Precision of body composition estimation from commercial bioelectrical impedance analysis devices in male Mexican soccer players

Precisión de la estimación de la composición corporal por dispositivos comerciales de bioimpedancia eléctrica en futbolistas mexicanos varones

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Abstract

Introduction: Bioelectrical Impedance Analysis (BIA) estimates fat-free mass in athletes; however, its precision can be affected by technical errors, biological variability, and fluctuations in hydration levels.
Objective: to evaluate the technical and biological measurement errors in the estimation of body composition in male Mexican soccer players using commercial BIA devices.
Methodology: A quantitative, comparative, correlational longitudinal cohort study was conducted including 31 male soccer players. Participants underwent three assessments across two consecutive laboratory visits: two measurements during the first visit (technical error) and one during the second (biological error). Fat-free mass (FFM) estimated using Omron HBF-306, Tanita BC-514 and Omron HBF-545 BIA devices. To determine the technical error and biological error of measurements, the root means square error (RMSE) and least significant change (LSC).
Results: HBF-514 provided the lowest FFM values across the devices. The body fat estimations from BC-545, significant differences were observed in day-to-day assessment ($p<0.05$). Reliability analysis revealed a RMSE values of 0.52 kg, 0.24 kg and 0.26 kg and LSC values of 2.36 kg, 1.92 kg and 1.68 kg for FFM using HBF-306, BC-545 and HBF-514 respectively.
Discussion: The precision of BIA devices was lower compared to other studies conducted on general populations, suggesting that athletes' characteristics may affect the reliability of these devices.
Conclusions: The HBF-306C showed greater variability compared to the other devices while the HBF-514 demonstrates the highest day-to-day reliability, making it a valuable tool for tracking BC in soccer players.

Keywords

Athlete; bioelectrical impedance; body composition; body fat; soccer.

Resumen

Introducción: La BIA estima la masa libre de grasa en deportistas, pero su precisión es afectada por errores técnicos, biológicos y fluctuaciones en la hidratación.
Objetivo: Evaluar los errores técnicos y biológicos en la estimación de la composición corporal en futbolistas varones mexicanos utilizando dispositivos comerciales de BIA.
Metodología: Se realizó un estudio longitudinal cuantitativo, comparativo y correlacional con 31 futbolistas. Los participantes se sometieron a tres evaluaciones en dos visitas consecutivas al laboratorio: dos mediciones en la primera visita (error técnico) y una en la segunda (error biológico). La masa libre de grasa (MLG) se estimó con los dispositivos Omron HBF-306, Tanita BC-514 y Omron HBF-545. Para determinar el error técnico y biológico, se utilizaron el error cuadrático medio (RMSE) y el cambio mínimo significativo (LSC).
Resultados: HBF-514 proporcionó los valores más bajos de MLG. Las estimaciones de grasa corporal del BC-545, se observaron diferencias significativas en la evaluación de día a día ($p < 0.05$). El análisis de fiabilidad reveló RMSE de 0.52 kg, 0.24 kg y 0.26 kg, y LSC de 2.36 kg, 1.92 kg y 1.68 kg para MLG utilizando HBF-306, BC-545 y HBF-514, respectivamente.
Discusión: La precisión de los dispositivos de BIA fue menor en comparación con otros estudios realizados en poblaciones generales, lo que sugiere que las características de los atletas pueden influir en la fiabilidad de estos dispositivos.
Conclusiones: HBF-306C mostró mayor variabilidad, mientras que HBF-514 demostró la mayor fiabilidad, siendo valioso para el seguimiento de la CC en futbolistas.

Palabras clave

Atleta; Composición corporal, grasa corporal, impedancia bioeléctrica, soccer.

