Original Article

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Physiology Section

Effect of Body Fat and BMI on Muscle Strength and Endurance in Young Adults: A Cross-sectional Study

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ABSTRACT

Introduction: Muscle strength and endurance are key determinants of physical fitness, cardiometabolic profile, and overall health. Clinically, they are tested by estimating Handgrip Strength (HGS) and Handgrip Endurance (HGE) through an isometric contraction of the flexors of the forearm and hand. Body Mass Index (BMI) and body fat content can both influence muscle performance, but there are wide variations regarding their effects. BMI and body fat also do not show unequivocal similarity to each other.

Aim: The aim of this study was to determine and compare the effects of BMI and body fat on muscle strength and endurance.

Materials and Methods: A descriptive cross-sectional study was conducted at the Department of Physiology, Himalayan Institute of Medical Sciences, Swami Rama Himalayan University, Jolly Grant, Dehradun from April 2019 to March 2020. A total of 100 subjects who fulfilled the selection criteria were included. BMI and body fat were measured, and HGS and HGE were recorded using a handgrip dynamometer. Statistical analysis was performed using SPSS version 17.0. Descriptive statistics, independent sample t-test, and one-way ANOVA were used for comparison. Pearson's correlation coefficient and linear regression were used to determine and quantify the nature of the effect, with a p-value of ≤0.05 considered statistically significant.

Results: The participants had a mean BMI of 23.809±3.798 kg/m^2 and a mean body fat percentage of 25.309±7.162%. The mean HGS and HGE of the participants were 36.08±9.956 kg and 18.46±14.2 seconds, respectively. Body fat percentage showed a negative and moderately significant correlation (p-value≤0.001) with both muscle strength and endurance. Approximately one-fifth of the variations in muscle strength and one-third of the variations in muscle endurance were determined by body fat content. HGS and HGE were higher in males, while body fat percentage was higher in females. Gender variation in body fat contributed to more than 40% of the variance.

Conclusion: The study revealed a negative correlation between total body fat and muscle strength and performance. Keeping body fat under control can improve muscle performance, which, in turn, enhances cardiometabolic health.

Keywords: Body fat percentage, Body mass index, Hand grip endurance, Hand grip strength, Muscle performance

INTRODUCTION

Muscles, one of the elementary tissues of the human body, constitute about 40% of the body mass [1] and are needed for a vast array of daily activities, ranging from the smallest movements of body parts to locomotion. Muscular strength refers to the ability to produce maximal force, while endurance refers to the ability to sustain a contraction without fatigue [2]. Apart from reflecting physical fitness, general health, and nutritional status of the individual, studies have shown that muscular strength is protective against a poor cardiometabolic profile [3,4,5]. It is now regarded as a modifiable risk factor, similar to diet and lifestyle [6]. Therefore, if an individual maintains good muscular fitness, he or she is less likely to develop derangements in cardiovascular physiology or metabolism. The strength and endurance of upper limb muscles can be clinically tested by assessing HGS and HGE. HGS is measured by generating maximal isometric contraction by the flexor muscles of the hand and forearm, while HGE is estimated as the duration of contraction sustained by these muscles at a sub-maximal level [7].

BMI is a widely-accepted measure of the nutritional status and overall physical fitness of an individual. A BMI below the normal range indicates a negative calorie balance, while a BMI above the normal range indicates fat accumulation or obesity. Obesity is a known risk factor for cardiovascular diseases and metabolic syndrome [8]. It has been observed that obesity or increased adipose tissue often occurs concurrently with sarcopenia, and they share common underlying pathophysiological mechanisms [9]. A prospective study from Korea even demonstrated that visceral fat specifically contributes to the loss of muscle mass [10], leading to the emergence of the term "sarcopenic obesity" to describe the confluence of these conditions [11]. The current consensus states that low or reduced muscle function in terms of strength or performance is also an important criterion for sarcopenia, along with skeletal muscle mass [12]. There is substantial evidence in the medical literature regarding the association between obesity and reduced muscular fitness.

