A comparison of body composition assessment methods in climbers: Which is better?

Maria José Arias Téllez1,2*, Fernando Carrasco1, Vanesa España Romero3,4, Jorge Inostroza1, Alejandro Bustamante5, Ignacio Solar Altamirano1,6*

1 Department of Nutrition, Faculty of Medicine, University of Chile, Independence, Santiago, Chile, 2 PROFITH “PRO-moting FITness and Health through physical activity” research group, Department of Physical and Sports Education, Sport and Health University Research Institute (iMUDS), Faculty of Sports Science, University of Granada, Granada, Spain, 3 MOVE-IT Research group, Department of Physical Education, Faculty of Education Sciences University of Cádiz, Cádiz, Spain, 4 Biomedical Research and Innovation Institute of Cádiz (INIBICA) Research Unit, Puerta del Mar University Hospital University of Cádiz, Cádiz, Spain, 5 Department of Kinesiology, Faculty of Medicine, University of Chile, Independence, Santiago, Chile, 6 High Performance Center, Pedro de Valdivia, Ñuñoa, Santiago, Chile

* mariajosearias@uchile.cl (MJAT); ignaciosolar@med.uchile.cl (ISA)

Abstract

Objective
To compare body composition estimations of field estimation methods: Durnin & Womersley anthropometry (DW-ANT), bioelectrical impedance analysis (BIA) and Deborah-Kerr anthropometry (DK-ANT) against dual-energy X-ray absorptiometry (DXA) in a male Chilean sport climbing sample.

Methods
30 adult male climbers of different performance levels participated in the study. A DXA scan (Lunar Prodigy®) was used to determine fat mass, lean mass and total bone mineral content (BMC). Total muscle mass (MM, kg) was estimated through a validated prediction model. DW-ANT and BIA (“non-athletes” and “athletes” equations) were used to determine fat mass percentage (FM%), while DK-ANT was utilized to estimate MM and BMC.

Results
A significant (p<0.01) inter-method difference was observed for all methods analyzed. When compared to DXA, DW-ANT and BIA underestimated FM% and DK-ANT overestimated MM and BMC (All p<0.01). The inter-method differences was lower for DW-ANT.

Discussion
We found that body composition estimation in climbers is highly method dependent. If DXA is not available, DW-ANT for FM% has a lower bias of estimation than BIA in young male Chilean climbers. For MM and BMC, further studies are needed to compare and estimate...
the DK-ANT bias level. For both methods, correction equations for specific climbing popula-
tion should be considered.

Introduction

Body composition assessment is a crucial component in athlete monitoring, not only as a per-
formance-related variable, but also as a training and dietary intervention follow-up, morpho-
logical optimization advisory, and health and weight control—especially in weight-sensitive
sports [1]. The methods for its evaluation can be classified, according to analysis techniques,
in: i) reference tests of molecular level (dual-energy X-ray absorptiometry [DXA], computer-
ized tomography, magnetic resonance imaging) ii) field tests: a) with molecular level: anthrop-
ometry (example: Durnin & Womersley anthropometry) or bioelectrical impedance analysis
(BIA) [1], and b) tissue anthropometry (example: Deborah-Kerr anthropometry [2] (Fig 1).

Body composition estimation with molecular anthropometry and BIA equations have been
developed and validated from general population samples. Thus, the techniques could be less
valid on physically active or high performance individuals [1,3]. Additionally, although the
anthropometry method at tissue level developed by Kerr [4] has been described in athlete pop-
ulations [5–7], there is no evidence of its validation against reference methods for different
sport disciplines.

With the climbers’ population, there is a topic of relevance because low fat mass percentage
(FM%) has been widely described as a determinant of performance [8–14]. As far as it is
known, the only study assessing the concordance of “on field techniques” and a “reference
technique” was conducted by Españ̜a-Romero et al (8). They compared 17 anthropometry
equations for FM% estimation against DXA. The authors reported that the Durnin &
Womersley [15] body density equation, using both Siri’s or Brozek FM% equations [16], did
not have significant inter-method difference in female and male climbers.

