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Body Composition Classification with Electrical Bioimpedance in Chilean Military by Sex

Clasificación de la Composición Corporal con Bioimpedancia Eléctrica en Militares Chilenos por Sexo

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SUMMARY: Military readiness relies heavily on the physical fitness and operational capability of its personnel. This study aims to enhance the effectiveness of body composition assessment and classification protocols within the military context. A comprehensive evaluation of 4370 active-duty Chilean military personnel was conducted, focusing on anthropometric characteristics, including adipose tissue, muscle tissue, and anthropometric indices. The study observed significant differences in body composition between genders, with men exhibiting lower levels of body fat percentage (men: 26.28 %; women: 34.62 %) but higher levels of muscle mass (men: 42.0 %; women: 36.0 %;), skeletal muscle index (men:11.81; women: 9.31), and fat-free mass index (men: 19.92; women: 18.45) compared to women. High levels of muscle tissue were observed in both groups. By integrating these findings into a standardized assessment protocol, a more accurate classification of military personnel was achieved, surpassing traditional methods used in sedentary obese populations. The study advocates the future adoption of an assessment model based on artificial intelligence (AI) algorithms, which consider the multifaceted nature of body composition and its impact on operational capability. Such a model would enable military forces to optimize their personnel's physical fitness and readiness, thus enhancing their effectiveness in deployment operations.

KEY WORDS: Military readiness; Body composition assessment; Anthropometric characteristics; Gender differences; Operational capability.

INTRODUCTION

The body composition and physical fitness of military personnel are perennially significant topics for research, as the defense and security level of individuals and material assets in a specific territory largely depend on the military skill level (Hormeño-Holgado *et al*., 2019). However, members of the armed forces constitute a heterogeneous group, marked by diverse abilities and characteristics, but also by daily needs, and the trend towards changing body composition and decreasing physical condition presents a current challenge that has not been overlooked in this population (Popovic *et al*., 2020). Historically, the classification of military body composition worldwide has been based on the exclusive assessment of adipose tissue, without considering other relevant indicators such as muscle tissue, a principal component for the development of operational activities (Bustamante-Sánchez *et al*., 2022). In this regard, it is pertinent to acknowledge that both high and low levels of adipose and muscle tissue are health risk factors (Sammito *et al*., 2021), hence guidelines for anthropometric evaluation should consider the assessment and interaction

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of both components for an optimal classification of military personnel. In the current political and social context, it is imperative for individuals in the armed forces to be in good physical shape to successfully engage in vocational activities requiring high levels of occupational fitness and operational aptitude (Sanderson *et al*., 2018). A high level of physical fitness and optimal body composition, combined with the required occupational skills, are crucial factors for success in an operational and deployed military environment (Pihlainen *et al*., 2023). Furthermore, it has been reported that a lower amount of fat mass and a higher muscle mass are associated with better occupational performance for various military tasks (Pihlainen *et al*., 2018). It is also important to note that the operative requirement of different military groups need a specific body composition, and its analysis is an efficient tool to maintain operative performance in actual units (Bustamante-Sánchez & Clemente-Suárez, 2020). Body composition is an indicator of health and is classified as one of the five components of physical fitness; it also has implications for military operational capacity, with negative effects of adipose tissue on strength, cardiorespiratory endurance, and speed being identified (Knihs *et al*., 2018) It has been shown that body composition variables are associated with many physical performance outcomes, including aerobic capacity, muscular endurance, strength and power output, and specialized occupational tasks involving heavy lifting and load carriage (Harty *et al*., 2022). Although all these attributes are significant, individuals aiming to enhance military performance should consider prioritizing strength, hypertrophy, and power production as the primary training goals, as these traits are deemed crucial for success in the new Army Combat Fitness Test introduced in 2020 (Harty *et al*., 2022). Along this line, it was also highlighted to take into consideration symmetry in body composition to avoid injuries and maintain operational performance, especially in military position where asymmetrical muscular performance is necessary (Curiel-Regueros *et al*., 2022). Various methods can be utilized to assess body composition, including anthropometry; bioelectrical impedance; and more precise techniques, such as potassium-40 counting, water iso-tope dilution, underwater weighing, imaging techniques, and dual-energy X-ray absorptiometry (DXA) (Heymsfield *et al*., 2015). Due to their high suitability and low cost, anthropometric techniques are the most widely used in many fields of application, including routine military practice (Gobbo *et al*., 2022). However, some of these methods are not very accurate in detecting the main body compartments. Thus, given the large number of individuals in the world's armies, there is a need for faster and more cost-effective field methods for assessment in military settings. Skinfold measurements (SKF) and bioelectrical impedance analysis (BIA) could be two alternative field methods for use in soldiers (Aandstad *et al*., 2014). The BIA method uses either a single-frequency bioelectrical impedance analysis instrument (SF-BIA) or a multi-frequency bioelectrical impedance analysis instrument (MF-BIA) to measure body composition (Ellis *et al*., 1999). Muscle tissue is one of the body composition parameters that is closely related to insulin sensitivity and is associated with metabolic disorders (Rubio-Ruiz *et al*., 2019). Moreover, it has a positive impact on health and military operational performance, and for its assessment, different indices such as the skeletal muscle index (SMI) and the fat-free mass index (FFMI) have been developed, which have been validated using DXA or bioelectrical impedance (Rubio-Ruiz *et al*., 2019).

