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Research Article

VALIDITY OF FAT-FREE WEIGHT EQUATIONS FOR PREDICTING ISOKINETIC PEAK TORQUE IN YOUNG WRESTLERS

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Abstract

The purpose of this investigation was to determine the validity of fat-free weight (FFW) equations derived on non-athletic children and adolescents for predicting concentric, isokinetic peak torque (PT) in young wrestlers. Seventy-one male wrestlers (mean age ± SD = 12.6 ± 1.1 years) volunteered to perform concentric, isokinetic leg extensions at 180 and 300°·s-1 on a Cybex II dynamometer to measure PT (Nm) and underwater weighing to determine FFW. Predicted PT values at 180 and 300°·s-1 were also estimated from FFW using the following equations:

EQ1: Leg Extension PT at 180°·s-1 in Nm = 3.3(FFW) – 54.4

EQ2: Leg Extension PT at 300°·s-1 in Nm = 2.4(FFW) – 38.5

The validity of the equations was determined by examining the constant error (CE), correlation coefficient (r), standard error of estimate (SEE), and total error (TE) values for measured PT versus predicted PT. There were significant ($p < 0.05$) mean differences (CE) between the measured PT (mean ± SD: 180°·s-1 = 69.3 ± 23.7 Nm; 300°·s-1 = 44.9 ± 16.9 Nm) and predicted PT (180°·s-1 = 79.6 ± 33.7 Nm; 300°·s-1 = 58.9 ± 24.5 Nm) at 180 and 300°·s-1. The r, SEE, and TE values at 180°·s-1 were 0.92, 9.5 Nm, and 18.3 Nm, respectively. The r, SEE, and TE values at 300°·s-1 were 0.92, 6.6 Nm, and 17.8 Nm, respectively. Although measured PT and predicted PT were highly correlated at both 180 and 300°·s-1, the TE values associated with the equations ranged from 26.4 to 39.6% of the mean measured PT values. It is likely that the magnitude of the errors was due to the fact that the equations cross-validated in the present study were derived on a non-athletic sample that included older subjects with greater PT per unit of FFW than the current sample of young wrestlers.

Keywords: athletes, strength, fat-free weight

Introduction

Increases in strength during childhood and adolescence have been shown to coincide with increases in body weight (BW) and fat-free weight (FFW) (1,3,7,20,21). Specifically, previous studies (1,7,9) have reported significant correlations for BW (r = 0.82 to 0.92) and FFW (r = 0.92 to 0.96) versus concentric, isokinetic peak torque (PT) at various velocities. Examination of the relationships for BW and FFW versus isokinetic PT can provide information regarding the neuromuscular mechanisms that underlie age-related changes in strength for athletes and non-athletes. For example, studies by Housh et al. (9-12) and Weir et al. (33) have reported an "age-effect" for isokinetic PT for extension and flexion movements at the knee, elbow, and shoulder joints in young male athletes (8.1 – 13.9 years) and high school wrestlers (14.2 – 18.4 years). The "age-effect" was characterized by age-related increases in strength that could not be accounted for by changes in BW, FFW, and/or estimated total skeletal muscle mass (MM). It has been suggested that the "age-effect" for isokinetic PT in athletes may be due to neural maturation and/or age-related increases in MM per unit of FFW (4,8,11-13,30,34). In a study of young (10-14 years), non-athletic males and females, however, De Ste Croix et al. (5) reported that age-related increases in leg extension PT could be accounted for by increases in BW and height (HT). Thus, unlike the findings of Housh et al. (8,11-13) for athletes, there was no "age-effect" for leg extension PT in non-athletes (5). In conjunction, these studies (5,8,11-13) suggest that there may be differences between athletes and non-athletes with regard to the development of strength during childhood and adolescence.

A recent study by Almuzaini (1) derived regression equations to predict concentric, isokinetic leg extension PT at 180 and 300°·s-1 from FFW in a sample of 44 non-athletic children and adolescents. Given the potential differences between athletes and non-athletes with regard to the development of strength across age (5,8,11-13), these equations (1) that were derived on non-athletes, may not accurately estimate PT in athletes. Furthermore, examination of the accuracy of these equations (1) may provide additional information regarding the relationships between FFW and strength development in athletes versus non-athletes. Therefore, the purpose of this investigation was to determine the validity of the equations of Almuzaini (1), that were derived on non-athletic children and adolescents, for predicting concentric, isokinetic leg extension PT in young wrestlers.