However, the use of BMI as the sole marker of adipose tissue raises a pertinent question: Does BMI accurately reflect adiposity, considering that total body mass includes both fat and fat-free mass (bones, muscles, fluids)? In fact, the population in the South Asian region often exhibits metabolic abnormalities and higher body fat at lower BMI [13,14]. Excess fat can also affect muscle efficiency. Contrary to the common notion, some authors have documented a positive correlation between grip strength and body fat percentage [15]. Additionally, some authors have suggested a "fat-but-fit" paradox, where obese individuals with cardiorespiratory fitness above a certain threshold show no significant difference in all-cause and cardiovascular mortality compared to their normal-weight counterparts [16,17]. These findings propose that obesity may not be associated with all the derangements as previously thought.

As mentioned above, studies investigating these effects show wide variations. The ambiguity regarding the effects of adiposity on muscle and the equivalence between BMI and body fat necessitated the present study. Its purpose was to determine the effects of both BMI and total body fat on the strength and endurance of young adults and provide a comparative analysis of these indices on muscle performance.

MATERIALS AND METHODS

A descriptive cross-sectional study was carried out in the Department of Physiology at the Himalayan Institute of Medical Sciences, Swami Rama Himalayan University, Jolly Grant, Dehradun, India, from April 2019 to March 2020, over a period of one year. The sample size was calculated using the formula $N=(Z^2 \times p \times q) \div L^2$, where N is the sample size, p is the prevalence, q is 1-p, L is the precision, and Z is 1.96 for a 95% confidence interval. Since the prevalence of impaired or reduced muscle strength and endurance is unknown in the Indian population, a prevalence of 50% and a precision of 10% were assumed. A prevalence of 50% yields the maximum required sample size as it assumes the worst-case scenario in terms of the variance of the binomial distribution [18]. The sample size in this study was determined to be 100.

Prior approval was obtained from the Institutional Ethics Committee (HIMS/RC/2019/103), and written informed consent was obtained from the participants before commencing data collection. The information obtained was treated with the utmost confidentiality.

Inclusion criteria: Young adults aged 18-25 years, non-smokers, non-alcoholics, and willing to participate in the study were included.

Exclusion criteria: Individuals with pre-existing conditions such as cardiorespiratory disorders, diabetes, neuromuscular disorders, paralysis or paresis, structural deformities of the upper limb, a history of upper limb fracture within the last three months, or those undergoing some form of training (aerobic or resistance) were excluded from the study. By employing these selection criteria, a simple random sampling technique was used to select 100 participants for the study.

Methodology:

i. **Anthropometric parameters and BMI:** Height was measured barefoot in centimetres to the nearest 0.1 cm. The subject was asked to stand straight with their head held in the Frankfurt horizontal plane. Two readings were taken, and the average of both was recorded as the subject's height. Weight was recorded to the nearest 0.1 kg by having the subject stand on a weighing machine (KRUPS, manufactured by Doctor Beli Ram and Sons) without shoes and wearing light clothes. Two readings were taken, and their average was recorded as the subject's weight [19,20]. BMI was calculated using Quetelet's index (BMI=weight in kg / height in m^2) [21] and classified according to ethnic-specific criteria for Indians: 18.5-22.9 kg/m^2 is considered normal, 23-24.9 kg/m^2 is classified as overweight, and ≥ 25 kg/m^2 is classified as obesity [13].

ii. **Body fat percentage:** Body fat was measured using a handheld bioelectric impedance analyser (OMRON Full Body Sensor Body Composition Monitor and Scale-HBF-514- [Table/Fig-1]). Bioelectric impedance analysis is a well-validated method for measuring body fat percentage [22,23].

