PHYSIOLOGY & REHABILITATION | RESEARCH ARTICLE

On the importance of the theoretical computation of the human body segments’ masses

Francisco-J Renero-C

Abstract: In this work, statistical formulae, with depend on anthropometric measurement and the age, are used to estimate the weight of the lower limb of 20 young, healthy, adults. Then, four clinical characteristics, the body mass index (BMI), the blood volume (BV), basal metabolic rate (BMR) and skin surface, also based on statistical formulae, are estimated for this sample population. Furthermore, the four clinical characteristics are estimated for 20 fictitious patients, with one lower limb amputated. From the sample population, the averaged results are the lower limb mass is 12.05 ± 2.79 kg, the BMI 22.89 ± 3.93 kg/m$^2$, BV 3.99 ± 0.82 l, BMR 1,543.32 ± 236.98 kCal and body surface (BS) 1.66 ± 0.20 m$^2$. While for the fictitious patients, the results are the BMI of 18.42 ± 3.17 kg/m$^2$, BV of 3.60 ± 0.74 l, BMR of 1,399.07 ± 183.38 kCal and BS of 1.51 ± 0.18 m$^2$. The clinic characteristics of the sample population, healthy-young adults showed, for instance, that the BV vary from 2.84 l and up to 5.67 l. The lower limb mass is approximately 20% of the total mass of the individual, while the BV, after the amputation, decreased by an amount of 10%. By having equations, depending on anthropometric measurements and age provides valuable information on the clinical characteristics of the patient. Thus, the clinicians, adding their experience to these results, may be more confident to the treatment and the evolution of the patient.

Subjects: Biophysics; Orthopedics; Prosthetics & Orthotics; Physiology

Renero-C, Francisco-J. Cogent Medicine (2018), 5: 1540963

https://doi.org/10.1080/2331205X.2018.1540963

© 2018 The Author(s). This open access article is distributed under a Creative Commons Attribution (CC-BY) 4.0 license.

Received: 08 February 2018
Accepted: 23 October 2018
First Published: 26 October 2018

*Corresponding author: Francisco-J Renero-C, Optics-Biomedicine, Instituto Nacional de Astrofisica Optica y Electronica, Calle Luis Enrique Erro No. 1. Sta. Ma. Tonantzintla, Puebla 72840, Mexico
E-mail: paco@inaoep.mx

Reviewing editor: Udo Schumacher, University Medical Center Hamburg-Eppendorf, Germany

ABOUT THE AUTHOR
Francisco-J Renero-C received the bachelor degree in physics from Universidad Autónoma de Puebla, Mexico, in 1987, while the M. E. and Ph.D. in Applied Physics from Osaka University, Japan, in 1992 and 1995, respectively. In 2013, he got a bachelor degree in Physiotherapy from Universidad del Valle de México, Campus Puebla, Mexico. He is currently titular researcher at the Optics and Biomedicine Department, INAOE, in Mexico. His research interests are in optical design, thermography of the plantar skin of the patient with diabetes, digital anthropometry and sensorial substitution for impaired visual patients.

PUBLIC INTEREST STATEMENT
The knowing of the body segments masses may be helpful to the health professional to evaluate the patient condition, to calculate the drug doses (particularly those depending of the patient weight), to establish a physical therapy, etc. In this work, the height and mass of 20 young individuals are used to compute, based on statistical formulae, the body mass index (BMI), the blood volume (BV), the basal metabolic rate (BMR) and the body surface (BS). This data is used, to estimate the four clinical parameters of 20 fictitious patients who were amputated from one lower limb. Thus, the average mass of the one lower limb is 10.22 ± 1.92 and 13.88 ± 2.3 kg for women and men, respectively. Then, the loss of the BMI and the BS is about 20% and 9%, respectively, while the BV and BMR may be reduced by an amount of 11% and 9%, respectively.
Keywords: mass of the lower limb; body mass index; blood volume; basal metabolic rate; body surface