Anthropometry and BIA are widely used methods because they are easy to apply and inex-
pensive. Nevertheless, no studies analyzing the molecular and tissue level methods, for the esti-
mation of fat mass (FM) and muscle mass (MM), respectively, at the same time in a specific
sport modality has been found. Therefore, the aim of the present study was to compare body
composition estimations of field estimation methods (Durnin & Womersley anthropometry,
bioelectrical impedance analysis and Deborah-Kerr anthropometry) against dual-energy X-ray
absorptiometry in a male Chilean sport climbing sample.

Materials and methods

Research design and participants

This cross-sectional study included a convenience sample of 30 male climbers (26.1 ± 4.9 years
old). Inclusion criteria were being >18 years old, having climbing experience >3 months, free
of disease or musculoskeletal injury. The climbers’ levels of performance were assessed trough
self-report using the International Rock Climbing Research Association’s (IRCRA) recom-
mendations [17,18]. A comprehensive verbal description of the nature and purpose of the
study, as well as the experimental risks were given to the participants. Written informed con-
sent was obtained before participation. The study protocol was approved by the Faculty of
Medicine, University of Chile (n° 217–2016) Ethics Committee and met the requirements of
the Declaration of Helsinki and the ethical standards in sports and exercise research [19].
Classic anthropometry measurements

Weight (kg) and height (m) were measured using a calibrated digital scale SECA (model gmbh & co. kg.Hammer Steindamm 3–25, 22089 Hamburg Germany), and a stadiometer brand SECA (model 220), respectively. BMI (kg/m$^2$) was calculated.

![Diagram of body composition]

**Fig 1. Types of levels of human body composition.** A) According to level of analysis B) According to degree of accuracy of referent or field tests.

https://doi.org/10.1371/journal.pone.0224291.g001
Body composition assessment

Each set of individual dual-energy X-ray absorptiometry (DXA) plus BIA measurements were performed in the same day by the same operator, under at least four hours of fasting conditions and without exercise the previous 24 hours to ensure adequate hydration conditions.

i. DXA: A Lunar Prodigy Advance equipment (General Electric Systems, Madison, WI), was used to determine FM (kg, and percentage), lean mass (LM, kg), and total bone mineral content (BMC, kg) DXA device was calibrated with phantoms before each set of measurements. In our laboratory, the variability coefficient was 0.01, 0.40 and 2.90% for FM, LM and BMC, respectively. Total MM (kg) was estimated through a predictive model validated by Kim et al. (21) against magnetic resonance imaging. MM (kg) = (appendicular lean mass (kg) x 1.19) - 1.01.

ii. Bioelectrical impedance analysis (BIA): A tetrapolar, four frequency BODYSTAT QuadScan 4000 device was used to determine FM (kg, and percentage) (Isle of Man, IM99 1DQ, BRITISH ISLES / Software Version 3.13). With the subject supine, and at least 30 minutes of previous rest, gel electrodes were placed on the right hand, distally 1 cm. on the knuckles, and proximal, immediately on the distal end of the ulna, and on the right foot, in the middle of metatarsus (distal electrode) and in the middle area of the line that joins the lateral and medial malleoli (proximal electrode). One measurement and two predictive equations provided by the manufacturer (“non-athletes” and “athletes”) were used to estimate FM%. The intra-individual variability coefficient of BIA measures was 3.0% for FM%, in our laboratory.

iii. Durnin & Womersley anthropometry (DW-ANT): A Lange skinfold caliper was used to make two skinfold thickness measurements at 4 anatomical sites according ISAK protocol [20]. The same trained technician performed the measurements, considering a technical measurement error (TME) of 7.5% for intra-evaluator and 10% inter-evaluator [21]. The right biceps, triceps, subscapular and suprailiac sites were measured. The average of the two measurements was used for the analyses. Body density was calculated by Durnin & Womersley equations [15] and converted into FM % via Siri’s equation [16].

iv. Deborah Kerr anthropometry equations (DK-ANT)[4]: According to ISAK protocol [20], 10 body perimeters (cm), 6 body diameters (mm), 9 lengths and segments (cm) and 8 skinfolds (mm) were measured using an inextensible metallic tape, anthropometer and caliper. The skinfolds measured were (at the right side): biceps, triceps, subcapular, supra spinal, iliac crest, abdominal, frontal thigh and calf. For intra-evaluator, a TME of 7.5% for skinfolds and 1.5% for other measurements were considered. For inter-evaluator, the TME considered wereETM of 10% and 2% respectively, were tolerated [21]. The average of the two measurements was used for the analyses Muscle mass (MM, kg) and BMC (kg) were estimated using AntropoS2 software (Holway, 2000).

