Original Article

Prediction of bench press performance in powerlifting: The role of upper limb anthropometry

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ABSTRACT

The bench press (BP) is a complex, multiarticular exercise known as one of the three powerlifting specialties. Although several variables contribute to the maximum load lifted, upper limb variables may also play an important role in BP performance. In this study, a cohort of 47 male Italian classic powerlifters underwent a direct anthropometric evaluation during two official competitions. The recorded parameters included body mass index, body composition, and variables of the upper limb (indirectly evaluated cross-sectional areas and lengths). IPF-GL points and maximal strength (1RM) adjusted for weight were used as proxies for performance. Statistical comparisons between weaker and stronger powerlifters, Pearson correlation and partial correlation analyses, and multiple linear regression models were performed. The upper arm cross muscular area (r = 0.56) and fat-free mass (r = 0.31) were positively correlated with Wilks points, whereas the arm fat index was negatively correlated with 1RM BP (r = -0.37). Moreover, we proposed two new indices (UALR and UAMR) that represent the ratio between upper arm areas and length. Both univariate and multivariate analyses confirmed the strong association between these two variables and BP performance. Further improvement of this study may confirm the important role of body proportion and body composition as predictors of performance in strength sports.
Keywords: Performance analysis of sport; Sports performance; Kinanthropometry; Body composition; Body proportions; Exercise.

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INTRODUCTION

Bench press (BP) is one of the three main specialties of powerlifting, in which athletes compete in absolute and maximal strength actions (Ferland and Comtois, 2019). BP execution requires a complex set of movements, such as adduction, extension, and internal rotation of the humerus. It mainly involves the scapulohumeral girdle (anterior deltoid, *triceps brachii* and stabilizing muscles), other than the *pectoralis major* muscle (Padulo et al., 2015). Competitions are based on powerlifters' performance over 3 tests of 1 repetition maximum (1RM). Tests must respect all technical rules imposed by official regulations to be valid (Ferland and Comtois, 2019; Padulo et al., 2015). Powerlifters are classified into different categories according to their weight (Bishop et al., 2018).

Several studies have investigated the predictability of BP performance based on anthropometric variables (Caruso et al., 2012; Ferland, Laurier, et al., 2020; Ferrari et al., 2022; J. Keogh et al., 2005; J. W. L. Keogh et al., 2007; Lovera and Keogh, 2015; Mayhew, Piper, et al., 1993). Body weight and size were often found to be positively correlated with 1RM performance in all powerlifting specialties (Brechue and Abe, 2002; Chau et al., 2019; Hetzler et al., 2010; J. Keogh et al., 2005; Latella et al., 2018; Marković and Sekulić, 2006), although the specialties of BP and squat are mostly influenced by body mass index (BMI) and weight (Ferland, Laurier, et al., 2020). Body composition, specifically lean body mass and fat-free mass (FFM), are known to be the main determinants of this influence due to the muscular component and thus hypertrophy level (Ferland, Laurier, et al., 2020). This fact is also confirmed by the strong association between the general performance in powerlifting and limb girths found in several studies, especially for flexed biceps girth (Ferrari et al., 2022; J. W. L. Keogh et al., 2009). Concerning body fat and skinfold thickness, the results are often controversial. Some studies have shown no significant differences in these variables of body composition between weaker and stronger powerlifters (J. W. L. Keogh et al., 2009; Lovera and Keogh, 2015). Ferland and colleagues highlighted a positive correlation between body fat and bench performance (Ferland, Laurier, et al., 2020). Conversely, a negative association was found in another recent study (Ferrari et al., 2022), suggesting an unclear relationship between body fat and performance. However, a possible explanation for the lack of consistency among results from different studies may be found in the low number of analyzed samples. The role of upper limb variables in BP performance is a fundamental, albeit less studied topic. In fact, the ability to lift 1RM loads depends both on the ability of the muscles to produce force and on the moment arm of the loads, and this information can be indirectly (in the case of muscle mass) and directly (in the case of arm length) obtained by anthropometric measurements (Ferland, Laurier, et al., 2020; J. Keogh et al., 2005; Mayhew, Piper, et al., 1993). Hence, several studies pointed out the influence of the proportion between stature and the length of the upper limb (Ferrari et al., 2022), demonstrating that BP performance is positively affected by shorter upper limbs, a, due to the reduction of the range of movement and the resistance moment arm (Ferrari et al., 2022; Lovera and Keogh, 2015). Moreover, the measures of the body segments of the upper limb also have many effects on the performance in BP. For example, the humerus length could modify the angle of the elbow and the shoulder (Reya et al., 2021). Nevertheless, lengths, especially of the upper limb, are still a discussed topic in this field, and contrasting results have been reported (Hart et al., 1991; J. W. L. Keogh et al., 2007, 2008, 2009; Lovera and Keogh, 2015; Mayhew, McCormick, et al., 1993; Mayhew, Piper, et al., 1993).