The Skeletal Muscle Index (SMI) is a measure of relative muscle mass. This method utilizes appendicular lean mass or muscle mass index adjusted for body size in various ways, for instance, using height squared, weight, or BMI (Cruz-Jentoft *et al*., 2019). A deficit in muscle mass is associated with reduced functional capacity and physical frailty (Cruz-Jentoft *et al*., 2019). Furthermore, recent studies have suggested a link between muscle mass deficit and cardiometabolic risk factors such as type 2 diabetes, hypertension, and metabolic syndrome (Zhang *et al*., 2018). The association of SMI with the metabolic phenotype of individuals with normal weight and with overweight/obesity remains uncertain; however, recent studies indicate that in adults, muscle mass assessed from the weight-adjusted skeletal muscle index and body mass index is inversely associated with metabolic syndrome in both sexes (Carvalho *et al*., 2021).

The main objective of this study was to evaluate the effectiveness of standardized body composition assessment protocols in the military, incorporating a holistic approach that considers the interaction between anthropometric characteristics, operational capability, and deployment operations. We hypothesize that a comprehensive body composition assessment protocol, which includes the evaluation of adipose tissue, muscle tissue, and anthropometric indices, will provide a more ac-curate classification of military personnel compared to traditional methods. This improved classification system, would better reflect the physical fitness and operational readiness of military personnel, facilitating targeted interventions to en-hance performance and reduce the risk of injury.

MATERIAL AND METHOD

Participants. To reach the study aim a non-experimental, cross-sectional, comparative, and associative study was performed. A total of 4370 active-duty Chilean military personnel participated, of which 3409 were men (35.6 ± 8.62 years) and 961 were women (26.4 ± 6.99 years). At the time of the assessment, all were physically inactive based on the World Health Organization's recommendations (Bull *et al*., 2020). All participants were healthy and engaged in regular service activities. Inclusion criteria were graduates from their training process in military academies, with no chronic non-communicable diseases. Exclusion criteria included physically active military personnel, military personnel with operational specialization courses (commandos, combat pilots, tactical divers, mountain warfare, etc.), participation in military specialization courses (special forces, tactical diving, mountain warfare, parachuting, etc.) at the time of evaluations, light duty excluding service activities, and being over 50 years of age.

Material and Procedures. The evaluations were carried out by higher-level nursing technicians at a hospital serving several military units. The evaluators were previously trained in the use of BIA. All participants were informed of the procedure prior to conducting the evaluations.

Bioelectrical Impedance. The assessments were conducted in a heated environment with an average temperature of 20°C and an approximate relative air humidity of 70 %. 48 hours prior to the assessment, participants refrained from exercising, consuming alcohol, or taking diuretic medications. The evaluation was performed after fasting for at least 4 hours and following urinary and gastric emptying. The assessments were carried out in a standing position, in underwear and barefoot, with jewelry and accessories such as watches removed. The assessment areas and electrodes were previously cleaned with 70 % isopropyl alcohol according to the hospital healthcare staff's recommendations (Yáñez-Sepúlveda *et al*., 2022). A portable stadiometer (model 213, SECA®), accurate to 0.5 cm, was used to measure height. To identify anthropometric characteristics, an octopolar multi-frequency electrical bioimpedance (20 to 100 kHz) model 270 from Inbody(r) was used; this instrument has been previously validated for the assessment of body composition in military personnel (Aandstad *et al*., 2014). All variables were extracted using the Lookin Body Software program (Inbody®). The data obtained included body weight (kg), height (m), BMI (weight/height2), adipose tissue (% and kg), muscle tissue (% and kg), fat-free mass (kg), TBW: Total Body Water; BFM: Body Fat Mass; FFM: Fat-Free Mass; SMM: Skeletal Muscle Mass; MM: Muscle Mass; BF: Body Fat; WHR: Waist Hip Ratio; SMI: Skeletal Muscle Index; FMI: Fat Mass Index; FFMI: Fat-Free Mass Index; BMR: Basal Metabolic Rate. The classification of nutritional status was based on the guidelines of Harty *et al*. (2022)

Anthropometric Indices. The following indices were used to describe the anthropometric characteristics of the participants.

