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# Anthropometric study of emergency medical services providers (EMSP) in the United States

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ABSTRACT

*Introduction:* Design of next-generation ambulance patient compartment requires up-to date anthropometric data of emergency medical service providers (EMSP). Currently, no such data exist in the U.S. A large-scale anthropometric study of EMSP in the U.S. were conducted. This report provided the summary statistics (means, standard deviation, and percentiles) of the study's results and examined the anthropometric differences between the EMSP dataset and the U.S. general population, and between the EMSP dataset and U.S. military personnel dataset, respectively. *Method:* An anthropometric study of 471 male and 161 female EMSP from across the continental US was conducted, using a sampling strategy that took into account age, sex, and race strata. *Results:* On average, male EMSP were found to be 18 mm taller and 7 kg heavier than US male general population, and 19 mm taller and 11 kg heavier than US male military personnel. Female EMSP were found to be 25 mm taller than US female general population, and 10 kg heavier than US female military personnel. *Conclusions:* These results showed that it would be inappropriate to apply general population or military data to the design of next-generation ambulance patient compartment. This new dataset provided the most recent and accurate EMSP anthropometric measurements available in the US. *Practical Application:* Data from this study provided an invaluable resource for the design of next-generation ambulances in the US.



## 1. Problems

Deaths or serious injuries among Emergency Medical Services Providers (EMSP) and their patients occur at a high rate while the ambulance is in the emergency transportation mode. According to a study by the National Institute for Occupational Safety and Health (NIOSH), EMSP have higher fatality rates compared to all workers in the United States, with 45% of EMSP deaths resulting from highway incidents, primarily due to vehicle collisions (Reichard, Marsh, & Moore, 2011). Data from the National Highway Traffic Safety Administration (NHTSA) showed that among the persons killed in crashes involving an ambulance between 1992 and 2011, 21% were EMSP and patients, while 4% were ambulance drivers (NHTSA, 2014).

To reduce the injury potential to EMSP and other ambulance occupants, NIOSH, U.S. Department of Homeland Security (DHS), U.S. General Services Administration (GSA), and National Institute of Standards and Technology (NIST), along with private industry partners, have committed to improving the workspace design in ambulance patient compartments for greater EMSP and patient safety, while enhancing EMSP's ability to deliver safe and efficient patient care. Up-to-date anthropometric information was key to successfully accomplishing the goal (Fig. 1). As a result, NIOSH conducted an anthropometric study of the EMSP throughout the continental United States between December 2013 and May 2015. This research was jointly funded through an interagency agreement between DHS and NIOSH.

In February 2015, DHS Science and Technology Directorate (S&T), First Responders Group (FRG), promulgated the Ambulance Patient Compartment Human Factors Design Guidebook (US Department of Homeland Security, 2015). The Guidebook incorporated key anthropometric measurements for the design of the patient compartment in emergency vehicles. This set of measurements was drawn from different sources of anthropometric data because no anthropometric data on current EMSP were available. These sources included the US general population in 2003–2006 obtained from the National Health and Nutrition Examination (NHANES; McDowell, Fryar, Ogden, & Flegal, 2008), military personnel (DOD, 2012), and Firefighters (Fire Apparatus Manufacturer's Association or FAMA, 2007).

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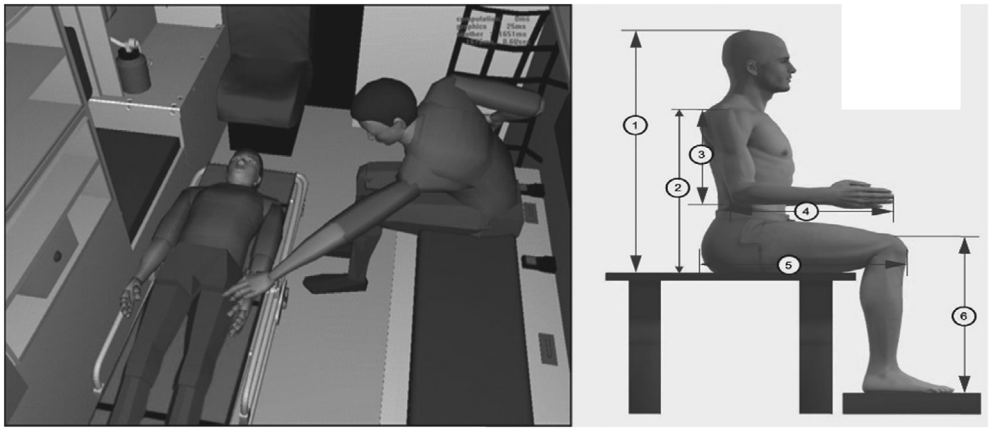


(a) (b)

**Fig. 1.** An illustration of the workspace design of the patient compartment. (a) An EMSP reaches for the patient who is lying on the gurney; (b) Selected key dimensions involved in the design: (1) sitting height; (2) acromial height, Sit; (3) shoulder-elbow length; (4) elbow-fingertip length; (5) buttock-knee length; and (6) knee height.

Prior studies showed that military anthropometric data does not represent the civilian population (Marras & Kim, 1993; Zhuang, Guan, Hsiao, & Bradtmiller, 2004). Additional studies have also indicated that some occupational groups have anthropometric characteristics different from those of the general population (Guan et al., 2012; Hsiao et al., 2014). Differences in anthropometric measurements have also been identified among occupational groups (Hsiao, Long, & Snyder, 2002). Due to these limitations, the Guidebook stated that its anthropometric data would be updated once NIOSH concluded its EMSP anthropometric study.

This paper summarized the study's results and examined the anthropometric differences between the current EMSP dataset and the U.S. general population dataset, and between the current EMSP dataset and U.S. military dataset, respectively (Fryar, Gu, Ogden, & Flegal, 2016; Gordon et al., 2014; Harrison & Robinette, 2002).

## 2. Methods

### 2.1. Participants

This study sample consists of 471 male and 161 female EMSP, collected from eight cities, with two cities in each of four different regions of the continental United States. A sampling strategy, considering age, sex, and race strata, was used. The final sample is presented in Table 1. The EMSP were divided into three age groups ($\leq$29, 30–44, and $\geq$45 years of age) and three race/ethnicity groups (White non-Hispanic, African American non-Hispanic, and Hispanic/Other) for male and female EMSP, respectively, which resulted in nine age $\times$ race/ethnicity cells. It is worth noting that Hispanic refers to a person of Cuban, Mexican, Puerto Rican, South or Central American, or other Spanish culture or origin regardless of race. Other relevant information (data collection sites and locations) is provided in Table 2. This sampling strategy only allowed male and female EMSP with a valid state certificate to participate in the study. This research complied with the American Psychological Association Code of Ethics and was approved by the NIOSH's Institutional Review Board. Informed consent was obtained from each participant.

### 2.2. Data collection equipment

Standard anthropometric instruments used in this study were an anthropometer, beam caliper (rearranged pieces of the anthropometer), sliding calipers and a Lufkin steel tape. Other equipment included a weight scale and a stool for seated measurements.