1. Introduction
In the clinical practice, the health professional follows several kinds of protocols (signs and symptoms scheme for a given sickness, questioning and filling questionaires for the given pathology, etc.), in different professional aspects (the rights of the health professional, admin- istrative protocols to attend a patient, etc.), some of them are difficult to quantify, some others have to be applied depending on the situation. For instance, to estimate the BV for a pro- gramed amputation is not easy task for the clinician, because several variable come out (Christian, Peter, & Morten et al., 2017), and some clinical characteristics should be approached like the BMI (Eckard, Pruziner, Sanchez, & Andrews, 2012; Himes, 1995; Miller et al., 2008). Thus, it seems to be important to know the mass of the body segments, which of course had been an old research topic (Clausser, McConville, & Young, 1969; Pearsall & Reid, 1994; Zartsioky, 1982). Another example, in which the knowing of the human body segments may be useful, is when assessing the muscular force, for a particular muscle group, here the health professional have to apply the “minimum” or the “maximum” force (Hislop & Montgomery, 1995), which is human depending. Thus, the importance of knowing the mass of the body segment has several applications in the clinic, just to compute the BMI or up to compute the blood requirements after an amputation.

In this work, the mass of the lower limbs are computed from a statistical formula, which depend on the weight and the size of the patient (Zartsioky, 1982). The sample is 20 young healthy adults, 10 women and 10 men. Then, four clinic characteristics, the BMI (Center for Disease Control and Prevention, 2017; World Health Organization, 2017), the BV (Nadler, Hidalgo, & Bloch, 1962), the BMR (Harris & Benedict, 1918) and the BS (Du Bois & Du Bois, 1989) are computed for the sample population and for 20 hypothetical patients who have lost one lower limb. From the sample population, the averaged lower limb mass is 12.05 ± 2.79 kg. The averaged clinical characteristics are BMI of 22.89 ± 3.93 kg/m², BV of 3.99 ± 0.82 l, BMR of 1,543.32 ± 236.98 kCal and BS of 1.66 ± 0.20 m². While for the fictitious patients the averaged clinical characteristics are BMI of 18.42 ± 3.17 kg/m², BV of 3.60 ± 0.74 l, BMR of 1,399.07 ± 183.38 kCal and BS of 151 ± 0.18 m². These are raw results, which may lead to misunderstanding in a real patient. However, the computed mass of a lower limb fluctuates between 7.43 kg and up to 18.30 kg. Then, for instance, the computed BV varies between 2.84 l and up to 5.67 l. Thus, the importance of these results resides on the fact that any clinical characteristics, that can be computed, should be done for the individual, and avoid the use of the averaged values.

Furthermore, once the mass of a body segment is known, the minimum and maximum force can be defined in terms of a weight, attached to the center of gravity of the body segment that is proportional to the mass of that body segment.

2. Method

2.1. Procedure
The weight, height and age of 20 young healthy adult were obtained so as to compute the human body segments, and the four clinic characteristics (the BMI, the BV, the BMR and the BS) which formulae depend on the mass, weight and the age of the individual. Tables 1 and 2 resume the measured data, the computed clinic characteristics and the mass of a lower limb for women and men, respectively. The columns, on the both tables, represent the identification of the volunteer (W and M stand for woman and male, respectively), height, weight, age, BMI, BV, BMR, BS and the mass of one lower limb according to the formula of Zatsiorsky (Clausser et al., 1969; Eckard et al., 2012; Himes, 1995; Pearsall & Reid, 1994; Zartsioky, 1982).
Table 1. The data of the women volunteers: height, weight and age. Blood volume (BV), basal metabolic rate (BMR), body surface (BS) and mass of a lower limb (Zartsioky, 1982)