Body Mass Index (BMI). The body mass index was obtained from dividing the body weight (kg) by the square of the height (m) - (weight/height2) (Quetelet, 1869).

Skeletal Muscle Index (SMI). The absolute muscle mass (kg) was normalized for height (muscle mass (kg)/height (m)2) to calculate the Skeletal Muscle Index (SMI) (Janssen *et al*., 2024)

Fat Mass Index (FMI). The FMI was calculated by dividing each subject's fat mass (kg) by their height squared (m) (fat/height2) (Liu *et al*., 2013).

Fat-Free Mass Index (FFMI). The fat-free mass index was calculated using the following formula: (fat-free mass, in kg) x (height, in meters (m))2, then a correction of 6.3 x (height in m - actual height) was applied (Kouri *et al*., 1995).

Ethical Considerations. Before the evaluations, all participants signed an informed consent form indicating their voluntary participation in the study. The objectives and procedures of the study were explained to them prior to measurement. All evaluations were conducted in accordance with the ethical guidelines of the Declaration of Helsinki for studies on human beings (World Medical Association, 2013). To ensure the participants safety, the International Ethical Guidelines for Biomedical Research In-volving Human Subjects (Nilstun, 1994) were also considered. The evaluation protocols were approved by the Scientific Ethics Committee of the Universidad Viña del Mar (Code R62-19a). The data from all study participants were stored on the principal investigator's computer, accessed through a password and fingerprint.

Statistical Analyses. The data obtained were presented in tables as mean and standard deviation, and contingency tables were also used to classify participants, with the tables distributed by sex among women and men. To compare differences by sex, a Kolmogorov- Smirnov normality test was applied, followed by an ANOVA with Bonferroni post hoc. The effect size of the differences between groups was then calculated using Cohen's d test, classified as follows: no effect (<0.2), small (>0.2 to 0.5), medium (>0.5 to 0.8), and large (≥ 0.8) (Cohen, 1988). A p-value <0.05 was considered statistically significant. The analysis was performed using JAMOVI® software version 23.1.1 for Windows®. The results are detailed below.

RESULTS

Table I shows the descriptive statistics of the study variables. In the comparison by sex, differences were observed in all variables except for BFM of Trunk (kg)

Table I. Anthropometric characteristics of the military group by sex.