Methods

Subjects

Seventy-one male wrestlers (mean age ± SD = 12.6 ± 1.1 years) volunteered for this study (Table 1). In addition to wrestling, 66 of the 71 subjects also participated in one or more other organized youth sports program. Twenty-five subjects had participated in three or more organized sports within the last year. The laboratory testing was performed during preseason training and 1-2 weeks prior to the beginning of the competitive wrestling season. The study was approved by the Institutional Review Board for Human Subjects, and written informed consent was obtained from the subjects and their parents prior to testing.

Experimental Approach to the Problem

The present study used a cross-validation design to determine the validity with which two regression equations, that were derived on non-athletes (Table 2), could predict isokinetic PT in a sample of young wrestlers. The predicted PT values from the equations were statistically compared to measured PT values from concentric, isokinetic strength testing.

Isokinetic Peak Torque

Concentric, isokinetic extension PT for the dominant leg (based on kicking preference) was measured using a calibrated Cybex II dynamometer at 180 and 300°·s-1. The subjects were positioned and stabilized using the procedures recommended by the manufacturer (14). Three to four submaximal warm-up trials were followed by three consecutive maximal efforts, with the highest PT value selected as the representative score. The PT values were not gravity corrected and damping on the Cybex II was set at 2. Previous test-retest reliability data from our laboratory for leg extension PT at velocities of contraction ranging from 30-300°·s-1 indicated that for young adult male subjects (n = 20) measured 2 to 7 days apart, the intraclass correlations (R) ranged from 0.85 to 0.97, with standard error of measurement values that were <5.0% of the means. These reliability coefficients are consistent with those from a number of previous studies reviewed by Perrin (24).

Underwater Weighing

Body density (BD) was assessed from underwater weighing (UWW), with correction for residual lung volume (RV) using the oxygen dilution method of Wilmore (35). Residual lung volume was determined on land with the subject seated in a position similar to that assumed during UWW. The average of similar scores (within 100 ml) from two to three trials was used as the representative RV. Underwater weight was measured in a hydrostatic weighing tank in which a metal swing seat was suspended from a Chatillon 9 kg scale. The average of the three highest values from 6 to 10 trials was used as the representative underwater weight (31). Percent body fat (% fat) was estimated from BD using the age-specific conversion constants of Lohman (19), and FFW was derived mathematically.

Previous test-retest reliability data for UWW from our laboratory indicated that for young adult male subjects (N = 16) measured 24-72 hours apart, the intraclass correlation (R) was 0.98, with a standard error of measurement of 0.9% fat. These values are comparable to those reported by Thomas and Cook (29) and Jackson et al (15). Furthermore, the UWW procedures used in the present investigation were standardized as a part of an interuniversity study (32) and found to be highly consistent with those from three other laboratories. BW and HT were measured using a physician's scale and wall scale with Broca plane, respectively.

Statistical Analyses

The equations of Almuzaini (1) were cross-validated in the present study (Table 2). The cross-validation analyses of these equations (Table 3) were based on an evaluation of the measured PT versus predicted PT from calculation of the constant error (CE = mean difference for measured PT – predicted PT), r, standard error of estimate), total error , and the similarity between the standard deviations of measured PT and predicted PT. In addition, the relationship between the CE and the average of measured PT and predicted PT was described using the method of Bland and Altman (2) (Figures 1 and 2). Furthermore, simple linear regression was used to derive equations to predict PT at 180 and 300°·s-1 from FFW for the sample of young wrestlers in the present study (Table 4). An alpha of $p < 0.05$ was used for statistical significance for all mean comparisons.

Results

Descriptive data of the subjects are presented in Table 1. Table 2 includes the PT equations of Almuzaini (1) that were cross-validated in the present study. Table 3 presents the cross-validation information for the equations in this study. The r, CE, SEE, and TE values at 180°·s-1 were 0.92, -10.30 Nm, 9.5 Nm, and 18.3 Nm, respectively. The r, CE, SEE, and TE values at 300°·s-1 were 0.92, -14.04 Nm, 6.6 Nm, and 17.8 Nm, respectively. The TE values at 180 and 300°·s-1 represent 26.4 and 39.6% of the mean measured PT values, respectively. In addition, there were significant mean differences between measured PT and predicted PT at both 180 and 300°·s-1. The relationship between the CE and the average of measured PT and predicted PT, as shown in the Bland-Altman (2) plots, was r = -0.67 at 180°·sec-1 (Figure 1) and r = -0.66 at 300°·sec-1 (Figure 2). The standard deviation (SD) values for measured and predicted PT were 23.7 and 33.7 Nm at 180°·s-1 and 16.9 and 24.5 Nm 300°·s-1, respectively.