| Volunteer | Height (cm) | Weight (kg) | Age (years) | BMI (kg/m²) | BV (liters) | BMR (kCal) | BS (m²) | Mass of one lower limb (kg) |
|-----------|-------------|-------------|-------------|-------------|-------------|------------|---------|---------------------------|
| W01       | 165         | 56          | 22          | 20.57       | 3.64        | 1,393.01   | 1.61    | 11.0                      |
| W02       | 157         | 68          | 22          | 27.59       | 3.81        | 1,492.96   | 1.69    | 13.10                     |
| W03       | 150         | 60          | 20          | 26.67       | 3.37        | 1,412.86   | 1.55    | 11.30                     |
| W04       | 150         | 44          | 20          | 19.56       | 2.84        | 1,259.85   | 1.36    | 8.30                      |
| W05       | 152         | 46          | 21          | 19.91       | 2.96        | 1,278.00   | 1.40    | 8.70                      |
| W06       | 162         | 51          | 20          | 19.43       | 3.38        | 1,348.99   | 1.53    | 10.00                     |
| W07       | 153         | 45          | 19          | 19.22       | 2.95        | 1,274.97   | 1.39    | 8.60                      |
| W08       | 156         | 47          | 27          | 19.31       | 3.09        | 1,266.91   | 1.44    | 9.00                      |
| W09       | 156         | 45          | 24          | 18.49       | 3.02        | 1,261.91   | 1.41    | 8.70                      |
| W10       | 159         | 70          | 19          | 27.69       | 3.93        | 1,529.82   | 1.72    | 13.50                     |
| Average   | 156.00      | 53.20       | 21.40       | 21.84       | 3.30        | 1,351.93   | 1.51    | 10.22                     |
| Standard deviation | 4.99  | 9.83         | 2.50        | 3.82        | 0.39        | 101.18     | 0.13   | 1.92                      |

Note: Body mass index (BMI).
| Volunteer | Height (cm) | Weight (kg) | Age (years) | BMI (kg/m²) | BV (liters) | BMR (kCal) | BS (m²) | Mass of one lower limb (kg) |
|-----------|-------------|-------------|-------------|-------------|-------------|------------|---------|--------------------------|
| M01       | 179         | 92          | 24          | 28.71       | 5.67        | 2,064.92   | 2.11    | 18.30                    |
| M02       | 173         | 68          | 21          | 22.72       | 4.69        | 1,725.16   | 1.81    | 13.60                    |
| M03       | 178         | 55          | 19          | 17.36       | 4.44        | 1,584.94   | 1.69    | 11.30                    |
| M04       | 170         | 60          | 19          | 20.76       | 4.34        | 1,613.67   | 1.69    | 12.00                    |
| M05       | 172         | 80          | 22          | 27.04       | 5.05        | 1,878.41   | 1.93    | 15.80                    |
| M06       | 169         | 67          | 21          | 23.46       | 4.53        | 1,691.40   | 1.77    | 13.30                    |
| M07       | 166         | 63          | 22          | 22.86       | 4.31        | 1,614.64   | 1.70    | 12.40                    |
| M08       | 167         | 86          | 24          | 30.84       | 5.08        | 1,922.38   | 1.95    | 16.80                    |
| M09       | 165         | 64          | 23          | 23.51       | 4.31        | 1,616.63   | 1.70    | 12.60                    |
| M10       | 170         | 64          | 24          | 22.15       | 4.47        | 1,634.89   | 1.74    | 12.7                     |
| Average   | 170.90      | 69.90       | 21.90       | 23.94       | 4.69        | 1,734.70   | 1.81    | 13.88                    |
| Standard deviation | 4.72       | 12.01       | 1.91        | 3.94        | 0.45        | 164.07     | 0.14    | 2.30                     |

Note: Body mass index (BMI).
2.2. Results

From Tables 1 and 2, the average measured height and weight were 156 ± 4.99 cm and 53.20 ± 9.83 kg for the women, while 170.90 ± 4.72 cm and 69.90 ± 12.01 kg for men, respectively.

The computed clinical characteristics for the women varies from healthy individuals (18.5 ≤ BMI (kg/m²) ≤ 24.9) and up to some individuals with overweight (BMI ≥ 25 kg/m²). The other three clinical characteristics showed widely fluctuations, for the BV from 2.84 to 3.93 l, the BMR from 1,259.85 to 1,529.82 kCal and for the BS from 1.36 to 1.72 m², respectively. The weight of one lower limb varies from 8.30 to 13.50 kg.