Regarding the cross-sectional area of the upper limb muscles, Reya and colleagues (Reya et al., 2021) found a significant correlation between these areas, directly collected by ultrasonography, and 1RM BP. Other less recent studies (Mayhew et al., 1991; Mayhew, McCormick, et al., 1993) reported a significant correlation between anthropometrically estimated cross-sectional areas of the upper limb and BP strength in non-powerlifter populations. Marcović and Sekulić (Marković and Sekulić, 2006) pointed out that the proportion between local muscle mass and length should be considered rather than the two measurements alone. Few studies have evaluated the relationship between handgrip strength (HGS) and performance in powerlifters, but the results are often conflicting. Suazo and Debelizo (Suazo and DeBeliso, 2021) reported a moderately significant relationship in female powerlifters, while another study conducted on males showed no association (Filingeri et al., 2013). An association between BP and digit ratio (2D:4D ratio), which is supposed to be an indicator of the level of prenatal estrogen and testosterone levels (is found in female Olympic athletes (Eklund et al., 2020), but to our knowledge, no studies have been conducted on male powerlifters.

Although some of these anthropometric and body features are genetically defined and thus cannot be modified (e.g., skeletal lengths), a few characteristics, such as weight and body composition, can undergo modifications depending on training, nutrition, and lifestyle. Therefore, the identification of modifiable predictive parameters could allow an improvement in the performance of every powerlifter, regardless of other fixed characteristics. The aims of this preliminary study are to evaluate 1) which anthropometric and body composition variables are the most correlated with performance in BP, with particular attention to upper limb measurements; and 2) whether the novel anthropometric indices can successfully predict 1RM BP. We hypothesize that these two new indices of body proportion, combining body composition and arm length, could be useful in BP performance predictions, rather than just body composition or body proportion parameters examined individually.

MATERIALS AND METHODS

Participants

This was a cross-sectional study carried out on 47 male classic powerlifters (mean age: 30.7 $\pm$ 8.8 years) who participated voluntarily during two official competitions of the FIPL (Italian Powerlifting Federation) between October 2021 and January 2022. The distribution among weight classes is described as follows: -66 kg = 10.6% (n = 5); -74 kg = 6.4% (n = 3); -83 kg = 14.9% (n = 7); -93 kg = 19.1% (n = 9); -105 kg = 29.8% (n = 14); -120 kg = 12.8% (n = 6); +120 kg = 6.4% (n = 3). Only athletes who participated in at least one official competition within a year and competed in the *raw* category were included. None of the participants were injured at the time of the competitions. These inclusion criteria were established to avoid possible bias concerning variations in weight and classic or equipped categories. Data concerning the total lifted load in BP (1RM BP) were obtained by published official results of the competitions. Participants were comprehensively informed of the aims and contents of the study and signed informed written consent forms before measurement collection.

Approval for the study was obtained from the University of Bologna Bioethics Committee (Prot. n. 25027 of 13 March 2017) and was conducted in accordance with the Helsinki Declaration.

Anthropometric measures and procedures

All anthropometric measurements were collected the day of the competition by the same trained operator following classic standardized protocols and on the left side of the body (Bedogni et al., 2001; Lohman et al., 1992). Fundamental measurements (stature and weight) were assessed with a portable stadiometer (Raven© equipment) and a mechanical scale (SECA©) and were recorded to the nearest 0.1 cm and 0.1 kg, respectively, with subjects barefoot and with light clothes. Skinfold thicknesses (biceps, triceps, subscapular, and suprailiac) were recorded with a Lange skinfold caliper (Beta Technology Incorporated©). A non-stretchable anthropometric tape (Hoechstmass©) was used for relaxed and flexed mid-upper arm circumferences (MUAC). Diameters and body lengths (2nd and 4th fingers length, hand width, forearm length, upper arm length, biacromial width) were collected with a sliding anthropometric caliper and a portable anthropometer (GPM©). A Smedley dynamometer (Takei 5001 Hand Grip Analog Dynamometer Takei©) was used for recording HGS in kg (HGS, the maximum value was chosen among left and right hands).

Body mass index (BMI, kg/m^2) was calculated by the ratio of weight to square height and was used to classify each athlete into weight status classes (underweight, normal weight, overweight, obese) according to the World Health Organization guidelines (James et al., 2004).

Body density was calculated using the age-specific equations proposed by Durnin and Womersely based on four skinfolds (biceps, triceps, subscapular and suprailiac) (Durnin and Womersley, 1974). Then, FM% was calculated by applying Siri's formula (Siri, 1961). FM (kg) = (FM%/100)*weight and FFM (kg) = weight – FM.

Based on %F and the cut offs by sex and age proposed by Gallagher et al.(Gallagher et al., 2000), the participants were classified into "*underfat*", "*normal fat*", "*overfat*" and "*very overfat*" categories.

Total upper arm area (TUA, cm^2), upper arm muscle area (UMA, cm^2), upper arm fat area (UFA, cm^2), and arm fat index (AFI, %) were also evaluated for a comprehensive evaluation of upper limb composition through the following formulas: TUA (cm^2) = MUAC^2/4π; UMA (cm^2) = [MUAC – (Ts. π)]^2/4π; UFA (cm^2) = TUA–UMA; AFI (%) = (UFA/TUA)*100, where MUAC = relaxed biceps girth and Ts = Triceps skinfold in cm (Frisancho, 1981, 2009). The digit ratio (2D:4D), brachial index (BI = forearm length (cm)/upper limb length (cm) and arm length index (ALI, upper limb length (cm)/height (cm)*100) were also calculated (Lohman et al., 1992). Moreover, we proposed two new indices, the upper arm area to length ratio (UALR) and the upper arm muscle area to length ratio (UMLR), as follows:

$$\frac{\mathbf{TUA\ (cm^2)}}{\mathbf{Upper\ arm\ length\ (cm)}} = \text{Upper arm area to length ratio (UALR, cm)}$$

$$\frac{\mathbf{UMA\ (cm^2)}}{\mathbf{Upper\ arm\ length\ (cm)}} = \text{Upper arm muscle-to-length ratio (UMLR, cm)}$$

