .764 .154
 41) .037 -290 .156 .240 .165  46) -272 -087 -002 .219 .130
 51) -025 -074 -040 -127 .554  56) .456 .618 .265 .593 .338
 61) .314 .449 .683 .584 .673  66) .709 .697 .447 -003 -159
 71) -251 -299 -188

123      CM-ANT ASPECT (FOREARM AND HAND)

  1) -033 .358 -049 -027 .485   6) .064 .057 .064 .023 .001
 11) .063 .208 .070 -129 -168  16) -368 -200 -220 -247 -195
 21) -141 .136 -203 .446 .423  26) .362 .105 .427 .378 .097
 31) .312 .440 .115 -023 .219  36) .225 .229 -158 .330 .454
 41) .237 .319 .422 .514 .548  46) .137 .110 .266 .420 .067
 51) .491 .575 .389 .565 .725  56) -014 .389 .234 .349 -246
 61) -091 .221 .163 -071 -130  66) .536 .287 .286 .075 .183
 71) .053 .085 .101           122) .913

124      WEIGHT OF FOREARM

  1) -182 .481 .017 .196 .761   6) .316 .332 .281 .205 .114
 11) .275 .336 .191 .080 -024  16) -130 .072 .014 .053 .067
 21) .048 .007 -277 .421 .273  26) .523 .578 .535 .407 .191
 31) .348 .413 .274 -202 .491  36) .500 .474 .346 .292 .624
 41) .310 .634 .639 .479 .580  46) .424 .325 .589 .583 .305
 51) .527 .752 .606 .792 .827  56) .329 .533 .695 .327 .094
 61) .161 .343 .584 .437 .262  66) .709 .355 .527 -128 .131
 71) .008 -017 -016
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CORRELATION COEFFICIENTS OF SEGMENTAL VARIABLES WITH ANTHROPOMETRY

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125       VOLUME OF FOREARM

  1) -180 .542 .060 .169 .807    6) .362 .373 .329 .252 .162
 11) .322 .411 .249 .167 .035   16) -082 .118 .057 .094 .119
 21) .097 .038 -277 .404 .280   26) .590 .634 .612 .669 .188
 31) .418 .419 .318 -158 .561   36) .567 .541 .403 .275 .614
 41) .322 .680 .708 .539 .643   46) .467 .397 .576 .574 .307
 51) .598 .803 .682 .838 .842   56) .327 .553 .706 .346 .149
 61) .217 .391 .564 .425 .241   66) .680 .351 .523 -042 .231
 71) .112 .084 .087

126       CM-RADIALE (FOREARM)

  1) .232 .008 -160 .663 .280    6) .612 .653 .635 .612 .558
 11) .625 .524 .538 .393 .496   16) .473 .610 .559 .566 .534
 21) .578 .529 .372 .200 .110   26) .092 .092 .271 .206 .408
 31) .254 .171 .178 .106 .241   36) .315 .301 .388 .609 .193
 41) .008 .034 .389 .268 .202   46) -292 -145 -123 .037 -061
 51) .180 .164 .315 .245 .636   56) .357 .483 .222 .461 .450
 61) .509 .615 .631 .463 .451   66) .788 .548 .412 .040 -056
 71) -082 -030 -026

128       CM-ANT ASPECT (FOREARM)

  1) .039 .314 .134 -397 .291    6) -276 -302 -302 -324 -333
 11) -299 -189 -286 -354 -469   16) -601 -469 -510 -503 -445
 21) -429 -118 -354 .219 .142   26) .264 .026 .085 .050 .129
 31) .140 .653 -088 -135 -001   36) -037 .152 -283 .332 .415
 41) -160 .182 .093 .408 .155   46) .115 .048 .389 .529 .316
 51) .119 .371 .186 .589 .412   56) .019 .058 .150 .005 -431
 61) -359 -298 .088 -056 -199   66) .315 -123 -120 -363 -067
 71) -320 -144 -257            127) .843

129       WEIGHT OF HAND

  1) .267 .410 .223 .302 .634    6) .498 .511 .470 .419 .294
 11) .415 .292 .348 .166 .106   16) -043 .162 .124 .216 .183
 21) .171 .228 .223 .405 .234   26) .139 .337 .466 .450 .165
 31) .475 .430 .432 .096 .547   36) .581 .565 .454 .757 .717
 41) .158 .200 .440 .508 .497   46) .706 .318 .428 .574 .247
 51) .266 .427 .347 .423 .863   56) .640 .735 .597 .596 .194
 61) .102 .369 .696 .608 .542   66) .696 .460 .546 -083 -050
 71) -155 -334 -180

130       VOLUME OF HAND

  1) .304 .448 .268 .280 .673    6) .534 .542 .506 .459 .333
 11) .453 .349 .391 .240 .154   16) -012 .194 .154 .246 .221
 21) .205 .256 .232 .414 .249   26) .176 .379 .534 .500 .173
 31) .548 .459 .478 .141 .610   36) .640 .623 .507 .763 .724
 41) .166 .230 .497 .572 .543   46) .235 .376 .407 .563 .236
 51) .311 .454 .393 .447 .885   56) .642 .754 .589 .621 .236
 61) .139 .403 .679 .600 .518   66) .667 .462 .523 -018 .029
 71) -079 -273 -105
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CORRELATION COEFFICIENTS OF SEGMENTAL VARIABLES WITH ANTHROPOMETRY