Variable	Men (n=3409)				Women (n=961)				All (n=4370)					
	Mean	SD	95%CI		Mean	SD	95%CI		Mean	SD	95%CI		p	ES
			Lower	*Upper*			*Lower*	*Upper*			*Lower*	*Upper*		
Height (cm)	173.9	6.04	173.7	174.1	161.8	5.29	161.4	162.1	171.2	7.74	171.0	171.5	< .001	0.872
Weight (kg)	85.8	11.62	85.4	86.2	68.4	9.86	67.8	69.0	81.9	13.36	81.5	82.3	< .001	0.751
TBW (l)	45.93	4.86	45.76	46.09	32.41	3.69	32.18	32.64	42.95	7.26	42.74	43.17	< .001	0.972
BFM (kg)	23.05	8.45	22.77	23.34	24.08	7.12	23.63	24.53	23.28	8.19	23.04	23.52	< .001	0.096
FFM (kg)	62.75	6.69	62.52	62.97	44.33	5.07	44.01	44.65	58.70	9.94	58.41	58.99	< .001	0.970
SMM (Kg)	35.77	4.01	35.63	35.90	24.44	3.08	24.25	24.64	33.27	6.05	33.10	33.45	< .001	0.972
BMI (Weight/Height^2)	28.34	3.42	28.22	28.45	26.09	3.29	25.89	26.30	27.84	3.51	27.74	27.95	< .001	0.363
MM (%)	42.0	4.09	41.9	42.1	36.0	3.68	35.8	36.2	40.7	4.71	40.5	40.8	< .001	1.50
BF (%)	26.28	7.04	26.05	26.52	34.62	6.52	34.21	35.03	28.12	7.74	27.89	28.35	< .001	0.615
WHR (cm)	0.950	0.07	0.948	0.953	0.918	0.07	0.914	0.922	0.943	0.07	0.941	0.946	< .001	0.259
SMI	11.81	0.91	11.66	11.80	9.31	0.84	9.26	9.26	11.3	1.37	11.21	11.34	< .001	0.956
FMI	7.64	2.82	7.54	7.73	9.20	2.70	9.03	9.37	7.98	2.87	7.90	8.07	< .001	0.327
FFMI	19.92	0.78	19.90	19.95	18.45	0.61	18.41	18.49	19.60	0.96	19.57	19.63	< .001	0.878
BMR (Kcal)	1.725	144.65	1.720	1.730	1.326	109.97	1.319	1.333	1.638	214.74	1.631	1.644	< .001	0.970
FFM of Right Arm (kg)	3.69	0.46	3.67	3.70	2.31	0.38	2.29	2.34	3.39	0.72	3.36	3.41	< .001	0.971
FFM of Left Arm (kg)	3.64	0.46	3.63	3.66	2.29	0.37	2.27	2.32	3.35	0.71	3.33	3.37	< .001	0.969
FFM of Trunk (kg)	28.53	2.76	28.43	28.62	20.34	2.35	20.19	20.49	26.73	4.32	26.60	26.86	< .001	0.969
FFM of Right Leg (kg)	9.55	1.09	9.51	9.58	6.78	0.86	6.73	6.84	8.94	1.55	8.89	8.98	< .001	0.958
FFM of Left Leg (kg)	9.45	1.06	9.42	9.49	6.76	0.84	6.70	6.81	8.86	1.51	8.82	8.91	< .001	0.958
BFM of Right Arm (kg)	1.47	0.87	1.44	1.50	1.74	0.71	1.69	1.78	1.53	0.85	1.50	1.55	< .001	0.246
BFM of Left Arm (kg)	1.50	0.88	1.47	1.53	1.75	0.72	1.71	1.80	1.55	0.85	1.53	1.58	< .001	0.238
BFM of Trunk (kg)	12.54	4.60	12.39	12.70	12.28	3.77	12.04	12.52	12.48	4.43	12.35	12.62	0.310	0.021
BFM of Right Leg (kg)	3.13	1.02	3.10	3.16	3.57	0.94	3.51	3.63	3.23	1.02	3.20	3.26	< .001	0.268
BFM of Left Leg (kg)	3.10	1.01	3.06	3.13	3.56	0.93	3.50	3.62	3.20	1.01	3.17	3.23	< .001	0.279

TBW: Total body wáter; BFM: Body fat mass; FFM: Fat free mass; SMM: Skeletal muscle mass; MM:Muscle mass; BF: Body Fat; WHR: Waist Hip Ratio; SMI: Skeletal muscle index; FMI: Fat mass index; FFMI: fat free mass index; BMR: Basal Metabolic Rate.

(p=0.310). Men had lower levels of fat percentage (BF(%)) than women (26.28 % and 34.62 %; p<0.001), men also had higher levels of muscle tissue (MM %) (42.0 % and 36.0 %; p<0.001), SMI (42.0 % and 36.0 %; p<0.001), FFMI (19.42 and 18.45; p<0.001). Differences in variables by sex are also observed.

In Table II, the classification of adipose and muscle tissue in Chilean military personnel by sex is presented. According to the results, 39.6 % of men have a very high level of adipose tissue (TAD), 21.7 % moderate, and 38.7 % normal. In women, 29.0 % have a very high level of TAD, 26.1 % moderate, and 44.9 % normal. For total TAD, 37.3

Table II. Adipose and muscle tissue distribution by sex.

Clasification adipose tissue	**Men (n=3409)**			**Women (n=961)**			**(All=4370)**			**p value**	**COC**	**V Cramers**
	N	**% Total**	**Cumulative %**	**N**	**% Total**	**Cumulative %**	**N**	**% Total**	**Cumulative %**			
High	1351	39.6	39.6	279	29.0	29.0	1630	37.3	37.3			
Moderate	738	21.7	61.3	251	26.1	55,1	989	22.6	59.9	<0.001	0.237	0.244
Normal	1320	38.7	100	431	44.9	100	1751	40.1	100			