### 2.3. Measurements

A total of 40 anthropometric measurements (including body weight) were taken using the anthropometric devices described above. The selection of these dimensions was based on their utility in the design of the ambulance patient compartment and personal protective equipment. In particular, four dimensions (thigh strap length front, thigh strap length back, torso strap length front, and torso strap length back) were defined specifically for this study to aid the design of a 5-point whole body harness system. Definitions for each of the body measurements acquired can be found in Appendix A.

The measuring team consisted of three experienced anthropometric data measurers. To ensure data quality, the measuring team repeated the measurements on practice subjects until the

**Table 1**
The distribution of participants by sex, age, and race/ethnicity.

| Sex | Age (Years) | Race/Ethnicity | | | Total |
|---|---|---|---|---|---|
| | | White non-Hispanic | African American non-Hispanic | Hispanic/Other | |
| Males | $\leq$29 | 105 | 6 | 11 | 122 |
| | 30–44 | 184 | 10 | 17 | 211 |
| | $\geq$45 | 120 | 9 | 9 | 138 |
| | Total | 409 | 25 | 37 | 471 |
| Females | $\leq$29 | 49 | 1 | 9 | 59 |
| | 30–44 | 59 | 4 | 6 | 69 |
| | $\geq$45 | 27 | 3 | 3 | 33 |
| | Total | 135 | 8 | 18 | 161 |
| Grand Total | 632 | | | | |

**Table 2**
Data collection region, city, organization and sample size (*n*).

| Region | City | Organization | n |
|---|---|---|---|
| Northeast | Richmond, VA | Richmond Ambulance Authority | 51 |
| | New Haven, CT | American Medical Response | 83 |
| South | Tallahassee, FL | Leon County EMS | 82 |
| | Fort Worth, TX | MedStar 911 | 80 |
| West | Phoenix, AZ | AZ Dept. of Health Services | 77 |
| | Boise, ID | Ada County Paramedics | 71 |
| Mid-West & Great Lakes | Mount View, MN | Allina Heath EMS | 80 |
| | Columbus, OH | Columbus Fire/EMS | 108 |
| Total | | | 632 |

inter-observer differences were at or below the levels specified in International Organization for Standardization, 2005. Although ISO 20685 is a standard for 3-D surface scans, results from extracted measurements from 3-D scans are compared to measurements obtained from traditionally measured dimensions. In addition, we employed data entry and editing software specifically designed for anthropometric studies to enhance accuracy in data collection. The software would signal the data entry operator when an unexpected value was entered into the database. A suspect value, that generated an alert to the measurer, was verified onsite by taking another measurement while the EMSP participant was still present. In addition, the measured anthropometric values for each participant were also recorded on a separate paper datasheet, which was employed as a backup for the electronic copy.

### 2.4. Procedure

The measuring team traveled to each data collection site where a measuring station was set up. The measuring station was usually located in a conference room at a local emergency medical services facility, with that facility acting as the host for the data collection event. Blinders were set up to divide the room into different sections: reception area, changing area, and measuring area.

When a participant arrived, an investigator checked his/her state issued EMSP card to establish eligibility. A consent form, which described the purpose of the study and the measurement procedures, was provided. If he/she agreed to participate, the participant signed the form. The participant was then asked to change into lab attire: shorts for males and shorts and sports bra for females. They were measured in standing or sitting postures. The investigator located body landmarks by palpating the bones and marked on the body or clothing overlying those points with an eye-liner pencil. After the marks were properly placed on the participant's body, anthropometric measurements were taken using the anthropometric devices. Female participants were measured by a female measurer. After the measurements were completed, the participant was reimbursed for their time and dismissed.

### 2.5. Data analysis

#### 2.5.1. Sample weighting

Before data were analyzed, each body dimension was examined by a separate box plot for possible outliers. Any value exceeding three standard deviations was compared with the value recorded on the paper datasheet. If the issue was still not resolved, the value was further compared with the corresponding value digitally derived from the whole-body scans taken of that participant during the data collection. Although whole-body scan data were collected, they were not reported in this article. If there was still any discrepancy, the digitally derived value was used in subsequent data analysis, instead. As a result, one female participant had digitally derived values for sitting height, head circumference, head breadth, and head length, respectively. One male participant had a digitally derived value for stature. After the preliminary data examination, a weighting procedure was applied to the male and female samples, respectively, to ensure that the sample represents the current EMSP population in age and race/ethnicity composition. For each of the nine age × race/ethnicity cells mentioned previously, the weight was calculated as the relative frequency of that cell (ratio of the cell total to population total) in the EMSP population, divided by the relative frequency of the same cell in the study sample. This is a standard approach in anthropometric studies (Gordon, 2000; Harrison & Robinette, 2002; International Organization for Standardization, 2010).

Information on race/ethnicity distribution in EMSP population came from *Employed Worker Population Estimates* (2011–2014) provided by the Employed Labor Force (ELF) Query System (CDC, 2016). The estimated number of EMSP in the United States was based on a subset of Bureau of Labor Statistics (BLS) Current Population Survey (CPS) public access data files maintained by the NIOSH Division of Safety Research (DSR). After males and female samples were weighted, they were compared with corresponding males and females in the U.S. general population (see Section 2.5.2.), a civilian American anthropometric dataset (Section 2.5.3), and a U.S. military personnel anthropometric dataset (Section 2.5.4), respectively.

#### 2.5.2. Current EMSP versus US general population

Measurements from the current dataset were compared to relevant measurements for the 2011–2014 U.S. adult population (20 years and over), which was obtained from the National Health and Nutrition Examination Survey (NHANES) (Fryar et al., 2016). NHANES is an annual survey conducted by the Centers for Disease Control and Prevention's National Center for Health Statistics. Each annual sample is nationally representative. Between 2011 and 2014, the anthropometric portion of the survey consisted of nine body dimensions for U.S. male and female adult populations. Only three body dimensions (weight, standing height, and waist circumference) were comparably measured between NIOSH's EMSP and NHANES databases. Each of the three body dimensions was evaluated by a 95% confidence interval (95% CI) using Bonferroni correction at $\alpha = 0.05/3 = 0.02$ (2-tailed), where the number of comparisons was $c = 3$ and degrees of freedom error was $df_{error} \geq 100$. It is worth noting that the data collection periods between the NHANES (years 2011–2014) and EMSP datasets (years 2013–2015) are somewhat different. Such a difference may be treated as a potential limitation for this comparison.

*2.5.3. Current EMSP versus Civilian Americans*

The current EMSP dataset was also compared with the Civilian American and European Surface Anthropometry Resource (CAESAR) (Harrison & Robinette, 2002). The CAESAR was a major anthropometric survey of the civilian populations in the United States, the Netherlands, and Italy. To date, the American portion of the resource, which was completed in the later 1990s and early 2000s, was the only survey specifically devoted to anthropometric measurements of the civilian population in the United States. The dataset consisted of 40 traditional measurements (measured by anthropometer, caliper and tape measures), taken from 1,119 male and 1,261 female participants. Eighteen body dimensions were comparably measured between NIOSH's EMSP and CAESAR datasets. Each of the 18 body dimensions was evaluated by an independent *t*-test with Bonferroni correction at $\alpha = 0.05/18 = 0.003$ (2-tailed), where $c = 18$ and $df_{error} \geq 100$. Equivalently, with $c = 18$ and $df_{error} \geq 100$, the critical Bonferroni *t* was set to be 3.02. Although CAESAR was the only large scale civilian American anthropometric dataset available for comparison, the difference in time period between the CAESAR and EMSP datasets is another limitation for this comparison.