IPF GL points

To compare the results of subjects from different weight categories, *IPF GL* points proposed by the International Powerlifting Federation were used (www.powerlifting.sport). Points were calculated by following the sex-specific formula:

$$\mathbf{IPF\ GL\ coefficient} = \frac{\mathbf{100}}{\mathbf{A - B * e^{-C*bw}}}$$

$$\mathbf{IPF\ GL\ Points = IPF\ GL\ coefficient * result\ (Kg)}$$

where BW = body weight; A, B, C = constants depending on the sex of the athlete and competition typology (complete, BP only, classic or geared); *e* = base of the natural logarithm; *result* = total sum of kilograms lifted.

Statistical analysis

Data distribution was verified through the Shapiro–Wilk test. Descriptive statistics were calculated for each variable through frequencies for categorical variables (weight and fat status) and means and standard deviations (SDs) for continuous variables. The sample was divided into two halves, weaker and stronger powerlifters, using the median value of 70.8 IPF GL points as the cutoff, given the lack of reference values in the literature. Differences between weaker and stronger powerlifters were performed using the Mann–Whitney U test and chi-squared test for fat-status and weight-status categories.

Pearson's *r* correlation coefficient was calculated among continuous variables (age, years of powerlifting practice, anthropometric measurements) and IPF GL points, while partial correlations were performed between the same variables and one-repetition maximum load in BP (1RM BP) after adjusting for weight as a continuous variable. Multiple linear regression models were calculated through the forward entry method to assess the anthropometric variables most predictive of BP performance. As dependent variables, we used IPF GL points and 1RM BP. Independent variables were selected among anthropometric measures and indices according to their results in univariate correlation analysis. Collinearity was considered by selecting only variables characterized by a variance inflation factor (VIF) >10. In the first model, the selected variables entered were BMI, UMLR, biacromial width and FFM (all continuous). In the secondo model, we entered BMI, AFI and UMLR. Moreover, the second model was adjusted for the weight of the subjects.

Values of $p < .05$ were considered statistically significant. All analyses were carried out with Statistica Software for Windows, Version 11.0 (StatSoft Srl, Tulsa, OK, USA) and Medcalc© (Medcalc Software, Ltd.).

RESULTS

Table 1 reports the anthropometric and body composition characteristics of the population included in the study. Concerning the anthropometric characteristics of the sample, the mean value of BMI fell into the obese category, and as reported in Table 2, only 8.5% of the powerlifters were normal weight, while most of them were overweight or obese. However, if we analyze the distribution of the athletes in body fat categories, only approximately 13% were in the category of very overfat, more than 61% in normal fat, and about a quarter in overfat (Table 2).

Table 1 Anthropometric and body composition characteristics of the athletes (n = 47).

Variables	**Mean (SD)**	**95%CI**
Age (years)	30.7 (8.8)	28.1 – 33.3
Power-lifting experience (years)	6.8 (8.2)	4.4 – 9.2
HGS (kg)	57.1 (12.3)	53.5 – 60.8
1RM BP (kg)	149.9 (29.1)	141.4 – 158.5
IPF GL points	71.2 (10.4)	68.1 – 74.2
Height (cm)	175.2 (7.8)	173.0 – 177.5
Weight (kg)	94.0 (19.2)	88.3 – 99.6
BMI (kg/m^2)	30.4 (5.1)	28.9 – 31.9
relaxed MUAC (cm)	38.7 (3.7)	37.7 – 39.8
flexed MUAC (cm)	40.5 (3.6)	39.4 – 41.6
Triceps ST (mm)	11.8 (5.2)	10.3 –13.3
Bicipital ST (mm)	6.6 (5.1)	5.1 – 8.1
Subscapular ST (mm)	15.9 (6.7)	13.9 – 17.9
Suprailiac ST (mm)	15.9 (8.8)	13.3 – 18.5
∑ STs (mm)	49.1 (22.1)	42.5 – 55.6
Upper arm length (cm)	34.6 (2.1)	34.0 – 35.5
Forearm length (cm)	25.8 (1.8)	25.3 – 26.3
Hand length (cm)	16.9 (1.4)	16.5 –17.3
Hand width (cm)	20.9 (2.0)	20.3 – 21.4
Forearm plus hand length (cm)	42.7 (3.0)	41.8 – 43.6
Upper limb length (cm)	77.3 (4.9)	75.9 – 78.8