Clasification muscle tissue	**Men (n=3409)**			**Women (n=961)**			**(All=4370)**			**p value**	**COC**	**V Cramers**
	N	**% Total**	**Cumulative %**	**N**	**% Total**	**Cumulative %**	**N**	**% Total**	**Cumulative %**			
Very high	974	28.6	28,6	553	57.5	57.5	1527	34.9	34.9			
High	1541	45.2	73,8	359	37.4	94.9	1900	43.5	78.4	<0.001	0.281	0.271
Normal	845	24.8	98,6	48	5.0	99.9	893	20.4	98.9			
Low	49	1.4	100	1	0.1	100.0	50	1.1	100.0			

% corresponds to very high, 22.6 % high, and 40.1 % normal. There are significant differences in the TAD classification between men and women (P = <0.001). Regarding muscle tissue (TM) classification, in men, 28.6 % have a very high level, 45.2 % high, 24.8 % normal, and 1.4 % low. In women, 57.5 % very high, 37.4 % high, 5 % normal, and 0.1 % very low. Regarding the total TM classification, 34.9 % have a very high level, 43.5 % high, 20.4 % normal, and 1.1 % low. There are significant differences in the TM classification between men and women (P = <0.001). In relation to the total sample, 51.2 % of the military population presents a high level of TAD, 22.9 % moderate, and 25.9 % normal. Regarding the total TM, 34.9 % have a very high level of TM, 43.5 % high, 20.4 % normal, and only 1.1 % low.

In Table III, the 5th, 25th, and 50th percentile distribution of anthropometric characteristics in the total military population, men, and women is presented. All measured dimensions were larger for men, except for the percentage of fat and fat mass index.

DISCUSSION

The key findings of our study revealed that despite relatively high levels of adipose tissue, military personnel exhibit elevated levels of muscle tissue. Furthermore, sex-based differences in body composition were observed, with men displaying higher levels of muscle tissue and women having higher levels of adipose tissue.

Body composition by sex. Sex-based differences in body composition among military personnel align with established patterns observed in both the general and military populations. Specifically, the observed lower levels of body fat percentage (BF %) in men compared to women, and conversely, higher levels of muscle mass (MM %), skeletal muscle index (SMI), and fat- free mass index (FFMI) in men, underscore fundamental physiological differences between sexes (Bredella, 2017). These differences are critical in the context of military readiness and performance, as they directly influence physical capabilities, endurance, and the ability to perform military-specific tasks. The lack of significant difference in the BFM of Trunk suggests that while overall body fat distribution may vary, the accumulation of fat in the trunk region does not significantly differ between sexes, at least within the parameters of this study. This could imply that the trunk fat, which is closely related to visceral fat, poses similar health risks for both sexes in the military context.

Several studies have highlighted the importance of muscle mass and lower body fat percentage in enhancing physical performance. For instance, a higher SMI and FFMI are associated with improved physical fitness, which is vital for military personnel who often engage in physically demanding tasks (Harty *et al*., 2022). Furthermore, research has demonstrated that specific body composition profiles are advantageous for certain military roles, emphasizing the need for targeted physical training and nutritional

Table III. Anthropometric characteristics of the military group by sex.

Variable	5th	25th	50th	75th	95th	5th	25th	50th	75th	95th	5th	25th	50th	75th	95th
Height (cm)	158.0	166.0	172.0	176.0	184.0	164.0	170.0	173.0	178.0	185.0	154.0	158.0	161.0	166.0	171.0
Weight (kg)	60.0	73.1	81.4	90.8	104.2	68.5	77.2	85.1	93.6	105.6	53.7	61.2	68.1	74.8	85.1
TBW (l)	29.3	38.7	43.9	48.3	53.9	38.6	42.1	45.7	49.3	54.3	27.0	29.7	32.1	34.8	38.4
BFM (kg)	11.0	17.7	22.5	28.3	37.4	10.6	17.5	22.1	28.1	37.6	13.6	18.9	23.9	28.7	36.6
FFM (kg)	40.1	52.7	60.0	66.0	73.7	52.7	57.5	62.4	67.4	74.2	36.9	40.6	43.8	47.6	52.6
SMM (Kg)	22.0	29.7	34.1	37.7	42.3	29.7	32.6	35.6	38.5	42.7	20.0	22.2	24.1	26.4	29.5
BMI (Weight/Height^2)	22.3	25.5	27.7	29.9	33.8	23.3	25.9	28.2	30.3	34.2	20.8	23.9	26.1	28.1	31.8
BF (%)	15.2	23.1	27.7	33.6	40.7	14.2	22.0	26.1	31.1	38.0	23.1	30.4	34.9	39.2	44.8
MM (%)	32.8	37.4	41.0	43.8	48.4	35.1	39.2	42.0	44.5	49.0	30.2	33.3	35.9	38.4	42.5
WHR (cm)	0.830	0.890	0.940	1.00	1.06	0.830	0.900	0.950	1.00	1.07	0.820	0.870	0.910	0.970	1.02
SMI	8.7	10.5	11.5	12.2	13.1	10.3	11.2	11.8	12.4	13.3	8.10	8.7	9.2	9.8	10.8
FMI	3.6	6.1	7.6	9.8	12.8	3.5	5.8	7.3	9.3	12.6	5.0	7.2	9.2	10.8	13.6
FFMI	18.0	18.9	19.6	20.2	21.1	18.8	19.4	19.8	20.4	21.3	17.6	18.0	18.4	18.9	19.4
BMR (kcal)	1.236	1.509	1.667	1795	1961	1.508	1.612	1.718	1.826	1973	1.168	1.246	1.317	1.399	1507