*2.5.4. Current EMSP versus ANSUR II*

Finally, the current EMSP dataset was compared with the 2012 Anthropometric Survey of U.S. Army Personnel (ANSUR II). ANSUR II is a comprehensive anthropometric survey of U.S. Army soldiers, completed in 2012 by the Department of Defense's Natick Soldier Research, Development and Engineering Center (Gordon et al., 2014). This sample consisted of 7,435 men and 3,922 women that were active duty, National Guard, or Army Reserve soldiers. Ninety-four body dimensions were directly measured, of which 30 dimensions were comparably measured with NIOSH's EMSP anthropometric study. Each of the 30 body dimensions was evaluated by an independent t-test with Bonferroni correction at $\alpha = 0.05/30 = 0.002$ (2-tailed), where $c = 30$ and $df_{error} \geq 100$. Equivalently, with $c = 30$ and $df_{error} \geq 100$, the critical Bonferroni *t* was set to be 3.14.

## 3. Results

### 3.1. Summary Statistics

The study results are summarized in Table 3. The SAS PROC SURVEYMEANS procedure (SAS Software 9.4) was used to generate the weighted estimates. The weighted and unweighted means for each body measurement were very close to each other, as were the weighted and unweighted standard deviations for each measurement. For males, the absolute differences between the weighted and unweighted means ranged from 0 to 1 mm, except for waist circumference natural indentation (absolute difference = 7 mm) and waist circumference omphalion (absolute difference = 5 mm). For females, the absolute differences for 34 out of 40 body dimensions ranged from 0 to 2 mm. For the remaining six dimensions (abdominal depth sitting, thigh strap length front, torso strap length front, waist circumference natural indentation, waist circumference omphalion, and waist height standing omphalion), the absolute differences ranged from 3 to 7 mm. This closeness between weighted and unweighted data suggests that this study sample was well representative of the EMSP population. All subsequent analyses were based on the weighted data only.

### 3.2. Current EMSP versus NHANES

The current NIOSH EMSP dataset were compared with the NHANES dataset on three comparably measured body dimensions (Table 4). The 95% confidence interval (CI) for the males in NIOSH EMSP dataset did not overlap with the 95% CI for the males in NHANES in stature or weight, indicating that the male EMSP were significantly different from the male general population in these two dimensions. On average, the male EMSP were 18 mm taller and 7 kg heavier, than the male general population in the NHANES. The 95% CI for the females in NIOSH EMSP dataset did not overlap with the 95% CI for the females in NHANES for stature. This indicates that the female EMSP were significantly different from the female general population in stature. On average, female EMSP were 25 mm taller than the female general population. No difference in body weight was found between the female EMSP and the female general population.

### 3.3. Current EMSP versus CAESAR

As shown in Table 5, for the males, 14 out of 18 body dimensions were found to be statistically significant. Of these 14 significantly different measurements, 13 EMSP body dimensions were larger than corresponding dimensions in the CAESAR. On average, the male EMSP were 13 kg heavier than the males in CAESAR. Consistent with body weight measurements, the EMSP were found to be significantly larger in bideltoid breadth and thigh circumference measurements. There was no difference in overall stature between the male EMSP and the males in CAESAR. However, the male EMSP were found to be greater in six stature-related measurements: acromial height, buttock-knee length, crotch height, eye height sitting, knee height, sitting height, and thumbtip reach.

For the females, 8 out of 18 body dimensions were statistically significant. Of the eight significantly different measurements, seven EMSP dimensions were greater than the corresponding dimensions in CAESAR. On average, the female EMSP were 8 kg heavier than the females in CAESAR. Consistent with the body weight measurements, the female EMSP were found to be significantly larger in bideltoid breadth and thigh circumference than the females in CAESAR. The female EMSP was not statistically different in stature from the females in CAESAR. However, the female EMSP were found to be significantly greater in crotch height, knee height sitting, and thumbtip reach. Other stature-related measurements (acromial height, buttock-knee length, sitting height, and eye height sitting) were not significantly different.

### 3.4. Current EMSP versus ANSUR II

Data from the NIOSH EMSP study and ANSUR II is presented in Table 6. For the males, 22 out of 30 body dimensions were found to be significantly different. Of these 22 significantly different measurements, 20 body dimensions were larger for the male EMSP than the male military personnel in ANSUR II. On average, the male EMSP were 11 kg heavier than the male military personnel. Consistent with body weight difference, the male EMSP were significantly larger in body breadth and circumference measurements, including abdominal depth sitting, biacromial breadth, bideltoid breadth, thigh circumference, and waist circumference. On average, the male EMSP were 19 mm taller than the male military personnel. In addition, the male EMSP were found to be greater in acromial height, buttock-knee length, buttock-popliteal length, crotch height, eye height sitting, knee height, shoulder-elbow length, sitting height, and thumbtip reach.

For the female EMSP, 16 out of 30 body dimensions were statistically significantly different. Of the 16 significantly different measurements, 11 dimensions were larger for the female EMSP than the female military personnel in ANSUR II. On average, female EMSP were 10 kg heavier than the female military personnel. Consistent with body weight difference, the female EMSP were significantly larger in most body girth and circumference