Biacromial diameter (cm)	39.4 (2.7)	38.6 – 40.2
2nd finger length (mm)	74.2 (6.6)	72.8 –76.7
4th finger length (mm)	76.8 (5.9)	75.0 – 78.5
BI	74.5 (3.4)	73.5 – 75.5
ALI	44.1 (2.1)	43.5 – 44.7
2D:4D	0.97 (0.04)	0.96 – 0.99
UMLR (cm)	2.8 (0.5)	2.7 – 3.0
UALR (cm)	3.5 (0.6)	3.3 – 3.7
FM %	19.1 (5.9)	17.3 – 20.8
FM (kg)	18.6 (8.8)	16.0 –21.2
TUA (cm^2)	120.5 (23.3)	113.7 – 127.4
UMA (cm^2)	98.5 (17.8)	93.3 – 103.7
UFA (cm^2)	22.0 (10.8)	18.9 – 25.2
AFI (%)	17.9 (6.6)	15.9 – 19.8

Note. HGS: handgrip strength; 1RM BP: one repetition maximum in BP; BMI: body mass index; MUAC: mid-upper arm circumference; ST: skinfold thickness; BI: brachial index; ALI: arm length index; UMLR: upper arm muscle area to length ratio; UALR: upper arm area to length ratio; FM%: fat mass percentage; FM: fat mass; FFM: fat free mass; TUA: total upper arm area; UMA; upper arm muscle area; UFA: arm fat area; AFI: arm fat index.

Table 2. Weight-status and fat-status of the sample of powerlifters.

Weight-Status	**n**	**%**
Underweight	0	0.0
Normal weight	4	8.5
Overweight	21	44.7
Obese	22	46.8
Fat-status	**n**	**%**
Underfat	0	0.0
Normal fat	29	61.7
Overfat	12	25.5
Very Overfat	6	12.8

Comparison between stronger and weaker powerlifters

No significant differences were found in age, weightlifting experience, or HGS between the two subgroups (Table 3). As expected, 1RM is significantly higher in stronger than weaker athletes, with a mean lifted load of approximately 170 kg for the former and 130 kg for the latter. In relation to anthropometric variables, stronger powerlifters displayed significantly higher mean values of the relaxed and flexed MUAC than weaker powerlifters. The new proposed indices showed significantly higher mean values in stronger athletes, indicating a higher total and muscled upper arm area in relation to the arm length. When analyzing the body composition parameters of the stronger and weaker athletes in more detail, we found no differences in the variables related to the total body FM and FFM but only in the peripheral body composition parameters, especially those related to the FFM, as underlined by the highest values of UMA in the former group (Table 3). No significant differences resulted in the comparison between weight-status (p = .38) and fat-status categories (p = .89) distribution among the two classes of powerlifters.

Table 3. Comparison of anthropometric and body composition characteristics between weaker (IPF GL points <70,8, n = 23) and stronger (IPF GL points ≥70,8, n = 24) powerlifters.

Variables	Weaker powerlifters (IPF GL points <70.8) Mean (SD)	Stronger powerlifters (IPF GL points ≥70.8) Mean (SD)	*p*-value
Age (years)	31.2 (11.0)	30.3 (6.4)	.59
Weightlifting experience (years)	6.5 (9.8)	7.1 (6.4)	.16
HGS (kg)	55.6 (10.7)	58.7 (13.7)	.47
1RM (kg)	128.8 (21.0)	170.1 (20.0)	<.001
Anthropometric characteristics			
Height (cm)	174.7 (8.3)	175.8 (7.4)	.84
Weight (kg)	89.8 (19.9)	98.0 (18.2)	.10
BMI (kg/m^2)	29.1 (4.2)	31.7 (5.7)	.08
relaxed MUAC (cm)	37.6 (3.7)	39.9 (3.4)	.025
flexed MUAC (cm)	39.5 (3.8)	41.6 (3.3)	.037
Triceps ST (mm)	11.7 (5.6)	11.9 (5.0)	.79
Bicipital ST (mm)	5.7 (4.9)	7.4 (5.3)	.22
Subscapular ST (mm)	13.9 (5.2)	17.7 (7.5)	.09
Suprailiac ST (mm)	14.8 (7.3)	16.9 (10.2)	.68
∑ STs (mm)	43.8 (15.6)	53.9 (26.2)	.34
Body lengths and widths			
Upper arm length (cm)	34.7 (2.2)	34.6 (2.1)	.79
Forearm length (cm)	26.1 (1.9)	25.5 (1.7)	.18
Hand length (cm)	17.2 (1.6)	16.6 (1.1)	.30
Hand width (cm)	20.5 (2.3)	21.2 (1.6)	.38
Forearm plus hand length (cm)	43.3 (3.3)	42.1 (2.7)	.17
Upper limb length (cm)	70.0 (5.3)	76.7 (4.5)	.32
Biacromial width (cm)	39.1 (2.9)	39.7 (2.6)	.45
2nd finger length (mm)	74.0 (6.4)	75.5 (6.9)	.44
4th finger length (mm)	76.1 (6.1)	77.4 (5.8)	.59
Body proportion			
BI	75.3 (3.2)	73.8 (3.5)	.07
ALI	44.7 (2.5)	43.6 (1.4)	.23
2D:4D	0.97 (0.05)	0.97 (0.04)	.22
UMLR (cm)	2.7 (0.4)	3.0 (0.5)	.007
UALR (cm)	3.3 (0.5)	3.7 (0.6)	.009
Body composition			
FFM (kg)	72.8 (13.8)	77.9 (10.6)	.11
FM (kg)	17.1 (8.2)	20.1 (9.4)	.30
FM%	18.4 (5.7)	19.7 (6.1)	.42
TUA cm^2	113.4 (22.8)	127.4 (22.0)	.025
UMA cm^2	92.2 (16.9)	104.5 (16.8)	.011
UFA cm^2	21.2 (11.4)	22.8 (10.4)	.431
AFI %	18.2 (7.2)	17.5 (6.1)	.77