While for the men, the clinical characteristics varies from underweight individuals (BMI ≤ 18.5 kg/m²) and up to individuals with obesity (BMI ≥ 30 kg/m²). Then, the other three clinical characteristics widely fluctuate for the BV from 4.31 (does not correspond to the underweight individual) to 5.67 l, the BMR from 1,584.94 to 2,064.92 kCal and for the BS from 1.69 to 2.11 m², respectively. The weight of the one lower limb varies from 11.30 to 18.30 kg.

Tables 3 and 4 show the clinics characteristics of the fictitious patients who lost one lower limb. The clinics characteristics were evaluated by subtracting the mass of the lower limbs from the total mass of the individual.

Most of the fictitious women patients show BMI<18.5, that is, they are underweight. Just, three of them show 18.5 ≤ BMI (kg/m²) ≤ 24.9. The BV fluctuates from 2.57 to 3.48 l, the BMR from 1,179.08 to 1,400.68 kCal and for the BS from 1.24 to 1.57 m², respectively.

While, half of the fictitious men patients belong to the underweight group, that is, BMI < 18.5 kg/m², the other half patients show up in the normal group, that is 18.5 ≤ BMI (kg/m²) ≤ 24.9. The BV fluctuates from 3.91 to 5.08 l, the BMR from 1,429.83 to 1,812.61 kCal and for the BS from 1.53 to 1.92 m², respectively.

3. Discussion

The sample population, young healthy adults, is chosen arbitrary with only one inclusion criteria, that is, the volunteers were not sick at the time of the interview. The sample is divided in women and men. The equations, used to compute lower limb weight and the clinical characteristics, depend on two

| Volunteer | BMI (kg/m²) | BV (l) | BMR (kCal) | BS (m²) |
|-----------|-------------|--------|------------|--------|
| W01       | 16.53       | 2.57   | 1,287.43   | 1.47   |
| W02       | 22.27       | 2.66   | 1,368.09   | 1.54   |
| W03       | 21.64       | 2.67   | 1,304.75   | 1.42   |
| W04       | 15.87       | 2.74   | 1,180.84   | 1.24   |
| W05       | 16.14       | 2.79   | 1,194.72   | 1.28   |
| W06       | 15.62       | 3.00   | 1,253.46   | 1.39   |
| W07       | 15.55       | 3.05   | 1,193.19   | 1.27   |
| W08       | 15.61       | 3.27   | 1,180.54   | 1.31   |
| W09       | 14.92       | 3.38   | 1,179.08   | 1.29   |
| W10       | 22.35       | 3.48   | 1,400.68   | 1.57   |
|           | 17.65       | 2.96   | 1,256.28   | 1.38   |
|           | 3.10        | 0.33   | 82.86      | 0.12   |

Table 3. The BMI, BV, BMR and BS for the fictitious women patients, who were amputated for one lower limb. The four characteristics were computed by subtracting the mass of the lower limb from the total mass of the patient

Note: Body mass index (BMI); blood volume (BV); basal metabolic rate (BMR); body surface (BS).
anthropometric measurements and the age, that is, can be filled up easily. A disadvantage, in these calculations, is the use of recurrent equations: one to compute the weight of human body segments and the other to compute the clinical characteristics. Thus, to simplify the calculations the body weight segments can be estimated as a percentage of the total body mass (Gowitzke & Milner, 1999).

However, both approaches can be easily programmed in the different programing platforms.

The statistic of the computed clinical characteristics is given in Table 5. Depending on how familiar is the clinician with these clinical characteristics, then it may not be impressive for some them, but very interesting for others, and it may be more interesting for those young clinicians and for students of different fields. The differences, between the maximum and the minimum computed value are 1.09 l