**Table 3**
Summary statistics for measured dimension in NIOSH EMSP study.

| Dimensions | M (SD) Unweighted | M (SD) Weighted | 5th %tile Weighted | SE 5th %tile Weighted | 95th %tile Weighted | SE 95th %tile Weighted |
|---|---|---|---|---|---|---|
| Males ($n$ = 471) | | | | | | |
| Abdominal Depth, Sit. | 289 (57.3) | 291 (58.0) | 213 | 2.5 | 397 | 13.0 |
| Acromial Height | 1,457 (63.1) | 1,457 (65.9) | 1,357 | 7.6 | 1,558 | 6.2 |
| Acromial Height, Sit. | 611 (31.0) | 612 (33.3) | 561 | 3.6 | 661 | 2.8 |
| Arm Length | 790 (38.3) | 790 (39.3) | 727 | 3.4 | 853 | 2.6 |
| Biacromial Breadth | 422 (20.5) | 422 (20.9) | 385 | 2.8 | 454 | 2.1 |
| Bideltoid Breadth | 517 (35.2) | 517 (35.5) | 464 | 3.5 | 578 | 5.5 |
| Bustpoint/Thelion Breadth | 238 (26.3) | 238 (26.8) | 199 | 2.6 | 281 | 2.7 |
| Buttock-Knee Length | 625 (31.6) | 625 (33.0) | 575 | 2.6 | 679 | 3.1 |
| Buttock-Popliteal Length | 508 (27.3) | 507 (28.5) | 464 | 2.0 | 554 | 2.6 |
| Crotch Height | 834 (48.5) | 833 (48.7) | 751 | 4.6 | 910 | 5.0 |
| Elbow-Fingertip Length | 483 (22.3) | 483 (22.6) | 446 | 1.4 | 519 | 2.2 |
| Elbow Rest Height | 247 (29.5) | 247 (31.4) | 196 | 2.9 | 292 | 1.9 |
| Eye Height, Sitting | 814 (34.5) | 813 (37.0) | 753 | 3.7 | 873 | 4.4 |
| Foot Breadth | 102 (5.9) | 102 (6.1) | 92 | 0.7 | 112 | 0.6 |
| Foot Length | 268 (12.9) | 268 (13.4) | 245 | 1.3 | 287 | 1.5 |
| Hand Breadth | 90 (4.5) | 90 (4.6) | 82 | 0.4 | 96 | 0.4 |
| Hand Circumference | 216 (10.8) | 216 (11.2) | 198 | 1.1 | 234 | 1.1 |
| Hand Length | 196 (9.6) | 196 (9.8) | 180 | 1.0 | 211 | 0.8 |
| Head Breadth | 154 (5.4) | 154 (5.5) | 145 | 0.4 | 162 | 0.6 |
| Head Circumference | 580 (16.6) | 580 (17.1) | 554 | 1.8 | 608 | 1.3 |
| Head Length | 202 (6.7) | 201 (6.9) | 190 | 0.7 | 212 | 0.5 |
| Hip Breath | 363 (28.6) | 363 (28.1) | 324 | 2.6 | 414 | 6.0 |
| Knee Height | 571 (29.2) | 571 (30.1) | 523 | 4.2 | 619 | 2.9 |
| Lateral Malleolus Height | 73 (5.9) | 73 (6.0) | 63 | 0.6 | 82 | 0.4 |
| Neck Breadth | 149 (10.4) | 149 (10.8) | 132 | 1.2 | 166 | 1.0 |
| Popliteal Height | 433 (26.2) | 432 (26.4) | 391 | 3.1 | 474 | 2.0 |
| Shoulder-Elbow Length | 368 (19.2) | 368 (19.9) | 337 | 2.5 | 399 | 1.7 |
| Sitting Height | 930 (35.2) | 929 (37.7) | 868 | 3.4 | 989 | 3.9 |
| Stature (Standing Height) | 1,776 (67.8) | 1,775 (70.0) | 1,667 | 7.0 | 1,882 | 4.6 |
| Thigh Circumference | 650 (69.7) | 649 (70.5) | 547 | 7.5 | 777 | 11.9 |
| Thigh Clearance | 179 (19.3) | 179 (19.9) | 147 | 2.8 | 211 | 1.8 |
| Thigh Strap Length Back | 786 (59.4) | 785 (59.2) | 699 | 6.4 | 882 | 5.7 |
| Thigh Strap Length Front | 164 (35.9) | 165 (36.7) | 125 | 1.2 | 236 | 5.9 |
| Thumb-Tip Reach | 823 (41.3) | 824 (43.7) | 754 | 4.0 | 894 | 4.1 |
| Torso Strap Length Back (mm) | 516 (31.7) | 516 (33.1) | 461 | 4.5 | 568 | 3.1 |
| Torso Strap Length Front Male | 1,373 (95.8) | 1,376 (98.4) | 1,242 | 5.7 | 1,544 | 21.0 |
| Waist circumference, natural Indentation | 983 (139.0) | 990 (141.1) | 790 | 9.7 | 1,250 | 16.9 |
| Waist Circumference, Omphalion | 1,024 (150.4) | 1,029 (150.0) | 820 | 8.2 | 1,315 | 26.3 |
| Waist Height Standing Omphalion | 1,057 (55.8) | 1,056 (56.8) | 970 | 6.1 | 1,148 | 5.5 |
| Weight | 96 (19.8) | 96 (20.3) | 68 | 1.1 | 134 | 2.4 |
| Females ($n$ = 161) | | | | | | |
| Abdominal Depth, Sitting | 266 (59.7) | 273 (63.2) | 189 | 4.2 | 392 | 11.9 |
| Acromial Height | 1,342 (62.5) | 1,343 (68.9) | 1,223 | 27.5 | 1,446 | 12.7 |
| Acromial Height, Sitting | 574 (28.4) | 573 (30.7) | 519 | 7.4 | 619 | 4.1 |
| Arm Length | 720 (36.8) | 720 (42.0) | 663 | 12.7 | 783 | 8.6 |
| Biacromial Breadth | 377 (16.5) | 377 (18.7) | 348 | 4.4 | 402 | 3.4 |
| Bideltoid Breadth | 465 (35.8) | 467 (38.0) | 419 | 6.8 | 527 | 11.6 |
| Bustpoint/Thelion Breadth | 159 (27.6) | 160 (30.0) | 118 | 3.6 | 207 | 5.5 |
| Buttock-Knee Length | 593 (34.0) | 595 (35.1) | 545 | 6.9 | 646 | 8.1 |
| Buttock-Popliteal Length | 474 (29.5) | 486 (30.1) | 441 | 4.9 | 531 | 5.8 |
| Crotch Height | 769 (49.5) | 770 (55.8) | 691 | 10.1 | 859 | 18.0 |
| Elbow-Fingertip Length | 437 (21.2) | 437 (24.6) | 404 | 7.4 | 473 | 6.3 |
| Elbow Rest Height | 229 (26.4) | 238 (30.6) | 192 | 11.3 | 290 | 5.6 |
| Eye Height, Sitting | 762 (33.6) | 761 (35.3) | 699 | 4.4 | 817 | 6.3 |
| Foot Breadth | 94 (5.3) | 94 (6.5) | 84 | 2.0 | 103 | 1.4 |
| Foot Length | 238 (12.4) | 238 (13.7) | 215 | 1.5 | 259 | 2.1 |
| Hand Breadth | 78 (3.6) | 78 (3.8) | 72 | 1.8 | 83 | 0.8 |
| Hand Circumference | 187 (8.9) | 188 (9.5) | 172 | 2.7 | 201 | 2.2 |
| Hand Length | 177 (9.3) | 177 (10.5) | 161 | 2.2 | 192 | 1.4 |
| Head Breadth | 146 (4.7) | 146 (5.2) | 137 | 0.6 | 153 | 0.9 |
| Head Circumference | 552 (15.8) | 551 (15.0) | 527 | 2.1 | 576 | 3.9 |
| Head Length | 190 (5.9) | 190 (6.0) | 180 | 1.6 | 198 | 1.0 |
| Hip Breath | 378 (40.8) | 380 (44.6) | 326 | 5.4 | 459 | 6.6 |
| Knee Height | 519 (28.8) | 520 (31.6) | 472 | 8.6 | 568 | 7.6 |
| Lateral Malleous Height | 66 (5.3) | 66 (5.8) | 56 | 0.9 | 74 | 1.0 |
| Neck Breadth | 131 (9.1) | 131 (10.6) | 117 | 2.4 | 148 | 2.1 |
| Popliteal Height | 388 (27.2) | 389 (30.3) | 346 | 11.2 | 438 | 4.9 |
| Shoulder-Elbow Length | 337 (19.8) | 338 (22.5) | 305 | 6.6 | 370 | 4.7 |
| Sitting Height | 874 (34.8) | 873 (36.4) | 812 | 8.2 | 934 | 5.2 |
| Stature (Standing Height) | 1,644 (68.2) | 1,643 (74.2) | 1,520 | 30.8 | 1,752 | 14.0 |
| Thigh Circumference | 638 (76.8) | 639 (82.2) | 535 | 10.9 | 791 | 18.9 |
| Thigh Clearance | 169 (22.8) | 170 (23.8) | 137 | 2.3 | 213 | 4.4 |