Note. HGS: handgrip strength; 1RM BP: one repetition maximum in BP; BMI: body mass index; MUAC: mid-upper arm circumference; ST: skinfold thickness; BI: brachial index; ALI: arm length index; UMLR: upper arm muscle area to length ratio; UALR: upper arm area to length ratio; FM%: fat mass percentage; FM: fat mass; FFM: fat free mass; TUA: total upper arm area; UMA; upper arm muscle area; UFA: arm fat area; AFI: arm fat index.

Correlations between anthropometric variables and performance

IPF GL points are significantly and positively correlated with BMI, upper arm circumferences, and muscle mass, both peripheral (UMA) and total body (FFM). No statistically significant correlation resulted between IPF GL points and body lengths and widths, even though biacromial width was almost significantly correlated with the score. Regarding body proportion, the UMLR and UALR were positively correlated with performance, with coefficients of correlation of .45 (Figure 1 A) and .57 (Figure 1 B), respectively (Table 4, first column). To more deeply examine the association between maximal strength and anthropometric variables, we performed a partial correlation using the dependent variable 1RM adjusted for the weight of the athletes, which was used as a covariate. The results are consistent with those obtained using the IPF GL points as the dependent variable, but in this analysis, the fat mass of the upper limb (AFI, UFA and triceps ST) was significantly and negatively associated with the maximal strength. Regarding the body dimensions, no anthropometric variables were significantly correlated with performance. Moreover, the high positive association between performance and the new proposed indices is confirmed (Table 4, second column) (Figure 1, C and D).

Table 4. Correlations and partial correlation (adjusted for the weight of the subjects) between anthropometric and body composition characteristics and IPF GL points and 1RM, respectively.

	IPF GL Points		1RM BP	
Variables	**R**	***p*-value**	**R**	***p*-value**
Age (years)	-0.21	.16	-0.17	.26
Weightlifting experience (years)	0.03	.84	0.03	.86
HGS (kg)	0.21	.17	0.10	.51
Anthropometric characteristics				
Height (cm)	0.11	.46	-0.06	.51
Weight (kg)	0.25	.08	-	-
BMI (kg/m^2)	0.28	.050	0.13	.38
Relaxed MUAC (cm)	0.40	.005	0.46	.001
Flexed MUAC (cm)	0.41	.004	0.47	.001
Triceps ST (mm)	-0.11	.45	-0.35	.018
Bicipital ST (mm)	0.07	.62	-0.22	.14
Subscapular ST (mm)	0.20	.17	0.01	.96
Suprailiac ST (mm)	0.12	.43	-0.12	.42
∑ STs (mm)	0.11	.46	-0.18	.25
Body lengths and widths				
Upper arm length (cm)	-0.02	.91	-0.16	.30
Forearm length (cm)	-0.04	.80	-0.16	.28
Hand length (cm)	-0.11	.47	-0.20	.18
Hand width (cm)	0.23	.11	0.16	.28
Forearm plus hand length (cm)	-0.07	.63	-0.19	.19
Upper limb length (cm)	-0.05	.73	-0.19	.21
Biacromial width (cm)	0.26	.07	0.14	.35
2nd finger length	0.13	.37	0.03	.83
4th finger length	0.10	.50	-0.01	.92
Body proportion				
BI	-0.04	.77	-0.05	.76
ALI	-0.18	.22	-0.19	.21
2D:4D	0.08	.58	0.07	.64
UALR (cm)	0.45	.002	0.46	.001
UMLR (cm)	0.57	.001	0.56	<.001

Body composition				
FFM (kg)	0.31	.033	0.21	.15
FM (kg)	0.11	.43	-0.21	.15
FM%	0.00	.98	-0.21	.17
TUA cm^2	0.45	.002	0.42	.003
UMA cm^2	0.56	.000	0.55	.001
UFA cm^2	-0.01	.97	-0.31	.037
AFI %	-0.22	.14	-0.37	.010

Note. HGS: handgrip strength; 1RM BP: one repetition maximum in BP; BMI: body mass index; MUAC: mid-upper arm circumference; ST: skinfold thickness; BI: brachial index; ALI: arm length index; UMLR: upper arm muscle area to length ratio; UALR: upper arm area to length ratio; FM%: fat mass percentage; FM: fat mass; FFM: fat free mass; TUA: total upper arm area; UMA; upper arm muscle area; UFA: arm fat area; AFI: arm fat index.