Statistical analysis

Descriptive statistics were performed to examine the characteristics of the study participants. Agreement between DXA and composition assessment methods was determined using Bland-Altman plots (Bland & Altman, 1986). Validity and lack of agreement between DXA and the equations was assessed by calculating the bias—that is, the inter-method differences and standard deviation (SD) of the differences. The 95% confidence intervals for the bias and the 95% limit of agreements (bias ± 1.96 sd) were also calculated. Differences between methods
(equation vs. DXA) were analyzed by paired t-tests. Heteroscedasticity was examined by the Pitman test to determine whether the absolute inter-method difference was associated with the magnitude of the measurement (i.e. inter-methods mean). A significant association ($P < 0.05$) would confirm heteroscedasticity. Statistical analyses were performed using STATA software version 14.0.

**Results**

Taking into consideration the IRCRA ability grouping statement, 9 novice climbers, 11 advanced climbers and 10 elite climbers composed the sample. The main characteristics of the participants are presented in Table 1.

| Method                  | Fat mass (%)| Method–DXA | 95% Limits of agreements | $P$  |
|-------------------------|-------------|------------|--------------------------|------|
| DXA                     | 15.04 ± 2.79|            | -                        | -    |
| BIA athletes            | 8.80 ± 1.80 | -6.24 (-7.27 to -5.20) | -11.79 to -0.69 | 0.014|
| BIA non-athletes        | 5.87 ± 2.30 | -9.17 (-9.99 to -8.34) | -13.60 to -4.74 | 0.163|
| DW-ANT                  | 12.30 ± 3.20| -2.73 (-3.39 to -2.06) | -6.30 to 0.85 | 0.154|

Values are mean ± standard deviation and range. DXA: dual energy X-ray absorptiometry.

https://doi.org/10.1371/journal.pone.0224291.t002

Table 2. Inter-methods differences in fat mass estimation: BIA (athlete and non-athlete equations) and Durnin & Womersley anthropometry (DW-ANT) against DXA.
Table 3. Inter-methods differences in muscle mass and bone mineral content estimation: anthropometry (DK-ANT) against DXA.

| Methods              | Mean ± SD | Method—DXA (95% CI) | 95% Limits of agreements | P*         |
|----------------------|-----------|---------------------|--------------------------|------------|
| DXA MM (kg)          | 29.3 ± 3.30 | -                   | -                        | -          |
| DK-ANT MM (kg)       | 34.5 ± 4.30 | 5.23 (4.30 to 6.16) | 0.25 to 10.20            | 0.031      |
| DXA BMC (kg)         | 2.91 ± 0.37 | -                   | -                        | -          |
| DK-ANT BCM (kg)      | 7.54 ± 1.20 | 4.62 (4.24 to 4.99) | 2.60 to 6.64             | <0.001     |

*Heterocedasticity by Pitman’s Test.

DXA, dual-energy X-ray absorptiometry; MM, muscle mass; BCM, bone mineral content.

Discussion

The present study compared body composition estimation by three different on-field estimation methods against DXA in a male Chilean sport climbers sample. In general, the results showed that DW-ANT and BIA underestimated FM%, and DK-ANT overestimated MM and BMC when compared with DXA. Moreover, inter-method differences was lower for DW-ANT Therefore, in a field scenario, DW-ANT for FM% has lower bias of estimation than other approaches in young male Chilean climbers. Nevertheless, for MM and BMC, further studies are needed to compare and estimate the DK-ANT bias level.

Our results are in line with the study of España-Romero et al. (10) in rock climbers. They suggested an anthropometry equations, i.e., Durnin & Womersley body density equation.