TBW: Total body water; BFM: Body fat mass; FFM: Fat free mass; SMM: Skeletal muscle mass; MM: Muscle mass; BF: Body Fat; WHR: Waist Hip Ratio; SMI: Skeletal muscle index; FMI: Fat mass index; FFMI: fat free mass index; BMR: Basal Metabolic Rate.

strategies to optimize performance and reduce injury risks (Pihlainen *et al*., 2018; Royer *et al*., 2018). The sex-based differences in body composition also raise considerations for physical training and health promotion within military organizations. Tailoring fitness and nutrition programs to address these differences can help in improving overall military readiness and operational effectiveness. For example, programs aimed at increasing muscle mass in women and reducing body fat in men could be beneficial in balancing the physical capabilities within mixed-sex units.

Specifically, Fat Mass Index (BFMI) values were found to be 1.8 to 5.2 kg/m^2 for men and 3.9 to 8.2 kg/m^2 for women within normal BMI ranges. BFMI values were 8.3 and 11.8 kg/m^2 in men and women, respectively, for BMI (Kyle *et al*., 2003). The likelihood of physical disability was compared in subjects whose measurements were above or below these cutoff points. Skeletal muscle cutoff points of 5.76-6.75 and ≤5.75 kg/m^2 were selected to indicate moderate and high risks of physical disability in women, respectively. The corresponding values in men were 8.51-10.75 and ≤8.50 kg/m^2. Compared to women with low-risk skeletal muscle values, those with moderate and high-risk skeletal muscle values had odds of physical disability of 1.41 (95 % confidence interval (CI): 0.97, 2.04) and 3.31 (95 % CI: 1.91, 5.73), respectively. The corresponding odds in men were 3.65 (95 % CI: 1.92, 6.94) and 4.71 (95 % CI: 2.28, 9.74) (Janssen *et al*., 2000).

Obesity and Muscle Tissue. The classification of adipose and muscle tissue in Chilean military personnel by sex, reveal significant sex differences in body composition, which echo broader trends observed in military and civilian populations worldwide. This data underscores the complex relationship between body compositions specifically, levels of adipose tissue and muscle mass and military performance. Research has consistently shown that body composition is a critical component of physical performance in military settings. Higher levels of muscle mass are generally associated with better performance on physical tasks, including those required in military operations. Conversely, higher levels of adipose tissue, or body fat, have been linked to decreased physical performance and an increased risk of injury and chronic diseases (Friedl, 2012; Cialdella-Kam *et al*., 2023). These associations emphasize the importance of maintaining a balance between fat mass and muscle mass to ensure operational readiness and minimize health risks.

Men tend to have higher levels of muscle mass and lower levels of body fat compared to women, which can influence their performance on certain military tasks. However, women's resistance to muscle fatigue and their endurance capabilities presents unique advantages in specific operational contexts. Therefore, while physiological differences exist, training and nutrition can significantly impact these variables, potentially narrowing the performance gap between sexes. The integration of women into combat roles has prompted military organizations to reconsider physical fitness standards to accommodate sex-specific physiological differences without compromising operational effectiveness. Proper training programs that focus on strength and endurance can enhance physical performance across both sexes, emphasizing the importance of tailored physical conditioning regimes in the military (Nindl *et al*., 2016)