The simple linear regression equations derived in the present study to predict PT at 180 and 300°·s-1 from FFW in the current sample of young wrestlers are shown in Table 4. At 180°·s-1, the r and SEE values were 0.92 and 9.5 Nm, respectively. At 300°·s-1, the r and SEE values were 0.92 and 6.6 Nm, respectively. These SEE values represented 13.7 and 14.7% of the mean measured PT values.

Discussion

The mean values for the physical characteristics (HT, BW, % fat, and FFW) of the subjects in the present study (Table 1) were comparable to those previously reported for young wrestlers (26,37). In addition, the mean HT and BW of the present sample of young wrestlers corresponded closely to the 50th percentiles of a national representative sample of 12 year-old boys from The National Center for Health Statistics (22). Therefore, when compared to standard growth curves for children in the United States (22), the athletes in the present study were similar in HT and BW to boys of comparable ages.

There are limited isokinetic peak torque data available for young athletes. Table 5 provides concentric isokinetic, leg extension data for non-athletes (1,7,17,27), as well as track athletes (30), basketball players (6), and soccer players (16,36) for comparison with the young wrestlers in the present study. The mean values for PT at 180 and 300°·s-1 from these previous studies (1,6,7,9,16,17,25,27,30,36) were all within one standard deviation of the means for the present sample of young wrestlers (Table 5). These findings indicated that there is substantial overlap in PT within this general age group, for non-athletes and athletes in various sports.

The results of the cross-validation analyses in the present study were evaluated based on the following criteria: (a) the mean value for measured PT and predicted PT should be comparable (i.e. non-significant CE value) (18); (b) measured PT and predicted PT should be highly correlated; (c) the SD values of measured PT and predicted PT should be similar (18); (d) a low SEE value is desirable (18); (e) there should be close agreement between TE and SEE (28); (f) there should be no significant relationship between the CE and the mean of measured PT and predicted PT (2); and (g) the slope coefficients for the equations cross-validated in the present study should be similar to those for the regression of FFW and PT in the current sample of young wrestlers (23).

The results of the present study indicated that the equations cross-validated (Table 2) in the present study significantly over-predicted PT at 180 (CE = -10.3 Nm) and 300°·s-1 (CE = -14.0 Nm). These CE values represented 15 and 31% of the means of the measured PT values at 180 and 300°·s-1, respectively. Thus, as a percent of the mean values, the equation that predicted PT at 300°·s-1 resulted in a substantially greater mean difference between measured PT and predicted PT than the equation that predicted PT at 180°·s-1.

Figures 1 and 2 describe the relationships between the CE and average peak torque ((measured PT + predicted PT)/2) at 180 and 300°·s-1 using the method of Bland and Altman (2). The correlation coefficients for these relationships were r = -0.67 and r = -0.66 at 180 and 300°·s-1, respectively. In general, the absolute CE values were greater at the high end of the average peak torque distribution and, in most cases, the equations cross-validated in the present study over-predicted PT at 180 (75% of subjects over-predicted) and 300°·s-1 (93% of subjects over-predicted).

The cross-validation validity coefficients (r) for measured PT versus predicted PT were 0.92 at both 180 and 300°·s-1 (Table 3). These findings were consistent with previous studies (1,9) that have found correlations between FFW and PT that ranged from r = 0.92 – 0.96 at 180°·s-1 and r = 0.92 – 0.93 at 300°·s-1. For example, in a sample of young male athletes that ranged in age from 8.1 to 13.9 years, Housh et al. (9) also reported correlations of r = 0.92 between FFW and PT at both 180 and 300°·s-1. In addition, Almuzaini (1) found correlations of r = 0.93 – 0.96 between FFW and PT at 180 and 300°·s-1 in a sample of non-athletic adolescent males. These current findings, as well as those of Housh et al. (9) and Almuzaini (1), indicated that FFW and PT are highly correlated in both young athletes and non-athletes.