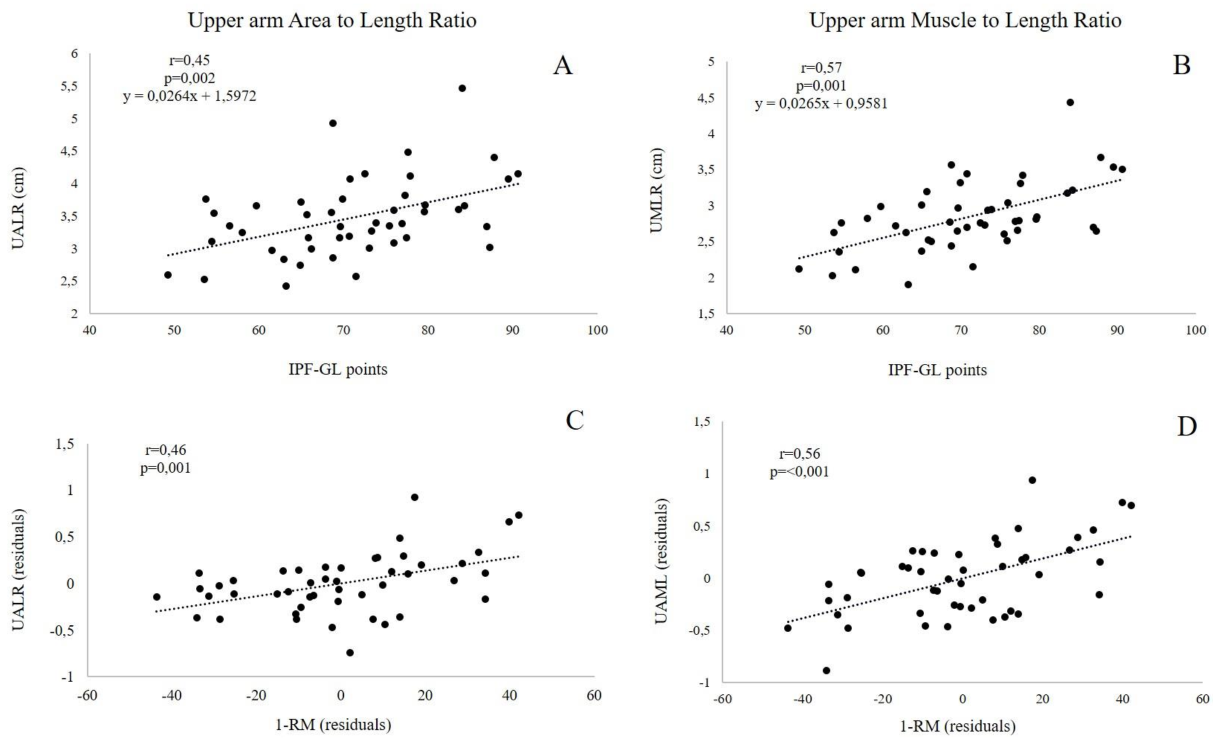

Figure 1. Scatterplot and regression line of correlation between performance (IPF-GL points) and Upper arm Area to Length Ratio (UALR, cm) (A) and Upper arm Muscle to Length Ratio (UMLR, cm) (B). Scatterplot and regression line of partial correlation between 1-RM bench press and Upper arm Area to Length Ratio (UALR, cm) (C) and Upper arm Muscle to Length Ratio (UMLR, cm) (D).

Regressions models for predicting performance

Two multiple regression models were performed, selecting IPF GL points (Table 5, first column) and 1RM BP (Table 5, second part) as the dependent variables. Both the models were significant, with an explained variance in the first model of 31.4% and in the second model of 61%. Although the selected covariates were different among the models, the only significant independent variable in both was the new index UMLR. Both models show a positive correlation between this index and performance, with higher values in athletes with a high upper arm muscle area in relation to the upper arm length. In particular, parameter B (not reported in the table) indicates that at an increase of one cm of the new index, the IPF GL point increases by 17.0 points, whereas the 1RM increases by 40.9 kg.

Table 5. Multiple linear regression models for the evaluation of the predictors of performance in powerlifting, using IPF GL points (in the left) and 1RM BP (in kg, in the right) as dependent variables.

IPF GL POINTS				
Variables	β	t	*p*-value	VIF
BMI (kg/m^2)	-0.259	- 1.179	.245	3.23
UMLR (cm)	0.786	4.245	<.001	2.30
Biacromial width (cm)	0.142	0.848	.40	1.88
FFM (kg)	-0.129	-0.532	.60	3.95
R^2	0.374			
Adjusted R^2	0.314			
p-value	0.001			
1RM BP				
Variables	β	t	*p*-value	VIF
Weight (kg)	0.426	1.836	.07	6.33
BMI (kg/m^2)	-0.253	-0.913	.37	9.03
AFI (%)	0.091	0.573	.57	2.99
UMLR (cm)	0.678	3.244	.002	5.13
R^2	0.642			
Adjusted R^2	0.608			
p-value	<0.001			

Note. BMI: Body Mass Index; UMLR: Upper arm Muscle to Length Ratio; FFM: fat free mass; AFI: Arm Fat Index.

DISCUSSION

This study aimed to investigate the role of several anthropometric variables, with a particular focus on upper limb variables, in BP performance in a cohort of Italian well-trained male powerlifters. Both length and cross-sectional areas of the upper limb were recorded using an anthropometric method. Moreover, we analyzed the possible relation between the role of two proposed indices, UMLR and UALR, as two novel possible predictors.