Introduction

Body composition (BC), commonly evaluated to provide health-related information, is traditionally divided into two body components: fat mass (FM) and fat-free mass (FFM). In the context of sport, tracking BC is essential due to its significant relationship with physical performance (Roelofs et al., 2017; Borga et al., 2018; Citarella et al., 2021). In soccer players, BC has been associated with key performance factors such as flexibility, agility, and peak power in various physical trials (Figueiredo et al., 2020). Moreover, other authors have described distinct body profiles corresponding to different playing positions (Sutton et al., 2009; Ceballos-Gurrola et al., 2020). Accurate and precise BC assessments in soccer players can provide valuable information to guide training and nutritional strategies tailored to each position.

Although there are various methods for assessing BC, the most accurate and reliable options are often inaccessible to sport professionals due to their high cost, and these are primarily focused on research. Consequently, anthropometry and bioelectrical impedance analysis (BIA) are the preferred methods for regular BC assessment in athletes.

The BIA is commonly used to estimate BC within a two-compartment model. BIA works by measuring the body's hydroelectric properties, applying low-frequency electrical impulses to estimate total body water, which is then used to derive FFM through established hydration factors (Bossingham et al., 2005). However, BC methodologies have an inherent technical error of measurement, defined as the variation observed between two consecutive measurements under identical conditions. This variation is typically reported by manufacturers in the technical manuals of each device.

In addition to technical errors, the literature has defined a biological error of measurement, which is characterized by the variation in body measurements taken on consecutive days (Barlow et al., 2015; Kerr, et al., 2017; Zemski et al., 2019; Farley et al., 2021). BIA devices are particularly susceptible to this error due to the minor biological changes, which can be significant in populations with considerable water fluctuations, such as soccer players as their hydration practices are compromised by the nature of the sport in addition to the common exposure to adverse climatic condition (Benjamin et al., 2021). Therefore, it is crucial to establish these potential variations in BIA devices to ensure the accurate interpretation of longitudinal body assessments in these populations, especially in commercially available devices which are the most used by sport professionals on a daily basis.

The objective of this study was to evaluate the technical and biological measurement errors in the estimation of BC in male Mexican soccer players using commercial BIA devices.

Method

Participants

A quantitative, comparative, correlational cohort study was conducted using a convenience sampling method, including 31 male soccer players affiliated with the Club Tijuana Xoloitzcuintles de Caliente, from the U-19 and U-23 divisions. The participants had a mean age of 17.9 ± 1.67 years. All participants met the following inclusion criteria, 1) at least two years of experience in the sport, 2) physical training related to their sport for 1 to 3 hours daily, 3) no medical conditions affecting body water, 4) no body implants, and 5) having provided signed informed consent and assent. This study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics committee from the Nursing Department of the University of Sonora.

Procedure

Participants were scheduled into two separate visits at the anatomy laboratory from Universidad Vizcaya de las Americas in Hermosillo, Sonora, Mexico, to conduct body assessments. The procedures were as follows: During the first visit, participants arrived in the morning in a fasting state and refrained from physical training for at least 12 hours. Measurements were taken while participants were dressed in minimal clothing. The second visit occurred 24 hours later under the same conditions. To determine the technical and biological measurement errors of the BIA devices, a measurement schedule established in previous studies was followed (Kerr et al., 2017; Farley et al., 2021). Each participant underwent three times: the first measurement was taken during the first visit (D1M1), followed by a second measurement 30 minutes later (D1M2). Finally, the third measurement was performed during the second visit (D2M1).

Height (Ht) was collected during the first visit according to the guidelines of the International Society for the Advancement of Kinanthropometry (ISAK) using a stadiometer (SECA model 213-I, Hamburg, GER). In both visits, body weight (BW) was recorded by two BIA devices, FitScan BC-545 (TANITA corp., Tokyo, JPN) and HBF-514C (Omron corp., Kyoto, JPN). BW were used to estimate body fat percentage (BF) and then FFM was calculated. For the estimation of BF using OMRON HBF-306C (Omron corp., Kyoto, JPN), BW from OMRON HBF-514 was used as the first device is incapable of taking this measure. These devices were selected by their low cost and availability in the market and have been studied in previous studies (Siedler et al., 2021, 2023).