The SD values for predicted PT at 180 and 300°·s-1 were 10.0 and 7.6 Nm larger than the SD values of the measured PT, respectively. This indicates that the error associated with predicted PT values would be greatest at the extremes of the PT distribution. As suggested by Lohman (18), a valid prediction equation results in similar predicted SD values compared to measured SD values. In the present study, the differences between the SD values for the measured and predicted PT at 180 and 300°·s-1 represented 42 and 45% of the SD values of the measured PT, respectively.

The cross-validation SEE values at 180 and 300°·s-1 were 9.5 and 6.6 Nm, which represented 13.7 and 14.7% of the mean PT values, respectively. Thus, with respect to the SEE, the equations yielded similar accuracy at 180 and 300°·s-1. In addition, the TE values at 180 and 300°·s-1 were 18.3 and 17.8 Nm, which represented 26.4 and 39.6% of the mean PT values, respectively. Therefore, the cross-validation TE values indicated that the FFW equations derived on non-athletes (1) did not accurately predict PT in the present sample of young wrestlers.

The slope coefficients for the equations cross-validated in the present study (Table 2) and the equations derived from young wrestlers (Table 4) to predict PT from FFW were 3.3 and 2.13 at 180°·s-1 and 2.4 and 1.52 at 300°·s-1, respectively. These results demonstrated that the non-athletes of Almuzaini (1) exhibited greater changes in PT per kg change in FFW than the current sample of young wrestlers. In addition, as shown in Figures 3 and 4, the non-athletes generally exhibited greater PT per kg of FFW at both 180 and 300°·s-1. Although these findings seem counterintuitive, it is possible that the greater slope coefficients for the equations of Almuzaini (1) were due to the wider age range and greater mean age of the non-athletic sample (mean age = 14.6 years; range = 11-19 years) compared to the current sample of young wrestlers (mean age = 12.6 years; range = 11-16 years). Previous studies (8,11-13,30,34) have shown increases in strength across age during adolescence that cannot be accounted for by changes in BW, FFW, and/or estimated total skeletal muscle mass (MM). Therefore, it is possible that the greater PT values per kg of FFW associated with the older, non-athletic sample may be attributable to this age-related increase in strength independent of changes in FFW. It has been suggested that the physiological mechanisms underlying this "age-effect" for strength increases may include an increase in MM per unit of FFW (9) and/or neural maturation (4,8,9,11-13,30,34). Thus, it is possible that the older subjects in the non-athletic sample of Almuzaini (1) had greater MM per unit of FFW and/or were more neutrally mature than the young wrestlers and, therefore, produced more PT per unit of FFW. This may account for the fact that the PT versus FFW slope coefficients for the non-athletes were greater than those for the sample of young wrestlers (Figures 3 and 4). Future studies could examine this hypothesis by comparing the relationships between PT and FFW in samples of athletes versus non-athletes that are more similar in age range than the samples in the present study. In addition, future studies should investigate the relationship between PT and FFW in athletes other than wrestlers.

In summary, the FFW equations derived on non-athletes (1) significantly over-predicted PT at both 180 and 300°·s-1 in the current sample of young wrestlers. These findings were likely due to the fact that the equations cross-validated in the present study were derived on a sample that included older subjects with greater PT per unit of FFW than the young wrestlers in the present study. In addition, the cross-validation TE values at 180 and 300°·s-1 represented 26.4 and 39.6% of the mean PT values, respectively. Therefore, the results of this study do not support the use of the FFW equations of Almuzaini (1) that were derived on non-athletes for predicting PT in young wrestlers.

Practical Applications

The cross-validation analyses indicated that the equations to predict PT from FFW of Almuzaini (1) that were derived on non-athletes resulted in large CE, SEE, and TE values when applied to the current sample of young wrestlers. Thus, equations derived on non-athletes are not recommended for predicting PT from FFW in young athletes.