iii. **Measurement of hand grip strength and endurance:** HGS and endurance were measured in the dominant hand using a handgrip dynamometer (INCO instruments and chemicals, Ambala). The subject placed their hand on a table, maintaining a 90° flexion at the elbow. Then, they were asked to squeeze the handle of the dynamometer with their maximum force, generating an isometric contraction. A valid reading was considered when such a contraction was sustained for atleast three seconds, and the best of three readings was recorded as the subject's maximal HGS [24]. Endurance is the maximum duration for which a contraction can be maintained at 50% of the maximal level. Brief or momentary bouts of maximal gripping are seldom required in our daily lives. Instead, a sub-maximal power that can be sustained for a considerable time is more important. Therefore, for endurance measurements, 50% of the maximum force is recommended. It has been found to show high reliability regardless of sex, hand, and work [25-27]. Since the maximal HGS for each subject is already recorded in the previous step, the subject was asked to maintain 50% of that value constantly for as long as possible without wavering. This was recorded in seconds [Table/Fig-2].

[Table/Fig-1]: Bio-impedance based full body composition monitor.
[Table/Fig-2]: Recording of Hand Grip Endurance (HGE). (Images from left to right)

STATISTICAL ANALYSIS

Data were analysed using SPSS version 17.0 (manufactured by SPSS Inc., Chicago, USA). The data were expressed in terms of mean, standard deviation, and proportions after applying descriptive statistics. Quantitative data in different groups were compared using independent samples t-test and one-way ANOVA. Pearson correlation coefficient (r) was calculated to ascertain the strength of correlation. Continuous quantitative data were also analysed using scatter plots and regression to determine the nature and quantify the effect. A p-value ≤ 0.05 was considered statistically significant.

RESULTS

In the present study, there were nearly equal numbers of male and female participants (M=46, F=54). The mean age (19.16±1.195 years) and BMI (23.809±3.798 kg/m^2) did not differ significantly between them, ensuring good comparability of muscle performance and fat. The mean HGS and HGE of the participants were 36.08±9.956 kg and 18.46±14.2 seconds, respectively, and both were significantly higher in males (p-value ≤ 0.001). The mean body fat percentage of the subjects was 25.309±7.162%, which was significantly higher in females [Table/Fig-3].

The mean HGS and HGE in different categories of BMI are shown in [Table/Fig-4]. A statistically significant (p-value=0.001), moderate negative correlation (r=-0.429, -0.528) was observed between muscle performance parameters and total body fat percentage [Table/Fig-5]. However, no correlation was observed between them and BMI [Table/Fig-6].

Linear regression analysis was used to quantify the correlation between muscle performance parameters (HGS, HGE) with total body fat percentage and BMI as independent or predictor variables. B coefficients and adjusted coefficients of determination (R^2) are shown in [Table/Fig-7]. Approximately 17.6% and 29.4% of the variance in HGS and HGE, respectively, were determined by total body fat alone, highlighting adiposity as an important, independent factor predicting muscle performance. When the effect of gender was incorporated, regression analysis revealed that the difference in body fat between males and females accounted for approximately 40% and 45% of the variance in HGS and HGE, respectively [Table/Fig-8].

Since both the dependent variables (HGS, HGE) and independent variables (body fat, BMI) are quantitative, the authors intended to quantify them with an equation if possible. Therefore, linear regression has been used. Since BMI did not show any significant correlation or coefficient of determination (adjusted R^2=0.000), in the next table, only body fat was considered for further analysis.

DISCUSSION

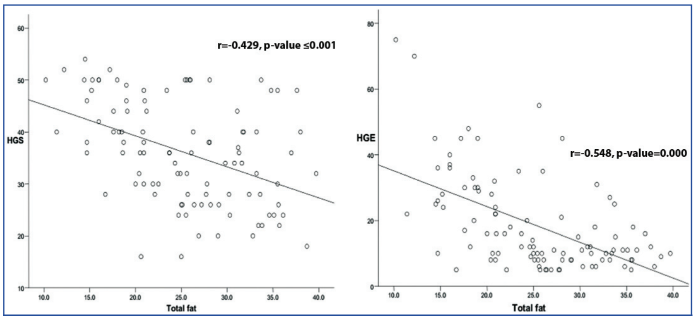
In the present study, the mean muscle strength, endurance of the upper limb, body fat percentage, and BMI of the subjects were recorded. It was also examined how body fat and BMI affect muscle performance and whether the effects of body fat and BMI concur with each other or not.