Data analysis

The general characteristics of the participants are reported as mean and standard deviation (SD). Normality of the variables was confirmed using the Shapiro-Wilk test. A one-way repeated measures ANOVA was employed to identify significant differences between inter-device and intra-device estimations. To determine the technical error, the coefficient of variation (CV) and the root mean square error (RMSE) between the values of D1M1 vs. D1M2 (test-retest) and D1M1 vs. D2M1 (day-to-day) were calculated. Biological errors were evaluated by the least significant change (LSC) according to other studies (Siedler et al., 2023). To assess bias between D1M1 and D2M1, a Bland-Altman analysis was performed (Bland & Altman, 1986). A significant level of 0.05 was set. Graphs were developed using Prism v.8 (GraphPad Software, Massachusetts, USA) and SPSS Statistics V.26.0 (IBM, New York, USA).

Results

A total of 27 players from the 31 initially recruited were included in the final analysis. Four players were excluded from the original sample as they did not complete the second visit due to scheduling conflicts with their training. The final sample had a mean Ht of 174.0 ± 5.29 cm. General BC characteristics are presented in Table 1.

The comparison of BC estimations across devices showed that HBF-514C resulted in statistically lower values of FFM compared to the other devices ($p<0.05$). No significant differences in BW or BF between devices were observed ($p>0.05$). One-Way repeated measures ANOVA showed significant difference in BF between D2M1 and D1M1 and D1M2 but only for BC-545 ($p<0.05$). No other statistical differences in BC estimations were observed across the different measure times.

Table 1. Body composition characteristics of the participants measured by the different BIA devices.

	D1M1	D1M2	D2M1
		HBF-306	
BW (kg)	--	--	--
BF (%)	15.7 ± 6.18	15.8 ± 6.14	15.3 ± 5.98
FFM (kg)	57.5 ± 5.81	57.4 ± 5.85	57.0 ± 5.78
		BC-545	
BW (kg)	68.6 ± 8.27	68.6 ± 8.21	68.4 ± 8.16
BF (%)	16.2 ± 5.51	16.4 ± 5.58	15.6 ± 5.37*, †
FFM (kg)	57.3 ± 6.09	57.1 ± 6.13	57.6 ± 5.96
		HBF-514	
BW (kg)	67.9 ± 8.21	67.8 ± 8.20	67.5 ± 7.86
BF (%)	17.3 ± 5.89	67.8 ± 5.90	17.0 ± 5.58
FFM (kg)	55.8 ± 4.94§, ‡	55.7 ± 5.09	55.8 ± 4.97

BW: body weight; BF: body fat; FFM: fat-free mass.
Data presented in mean ± S.D.
* $p<0.05$ statistical difference from D1M1
† $p<0.05$ statistical difference from D1M2
§ $p<0.05$ statistical difference from HBF-306
‡ $p<0.05$ statistical difference from BC-545

Reliability analysis results are presented in Table 2. HBF-306 exhibited the highest technical error across all evaluated metrics. Although the reliability metrics for the BC-545 and HBF-514 were quite similar, BC-545 resulted in better reliability in test-retest measurements. However, BW measurements were more consistent in HBF-514.

