ANTHROPOMETRIC MEASURES, CROSS-SECTION AREA AND MUSCLE MASS AS PREDICTORS OF ONE-REPETITION MAXIMUM OF MUSCLE CONTRACTION

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Introduction

Muscular strength has been mostly defined as the ability to exert force on an external object or resistance (Stone, 1993). Sports such wrestling, track-and-field events or weightlifting often require use of maximal muscular strength production in its performance (Siff, 2001). Sport scientists and practitioners are unable to change athlete's genetic characteristics through sport training, while muscular strength can be improved, especially through resistance training, which gives support to future researches in this type of training (Suchomel et al., 2016). If the main goal (i.e. improving muscular strength) of resistance training is put aside, its benefits are numerous. These benefits include increase in bone mass, reduced blood pressure, increase muscle and connective tissue cross-sectional area, reduced body fat, and it may relive low back pain if is used correctly (Kraemer et al., 2002). Muscle hypertrophy (grow of skeletal muscle) and gains in strength production (neuro-muscular adaptations) are fields of interest not only for athletes who wants to upgrade performance, but also for recreationalists who simply wants to promote its body composition or to increase their capacity to perform tasks which require muscular strength (Bird et al., 2005).

General factors that influence production of maximal muscular strength are morphological (i.e. muscle cross-sectional area, architecture and anthropometric factors) and neural factors (musculo-tendinous stiffness, motor unit recruitment, rate coding, motor unit synchronization, and neuromuscular inhibition) (Suchomel et al., 2018). Morphological factors are often neglected in importance of production of muscular strength, but they play very important role in its production. Related to this are the anthropometric factors such as body mass, height and segment lengths. An individual's anthropometry will contribute to their capacity to produce muscular strength and force, so this needs to be considered with resistance training. Studies suggest that for strength-based resistance training sports such as powerlifting and weightlifting anthropometry plays an important role in performance (Keogh et al., 2007; Lovera and Keogh, 2015; Fry et al., 2006; Storey and Smith, 2012; Reya et al., 2019; Cholewa et al., 2019).

To our knowledge studies that have examined influence of different morphological variables (derived from electrical bioimpedance, anthropometry and ultrasound diagnostics) on muscular strength are very rare, in single-joint and multi-joint exercises. With the above backdrop in mind, the present paper aims to assess the predictor contribution of different morphological variables in the manifestation of muscle strength in biceps curl and parallel squat exercises. Expectations are that the obtained experimental data could significantly contribute to the understanding of influence different morphological factors on muscular strength production, what is of the most significance for programing resistance training, either for athlete or recreationalists.

Methods

This transversal research included 15 subjects (8 males and 7 females, mean age 23.8 ± 1.4 years), student of the Faculty of sports and physical education. All subjects had no previous resistance training experience and prior to participation signed a written informed concept form which explained experimental procedures and potential risks. Study was approved by Institutional Ethical Committee (protocol ID: 2316/19-2) and realized according to Declaration of Helsinki.

Muscle strength (one repetition maximum – 1RM) for arms was assessed by the biceps curl (BC) test on a Scott bench, while parallel squat test (PS) on Smith rack was use for leg strength, according to the standard procedures (Beachle & Earl, 2008). The test was preceded by a 10-minute warm-up (light running and warm-up exercises) followed by 8-10 repetitions of exercise with a load of ~ 50% RM and 2-3 repetitions of exercise with a load of 60-80% RM. Each subject had 5 attempts to lift the maximum weight. The pauses between trials were set at 3 minutes (Beachle & Earl, 2008).

Body height (BH) and body weight (BM) were determined using a portable Martin anthropometer (Siber-Hegner, Switzerland) and a digital scale, respectively. Body composition variables, including total (SMM) and regional muscle mass of the dominant arm / leg (arm - ASMM, leg - LSMM) were measured by In-Body 720 (Biospace Co., Seoul, Korea) using Direct Segmental Multi frequency–Bioelectrical Impedance Analysis (DSM–BIA method).

Muscle size was determined by a ultrasound diagnostics (Siemens, Erlangen, Germany), using the 2D ellipse diagnostic method, with a 7.5 MHz linear probe. The anatomical cross – section area (CSA) of the elbow flexor (biceps brachii – BB) and 4 knee extensors muscles were evaluated. Total quadriceps femoris (QF) CSA was determined as the sum of the CSA of all four extensor muscles in the knee joint (rectus femoris + vastii muscles). The entire ultrasound diagnosis was performed according to the standard procedure (Zhang, Ng, Lee, & Fu, 2014; Perkisas et al., 2018).