To establish an absolute winner (i.e., champion of champions), two main ranking scores are used among federations, the Wilks score and the International Powerlifting Federation good lift points (IPF-GL points). They estimate a score based on athlete performance (sum of maximum loads obtained among all specialties) and weight [8,9], allowing the comparison between athletes of different weight categories. In our study, the newly updated IPF-GL points were chosen as a proxy of performance (www.powerlifting.sport/rules/codes/info/ipf-formula), as the new formula introduces the differentiation between classic and equipped powerlifting, and it is considered the best formula for the evaluation of relative strength (Ferland, Allard, et al., 2020). Nevertheless, the same analyses were performed using Wilks points, and no significant differences in results were highlighted for our sample. In this study, absolute load of BP (1RM BP) statistically adjusted for athlete's weight was also analyzed, as already done by similar studies (Caruso et al., 2012; J. Keogh et al., 2005). However, there is no agreement in the literature on which parameter is the best proxy for performance in powerlifting. Some researchers adopted the 1RM and the Wilks score (Ferrari et al., 2022; J. W. L. Keogh et al., 2009), while others adopted the Wilks score alone (Lovera and Keogh, 2015). A recent study recommended the adoption of absolute maximal strength rather than relative strength (intended as the Wilks score) (Ferland, Laurier, et al., 2020) due to weaker correlations of the latter with performance. The Wilks formula was also criticized in other studies (Bishop et al., 2018; Ferland, Allard, et al., 2020) due to its lack of a scientific basis and the lack of differentiation between classic and equipped powerlifters. However, a general need for a standardized approach is reported in this field (Ferland, Allard, et al., 2020). The use of different scores as indicators of performance makes the results from different studies difficult to compare and discuss.

The role of upper limb variables in BP performance is conflicting, and several studies have reported contrasting results, especially regarding length (Hart et al., 1991; J. W. L. Keogh et al., 2007, 2008, 2009; Lovera and Keogh, 2015; Mayhew, McCormick, et al., 1993; Mayhew, Piper, et al., 1993) and HGS ([38, 40]. The International Powerlifting Federation has recently updated the Technical Rules Book, which will go into effect from January 2023 (https://www.powerlifting.sport/rules/codes/info/technical-rules). The main update concerns the elbow position relative to the shoulder during BP execution to prevent athletes from an excessive reduction in their range of movement. Consequently, the upper limb may play a more important role in the final performance, and this underlines the necessity to investigate its role in BP performance more in depth. To our knowledge, few studies have analyzed the association between the cross-sectional area of the upper limb and 1RM BP in powerlifters, but all of them found a significant association (Mayhew et al., 1991; Mayhew, Piper, et al., 1993; Reya et al., 2021). The main difficulty is that direct evaluation needs to be performed in a laboratory using specific instruments (such as ultrasonography). However, indirect evaluation seems to be promising given the results of our study and those of Mayhew et al. (Mayhew et al., 1991; Mayhew, McCormick, et al., 1993). The data collection in the field during an official competition implies that other measurements that are found to be associated with performance in BP, such as the height of the lumbar spine arch and force against the ground exerted by the feet(Reya et al., 2021), cannot be collected.

In this study, anthropometric parameters of the hand (including 2D:4D, HGS and hand length and width) were not significantly associated with BP performance. This evidence may be explained by the low heterogeneity of the analyzed sample. The mean values of HGS in our sample were higher than the average European population (males aged 35-40 years) (J. W. L. Keogh et al., 2018; Leong et al., 2016; Ruprai et al., 2016). However, HGS is not often considered in research focused on powerlifting (Haynes and DeBeliso, 2019; J. W. L. Keogh et al., 2018; Marković and Sekulić, 2006; Ruprai et al., 2016). Schoffstall found strong correlations between HGS and performance in classic powerlifting (Schoffstall, 2010), although the study did not distinguish among specialties and considered a small sample (Cronin et al., 2017). This result is thus consistent with our findings since no significant correlation was observed between performance indicators and HGS in the considered sample. However, new data need to be collected to understand whether HGS could be used as a simple and economic measure of progress to predict performance (Suazo and DeBeliso, 2021). Concerning hand dimensions (length, width), only a few studies offer comparative data (Cholewa et al., 2019; J. W. L. Keogh et al., 2007; Ruprai et al., 2016), although no correlation with performance indicators was carried out. Similarly, to our knowledge, no studies have analyzed the association between 2D:4D and performance in powerlifters, although lower values of this index, indicating a higher level of testosterone, have been found to be associated with performance in many sports, such as rugby (Bennett et al., 2010), sumo (Tamiya et al., 2012) and football (Manning and Taylor, 2001).

Anthropometric parameters concerning bodily proportions (BI, ALI) have shown negative correlations with performance, as previously observed (Ferrari et al., 2022; J. Keogh et al., 2005; Mayhew, Piper, et al., 1993; Reya et al., 2021). Conversely, biacromial width and upper limb lengths did not show strong associations with 1RM BP, in contrast to similar research (Caruso et al., 2012; Ferrari et al., 2022; J. Keogh et al., 2005; Lovera and Keogh, 2015). This discordance concerning upper limb length's role in BP performance is well known (Caruso et al., 2012; J. Keogh et al., 2005; J. W. L. Keogh et al., 2007; Rambaud et al., 2008); however, our results are consistent with the main hypothesis that a shorter upper arm would enhance BP performance (Mayhew, McCormick, et al., 1993; Mayhew, Piper, et al., 1993). Concerning bodily proportions, UMLR and UALR exhibited very strong associations with performance in both univariate and multivariate analyses. These novel indices are based on the ratio between length and body composition (total area and muscle area) of the upper arm, which is the main body part involved during BP execution (Ferland and Comtois, 2019; Padulo et al., 2015). Thus, UMLR and UALR combine the two anthropometric key elements for optimal BP performance, and their use by athletes and coaches could be advantageous in performance improvement and talent identification programs. Indeed, proportions are usually considered important parameters for talent identification (Abbott et al., 2005; Çatıkkaş et al., 2013; Ebada, 2013; Hume and Stewart, 2018; Roth, 2012), but bodily lengths are a fixed parameter that unfortunately can be just minimally modified by training, contrary to muscle mass.