Fig 2. Comparison of predicted percentage of fat mass (FM %) between Durnin & Womersley anthropometry (DW-ANT) and dual-energy X-ray absorptiometry (DXA) in climbers by Bland and Altman plots. The central line represents inter-method differences. Upper and lower broken lines represent the 95% limit of agreement (inter-methods difference ± 1.96 sd of the differences).

https://doi.org/10.1371/journal.pone.0224291.g002
using both, Siri’s or Brozek FM% equations [16], as the most accurate to estimate FM% among men elite climbers. Nevertheless, the lack of previous studies for validation of DK-ANT method against reference methods, does not allow performing more comparisons.

Previous studies have compared field method as anthropometry and BIA for other specific athlete populations. Specifically, Lopez-Taylor et al. analysed the accuracy of 31 anthropometry equations to estimate body FM% among professional male soccer players using DXA. Only 12 equations showed non-significant differences with DXA and 4 showed narrower limits of agreement [22]. Lozano et al. found significant differences for FM% estimation using DXA, anthropometry (Slaughter equation), BIA and air displacement plethysmography in young football players, proposing these methods are not interchangeable in this population [23]. Similar results found Zemski et al. and Carvalho et al. when comparing skinfold equations against DXA in professional rugby players [24,25]. The existing formulas tended to underestimate FM % at low levels of adiposity, whilst overestimating it at the higher levels. Other sport disciplines and comparisons can be found in the review of Mazic et al., 2014 [26]. Finally, as far as we know, our FM% estimation -both with on field methods and DXA- are in line with those previously described in climbers -with values between 4.7–15.3% [12,27–29] and 13.3–20.4 [8], respectively.

As expected, when FM% was determined using two predictive equations provided by the BIA manufacturer (non-athletes and athletes), it was observed BIA athletes-equation had a smaller difference that BIA non-athletes in the FM% calculation with respect DXA. Nevertheless, the lack of public access to the equations used for the estimation appear as a limitation for further analysis.

Fig 3. Comparison of predicted muscle mass (kg) between Deborah-Kerr anthropometry (DK-ANT) and dual-energy X-ray absorptiometry (DXA) in climbers by Bland and Altman plots. Central line represents inter-method differences. Upper and lower broken lines represent the 95% limit of agreement (inter-method difference ± 1.96 sd of the differences).

https://doi.org/10.1371/journal.pone.0224291.g003
Despite the absence of previous studies that validate the estimation of muscle mass with the DK-ANT method, its low cost and lower technical complexity make it attractive as a method in a field setting. However, the results of this study suggest that, when compared to DEXA, DK-ANT does not provide a reliable estimate of muscle mass, unless appropriate equations are developed to decrease the estimation error.

Although BMC for DK-ANT presents smaller inter-methods differences than MM estimated, the higher heteroscedasticity observed -possibly for lack of validity and/or accuracy of lengths and diameters measurements used and the absence of studies about equations to estimate BMC compared with DXA in elite climbers- suggest the need of further analyses in this topic.

Some strengths of the present study must be highlighted. The use of a reference method for the estimation and comparison of body composition, the comparison of techniques in regard to level of analysis of body composition (level II and IV), the inclusion of different performance level climbers and the register of the athletes under the IRCRA classification and grouping statement, allowing comparison in future studies. On the other hand, we acknowledge that some limitations when interpreting and comparing the results could be: i) the lack of previous studies examining the validation of DK-ANT method against reference methods, especially in the climbing population ii) the absence of female athletes and iii) the lack of knowledge of the equations for the estimation of FM% by BIA.

In conclusion, according to our findings, the results of body composition analysis in climbers are highly dependent on the methods used. Taken together, we suggest that in the case when DXA is not available, DW-ANT (Durnin & Womersley and Siri equations) for FM% would have advantages over BIA for body composition estimation in Chilean climbers. It is uncertain if the BIA bias could be less with other devices or other equations. Further studies are needed to compare and estimate the DK-ANT bias level. In addition, for both methods, correction equations for specific climbing population should be considered.

Supporting information
S1 Data Set.
(RAR)

Acknowledgments
We are grateful to Chilean climbing population for participate in this present study.