| Volunteer | BMI (kg/m²) | BV (liters) | BMR (kCal) | BS (m²) |
|-----------|-------------|-------------|------------|---------|
| M01       | 23.00       | 5.08        | 1,429.83   | 1.92    |
| M02       | 18.18       | 4.26        | 1,449.12   | 1.65    |
| M03       | 13.79       | 4.08        | 1,459.89   | 1.53    |
| M04       | 16.61       | 3.95        | 1,538.34   | 1.54    |
| M05       | 21.70       | 4.54        | 1,444.07   | 1.76    |
| M06       | 18.80       | 4.10        | 1,509.01   | 1.61    |
| M07       | 18.36       | 3.91        | 1,443.91   | 1.55    |
| M08       | 24.81       | 4.54        | 1,660.66   | 1.78    |
| M09       | 18.88       | 3.91        | 1,812.61   | 1.55    |
| M10       | 17.75       | 4.06        | 1,691.22   | 1.59    |
| M11       | 19.19       | 4.24        | 1,543.87   | 1.65    |
| M12       | 3.20        | 0.37        | 132.42     | 0.13    |

Note: Body mass index (BMI); blood volume (BV); basal metabolic rate (BMR); body surface (BS).

Table 4. The BMI, BV, BMR and BS for the fictitious men patients, who were amputated for one lower limb. The four characteristics were computed by subtracting the mass of the lower limb from the total mass of the patient.

| Clinical characteristic | Minimum | Maximum | Average |
|-------------------------|---------|---------|---------|
| Women BMI (kg/m²)       | 18.49   | 27.69   | 21.84 ± 3.82 |
| BV (l)                  | 2.84    | 3.93    | 3.30 ± 0.39 |
| BMR (Kcal)              | 1,259.85| 1,529.82| 1,351.93 ± 101.18 |
| BS (m²)                 | 1.36    | 1.72    | 1.51 ± 0.13 |
| Mass of lower limb (kg) | 8.30    | 13.50   | 10.22 ± 1.92 |
| Men BMI (kg/m²)         | 17.36   | 30.44   | 23.94 ± 3.94 |
| BV (liters)             | 4.31    | 5.67    | 4.69 ± 0.45 |
| BMR (Kcal)              | 1,584.94| 2,064.92| 1,734 ± 164.07 |
| BS (m²)                 | 1.69    | 2.11    | 1.81 ± 0.14 |
| Mass of lower limb (kg) | 11.30   | 18.30   | 13.88 ± 2.30 |

Note: Body mass index (BMI); blood volume (BV); basal metabolic rate (BMR); body surface (BS).
and 1.36 l (BV), 269.97 kCal and 479.98 kCal (BMR), 0.36 m$^2$ and 0.42 (BS) and 5.02 and 7.0 kg (mass of a lower limb) for women and men, respectively. This wide variation in the clinical characteristics shows the importance of not using the median or the average to estimate them.

Another useful application from knowing the masses of the body segments is when assessing the muscle force of specific group. For instance, in a transtibial amputation, the hamstring muscles are still functioning. Then, after the amputation surgery and without any risk of injury, these muscles can be stretched by attaching an object on the stump with an equivalent mass to the leg and the foot. Because of, before the amputation, the hamstring muscles could flexed, at least, a weight composed of the leg and foot, against the gravity force.

Furthermore, the minimum and maximum force, in the muscle force assessment (Hislop & Montgomery, 1995), may be defined in terms of a weight proportional to that of the body segment mass to be assessed. It is known that when a muscle group can move the body segment against gravity, the next assessment is to apply the minimum force. Thus, this force may be evaluated by attaching to the center of gravity of the body segment to be assessed, a weight proportional to the mass of the body segment. That is, if $M_{bs}$ designates the mass of the body segment, then the mass to be attached to the center of gravity may be $1/4 M_{bs}$, $1/2 M_{bs}$, $1 M_{bs}$, $2 M_{bs}$, etc. The same strategy can be applied to define the maximum force.

The knowing of the body mass segment is useful to estimate clinics characteristics of the patient to assess muscle force for a given muscle group, and those pathologies where the limbs of the human body are affected, like bone cancers, lymphomas, peripheral neuropathies, peripheral artery disease, etc.

4. Conclusions

By means of a sample population of young healthy adults, it was shown the importance to compute the clinical characteristics for the patient in front of the clinician. The weight of the lower limbs and the BMI, BV, BMR and BS showed a wide variation within the sample population.