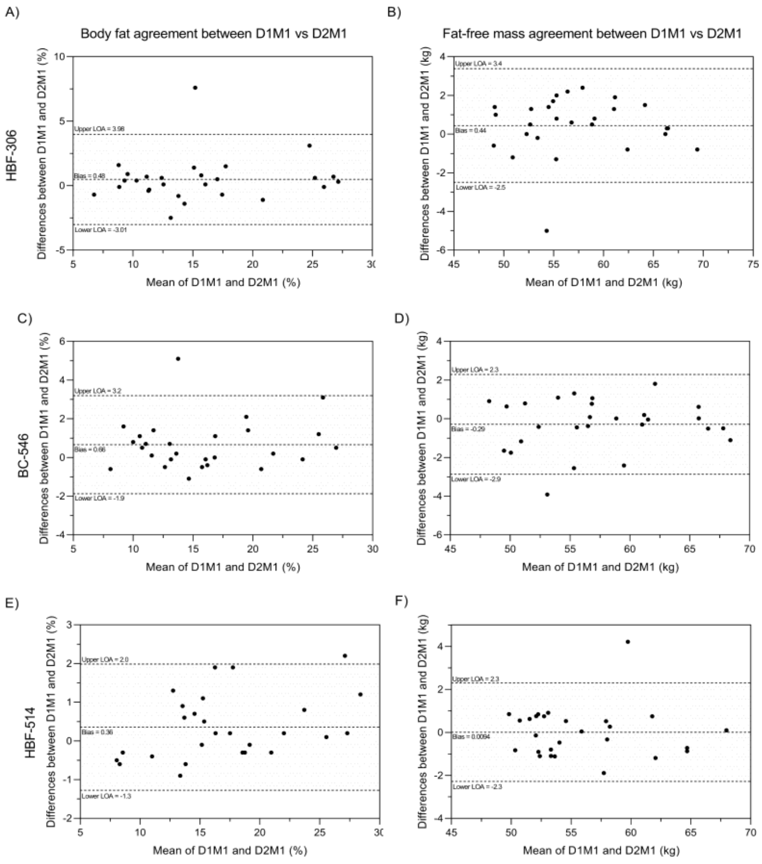
Table 2. Technical and biological errors of the different BIA devices.

	Technical error (D1M1 vs D1M2)				Biological error (D1M1 vs D2M1)			
	RMSE	%CV	LSC	ICC	RMSE	%CV	LSC	ICC
HBF-306								
BW (kg)	--	--	--	--	--	--	--	--
BF (%)	0.66	4.63	0.36	0.98	0.77	5.36	2.13	0.97
FFM (kg)	0.52	0.92	1.43	0.98	0.85	1.52	2.36	0.98
BC-545								
BW (kg)	0.13	0.19	0.37	1.00	0.54	0.81	1.49	0.99
BF (%)	0.36	2.23	1.01	0.99	0.68	4.63	1.87	0.98
FFM (kg)	0.24	0.42	0.66	0.99	0.69	1.25	1.92	0.98
HBF-514								
BW (kg)	0.12	0.18	0.32	1.00	0.67	1.00	1.86	0.99
BF (%)	0.42	2.46	1.17	0.98	0.48	3.05	1.33	0.99
FFM (kg)	0.26	0.48	0.73	0.99	0.61	0.48	1.68	0.98

BW: body weight; BF: body fat; FFM: fat-free mass; RMSE: Root means square error; CV: coefficient of variation; LSC: Least significant change; ICC: Intraclass correlation coefficient.

Regarding biological errors, HBF-306 exhibited the greatest variability. It is worth mentioning that BC-545 and HBF-514 showed similar reliability in day-to-day measurements, although both devices showed good overall reliability. Bias and limit of agreement (LOAs) according to Bland-Altman analysis between D1M1 and D2M1 are illustrated in figure 1. None of the devices showed significant bias (p>0.05). HBF-306 had the widest LOAs among devices, while HBF-514 showed slightly narrower LOAs compared to BC-545.

Figure 1. Bland-Altman analysis between D1M1 and D2M1 from the different devices.



Source: Own elaboration.

Discussion

The main purpose of the present study was to evaluate the reliability of three different popular commercial BIA devices in male Mexican soccer players by exploring different reliability metrics to evaluate the capacity of each device to provide accurate longitudinal data. Subjects from soccer were selected due to compromised hydration practices seen in this population (Benjamin et al., 2021). As mentioned, BIA works through body fluids and hydration status fluctuation may affect assessment, this highlights the relevance in defining BIA measurements errors in this population.