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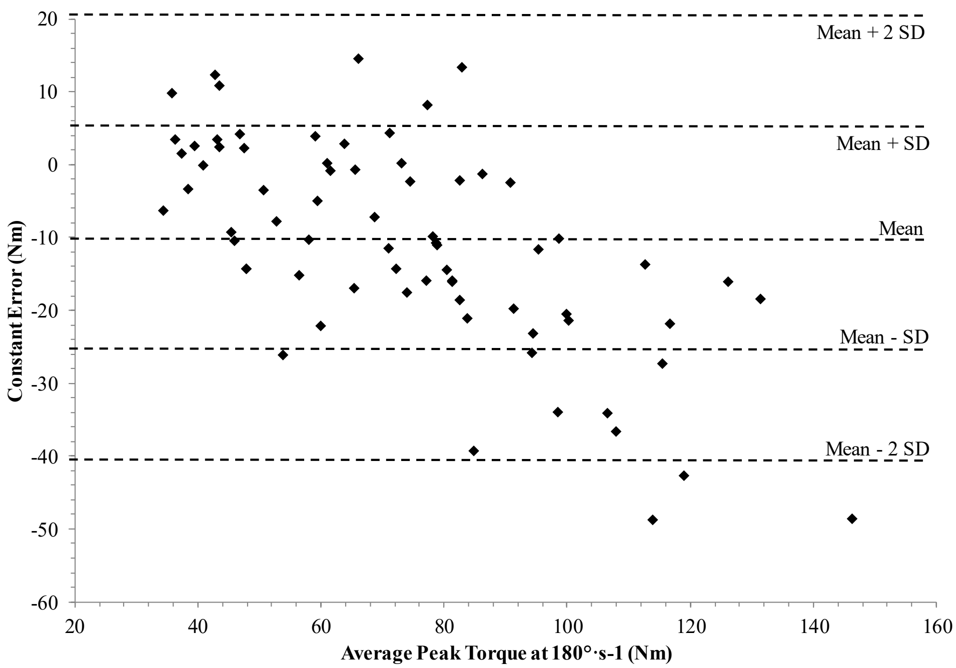

Figure 1. The relationship between constant error (CE) and average PT ((measured PT + predicted PT)/2) at 180°·sec^{-1} in the current sample of young wrestlers (r = -0.67).

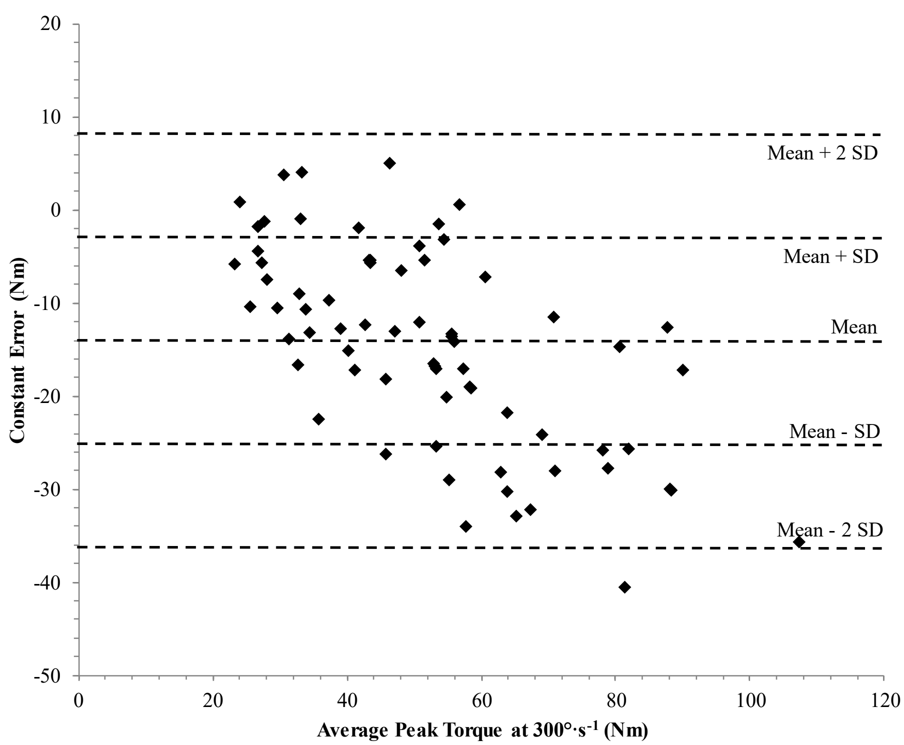

Figure 2. The relationship between constant error (CE) and average PT ((measured PT + predicted PT)/2) at 300°·sec^{-1} in the current sample of young wrestlers (r = -0.66).