In the military, body composition standards are set to ensure operational readiness and reduce the risk of injuries, diseases, and chronic conditions (Peterson, 2015). Yet, the overweight and obesity epidemic poses a challenge 37, leading to a smaller recruitment pool (approximately 19 % of young adults aged 20 to 24 are disqualified for service due to obesity) (Tompkins, 2020), increased risk of injuries, compromised physical readiness, and potentially higher health care costs (Police & Ruppert, 2022). Obesity is linked to functional limitations in muscle performance and a higher likelihood of developing functional disabilities, such as mobility, strength, posture, and dynamic balance limitations. Interestingly, obese individuals, regardless of age, exhibit greater absolute maximum muscle strength compared to non-obese individuals, suggesting increased adiposity acts as a chronic overload stimulus on antigravity muscles, thus enhancing muscle mass and strength. However, when normalized for body mass, obese individuals appear weaker, possibly due to reduced mobility, neural adaptations, and changes in muscle morphology (Tomlinson *et al*., 2016). In the military population, physical demands are varied, and operational capability is closely linked to physical fitness and body composition, with negative effects of adipose tissue on strength, cardiorespiratory endurance, and speed observed (Knihs *et al*., 2018). Recent studies, including Boffey *et al*. (2023) haveexamined the relationship between Army Combat Fitness Test (ACFT) performance, body composition, and speed profiles, finding muscle mass and body fat percentage accounted for 49 % of the shared variance in ACFT scores, highlighting the impact of body composition on military performance (Pletcher *et al*., 2023).

Anthropometric Indices in Military. The percentile distribution of anthropometric characteristics among the total military population, men, and women, reveal significant sex differences in body composition. The men in this study exhibit greater values in height, weight, TBW, FFM, SMM, MM %, and SMI compared to women, which is consistent with the general understanding of physiological differences between sexes. Women, on the other hand, show higher BF % and FMI, reflecting a predisposition towards a higher fat mass, a characteristic typically observed in non-military populations as well. Research has consistently shown that men tend to have higher lean body mass and lower body fat percentage than women. For instance, Janssen *et al*. (2000) found that skeletal muscle mass accounts for a larger proportion of total body mass in men compared to women, which contributes to the differences in physical performance capabilities and metabolic rates between sexes. These differences are crucial for military organizations to consider when designing physical training programs and nutritional guidelines to optimize the health and operational readiness of their personnel.

Furthermore, the higher muscle mass and lower fat mass in men are associated with higher basal metabolic rates, as muscle tissue is more metabolically active than fat tissue, fact corroborated by previous authors, who demonstrated significant sex differences in energy expenditure attributable to differences in body composition (Gallagher *et al*., 1998). The variations in WHR, a surrogate marker for the distribution of body fat, further emphasize the sex-specific patterns of adiposity, with women generally exhibiting a pear-shaped body (higher fat accumulation around the hips and thighs) and men a more apple-shaped body (higher fat accumulation around the abdomen). This distribution pattern has implications for cardiovascular risk, as abdominal fat is more strongly associated with metabolic syndrome and cardiovascular disease (Després & Lemieux, 2006).

The use of anthropometric indices for the classification of military personnel highlights the limitations of Body Mass Index in distinguishing lean mass from fat mass (Ode *et al*., 2007; Buffa *et al*., 2017), thus failing to evaluate the increase in muscle mass concurrent with fat loss, a common outcome of intense military training (Malavolti *et al*., 2008; Campos *et al*., 2017). Pierce *et al*. (2017) found that BMI is not linked to performance in relevant military tasks for US Army soldiers. Furthermore, individuals within the same BMI category can exhibit substantial metabolic characteristic heterogeneity. Those with a metabolically healthy obese phenotype might not be at risk for cardiovascular complications, presenting favorable lipid and glucose profiles (Phillips, 2013; Lv *et al*., 2022). Conversely, not all individuals of normal weight exhibit a healthy metabolic profile, being classified as metabolically un-healthy obese (Schulze, 2019; Lv *et al*., 2022). This suggests the existence of diverse metabolic phenotypes within the same BMI, indicating that other determinants may influence cardiometabolic health outcomes (Gonçalves *et al*., 2016). New proposals for body composition assessment should include data from physical condition, health, and operational capability. The use of the fat-free mass index could serve as a tool to identify personnel with low muscle tissue levels, guiding better nutritional and physical interventions (Harty *et al*., 2022). A recent study on the effects of six months of deployment in Afghanistan involving sedentary soldiers highlighted the essential role of promoting physical activity during soldiers' free time to maintain combat readiness, emphasizing the importance of keeping troops trained to optimize muscle and adipose tissue during operational activities (Sedliak *et al*., 2021) Finally, a recent meta-analysis revealed that low levels of muscle tissue are associated with increased all-cause mortality (Wang *et al*., 2023), which supports the inclusion of not only adipose tissue but also muscle tissue in the nutritional status classification, this approach to nutritional status classification provides abroader view of body composition profiles in the military.