For technical errors, all devices showed only trivial differences between test-retest measurements, although these were not significant. This is expected since every method has some inherent error related to repositioning, clothing and equipment calibration (Farley et al., 2021). However, these errors can vary across different populations and devices (Hangartner et al., 2013) and understanding these variations can offer valuable insights for tracking longitudinal data and developing appropriate nutritional or training strategies. Regarding biological errors, only BF measurements from the BC-545 device showed statistical differences in day-to-day measurements. It is important to note that mean comparison testing primarily detects mean group differences, potentially masking individual differences (Atkinson & Nevill, 1998). In this context, these results suggest that these devices may be useful for tracking BC in groups of subjects, as biological fluctuations in water and weight may not significantly affect the precision of the devices, except for the BC-545 which seems to be more sensible to these changes.

While the capacity of a BC method to provide reliable measurements in a group of athletes, individual BC tracking is crucial. Individual BC variations can be better understood by considering some of the parameters reported in Table 2. All devices showed high ICC (>97), with the HBF-306 showing the lowest BF in day-to-day measurement. The ICC levels of all devices are considered optimal in test-retest studies according to some authors (Atkinson & Nevill, 1998). Additionally, these authors suggest that reliability can be analyzed more accurately by observing parameters such as RMSE and CV. HBF-306 exhibited more variability than other devices. The body component with the greatest variability across all devices was BF, with the HBF-306 reaching a CV of up to 4.63%, while other devices maintained a CV of less than 3% for both BF and FFM. Although there are no definitive cut-off points for CV in test-retest analysis, the interpretation of CV should consider the nature of the variable analyzed and the clinical implications of those variations. As expected, variability in day-to-day assessment increases, with HBF-514 displaying the most consistent metrics. BC-545 yielded the lowest RMSE values among all devices in test-retest measures, while the HBF-306 resulted in higher values.

Differences in the reliability of BIA devices may be attributed to several factors, including the number of electrodes and the measurements protocol. HBF-306 uses a hand-to-hand (tetrapolar) protocol, while other devices use a hands-to-feet (octopolar) protocol. More electrodes may increase the accuracy and precision of BIA devices in detecting fluctuations in current conductivity, as greater consistency was seen in hands-to-feet devices. Although, this finding is supported by other studies, which indicate that hands-to-feet devices showed higher reliability, these authors support that some BIA estimative models incorporate algorithms to reduced variability across multiple consecutive readings for the same registered user (Merrigan et al., 2022; Siedler et al., 2023). In the current study, BIA devices were programed in the “guest mode” thus we considered that the reliability observed in the current results may be “real” considering that D1M2 were within 30-40 min apart from D1M1.

Studies evaluating reliability of commercial BC devices are limited, as most studies have focused on laboratory methods such dual energy X-ray absorptiometry, magnetic resonance imaging, or more sophisticated BIA devices. Siedler et al. (2023) reported the reliability from 15 BIA devices in healthy adults including males and females, including some BIA models evaluated in the current study. They reported RMSE values of 0.37 % and 0.33 % for BF in HBF-306 and HBF-516, respectively. It is worth mentioning that Siedler et al. (2023) found a higher ICC (1.00) than the observed in our results. Previously, same authors reported RMSE values of 0.6%, 0.4 kg and 0.6 kg for BF, FM and FFM, respectively (Siedler et al., 2021), which were lower than those found in the current study for all metrics.

Even though the sample in Siedler et al.’s study is focused on general population and included a wide age range (18 to 50 years of age), we hypothesize that certain boy characteristics, such as adiposity, may influence BIA principles and affect reliability. Participants in our study were taller and heavier than

Siedler et al.'s report, and their BF was around 25.9% (Siedler et al., 2023), considering the average across all devices included, while our subjects had an average BF of 16.4% (average from the three devices). Different levels of BF may affect BIA conductivity, potentially influencing reliability. Further research is needed to explore how different BF levels impact reliability.