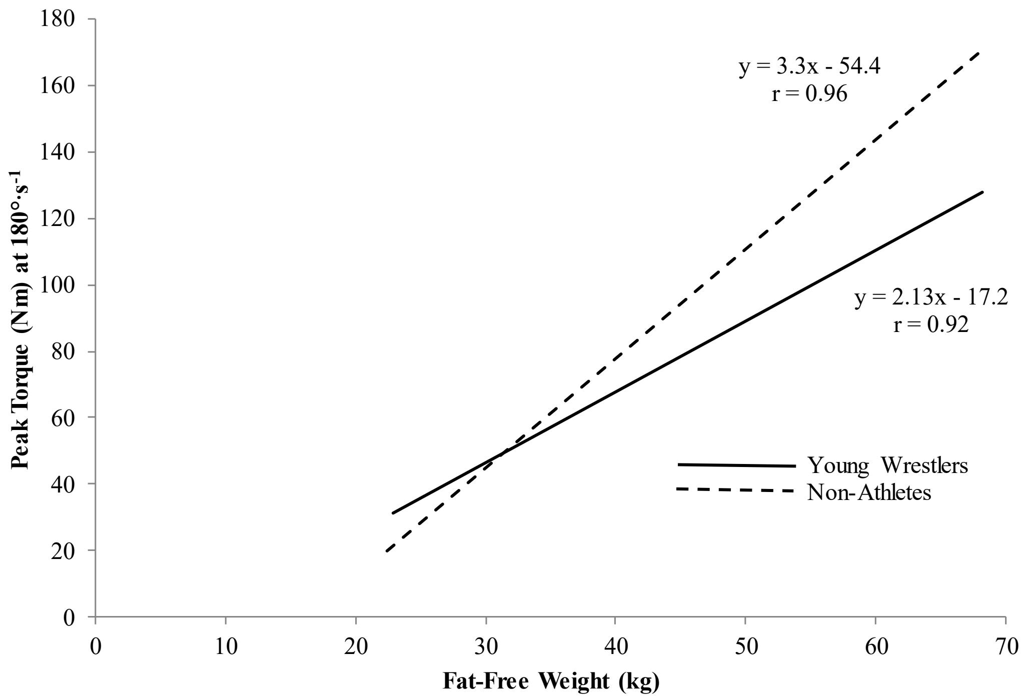

Figure 3. Peak torque (Nm) at 180°·sec^{-1} vs. fat-free weight (kg) in the current sample of young wrestlers (r = 0.92) and non-athletes of Almuzaini (1) (r = 0.96). The solid regression line reflects the equation derived on the current sample of young wrestlers (Table 4) and the dashed regression line reflects the equation of Almuzaini (1) that was derived on non-athletes (Table 2).