By using a linear equation, which in function of the weight and height of the patient, the mass of lower limbs were computed and used to estimate the clinics characteristics of 20 fictitious patients who lost one lower limb. These, clinics characteristics showed that the patients have different requirements than before the amputation.

The knowing of the mass of the body segments allow to estimate the minimum and maximum force to be applied to the assessments of a muscular force. Furthermore, the patient, in the rehabilitation process, may be referred in terms of the weight, attached to the center of gravity of the body segment, moved by the muscles in rehabilitation against gravity force.

Acknowledgments

None.

Funding

The author received no direct funding for this research.

Declaration of interest

There are no known conflicts of interest.

Author details

Francisco-J Renero-C

E-mail: paco@inaoep.mx

ORCID ID: http://orcid.org/0000-0003-1273-4725

Optics - Biomedicine, INAOE, Atlanta, Puebla, México, USA.

Citation information

Cite this article as: On the importance of the theoretical computation of the human body segments’ masses, Francisco-J Renero-C, Cogent Medicine (2018), 5: 1540963.

Note

1. This means that the volunteer, according to their knowledge, was in good health condition. Then, it is the only inclusion criteria.

References

Center for Disease Control and Prevention. About BMI for adults. Retrieved December 20, 2017, from. https://www.cdc.gov/healthyweight/assessing/bmi/index.html

Christian, W., Peter, T., Morten, T., et al. (2017). Total blood loss after transfemoral amputations is twice the intraoperative loss: An observational cohort study of 81 nontraumatic amputations. Geriatric Orthopaedic Surgery & Rehabilitation, 8(3), 123–127. doi:10.1177/2151458517706595

Clausser, C. E., McConville, J. T., & Young, J. W. (1969). Weight, volume, and center of mass segments of the human body. Oklahoma US: Aerospace Medical Research Laboratory. 1–97, National
Du Bois, D., & Du Bois, E. F. (1989). A formula to estimate the approximate surface area if height and weight be known. 1916. Nutrition, 5(S), 303–311.

Eckard, C. S., Pruziner, A. L., Sanchez, A. D., & Andrews, A. M. (2012). Metabolic and body composition changes in first year following traumatic amputation. JRRD, 52(5), 553–561. doi:10.1682/JRRD.2014.02.0044

Gewitzke, B. A., & Milner, M. (Ed.). (1999). El cuerpo y sus movimientos, bases científicas (Primera ed.). España: Paidotribo, Barcelona.

Harris, J. A., & Benedict, F. G. (1918). A biometric study of human basal metabolism. Proceedings of the National Academy of Sciences, 4(12), 70–373. doi:10.1073/pnas.4.12.370

Himes, J. H. (1995). New equation to estimate body mass index in amputees. Journal of the American Dietetic Association, 95(6), 646. doi:10.1016/S0002-8223(95)00175-1

Hislop, H. J., & Montgomery, J. (1995). Daniels-Worthington’s muscles testing (6th ed.). Philadelphia, U.S.: W. B. Saunders Co.

Miller, M., Wong, W. K., Wu, J., Cavenett, S., Daniels, L., & Crofty, M. (2008). Upper-arm anthropometry: An alternative indicator of nutritional health to body mass index in unilateral lower-extremity amputees? Archives of Physical Medicine and Rehabilitation, 89(10), 2031–2033. doi:10.1016/j.apmr.2008.03.025

Nadler, S. B., Hidalgo, J. U., & Bloch, T. (1962). Prediction of blood volume in normal human adults. Surgery, 51(2), 224–232.

Pearsall, D. J., & Reid, J. G. (1994). The study of human body segment parameters in biomechanics. Sports Medicine, 18(2), 126–140. doi:10.2165/00007256-199418020-00005

World Health Organization. BMI classification. (2017). Retrieved December 20, 2017, from, http://apps.who.int/bmi/index.jsp?introPage=intro_3.html

Zartsioky, V. (1982). The mass and inertia of the main segment of human body, research gate. Retrieved December 20, 2017, from, https://www.researchgate.net/publication/263065659_The_mass_and_inertia_characteristics_of_the_main_segment_of_human_body