In another study, Leonneke et al. (2013) reported a day-to-day ICC of 0.937 for BF using HBF-306 on college students, lower than our results, while minimal differences to considered real was close to 3% for BF. Tinsley et al. (2022) reported an ICC of 0.99, a CV of 2.05% and a RMSE of 0.30 for BF using a single-frequency BIA on general population. These values are similar to those found in our study for BC-545, which also works on a single-frequency current. Even though some similarities were observed comparing our findings with other studies, caution is advised due to the differences in the BIA device used in Tinsley et al. (2022). We suggest that differences in reliability between studies may be primarily explained by variations in the populations studied. To our knowledge, no other studies have evaluated reliability metrics on commercial BIA devices in soccer players. Future studies that group participants by BC characteristics could clarify whether reliability is dependent on the subject's BC.

Recent research has introduced the concept of LSC as a metric to establish the minimal change that evaluators may observe for it to be considered real and not attributable to inherent device error. While this metric has commonly been used to analyze changes in bone variables (Nelson et al., 2010), it has been extrapolated to other body components. In this context, the devices in the current study showed a LSC ranged from 1.33% to 2.13% for BF and 1.68 kg to 2.36 kg for FFM, depending on the device. The HBF-514 exhibited the lowest LSC in day-to-day assessment for both BF and FFM, suggesting the most reliable device for longitudinal assessments. Other studies have reported LSC values up to ~1.30% for BF in commercial BIA devices (Siedler et al., 2023). Specifically, for the HBF-306, LSC values of less than 1.5% for BF and 1.6 kg for FFM have been reported (Siedler et al., 2021, 2023), which are considerably lower than those observed in the present study. Other authors have reported an LSC of ~4.0% for the same devices (Loenneke et al., 2013). To our knowledge, there are no other reports of LSC for the remaining devices evaluated in the current study.

It is well known that BIA devices require some subject preparations. Many authors have reported some standardization conditions to ensure reliable assessments (Kerr et al., 2017; Hume et al., 2018; Tinsley et al., 2022). Understanding the application of reliability metrics is crucial for accurate longitudinal evaluation, especially regarding the LSC. As previously mentioned, the LSC represents the minimum change that must be exceeded for it to be considered a true change. For example, for a player needing body recomposition based on their playing position, the HBF-514, which provides an LSC of 1.68 kg for FFM in day-to-day measurements, suggests that the athlete must gain or lose more than this amount through nutrition, training, or other interventions to achieve a meaningful impact on BC. For an 80 kg athlete, gaining this amount of FFM would require a combination of resistance/strength training and hypercaloric, high-protein diet. It is established that gaining FFM during a lean phase requires a calorie surplus of approximately 200 to 500 kcal, resulting in an average weekly gain of ~0.5 kg (Iraki et al., 2019). This implies that that BIA devices would detect real BC changes after about three weeks of a consistent nutrition and training program, assuming that all weight gained is attributable to FFM. Conducting assessments too often, without allowing sufficient time for detectable changes, may lead to misinterpretation of BC evaluations. This could result in unnecessary adjustments to diet and training, potentially prolonging an unwarranted calorie deficit or surplus.

Limitations and further recommendations

The primary limitation of this study is the limited number of devices evaluated. While few studies have assessed the reliability of commercially available BIA devices, those that do typically include a wider range of models and brands. Considering the vast number of options on the market, it is essential to evaluate more devices to provide sports professionals with a more comprehensive understanding of each device's strengths and limitations.

Additionally, caution should be taken when comparing the present results with those of other studies, given differences in the populations studied. Fluid fluctuations, common among athletes such as soccer players, can affect BIA reliability, and technical and biological measurement errors observed in the general population may differ from those in athletes.

Lastly, based on the variability in precision reported by other authors, we hypothesize that BC itself may influence the reliability of these devices. Future research should focus on examining reliability across different sports, body fat ranges and population characteristics to better understand how variations in BC may affect the accuracy and precision of BIA devices.

Conclusions

Technical and biological errors of measurements varied across the different devices mainly between tetrapolar and octopolar protocols.

All devices showed acceptable reliability for group-based assessments, particularly in body fat percentage. However, for individual reliability, the HBF-306 showed greater variability compared to the other devices. The HBF-514 was the most consistent device in day-to-day reliability.