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131     CM-META 3 (HAND)

  1) .317 .372 -422 .093 .294   6) .238 .195 .189 .224 .260
 11) .229 .233 .289 .147 .253  16) -092 .057 .024 .004 .092
 21) .178 .402 .458 .391 .507  26) .084 -177 .175 .216 -023
 31) .430 .244 .527 .639 .183  36) .186 .281 -299 .272 -077
 41) .259 -009 .161 .477 .403  46) .174 .228 .499 .503 .709
 51) .052 .115 .035 .095 .077  56) -218 .345 .160 .328 -019
 61) .019 -061 .302 .242 .257  66) .339 .263 .034 -153 .172
 71) -009 .019 -014

132     CM-MED ASPECT (HAND)

  1) .481 -010 .197 .149 .109   6) .112 .129 .091 .096 .013
 11) .043 -238 -007 -197 -173  16) -290 -171 -152 -060 -143
 21) -146 .060 .281 .184 .022  26) -355 -200 -020 -064 .068
 31) .134 .342 .170 .069 .101  36) .102 .101 .018 .769 .553
 41) -201 -229 -126 .165 -008  46) -186 -039 .182 .373 .081
 51) -372 -190 -309 -107 .436  56) .396 .413 .122 .421 -128
 61) -283 -064 .376 .341 .326  66) .349 .212 .188 -446 -548
 71) -620 -828 -670
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Appendix G

DENSITIES OF HUMAN TISSUES

A number of studies reporting the density characteristics of freshly isolated (nonpreserved) human tissue are found throughout the literature. The more recent studies are concerned with the density of tissues from which the fat has been removed by chemical extraction and the water removed by hydration or prolonged drying. Few studies report densities (or specific gravities) of fresh "whole" tissues and with the exception of bone, the densities of tissues from embalmed cadavers are apparently undocumented. The lack of comparative information presents a serious difficulty in properly assessing the relationship of freshly isolated and preserved tissue. Our study afforded an opportunity to measure the densities of samples of skin, fat, muscle, and bone tissues dissected from cadavers randomly selected from the study population.

In all, the density of 135 tissue samples was determined. Skin, fat, and muscle samples were taken from sites at which the thicknesses of the skin and panniculus adiposus were measured. Soft tissue samples weighed about one gram, and bone samples were halved disks cut from the shaft of the humerus. As much dissimilar tissue as possible was dissected from each sample, but no drying or fat extraction was attempted since the primary purpose of the study was to compare only the densities of whole fresh and whole preserved tissues.

The volume of each tissue sample was determined by placing it in a 25 ml pycnometer filled with triple-distilled water, measuring the weight of the water displaced by the sample and correcting for the temperature of the water. All weighing was done on a balance which measured grams to four decimal places. The water and tissue samples were at room temperature (23.6 to 25 C). Care was taken to remove any air that was trapped in the samples.

Table 33 lists the results of this study and permits comparing the data of this study with what is believed may be the most comparable data on nonpreserved whole human tissue. Since very few modern investigators have measured the density of fresh, untreated human tissue, the works of Davy (1840) and Krause and Kapff (as given in Vierordt, 1906) are reported here even though their methods of derivation are not known. The data of Leider and Buncke (1954) on skin and Blanton and Biggs (1968) on bone are considered directly comparable. The standard deviations of the densities decrease with each cadaver studied in this present effort. This undoubtedly reflects an improvement in measuring techniques as the study progressed.

We do not believe that this study has demonstrated adequately the similarity or difference between preserved and unpreserved tissue, since so little fresh tissue has been tested in a manner similar to the treatment of the preserved tissue. With the exception of muscle tissue, however, it is encouraging that there are no apparent gross differences between the densities of the two types of tissues. Our data on the density of muscle tissue appear to be high. We can offer no explanation for this other than to suggest that the technique of measuring the density of muscle tissue was at fault.

TABLE 32

DENSITIES OF BODY TISSUES

Source (Nonpreserved)		*Skin*			*Muscle*			*Fat*			*Bone*					
Davy* (1840)		1.100 to 1.108			1.058 to 1.058			0.942			1.383 to 1.944					
Kapff and Vierordt (1906)								0.971								
Krause and Vierordt (1906)					1.0382 to 1.0591											
Leider and Buncke (1954)		1.102 (SD = .010)														
Blanton and Biggs (1968)											*Cancellous*			*Compact*		
Preserved											1.09			1.85		
Fresh											1.08			1.85		
This study (Preserved)																
	Age	*N of Samples*	$\bar{X}$	SD	*N of Samples*	$\bar{X}$	SD	*N of Samples*	$\bar{X}$	SD	*N of Samples*	$\bar{X}$	SD	*N of Samples*	$\bar{X}$	SD
Cadaver A	55	4	1.201	0.112	15	1.095	0.036	—	—	—	3	1.112	0.055	—	—	—
Cadaver B	61	6	1.086	0.066	12	1.078	0.027	9	0.970	0.056	3	1.099	0.037	—	—	—
Cadaver C	52	11	1.079	0.008	17	1.090	0.020	16	0.955	0.013	—	—	—	9	1.739	0.078
Cadaver D	38	6	1.095	0.005	18	1.084	0.011	—	—	—	—	—	—	6	1.892	0.064
	Mean		1.102	0.070		1.087	0.025		0.981	0.036		1.105	0.047		1.800	0.105

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*Specific gravity (7).

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