Following descriptive statistics (arithmetic mean - AM, standard deviation - SD, minimum - MIN, maximum - MAX), Pearson 's correlation coefficient was used to determine the relationship between 1RM test of both exercises and morphological variables. According to Hopkins, Marshall, Batterham & Hanin (2009) r coefficients were classified as trivial (0.00-0.09), small (0.10-0.29), moderate (0.30-0.49), large (0.50-0.69), very large (0.70-0.89), almost perfect (0.90-0.99) and perfect (1.00). In the further procedure, in order to extract the most important predictor model for 1RM, backward linear regression was applied. Statistical analysis was processed using the IBM SPSS Statistics software package (version 21, SPSS Inc, Chicago, IL, USA). $p \leq 0.05$ was taken as a statistically significant determinant.

Results

The results of descriptive statistics are shown in Table 1.

Table 1. Descriptive statistics for tested variables

Variables	AM	SD	MIN	MAX
BH (m)	1,75	0,08	1,60	1,89
BM (kg)	70,13	12,68	50,0	100,0
SMM (kg)	33,05	7,23	20,10	45,10
ASMM (kg)	3,25	0,98	1,67	5,15
LSMM (kg)	9,19	1,93	5,59	11,96
CSA BB (mm)	20,29	6,18	12,80	33,70
CSA QF (mm^2)	1265,53	292,78	763,00	1786,0
1RM BC (kg)	26,80	11,86	11,00	53,00
1RM PS (kg)	96,67	23.65	65,00	145,00

Legend: BH – body height, BM – body mass, SMM – whole body skeletal muscle mass, ASMM – arm muscle mass, LSMM – leg muscle mass, CSA BB – biceps brachii cross-section area, CSA QF – quadriceps femoris cross-section area, 1RM BC – biceps flexion one-repetition maximum section area, 1RM PS – parallel squat one-repetition maximum

A significant positive correlation was observed between arm strength and all morphological variables (table 2). Further regression analysis singled out the variable CSA of BB as the most important predictor of strength for BC exercise, which explains about 87% of 1RM scores (adjusted $R^2 = 0.873$, $p < 0.01$). The equation for the model was: 1,801 x BBCSA - 9,733 (figure 1).

Table 2. Correlation matrix between morphological variables and 1RM for biceps curl exercise

Variables	**1RM biceps curl**	
	r	***p***
Body height (m)	,514	,050
Body mass (kg)	,623	,013
Skeletal muscle mass (kg)	,873	,000
Arm muscle mass (kg)	,906	,000
Cross-section area BB (mm)	,939	,000

Legend: 1RM – one-repetition maximum; BB – biceps brachii

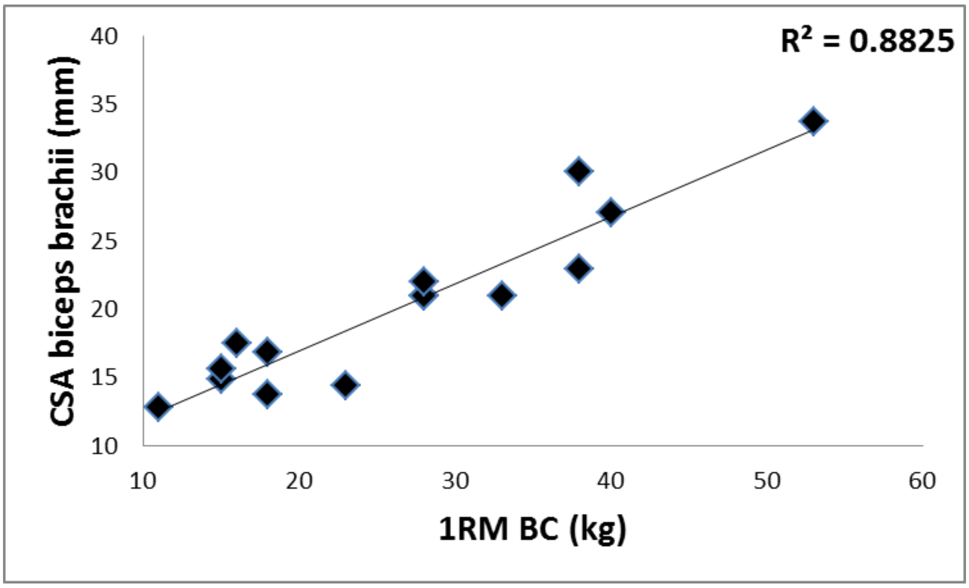

Figure 1. 1RM prediction for biceps curl (BP) exercise based on the cross-section area (PP) of the biceps brachii muscle