Parameters	N=100	Mean	Std. deviation	p-value*
Age (years)				
Male	46	19.30	1.348	0.267
Female	54	19.04	1.045	
Total	100	19.16	1.195	
BMI (kg/m²)				
Male	46	24.263	3.7218	0.272
Female	54	23.423	3.8547	
Total	100	23.809	3.798	
Total body fat %				
Male	46	20.876	6.7565	≤0.001
Female	54	29.085	5.0458	
Total	100	25.309	7.162	
Handgrip Strength (HGS) (kg)				
Male	46	42.89	7.156	≤0.001
Female	54	30.28	8.192	
Total	100	36.08	9.956	
Handgrip Endurance (HGE) (seconds)				
Male	46	28.39	15.040	≤0.001
Female	54	10.00	5.106	
Total	100	18.46	14.200	

[Table/Fig-3]: Comparison of the parameters between males and females.
*Independent sample t-test, p-value <0.05 statistically significant

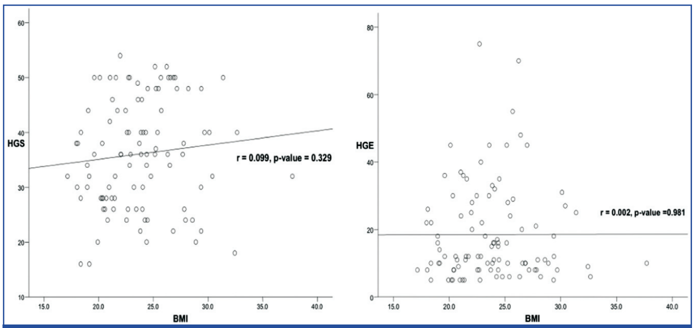
BMI categories	N=100	Mean	Std. deviation	p-value*
Handgrip strength (HGS) (Kg)				
Underweight	7	31.71	8.281	0.099
Normal	49	35.10	9.517	
Overweight	37	39.96	10.416	
Obese	7	33.71	10.735	
Handgrip Endurance (HGE) (seconds)				
Underweight	7	14.43	8.561	0.787
Normal	49	18.29	13.584	
Overweight	37	20.26	17.512	
Obese	7	17.00	10.247	

[Table/Fig-4]: Comparison of Handgrip Strength (HGS) and Handgrip Endurance (HGE) among different categories of BMI.
*One-way ANOVA, p-value <0.05 statistically significant



[Table/Fig-5]: Scatter plot diagrams of measurements made between muscle performance parameters (HGS, HGE) and body fat percentage.

The mean Hand Grip Strength (HGS) of the participants was 36.08±9.956 kg. It was almost similar to the findings reported by other authors, such as Shrestha et al., (34.24±9.72 kg), Al-Asadi (34.1±11.9 kg), and Lad et al., (33.33±2.58 kg) [28-30]. However, it was considerably higher than that reported by Prakash et al., (26.51±0.75 kg) [31]. Carmelli and Reed reported values in the higher range (47±9.5 kg) in the Australian population [32]. These differences can be attributed to racial variations in muscle fibre phenotype. Each muscle is composed of red and white muscle fibres, which differ in their force and fatigue characteristics. The proportion of each type of muscle fibre in an individual is genetically determined [33,34].



[Table/Fig-6]: Scatter plot diagrams of measurements made between muscle performance parameters (HGS, HGE) and BMI.