(*continued on next page*)

**Table 3** (*continued*)

| Dimensions | M (SD) Unweighted | M (SD) Weighted | 5th %tile Weighted | SE 5th %tile Weighted | 95th %tile Weighted | SE 95th %tile Weighted |
|---|---|---|---|---|---|---|
| Thigh Strap Length Back | 736 (62.3) | 737 (68.2) | 635 | 15.9 | 850 | 10.4 |
| Thigh Strap Length Front | 162 (36.9) | 166 (42.0) | 121 | 4.3 | 244 | 19.7 |
| Thumb-Tip Reach | 754 (39.7) | 754 (40.9) | 694 | 9.5 | 824 | 6.3 |
| Torso Strap Length Back | 471 (30.2) | 471 (32.6) | 412 | 7.3 | 513 | 2.5 |
| Torso Strap Length Front | 1,274 (91.4) | 1,279 (97.8) | 1,162 | 17.7 | 1,449 | 23.2 |
| Waist circumference (natural Indentation) | 852 (139.0) | 867 (144.0) | 669 | 13.0 | 1,120 | 24.9 |
| Waist Circumference (omphalion) | 959 (167.2) | 975 (172.5) | 740 | 12.7 | 1,284 | 44.4 |
| Waist Height Standing Omphalion | 973 (61.0) | 970 (67.9) | 871 | 33.6 | 1,075 | 11.9 |
| Weight | 77 (17.9) | 78 (19.3) | 55 | 2.8 | 111 | 4.5 |

*Note.* All values are in mm except for weight, which is in kg.

**Table 4**
Comparing weighted means of three body dimensions for the EMSP and the NHANES using 95% confidence interval.

| | EMSP (i) | | | NHANES (j) | | | *Mi – Mj*^ | Sig |
|---|---|---|---|---|---|---|---|---|
| | n | *M* (SE) | 95% CI# | n | *M* (SE) | 95% CI# | | |
| *Male* | | | | | | | | |
| Stature | 471 | 1,775 (3.2) | [1,768, 1,783] | 5,232 | 1,757 (2.1) | [1,752, 1,762] | 18 | * |
| Waist circ. | 471 | 1,029 (6.5) | [1,014, 1,045] | 5,410 | 1,009 (4.1) | [999, 1,019] | 20 | |
| Weight (kg) | 471 | 96 (0.9) | [94, 98] | 5,236 | 89 (0.4) | [88, 90] | 6.9 | * |
| *Female* | | | | | | | | |
| Stature | 161 | 1,643 (5.9) | [1,629, 1,657] | 5,447 | 1,618 (2.1) | [1,613, 1,623] | 25 | * |
| Waist circ. | 161 | 975 (11.4) | [948, 1,003] | 5,116 | 969 (3.8) | [960, 978] | 6 | |
| Weight (kg) | 161 | 78 (1.5) | [74, 81] | 5,425 | 76 (0.4) | [75, 77] | 2 | |

*Note.* All values are in mm except for weight, which is in kg.
^ *Mi – Mj* denotes difference in mean between the NIOSH EMSP study and the NHANES
# 95% Confidence Interval with Bonferroni adjustment at $c = 3$. 95% CI = Xbar ± $t_{0.05/3\ (2\text{tailed})} \times$ SE.
* $p < 0.05/3 = 0.017$, 2-tailed.

measurements, including abdominal depth sitting, biacromial breadth, bideltoid breadth, thigh circumference, and waist circumference. Although the female EMSP were, on average, not significantly taller than the female U.S. military personnel, they were found to be larger in eye height sitting, knee height, and sitting height. No differences were found in buttock-knee length, buttock-popliteal length, elbow fingertip length, popliteal height, shoulder elbow length, and waist height omphalion.

## 4. Discussion

### 4.1. EMSP versus general population

A comparison of the current EMSP dataset developed by NIOSH and the NHANES dataset revealed that the male EMSP were significantly taller and heavier than the male general population and the female EMSP were significantly taller, but not heavier, than the female general population. Since NHANES is a true representative sample of the U.S. general population, these differences have a practical implication. However, the comparison also has limited applications because there were only three comparably measured body dimensions between the two datasets.

A further comparison of NIOSH's EMSP dataset and the CAESAR dataset, which is a large scale civilian anthropometric survey, revealed more useful information. This comparison produced somewhat different results. Namely, both the male and the female EMSP in the NIOSH dataset were found to be significantly heavier, but not taller, than the males and the females in the CAESAR dataset, respectively. The significant differences in body weight were consistent with the significant differences in body breadth and circumference measurements between the two surveys. On the other hand, although there was no significant difference in stature for both males and females, the male EMSP were found to be larger in six stature related measurements, and the female EMSP were found to be larger in four stature related measurements.

These results were interpreted as indicating that EMSP are significantly different from the U.S. general population in body size, despite some discrepancies in the analysis involving the two civilian population datasets. In general, males were found to be significantly different in more (14 out of 18) dimensions than females (8 out of 18) in both datasets. More studies are warranted to confirm this gender-related anthropometric differences across occupational groups.

### 4.2. EMSP versus military personnel

A comparison of the current male EMSP dataset collected by NIOSH with males in the ANSUR II dataset showed that the male EMSP were both taller and heavier than the male military personnel. The differences in stature and body weight were consistent with other key dimensions highly correlated with body weight and stature. A comparison of the current female EMSP dataset with the females in ANSUR II showed that the female EMSP were both

**Table 5**
Comparing weighted means of eighteen body dimensions for the EMSP and the CAESAR using Bonferroni correction.