Limitations and Future Research lines. One limitation of this study is its cross-sectional design, which precludes the ability to establish causal relationships between anthropometric characteristics and military performance outcomes. Additionally, the study's reliance on BMI and other traditional anthropometric indices may not fully capture the nuances of body composition, particularly in distinguishing between muscle and fat mass or accounting for the distribution of body fat. Future research should explore longitudinal designs to understand the causal effects of specific training programs on body composition changes over time. Incorporating more sophisticated body composition assessment tools, such as dual-energy X-ray absorptiometry (DXA) or magnetic resonance imaging (MRI), could provide a more detailed analysis of how different types of training impact muscle and fat distribution, potentially leading to more tailored and effective training programs. Investigating the role of dietary intake and nutritional status in conjunction with physical training could also offer insights into optimizing military personnel's health and operational performance. Moreover, expanding the demographic scope to include diverse military populations from various geographical regions and different branches of the military might reveal more generalized findings and identify specific body composition profiles associated with optimal performance in varied military tasks and environments.

Practical Applications. This study underscores the necessity for armed forces to adopt standardized protocols for assessing and classifying body composition, moving beyond simplistic measures to a more holistic understanding that incorporates the interplay between anthropometric characteristics and operational capabilities. The proposition to employ an assessment model powered by artificial intelligence (AI) algorithms represents a forward-thinking approach. This model would not only consider a range of variables impacting a military member's health and operational proficiency but also facilitate personalized and dynamic interventions. By integrating data on physical fitness, dietary intake, and other health indicators, such AI-driven tools could offer tailored recommendations for training, nutrition, and recovery, ultimately enhancing the readiness and effectiveness of military personnel. This approach aligns with the evolving needs of modern military operations, where physical and cognitive demands on soldiers necessitate innovative solutions to optimize performance and maintain strategic advantages.

CONCLUSSION

Finally, despite the high levels of adiposity observed, military personnel exhibit elevated levels of muscle tissue, with notable sex differences also identified. When adjusting the variables to the anthropometric indices used, a better correlation between the anthropometric characteristics in this group was observed compared to sedentary obese individuals. It is recommended that anthropometric assessments consider the evaluation of adipose tissue, muscle tissue, and anthropometric indices for an optimal anthropometric classification of military personnel. This approach highlights the importance of a comprehensive evaluation framework that acknowledges the complex interplay between different body composition components in determining the overall fitness and operational readiness of military personnel.

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RESUMEN: La preparación militar depende en gran medida de la aptitud física y la capacidad operativa de su personal. Este estudio tiene como objetivo mejorar la eficacia de los protocolos de evaluación y clasificación de la composición corporal dentro del contexto militar. Se realizó una evaluación integral de 4.370 militares chilenos en servicio activo, centrándose en las características antropométricas, incluido el tejido adiposo, el tejido muscular y los índices antropométricos. El estudio observó diferencias significativas en la composición corporal entre sexos, con los hombres exhibiendo niveles más bajos de porcentaje de grasa corporal (hombres: 26,28 %; mujeres: 34,62 %) pero niveles más altos de masa muscular (hombres: 42,0 %; mujeres: 36,0 %;), índice de músculo esquelético (hombres: 11,81; mujeres: 9,31) e índice de masa magra (hombres: 19,92; mujeres: 18,45) en comparación con las mujeres. Se observaron altos niveles de tejido muscular en ambos grupos. Al integrar estos hallazgos en un protocolo de evaluación estandarizado, se logró una clasificación más precisa del personal militar, superando los métodos tradicionales utilizados en poblaciones obesas sedentarias. El estudio aboga por la adopción futura de un modelo de evaluación basado en algoritmos de inteligencia artificial (IA), que consideren la naturaleza multifacética de la composición corporal y su impacto en la capacidad operativa. Un modelo de este tipo permitiría a las fuerzas militares optimizar la aptitud física y la preparación de su personal, mejorando así su eficacia en las operaciones de despliegue.

PALABRAS CLAVE: Disponibilidad militar; Evaluación de la composición corporal; Características antropométricas; Diferencias de sexo; Capacidad operativa.

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