Independent predictors/ variables	Model significance	Regression equation			Adjusted R^2
		Constant (95% CI)	B coefficient (95% CI)	p-value	
HGS					
Body fat	F (1,98)= 22.122, p=0.000	51.79 (44.561 - 57.798)	-0.429 (-0.848 to -0.345)	<0.001	0.176
BMI	F (1,98)= 0.976, p=0.326	29.882 (17.278 - 42.486)	0.099 (-0.263 to 0.783)	0.326	0.000
HGE					
Body fat	F (1,98)= 42.152, p=0.000	45.981 (37.242 - 54.720)	-0.548 (-1.420 to -0.755)	<0.001	0.294
BMI	F (1,98)= 0.001, p=0.981	18.241 (0.175- 36.307)	0.002 (-0.740 to 0.759)	0.981	-0.010

[Table/Fig-7]: Regression coefficient and constant for Handgrip Strength (HGS) and Handgrip Endurance (HGE) with body fat and BMI (N=100).
Linear regression with Predictor/independent variables: Body fat, BMI separately; Outcome/dependent variables: HGS, HGE; Level of significance of p-value <0.05; F-statistic obtained on ANOVA, numbers in parentheses represent degrees of freedom

Dependent/outcome variables	Model Significance (Body fat* Gender)	Adjusted R^2
HGS	F (2,97)= 33.562, p=0.000	0.397
HGE	F (2,97)= 42.502, p=0.000	0.456

[Table/Fig-8]: Regression analysis to determine effect of gender differences in body fat on Handgrip Strength (HGS) and Handgrip Endurance (HGE).
Linear regression with Predictor/independent variable: Gender variability in body fat percentage Outcome/dependent variables: HGS, HGE; Level of significance of p-value <0.05; F-statistic obtained on ANOVA, numbers in parentheses represent degrees of freedom

Regarding endurance (HGE), a mean value of 18.46±14.2 seconds was recorded, which is similar to the findings of Prakash et al., (19.40±90s) [31]. Endurance values vary widely in the literature. Lad et al., reported 199.73±29.09 s [30]; Shrestha et al., reported 113.45±44.61s, Ravisankar et al., reported 104±40s, Gupta et al., reported 43.55±28.84 s, and Dhananjaya et al., found 79.77±39.57s in males and 54.35±22.98 s in females [28,35-37]. The variations are because endurance time was recorded at 50% of the maximal load in the present study, whereas in many of the above-mentioned studies, authors have used contractions ranging from 30% to 70% of maximal strength for measuring HGE. Both parameters were significantly higher in males. This is consistent with most similar studies that found gender to be a significant factor and documented significantly higher values in males [30,31,35-38]. However, Shrestha et al., documented the opposite pattern. Endurance time was found to be higher in females (123.60±50.65s) than in males (103.30±35.48 s) [28].

The mean BMI of the participants in the present study was 23.809±3.798 kg/m², which closely aligns with values reported by other authors in their studies. For instance, Shrestha L et al., reported a mean BMI of 20.76±2.71 kg/m², Al-Asadi JN reported 23.82±2.73 kg/m², and Dhananjaya JR et al., reported 23.1±3.6 kg/m² [28,29,37].

The mean body fat percentage of the subjects in our study was 25.309±7.162%. It was significantly higher in females (males=20.876%, females=29.09%). These findings are consistent with existing literature. Studies conducted on the Indian population have found body fat percentages of 22.09% in males and 30.61% to 33.6% in females [39,40]. Similarly, studies from other parts of the world have reported similar values. A large study with more than 5000 participants in China found body fat percentages of 25.74% in males and 34.01% in females [41]. In a study conducted in Southeast Asia (Indonesia), body fat was found to be 21.18% in males [42]. Additionally, a study conducted on young adults in Europe reported total body fat percentages of 24.16% in males and 32.15% in females [43]. Interestingly, the mean BMI of the participants in the aforementioned studies is also around 23 kg/m^2, similar to the present study.