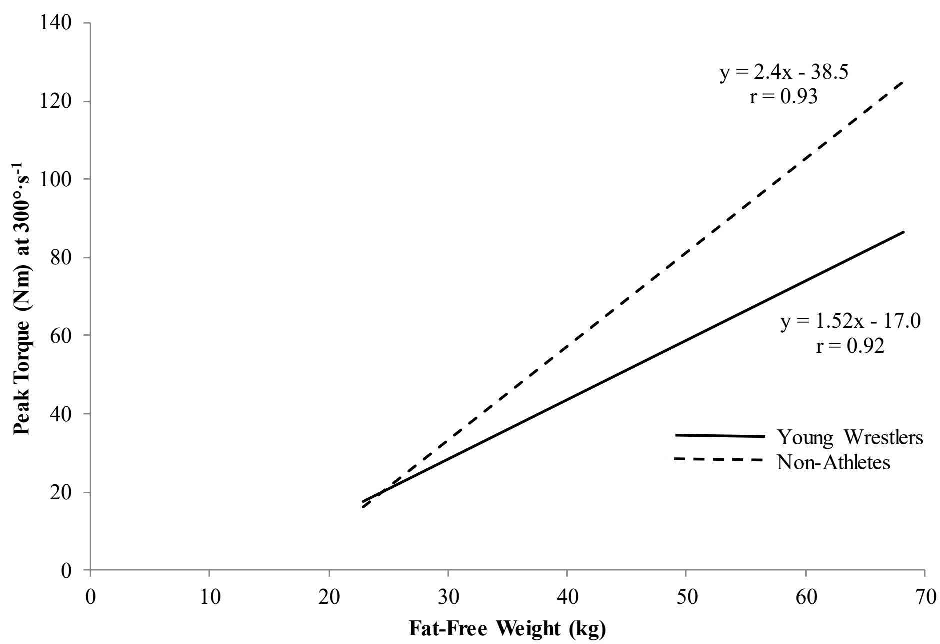

Figure 4. Peak torque (Nm) at 300°·sec^{-1} vs. fat-free weight (kg) in the current sample of young wrestlers (r = 0.92) and non-athletes of Almuzaini (1) (r = 0.93). The solid regression line reflects the equation derived on the current sample of young wrestlers (Table 4) and the dashed regression line reflects the equation of Almuzaini (1) that was derived on non-athletes (Table 2).

Table 1. Characteristics of the young wrestlers (*N* = 71).

Variable	M ± SD	Range
Age (yrs)	12.6 ± 1.1	11.1 - 16.1
Body Weight (kg)	45.8 ± 11.6	27.6 - 87.8
Height (cm)	153.6 ± 10.5	134.8 - 181.1
Fat-Free Weight (kg)	40.6 ± 10.2	22.8 - 68.2
Peak Torque at 180°·s^{-1} (Nm)	69.3 ± 23.7	31.2 - 142.0
Peak Torque at 300°·s^{-1} (Nm)	44.9 ± 16.9	20.3 - 89.5

Table 2. Equations to predict peak torque (PT) from fat-free weight (FFW) that were cross-validated.

Eq. #	Source	Equation	r	SEE
1	Almuzaini (1)	PT (Nm) at 180°·s^{-1} = 3.3 (FFW) - 54.4	0.96	8.4
2	Almuzaini (1)	PT (Nm) at 300°·s^{-1} = 2.4 (FFW) - 38.5	0.93	8.0

Table 3. Cross-validation of equations on young wrestlers (*N* = 71).

Eq. #	Source	Predicted PT (M ± SD)	t	CE	r	intercept	slope	SEE	TE
1	Almuzaini (1)	79.6 ± 33.7	-5.8	-10.3	0.92	17.9	0.65	9.5	18.3
2	Almuzaini (1)	58.9 ± 24.5	-10.7	-14.0	0.92	7.50	0.64	6.6	17.8

Note: The mean, SD, CE, SEE, and TE values are expressed in Nm.

Table 4. Equations derived in the present study to predict peak torque from fat-free weight in young wrestlers (*N* 71).

Eq. #	Equation	r	SEE
1	PT (Nm) at $180°\cdot s^{-1}$ = 2.13 (FFW) - 17.2	0.92	9.5
2	PT (Nm) at $300°\cdot s^{-1}$ = 1.52 (FFW) - 17.0	0.92	6.6

Table 5. Concentric, isokinetic peak torque for leg extension in athletes and nonathletes.

Source	Age (yrs)	*N*	Group	Velocity ($°\cdot s^{-1}$)	PT (Nm)
Present Study	12.6 ± 1.1	71	Wrestlers	180	69 ± 24
				300	45 ± 17
Almuzaini (1)	12.3 ± 0.5	18	Nonathletes	180	48 ± 9
				300	34 ± 7
Gerodimos et al. (6)	12.3 ± 0.1	30	Basketball players	180	76 ± 17
Gross et al. (7)	13.0 ± 3.5	4	Nonathletes	180	46 ± 22
Housh et al. (9)	12.5 ± 0.3	28	Wrestlers	180	47 ± 13
				300	34 ± 10
Kellis et al. (16)	13.0 ± 0.4	13	Soccer players	180	75 ± 11
Larsson et al. (17)	12.3 ± 0.3	11	Nonathletes	180	57 ± 12
Ramos et al. (25)	11.8 ± 0.4	15	Trained	180	88 ± 15
Seger and Thorstensson (27)	11.0	10	Nonathletes	180	52 ± 13
Thorland et al. (30)	11.9 ± 1.1	12	Sprinters	180	63 ± 22
				300	44 ± 11
Thorland et al (30)	12.0 ± 0.9	12	Middle distance	180	49 ± 12
			runners	300	35 ± 6
Zakas et al. (36)	13.0 ± 0.5	16	Soccer players	180	74 ± 9
				300	52 ± 7

Note: Values are mean or mean ± SD. PT = peak torque.