The results concerning body composition from the examined sample exhibited lower FM% and higher FFM (kg) values compared to similar studies (Ferland, Laurier, et al., 2020; Ferland, St-Jean Miron, et al., 2020; Ferrari et al., 2022; J. Keogh et al., 2005; J. W. L. Keogh et al., 2007, 2009; Lovera and Keogh, 2015; Vidal Pérez et al., 2021). Body composition parameters (especially those of the upper limb) were found to be the most associated with performance in our sample. Nevertheless, the results slightly differed when using IPF-GL points or 1RM as a proxy for BP performance. With IPF-GL, parameters concerning FFM are the most relevant, as FM did not show any association. Conversely, 1RM (adjusted for weight) showed a significant positive correlation with FFM and a negative correlation with FM, thus highlighting an adverse effect of adiposity on lifted load. Similar results have been reported in other studies (Ferrari et al., 2022; Mayhew, McCormick, et al., 1993; Reya et al., 2021). Conversely, other authors underlined a moderate positive correlation between BP performance and FM% (Ferland, Laurier, et al., 2020; J. Keogh et al., 2005). These intersample differences may be related to the different samples and characteristics, and they should be adequately deepened in future studies. However, the most important role seems to be played by FFM and muscle mass, as highlighted also by the multiple regression model consistent with other studies (Ferland, St-Jean Miron, et al., 2020; Ferrari et al., 2022; J. Keogh et al., 2005; Mayhew, Piper, et al., 1993). It must be emphasized that the evaluation of body composition is a difficult task in power sports athletes, especially for powerlifters, weightlifters and bodybuilders, as they have on average a low percentage of body fat [11-13], which can introduce bias (Huygens et al., 2002). Among the various methods, we decided to estimate body composition parameters through Durnin and Womersley's equations (4 skinfolds) [28], as it was the most accurate method for power athletes, according to Huygens et al. (Huygens et al., 2002).

Strength, limitations and future perspectives

The study has several strengths and limitations. The major strength of this study is that we collected anthropometric measures on the day of the competition, thus eliminating the issue of the modification of body composition variables prior to and after the contest. However, this implied that we could not collect some variables and that cross-sectional areas of the limbs were estimated and not directly measured. Another limitation is that the cutoff between weaker and stronger athletes was deliberately set by authors as the median point among IPF-GL points of the total sample. This choice was made due to the absence of reference cutoffs in scientific literature from this field. Moreover, the sample size is relatively small and limited to a Mediterranean population of male-only participants. Nevertheless, other studies were successfully carried out under the same sampling conditions (i.e., a relatively small sample of male powerlifters belonging to a single ethnicity) (Ferland, Laurier, et al., 2020; J. Keogh et al., 2005; J. W. L. Keogh et al., 2007, 2009; Lovera and Keogh, 2015; Mayhew, McCormick, et al., 1993). However, these limitations contribute to making this research a preliminary study due to the need for a more inclusive population in terms of sample size, sex, and ethnicity. A future extension of the study may include an enlargement of the sample size and the inclusion of other populations other than the Mediterranean population. Other future perspectives may enlarge the study to a female group of athletes, include other powerlifting specialties (i.e., deadlift and squat) and add other anthropometric and BP technique variables.

CONCLUSIONS

In conclusion, the results of this preliminary study underlined that body composition variables, especially cross-sectional areas of the upper limb, represent important predictive parameters for BP performance, evaluated through both IPF-GL points and 1RM adjusted for weight. Particularly important were the two newly proposed indices, which represent the ratio between upper arm areas and length. Indeed, this preliminary provides a better understanding of the factors that might influence performance in BP and suggests that UALR and UMLR could be useful estimators of the total and muscular upper arm areas required in relation to the individual upper arm length.

Thus, the use of this evidence during the preparation of a powerlifter would allow coaches and athletes from all categories to accomplish predictable results by operating on their body composition.

AUTHORS CONTRIBUTIONS

Conceptualization, N. R., L. Z., S. T., and F. M.; methodology, A .P., E. B., N. L., and S. T.; formal analysis, N. R., L. C., and N. L.; investigation, A. P., E. B., and L. C.; data curation, N. R., N. L., and L. C.; writing—original draft preparation, A. P., and N. R.; writing—review and editing, A. P., N. R., L. C., N. L., F. M., L. Z., S. T., and E. B.; visualization, F. M., N. L., L. Z., and S. T.; supervision, F. M., N. R., and L. Z.; project administration, A. P., N. R. All authors have read and agreed to the published version of the manuscript.

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