| | EMSP (*i*) | | | CAESAR (*j*) | | | Mi – Mj^ | *t* |
|---|---|---|---|---|---|---|---|---|
| | *n* | *M* | *SD* | *n* | *M* | *SD* | | |
| *Male* | | | | | | | | |
| Acromial Height, Sitting | 471 | 612 | 33.3 | 1,119 | 602 | 37.8 | 10 | 4.86* |
| Bideltoid Breadth | 471 | 517 | 35.5 | 1,119 | 490 | 37.8 | 27 | 13.14* |
| Buttock-Knee Length | 471 | 625 | 33.0 | 1,119 | 614 | 36.5 | 11 | 5.59* |
| Crotch Height | 471 | 833 | 48.7 | 1,119 | 797 | 54.9 | 36 | 12.43* |
| Elbow Rest Height | 471 | 247 | 31.4 | 1,119 | 239 | 35.1 | 8 | 4.16* |
| Eye Height, Sitting | 471 | 813 | 37.0 | 1,119 | 803 | 41.5 | 10 | 4.65* |
| Foot Length | 471 | 268 | 13.4 | 1,119 | 267 | 15.4 | 1 | 1.07 |
| Hand Circumference | 471 | 216 | 11.2 | 1,119 | 211 | 12.0 | 5 | 7.28* |
| Hand Length | 471 | 196 | 9.8 | 1,119 | 202 | 12.4 | −6 | −8.83* |
| Head Breadth | 471 | 154 | 5.5 | 1,117 | 155 | 6.7 | −1 | −1.09 |
| Head Circumference | 471 | 580 | 17.1 | 1,119 | 577 | 18.0 | 3 | 3.49* |
| Head Length | 471 | 201 | 6.9 | 1,119 | 200 | 10.4 | 1 | 2.93 |
| Knee Height | 471 | 571 | 30.1 | 1,119 | 558 | 32.1 | 13 | 7.50* |
| Sitting Height | 471 | 929 | 37.7 | 1,119 | 921 | 42.8 | 8 | 3.88* |
| Stature | 471 | 1,775 | 70.0 | 1,119 | 1,767 | 80.6 | 8 | 2.07 |
| Thigh Circumference | 471 | 649 | 70.5 | 1,119 | 600 | 63.2 | 49 | 13.58* |
| Thumb-Tip Reach | 471 | 824 | 43.7 | 1,119 | 808 | 45.5 | 16 | 6.67* |
| Weight (kg) | 471 | 96 | 20.3 | 1,119 | 83 | 17.4 | 13 | 12.77* |
| *Female* | | | | | | | | |
| Acromial Height, Sitting | 161 | 573 | 30.7 | 1,261 | 568 | 31.6 | 5 | 1.93 |
| Bideltoid Breadth | 161 | 467 | 38.0 | 1,261 | 431 | 39.1 | 36 | 10.92* |
| Buttock-Knee Length | 161 | 595 | 35.1 | 1,260 | 588 | 40.5 | 7 | 2.09 |
| Crotch Height | 161 | 770 | 55.8 | 1,260 | 748 | 52.9 | 22 | 4.98* |
| Elbow Rest Height | 161 | 238 | 30.6 | 1,260 | 237 | 29.8 | 1 | 0.59 |
| Eye Height, Sitting | 161 | 761 | 35.3 | 1,260 | 755 | 36.6 | 6 | 1.98 |
| Foot Length | 161 | 238 | 13.7 | 1,261 | 239 | 14.2 | −1 | −0.95 |
| Hand Circumference | 161 | 188 | 9.5 | 1,261 | 184 | 12.0 | 4 | 3.74* |
| Hand Length | 161 | 177 | 10.5 | 1,259 | 182 | 11.4 | −5 | −4.65* |
| Head Breadth | 161 | 146 | 5.2 | 1,260 | 146 | 5.3 | 0 | −0.97 |
| Head Circumference | 161 | 551 | 15.0 | 1,260 | 552 | 18.1 | −1 | −0.45 |
| Head Length | 161 | 190 | 6.0 | 1,260 | 189 | 7.1 | 1 | 1.72 |
| Knee Height | 161 | 520 | 31.6 | 1,259 | 508 | 31.3 | 12 | 4.43* |
| Sitting Height | 161 | 873 | 36.4 | 1,260 | 864 | 38.7 | 9 | 2.63 |
| Stature | 161 | 1,643 | 74.2 | 1,261 | 1,638 | 78.4 | 5 | 0.71 |
| Thigh Circumference | 161 | 639 | 82.2 | 1,261 | 611 | 86.7 | 28 | 3.86* |
| Thumb-Tip Reach | 161 | 754 | 40.9 | 1,261 | 737 | 43.3 | 17 | 4.80* |
| Weight (kg) | 161 | 78 | 19.3 | 1,261 | 70 | 19.9 | 8 | 4.91* |

*Note.* All values are in mm except for weight, which is in kg.
^ *Mi – Mj* denotes difference in mean between the EMSP study and CAESAR.
* $p < 0.05/18 = 0.003$, 2-tailed; equivalently, critical Bonferroni $t = 3.02$ with $c = 18$ and $df_{error} \geq 100$.

heavier and larger in breadth and circumference measurements than the female military personnel. However, no differences were found in stature and most of the stature related key dimensions (i.e., buttock-knee length, buttock-popliteal length, elbow fingertip length, popliteal height, shoulder elbow length, and waist height omphalion).

Although military anthropometric data has been used for in civilian applications for many years, caution must be exercised in these applications. Military anthropometric data does not represent the civilian population because of selection biases and different age, race, and gender distributions (Bradtmiller, Ratnaparkhi, & Tebbetts, 1985; Pheasant & Haslegrave, 2006). This study's results provide further evidence supporting the above conclusions by comparing up-to-date EMSP dataset with the most recently obtained military dataset. Although there was a substantial increase in weight for both males (7 kg) and females (6 kg) in the ANSUR II dataset compared to the ANSUR I dataset (1988 Anthropometric Survey of US Army Personnel; Gordon et al., 1989) in the span of 24 years, the study showed that it is still not advisable to apply military data to civilian applications because of substantial differences in body dimension compositions.

Secular changes in anthropometric measures were also observed for the civilian population (Gordon & Bradtmiller, 2012). These anthropometric changes were primarily attributed to the obesity epidemic that had been sweeping the United States for decades. According to the National Center for Health Statistics (NCHS), the prevalence of adult obesity in 2017–2018 were 42.4% compared with the 30.5% in the 1999–2000 (CDC, 2020). The effect of obesity on anthropometric changes among the EMSP population have not been scientifically evaluated. Future research is needed to address this issue.

## 5. Summary

This study presents data from the first ever national anthropometric study of EMSP in the United States. These findings have implications for the design of the next generation of ambulance patient compartments. The study found that this occupational group has unique anthropometric characteristics. On average, both the male and female EMSP were taller than the U.S. general population. The male EMSP were also found to be heavier than the male U.S. general population. The male EMSP were found be taller and heavier than male U.S. military personnel, while the female EMSP were heavier than the female military personnel in the United States. Given these findings, it is not advisable to apply

**Table 6**
Comparing weighted means of eighteen body dimensions for the EMSP and the ANSUR II datasets using Bonferroni correction.