Author Contributions
Conceptualization: María José Arias Téllez, Fernando Carrasco, Ignacio Solar Altamirano.
Formal analysis: María José Arias Téllez, Fernando Carrasco, Vanesa España Romero, Ignacio Solar Altamirano.
Investigation: María José Arias Téllez, Fernando Carrasco, Jorge Inostroza, Alejandro Bustamante, Ignacio Solar Altamirano.
Methodology: María José Arias Téllez, Fernando Carrasco, Ignacio Solar Altamirano.
Project administration: Fernando Carrasco, Ignacio Solar Altamirano.
Supervision: Ignacio Solar Altamirano.
Writing – original draft: María José Arias Téllez, Fernando Carrasco, Vanesa España Romero, Ignacio Solar Altamirano.
Writing – review & editing: María José Arias Téllez, Fernando Carrasco, Vanesa España Romero, Ignacio Solar Altamirano.

References

1. Ackland TR, Lohman TG, Sundgot-Borgen J, Maughan RJ, Meyer NL, et al. (2012) Current status of body composition assessment in sport: review and position statement on behalf of the ad hoc research working group on body composition health and performance, under the auspices of the I.O.C. Medical Commission. Sports Med 42: 227–249. https://doi.org/10.2165/11597140-000000000-00000 PMID: 22303996

2. Wang ZM, Pierson RN Jr., Heymsfield SB(1992) The five-level model: a new approach to organizing body-composition research. Am J Clin Nutr 56: 19–28. https://doi.org/10.1093/ajcn/56.1.19 PMID: 1609756

3. Fogelholm M, van Marken Lichtenbelt W (1997) Comparison of body composition methods: a literature analysis. Eur J Clin Nutr 51: 495–503. https://doi.org/10.1038/sj.ejcn.1600448 PMID: 11248873

4. Kerr DA (1988) An anthropometric method for the fractionation of skin, adipose, muscle, bone and residual tissue masses in males and females age 6 to 77 years: Simon Fraser University.

5. Spent LF, Martin AD, Drinkwater DT (1993) Muscle mass of competitive male athletes. J Sports Sci 11: 3–8. https://doi.org/10.1080/02640419308729956 PMID: 8450582

6. Kerr DA, Ross WD, Norton K, Hume P, Kagawa M, et al. (2007) Olympic lightweight and open-class rowers possess distinctive physical and proportionality characteristics. J Sports Sci 25: 43–53. https://doi.org/10.1080/02640410600812179 PMID: 17127580

7. Lovera M, Keogh J (2015) Anthropometric profile of powerlifters: differences as a function of bodyweight class and competitive success. J Sports Med Phys Fitness 55: 478–487. PMID: 25611080

8. Espasa Romero V, Ruiz JR, Ortega FA, Arteaga EG, Vicente-Rodriguez G, et al. (2009) Body fat measurement in elite sport climbers: comparison of skinfold thickness equations with dual energy X-ray absorptiometry. J Sports Sci 27: 469–477. https://doi.org/10.1080/0264010802603863 PMID: 19204847

9. Mermier CM, Janot JM, Parker DL, Swan JG (2000) Physiological and anthropometric determinants of sport climbing performance. Br J Sports Med 34: 359–365; discussion 366. https://doi.org/10.1136/bjsm.34.5.359 PMID: 11049146

10. Ozimek M, Krawczyk M, Zadarko E, Barabasz Z, Ambrozy T, et al. (2017) Somatic Profile of the Elite Boulderers in Poland. J Strength Cond Res 31: 963–970. https://doi.org/10.1519/JSC.0000000000001673 PMID: 28328714

11. Watts PB (2004) Physiology of difficult rock climbing. Eur J Appl Physiol 91: 361–372. https://doi.org/10.1007/s00421-003-1036-7 PMID: 14985990

12. Watts PB, Joubert LM, Lish AK, Mast JD, Wilkins B (2003) Anthropometry of young competitive sport rock climbers. Br J Sports Med 37: 420–424. https://doi.org/10.1136/bjsm.37.5.420 PMID: 14514533

13. Jiří Baláš OP, Andrew J. Martin, Darryl Cochrane Hand–arm strength and endurance as predictors of climbing performance. European Journal of Sport Science 2011.