Day-to-day variations increased, highlighting the impact of daily fluid fluctuations on BC estimations. Dietitians and trainers should account for these variations to ensure accurate BC tracking and informed decision-making in nutrition and training for soccer players. Further research is needed to assess whether varying body fat levels influence the reliability of BIA devices. Additionally, studies should consider including a broader range of BIA devices and exploring their application across different sports.

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Declaration of Artificial Intelligence Usage

Artificial intelligence, specifically the ChatGPT web application, was used in the drafting of this document with the aim of improving the writing and grammar of the English language.

References

Atkinson, G., & Nevill, A. M. (1998). Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Medicine*, 26(4), 217–238. https://doi.org/10.2165/00007256-199826040-00002

Barlow, M. J., Oldroyd, B., Smith, D., Lees, M. J., Brightmore, A., Till, K., Jones, B., & Hind, K. (2015). Precision error in dual-energy x-ray absorptiometry body composition measurements in elite male rugby league players. *Journal of Clinical Densitometry,* 18(4), 546–550. https://doi.org/10.1016/j.jocd.2015.04.008

Benjamin, C. L., Sekiguchi, Y., Morrissey, M. C., Butler, C. R., Filep, E. M., Stearns, R. L., & Casa, D. J. (2021). The effects of hydration status and ice-water dousing on physiological and performance indices during a simulated soccer match in the heat. *Journal of Science and Medicine in Sport*, 24(8), 723–728. https://doi.org/10.1016/j.jsams.2021.05.013

Bland, J. M., & Altman, D. G. (1986). Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*, 1(8476), 307–310.

Borga, M., West, J., Bell, J. D., Harvey, N. C., Romu, T., Heymsfield, S. B., & Leinhard, O. D. (2018). Advanced body composition assessment: from body mass index to body composition profiling. *Journal of Investigative Medicine*, 66(5), 887–8895. https://doi.org/10.1136/jim-2018-000722

Bossingham, M. J., Carnell, N. S., & Campbell, W. W. (2005). Water balance, hydration status, and fat-free mass hydration in younger and older adults. *American Journal of Clinical Nutrition*, 81(6), 1342–1350. https://doi.org/10.1093/ajcn/81.6.1342

Ceballos-Gurrola, O., Bernal-Reyes, F., Jardón-Rosas, M., Enríquez-Reyna, M. C., Durazo-Quiroz, J., & Ramírez-Siqueiros, M. G. (2020). Composición corporal y rendimiento físico de jugadores de fútbol soccer universitario por posición de juego. *Retos*, 39, 52–57. https://doi.org/10.47197/retos.v0i39.75075

Citarella, R., Itani, L., Intini, V., Zucchinali, G., Scevaroli, S., Tannir, H., El Masri, D., Kreidieh, D., & El Ghoch, M. (2021). Association between dietary practice, body composition, training volume and sport performance in 100-Km elite ultramarathon runners. *Clinical Nutrition ESPEN*, 42, 239–243. https://doi.org/10.1016/j.clnesp.2021.01.029

Farley, A., Slater, G. J., & Hind, K. (2021). Short-term precision error of body composition assessment methods in resistance-trained male athletes. *International Journal of Sport Nutrition and Exercise Metabolism*, 31(1), 55–65. https://doi.org/10.1123/IJSNEM.2020-0061

Figueiredo, D. H., Dourado, A. C., Stanganelli, L. C. R., & Gonçalves, H. R. (2020). Evaluation of body composition and its relationship with physical fitness in professional soccer players at the beginning of pre-season. *Retos*, 40, 117–125. https://doi.org/10.47197/retos.v1i40.82863

Hangartner, T. N., Warner, S., Braillon, P., Jankowski, L., & Shepherd, J. (2013). The official positions of the international society for clinical densitometry: acquisition of dual-energy x-ray absorptiometry body composition and considerations regarding analysis and repeatability of measures. *Journal of Clinical Densitometry*, 16(4), 520–536. https://doi.org/10.1016/j.jocd.2013.08.007