The present study has revealed a moderately strong, negative, and significant correlation between body fat percentage and muscle strength (HGS) and endurance (HGE). This means that as the fat content of the body increases, both muscle strength and endurance decrease. Approximately 18% of the variations in HGS and 29% in HGE are solely attributed to body fat. Studies investigating the effect of fat on muscle performance show varying results. Lad UP et al., showed a negative relationship between body fat and endurance [30]. Ingrova P et al., and Sartorio A et al., found an inverse correlation between strength and body fat, consistent with the current observations [44,45]. However, Gale CR et al., showed a positive correlation between body fat percentage and HGS [15]. In terms of BMI, our study did not find any significant correlation, with an age and sex-adjusted coefficient of determination (R2) of 0.000. Available literature shows diverse patterns in the effect of BMI. Similar observations to the present study were also made by Gupta M et al., [36]. In contrast, Lad UP et al., found that endurance decreased in both males and females on both sides of normal BMI. They found the same effect in terms of grip strength in males [30]. Dhananjaya JR et al., reported a negative correlation between BMI and HGS in males but not in females [37]. On the other hand, many authors found a positive correlation between HGS, endurance, and BMI [28,29,35]. Al-Asadi JN additionally found that BMI accounted for 70% of the variation in HGS [29]. The findings showed that adiposity specifically, and not BMI, affects muscle performance. BMI has been used as a screening and prognostic tool for obesity for a long time because it is convenient to use, easily interpreted, and reproducible. However, there is an inherent limitation in BMI as an accurate marker of adiposity because it doesn't differentiate between fat and fat-free mass, such as muscle, bone, fluids, etc., in the body. The present study adds evidence to this fact and could explain why such wide variability exists in the nature of the association between these factors in medical literature.

Muscle strength is broadly determined by its structural and base-material properties. Structural features include muscle fibre length, the angle of pennation of fibres relative to the force-generating axis of the muscle, the number of fibres, and their physiological cross-sectional area. The base-material properties depend on the relative proportion of different constituent components such as contractile proteins, elastic proteins, and fat, among others [46,47]. Intramuscular fat can be deposited both inside the muscle fibres ("intramyocellular") and outside of them ("extramyocellular"). Studies have shown that muscle force decreases with an increase in fat, regardless of whether the fat deposits as a single clump in the muscle belly or is distributed uniformly throughout. The decrease in force is more pronounced in the second scenario [48]. This is attributed to the stiffer material properties of fat [49]. The greater the stiffness, the more resistance there is to muscle shortening during contraction, resulting in a reduction in strength. Some authors, on the contrary, have argued that muscles in this situation will need to work harder because of the extra fat, and this could have a certain positive effect similar to training [50]. However, most studies do not agree with this proposition, especially in light of several other factors. Fat could also hamper the generation of force if it gets deposited at sites critical to the angle of pennation of muscle fibres and the aponeurosis [48]. When considering the molecular effects of fat in muscle, the predominant effect is deranged calcium signaling. In fact, the effect of obesity has been found to be similar to the process of ageing in terms of reducing muscle mass [51]. This further explains why muscle strength would be lower as fat content increases. Muscle endurance refers to the ability of the muscle to resist fatigue. Researchers have suggested that obesity alters the fibre composition within muscle and shifts them towards a fast-type fibre phenotype, which has lower fatigue resistance [52,53]. At the cellular level, excess fat in muscle disrupts 5'-Adenosine Monophosphate-activated Protein Kinase (AMPK) activity and intracellular calcium signaling, produces Reactive Oxygen Species (ROS), and reduces adiponectin levels and insulin sensitivity. Each of these factors alters the energy balance and metabolism of the muscle, resulting in decreased resistance to fatigue [51]. Therefore, the existing body of scientific evidence clearly supports the findings of the present study.

Limitation(s)

Although the present study brings forth important points, incorporating additional factors such as regional fat distribution and biochemical markers of adiposity can further explore the topic.

CONCLUSION(S)

The present study demonstrates that total body fat percentage has a significantly negative correlation with both muscle strength and endurance. It was found that approximately one-fifth of the variations in muscle strength and one-third of the variations in muscle endurance are determined by body fat content. Additionally, body fat percentage tends to be higher in females. The gender variation in body fat contributes to more than 40% of the variance. Therefore, body fat content should be considered a key factor in screening and prognosticating cases of obesity instead of relying solely on BMI. These findings also have potential implications for athletes and the elderly population. In any training programme, the primary objective is to maximise performance, and this study highlights that body fat is a crucial determinant of achieving that goal. For the elderly population, excessive fat, coupled with age-related muscle decline, can further exacerbate the loss of muscle vitality and efficiency.

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