| | EMSP (*i*) | | | ANSUR II (*j*) | | | *Mi – Mj* | *t* |
|---|---|---|---|---|---|---|---|---|
| | *n* | *M* | *SD* | *n* | *M* | *SD* | | |
| *Male* | | | | | | | | |
| Abdominal Depth, Sitting | 471 | 291 | 58.0 | 4,082 | 255 | 37.3 | 36 | 18.74* |
| Acromial Height | 471 | 1,457 | 65.9 | 4,082 | 1,441 | 63.3 | 16 | 5.18* |
| Biacromial Breadth | 471 | 422 | 20.9 | 4,082 | 416 | 19.2 | 6 | 6.60* |
| Bideltoid Breadth | 471 | 517 | 35.5 | 4,082 | 510 | 32.5 | 7 | 4.26* |
| Buttock-Knee Length | 471 | 625 | 33.0 | 4,082 | 618 | 30.6 | 7 | 4.58* |
| Buttock-Popliteal Length | 471 | 507 | 28.5 | 4,082 | 503 | 27.4 | 4 | 3.37* |
| Crotch Height | 471 | 833 | 48.7 | 4,082 | 846 | 46.5 | −13 | −5.56* |
| Elbow-Fingertip Length | 471 | 483 | 22.6 | 4,082 | 480 | 23.3 | 3 | 2.67 |
| Elbow Rest Height | 471 | 247 | 31.4 | 4,082 | 245 | 28.7 | 2 | 1.30 |
| Eye Height, Sitting | 471 | 813 | 37.0 | 4,082 | 805 | 33.2 | 8 | 5.50* |
| Foot Breadth | 471 | 102 | 6.1 | 4,082 | 102 | 5.2 | 0 | 0.87 |
| Foot Length | 471 | 268 | 13.4 | 4,082 | 271 | 13.1 | −3 | −5.67* |
| Hand Breadth | 471 | 90 | 4.6 | 4,082 | 88 | 4.4 | 1 | 6.53* |
| Hand Circumference | 471 | 216 | 11.2 | 4,082 | 212 | 10.2 | 4 | 7.64* |
| Hand Length | 471 | 196 | 9.8 | 4,082 | 193 | 9.9 | 3 | 6.31* |
| Head Breadth | 471 | 154 | 5.5 | 4,082 | 154 | 5.5 | 0 | −0.52 |
| Head Circumference | 471 | 580 | 17.1 | 4,082 | 574 | 16 | 6 | 7.75* |
| Head Length | 471 | 201 | 6.9 | 4,082 | 200 | 7 | 1 | 5.75* |
| Knee Height, Sitting | 471 | 571 | 30.1 | 4,082 | 554 | 27.9 | 17 | 12.28* |
| Lateral malleolus Height | 471 | 73 | 6.0 | 4,082 | 73 | 5.7 | 0 | −0.79 |
| Popliteal Height | 471 | 432 | 10.8 | 4,082 | 430 | 24.8 | 2 | 2.08 |
| Shoulder-Elbow Length | 471 | 368 | 26.4 | 4,082 | 364 | 18.2 | 4 | 4.50* |
| Sitting Height | 471 | 929 | 37.7 | 4,082 | 918 | 35.7 | 11 | 6.35* |
| Stature | 471 | 1,775 | 70.0 | 4,082 | 1,756 | 68.6 | 19 | 5.74* |
| Thigh Circumference | 471 | 649 | 70.5 | 4,082 | 625 | 58.5 | 24 | 8.28* |
| Thigh Clearance | 471 | 179 | 19.9 | 4,082 | 181 | 15.6 | −2 | −2.36 |
| Thumb-Tip Reach | 471 | 824 | 43.7 | 4,082 | 812 | 43.7 | 12 | 5.80* |
| Waist Circ. (Omphalion) | 471 | 1,029 | 150.0 | 4,082 | 941 | 111.7 | 88 | 15.70* |
| Waist Height (Omphalion) | 471 | 1,056 | 56.8 | 4,082 | 1,057 | 52.2 | −1 | −0.23 |
| Weight (kg) | 471 | 96 | 20.3 | 4,082 | 86 | 14.2 | 11 | 14.47* |
| *Female* | | | | | | | | |
| Abdominal Depth, Sitting | 161 | 273 | 63.2 | 1,986 | 230 | 31.5 | 43 | 14.98* |
| Acromial Height, Sitting | 161 | 1,343 | 68.9 | 1,986 | 1,335 | 58.1 | 8 | 1.58 |
| Biacromial Breadth | 161 | 377 | 16.7 | 1,986 | 365 | 18.3 | 12 | 7.78* |
| Bideltoid Breadth | 161 | 467 | 38.0 | 1,986 | 450 | 28.7 | 17 | 6.90* |
| Buttock-Knee Length | 161 | 595 | 35.1 | 1,986 | 591 | 32.6 | 4 | 1.52 |
| Buttock-Popliteal Length | 161 | 486 | 30.1 | 1,986 | 485 | 28.7 | 1 | 0.56 |
| Crotch Height | 161 | 770 | 55.8 | 1,986 | 782 | 44.6 | −12 | −3.33* |
| Elbow-Fingertip Length | 161 | 437 | 24.6 | 1,986 | 440 | 23.4 | −3 | −1.57 |
| Elbow Rest Height | 161 | 238 | 30.6 | 1,986 | 232 | 26.3 | 6 | 2.75 |
| Eye Height, Sitting | 161 | 761 | 35.3 | 1,986 | 748 | 30.4 | 13 | 5.09* |
| Foot Breadth | 161 | 94 | 6.5 | 1,986 | 93 | 4.8 | 1 | 4.32* |
| Foot Length | 161 | 238 | 13.7 | 1,986 | 246 | 12.4 | −8 | −8.14* |
| Hand breadth | 161 | 78 | 3.8 | 1,986 | 78 | 3.8 | 0 | 0.40 |
| Hand Circ. | 161 | 188 | 9.5 | 1,986 | 187 | 8.8 | 1 | 1.83 |
| Hand Length | 161 | 177 | 10.5 | 1,986 | 181 | 10.1 | −4 | −4.56* |
| Head Breadth | 161 | 146 | 5.2 | 1,986 | 148 | 5.2 | −2 | −4.72* |
| Head Circumference | 161 | 551 | 15.0 | 1,986 | 561 | 19.4 | −10 | −6.25* |
| Head Length | 161 | 190 | 6.01 | 1,986 | 190 | 7.4 | 0 | −0.61 |
| Knee Height | 161 | 520 | 31.6 | 1,986 | 511 | 27.1 | 9 | 3.91* |
| Lateral malleolus Height | 161 | 66 | 5.8 | 1,986 | 63 | 5.1 | 3 | 8.65* |
| Popliteal Height | 161 | 389 | 30.3 | 1,986 | 388 | 23.6 | 1 | 0.55 |
| Shoulder-Elbow Length | 161 | 338 | 22.5 | 1,986 | 334 | 17.3 | 4 | 2.24 |
| Sitting Height | 161 | 873 | 36.4 | 1,986 | 857 | 33.1 | 16 | 5.85* |
| Stature | 161 | 1,643 | 74.2 | 1,986 | 1,629 | 64.2 | 14 | 2.65 |
| Thigh Circumference | 161 | 639 | 82.23 | 1,986 | 616 | 55.8 | 23 | 4.87* |
| Thigh Clearance | 161 | 170 | 23.8 | 1,986 | 168 | 14.1 | 2 | 1.69 |
| Thumb-Tip Reach | 161 | 754 | 40.9 | 1,986 | 744 | 42.8 | 10 | 2.97 |
| Waist Circ. (Omphalion) | 161 | 975 | 172.5 | 1,986 | 861 | 99.9 | 114 | 13.06* |
| Waist Height (Omphalion) | 161 | 970 | 67.9 | 1,986 | 980 | 50.0 | −10 | −2.28 |
| Weight (kg) | 161 | 78 | 19.3 | 1,986 | 68 | 11.0 | 10 | 10.27* |

*Note.* All values are in mm except for weight, which is in kg.
^*Mi – Mj* denotes difference in mean between the EMSP Study and ANSUR II.
* $p < 0.05/30 = 0.002$, 2-tailed; equivalently, critical Bonferroni $t = 3.14$, where $c = 30$ and $df_{error} \geq 100$.

anthropometric data from either general or military populations to the design of next-generation ambulance patient compartment.