Hume, P. A., Kerr, D. A., & Ackland, T. R. (2018). Best practice protocols for physique assessment in sport. *Springer Singapore*. https://doi.org/10.1007/978-981-10-5418-1

Iraki, J., Fitschen, P., Espinar, S., & Helms, E. (2019). Nutrition recommendations for bodybuilders in the off-season: a narrative review. *Sports*. MDPI. https://doi.org/10.3390/sports7070154

Kerr, A., Slater, G. J., & Byrne, N. (2017). Impact of food and fluid intake on technical and biological measurement error in body composition assessment methods in athletes. *British Journal of Nutrition*, 117(4), 591–601. https://doi.org/10.1017/S0007114517000551

Loenneke, J. P., Barnes, J. T., Wilson, J. M., Lowery, R. P., Isaacs, M. N., & Pujol, T. J. (2013). Reliability of field methods for estimating body fat. *Clinical Physiology and Functional Imaging*, 33(5), 405–408. https://doi.org/10.1111/cpf.12045

Merrigan, J., Stute, N., Eckerle, J., Mackowski, N., Walters, J., O'Connor, M., Barrett, K., Robert, R., Strang, A., & Hagen, J. (2022). Reliability and validity of contemporary bioelectrical impedance analysis devices for body composition assessment. *Journal of Exercise and Nutrition*, 5(4). https://doi.org/10.53520/jen2022.103133

Nelson, L., Gulenchyn, K. Y., Atthey, M., & Webber, C. E. (2010). Is a fixed value for the least significant change appropriate? *Journal of Clinical Densitometry*, 13(1), 18–23. https://doi.org/10.1016/j.jocd.2009.10.001

Roelofs, E. J., Smith-Ryan, A. E., Trexler, E. T., & Hirsch, K. R. (2017). Seasonal effects on body composition, muscle characteristics, and performance of collegiate swimmers and divers. *Journal of Athletic Training*, 52(1), 45–50. https://doi.org/10.4085/1062-6050-51.12.26

Siedler, M. R., Harty, P. S., Stratton, M. T., Rodriguez, C., Keith, D., Green, J., Boykin, J., White, S., Williams, A., Dehaven, B., & Tinsley, G. M. (2021). Day-to-day precision error and least significant change for two commonly used bioelectrical impedance analysis devices. *International Journal of Exercise Science: Conference Proceedings*, 2(13).

Siedler, M. R., Rodriguez, C., Stratton, M. T., Harty, P. S., Keith, D. S., Green, J. J., Boykin, J. R., White, S. J., Williams, A. D., Dehaven, B., & Tinsley, G. M. (2023). Assessing the reliability and cross-sectional and longitudinal validity of fifteen bioelectrical impedance analysis devices. *British Journal of Nutrition*, 130(5), 827–840. https://doi.org/10.1017/S0007114522003749

Sutton, L., Scott, M., Wallace, J., & Reilly, T. (2009). Body composition of English premier league soccer players: influence of playing position, international status, and ethnicity. *Journal of Sports Sciences*, 27(10), 1019–1026. https://doi.org/10.1080/02640410903030305

Tinsley, G. M., Harty, P. S., Stratton, M. T., Smith, R. W., Rodriguez, C., & Siedler, M. R. (2022). Tracking changes in body composition: comparison of methods and influence of pre-assessment standardization. *British Journal of Nutrition*, 127(11), 1656–1674. https://doi.org/10.1017/S0007114521002579

Zemski, A. J., Hind, K., Keating, S. E., Broad, E. M., Marsh, D. J., & Slater, G. J. (2019). Same-day vs consecutive-day precision error of dual-energy x-ray absorptiometry for interpreting body composition change in resistance-trained athletes. *Journal of Clinical Densitometry*, 22(1), 104–114. https://doi.org/10.1016/j.jocd.2018.10.005

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