14. Miloš Puletić DS The Influence of somatotype components on success in sport climbing. Physical Education and Sport 2014 12: 105–111.

15. Durnin JV, Womersley J (1974) Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16 to 72 years. Br J Nutr 32: 77–97. https://doi.org/10.1079/bjn19740080 PMID: 4943734

16. Siri WR, 1961. (1961) Body composition from fluid spaces and density; analysis of methods. In: Techniques for measuring body composition Ed. Brozek J. and Henschel A., Nat.Acad.Sci.Washington D. C. pp. 223–244.

17. Draper N, Dickson T, Blackwell G, Fryer S, Priestley S, et al. (2011) Self-reported ability assessment in rock climbing. J Sports Sci 29: 851–858. https://doi.org/10.1080/02640414.2011.565362 PMID: 21491325

18. Nick Draper DG, Schoffel Volker(2016) Comparative grading scales, statistical analyses, climber descriptors and ability grouping: International Rock Climbing Research Association position statement. Sports Technology.

19. Harris DJ, Atkinson G (2015) Ethical Standards in Sport and Exercise Science Research: 2016 Update. Int J Sports Med 36: 1121–1124. https://doi.org/10.1055/s-0035-1565186 PMID: 26671845
20. Stewart A, Marfell-Jones M, Olds T, De Ridder H (2001) International society for the advancement of kinanthropometry: international standards for anthropometric assessment. Lower Hutt, New Zealand: International Society for the Advancement of Kinanthropometry.

21. Norton K, Olds TA (2000) Biosystem Servicio Educativo. Rosario, Argentina.

22. Lopez-Taylor JR, Gonzalez-Mendoza RG (2018) Accuracy of Anthropometric Equations for Estimating Body Fat in Professional Male Soccer Players Compared with DXA. 2018: 6843792. https://doi.org/10.1155/2018/6843792 PMID: 29736402

23. Lozano Berges G, Matute Llorente A, Gomez Bruton A, Gonzalez Aguero A, Vicente Rodriguez G, et al. (2017) Body fat percentage comparisons between four methods in young football players: are they comparable? Nutr Hosp 34: 1119–1124. https://doi.org/10.20960/nh.760 PMID: 29130710

24. Zemski AJ, Broad EM, Slater GJ (2018) Skinfold Prediction Equations Fail to Provide an Accurate Estimate of Body Composition in Elite Rugby Union Athletes of Caucasian and Polynesian Ethnicity. Int J Sport Nutr Exerc Metab 28: 90–99. https://doi.org/10.1123/ijsnem.2017-0251 PMID: 29035601

25. Carvalho HM, Coelho-e-Silva MJ, Franco S, Figueiredo AJ, Tavares OM, et al. (2012) Agreement between anthropometric and dual-energy X-ray absorptiometry assessments of lower-limb volumes and composition estimates in youth-club rugby athletes. Appl Physiol Nutr Metab 37: 463–471. https://doi.org/10.1139/h2012-027 PMID: 22497291

26. Mazic S, Lazovic B, Delic M, Lazic JS, Acimovic T, et al. (2014) Body composition assessment in athletes: a systematic review. Med Pregl 67: 255–260. https://doi.org/10.2298/mpns1408255m PMID: 25151767

27. Grant S, Hynes V, Whittaker A, Aitchison T (1996) Anthropometric, strength, endurance and flexibility characteristics of elite and recreational climbers. J Sports Sci 14: 301–309. https://doi.org/10.1080/02640419608727715 PMID: 8887209

28. Watts PB, Martin DT, Durtschi S (1993) Anthropometric profiles of elite male and female competitive sport rock climbers. J Sports Sci 11: 113–117. https://doi.org/10.1080/02640419308729974 PMID: 8497013

29. Watts PB, Daggett M, Gallagher P, Wilkins B (2000) Metabolic response during sport rock climbing and the effects of active versus passive recovery. Int J Sports Med 21: 185–190. https://doi.org/10.1055/s-2000-302 PMID: 10834350