## 6. Practical Application

NIOSH's EMSP dataset will prove to be an invaluable resource for standard-setting organizations, for EMS vehicle manufacturers and parts suppliers in their effort to improve product quality and safety. The complete NIOSH EMSP dataset is available on the NIOSH website at https://www.cdc.gov/niosh/topics/anthropometry/default.html.

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## Disclaimer

The findings and conclusions in this article are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health (NIOSH). Mention of any company or product does not constitute an endorsement by NIOSH, Centers for Disease Control and Prevention (CDC).

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**Appendix A Definition of measurements.**

| Dimension | Posture | Definition | Compatible Source |
|---|---|---|---|
| Abdominal Depth | Sitting | Horizontal distance between the anterior point of the abdomen (abdominal point anterior, sitting) and the back at the same level | ANSUR |
| Acromial Height | Standing | Vertical distance between the standing surface and the acromion landmark on the tip of the right shoulder | ANSUR |
| Acromial Height | Sitting | Vertical distance between a sitting surface and the acromion landmark on the tip of the right shoulder | ANSUR |
| Arm Length | Standing | Distance between the acromion landmark on the tip of the right shoulder and the dactylion III landmark at the tip of the middle finger | Guan et al. (2012) |
| Biacromial Breadth | Sitting | Distance between the right and left acromion landmarks at the tips of the shoulders | ANSUR |
| Bideltoid Breadth | Sitting | Maximum horizontal distance between the lateral margins of the upper arms on the deltoid muscles | ANSUR |
| Bustpoint/Thelion Breadth | Standing | Distance between the left and right bustpoint landmarks on women and the center of the nipple (thelion) on men | ANSUR |
| Buttock-Knee Length | Sitting | Horizontal distance between the buttock plate and the anterior point of the right knee (knee point, anterior) | ANSUR |
| Buttock-Popliteal Length | Sitting | Horizontal distance between the buttock plate and the back of the right knee (the popliteal fossa at the dorsal juncture of the calf and thigh) | ANSUR |
| Crotch Height | Standing | Vertical distance between the standing surface and the crotch. The participant stands erect looking straight ahead | ANSUR |
| Elbow-Fingertip Length | Standing | Horizontal distance between the back of the tip of the right elbow (olecranon, rear) and the tip of the right middle finger (dactylion III) when the right elbow is flexed 90 degrees | ANSUR |
| Elbow Rest Height | Sitting | Vertical distance between a sitting surface and the bottom of the right elbow (olecranon, bottom) | ANSUR |
| Eye Height | Sitting | Vertical distance between a sitting surface and the outer corner of the right eye (ectocanthus). | ANSUR |
| Foot Breadth | Standing | Distance between the first metatarsophalangeal-protrusion landmark and the fifth metatarsophalangeal-protrusion landmark on the right foot | ANSUR |
| Foot Length | Standing | Distance between the most posterior protrusion of the heel and the most anterior tip of the toes on the right foot | ANSUR |
| Hand Breadth | Palm on table | Breadth of the hand between the landmarks at metacarpal II and metacarpale V | ANSUR |
| Hand Circumference | Palm on table | Circumference of the right hand over the landmarks at metacarpale II and metacarpale V | ANSUR |
| Hand Length | Palm on table | Length of the right hand between the stylion landmark on the wrist and the tip of the middle finger (dactylion III) | ANSUR |
| Head Breadth | Sitting | Maximum horizontal breadth of the head above the attachment of the ears | ANSUR |
| Head Circumference | Sitting | Maximum circumference of the head above the attachment of the ears to the head above the ridges of the eyebrows and around the back of the head | ANSUR |
| Head Length | Sitting | Distance from the glabella landmark between the brow-ridges to the posterior point on the back of the head | ANSUR |
| Hip Breadth | Sitting | Maximum distance between the lateral points of the hips or thighs (whichever is greater) | ANSUR |
| Knee Height | Sitting | Vertical distance between the footrest surface and the suprapatella landmark at the top of the right knee | ANSUR |
| Lateral Malleolus Height | Standing | Vertical distance between a standing surface and the lateral malleolus landmark on the outside of the right ankle | ANSUR |
| Neck Breadth | Sitting | Distance between the left and right lateral landmarks at the base of the neck | Defined for this study |
| Popliteal Height | Sitting | Vertical distance from a footrest surface to the back of the right knee (the popliteal fossa at the dorsal juncture of the right calf and thigh) | ANSUR |
| Shoulder-Elbow Length | Standing | Distance between the acromion landmark on the tip of the right shoulder and the bottom of the right elbow (olecranon, bottom) | ANSUR |
| Sitting Height | Sitting | Vertical distance between the sitting surface and the top of the head | ANSUR |
| Stature | Standing | Vertical distance between the standing surface and the top of the head | ANSUR |
| Thigh Circumference | Standing | Circumference of the right thigh at its juncture with the buttock | ANSUR |
| Thigh Clearance | Sitting | Vertical distance between the sitting surface and the highest point on the top of | ANSUR |

**Appendix A Definition of measurements.** (*continued*)

| Dimension | Posture | Definition | Compatible Source |
|---|---|---|---|
| | | the right thigh (thigh point, top) | |
| Thigh Strap Length, Back | Standing | Distance from the anterior superior iliac spine (right) landmark, down the gluteal furrow point, across the crotch, to the central release buckle (CRB) point* | Defined for this study |
| Thigh Strap Length, Front | Standing | Distance from anterior superior iliac spine (right) landmark to the central release buckle (CRB) point* | Defined for this study |
| Thumbtip Reach | Standing | The distance between the surface of the back and the tip of the right thumb. | ANSUR |
| Torso Strap Length Back | Standing | Distance between cervicale to posterior superior iliac crest on the right | Defined for this study |
| Torso Strap Length Front | Standing | Distance from the center release buckle (CRB) point* across the back of the neck, and back to the CRB | Defined for this study |
| Waist Circumference (Natural Indentation) | Standing | horizontal circumference of the waist at the level of its greatest indentation of the torso | ANSUR |
| Waist Circumference (Omphalion) | Standing | Horizontal circumference at the level of navel (omphalion) | ANSUR |
| Waist Height (Omphalion) | Standing | vertical distance between a standing surface and the center of the navel (omphalion) | ANSUR |
| Weight | Standing | Body weight of a participant, which is taken while the participant stands on the platform of a scale | ANSUR |

*Note*: ANSUR = 1988 Anthropometric Survey of US Army Personnel: Methods and Summary Statistics (Gordon et al., 1989).

*Central release buckle (CRB) point is defined as a point directly under the omphalion (center of the navel) by a magnitude of one fourth of the difference between waist height omphalion and crotch height).