Also, squat strength was significantly positively correlated with all morphological variables (table 3). In further regression analysis, the best model extracted the variables LSMM, BM and BH as the most significant predictors of 1RM results for PS exercise (adjusted $R^2 = 0.793$, $p < 0.01$). The model with the above three variables explained about 79% of the 1RM results for the squat exercise, with the equation: 11,060 x LSMM + 1,676 x BM - 292,730 x BH + 388,948 (figure 2).

Table 3. Correlation matrix between morphological variables and 1RM for parallel squat exercise

Variables	**1RM parallel squat**	
	r	***p***
Body height (m)	,512	,051
Body mass (kg)	,742	,002
Skeletal muscle mass (kg)	,823	,000
Leg muscle mass (kg)	,784	,001
Cross-section area QF (mm^2)	,718	,003

Legend: 1RM – one-repetition maximum; QF – quadriceps femoris

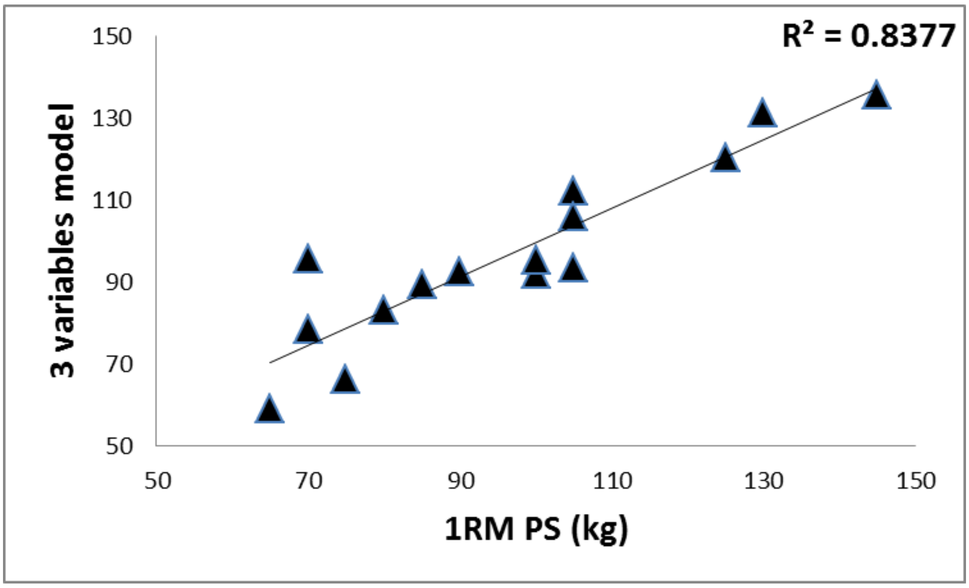

Figure 2. 1RM prediction for parallel squat (PS) exercise based on a model with three predictor variables (NSMM, TM, TV)

Discussion

The goals of the present study were to assess the predictor contribution of different morphological variables in the manifestation of muscle strength in biceps curl and parallel squat exercises. The results of correlative analysis indicate that 1RM of both exercises were significantly related to all morphological variables. However, based on the regression analysis, the main finding revealed that: 1) biceps brachii CSA is most important factor of arm strength (biceps curl 1RM), 2) various morphological components, including body mass, height and muscle mass of lower extremities, are the main determinants of squat strength.

The level of maximum muscle strength is influenced by numerous neuromuscular and morphological factors such as muscle size, architecture, activation and longitudinal dimensions (Narici et al., 1996; Jaric, 2002; Trezise & Blazevich, 2019). Numerous researches showed that muscle CSA is one the most important factors in strength performance and can explain around 60% of the inter-individual variability in strength in different populations (Trezise et al., 2016; Trezise & Blazevich, 2019). Different strength training approaches induce different effects. Researches showed that strength training using single joint exercises in compare to multi joint exercises produce different effects, where multi joint exercises produce higher neural challenge and seems to be more efficient for improving muscle strength as well as maximal oxygen consumption (Paoli et al. 2017). In addition, when the goal is to improve body composition or local muscle mass, an exercise program based on single joint exercises can be a possible solution (Paoli et al. 2017).

The present results, show that in single joint movements such as biceps curl exercise, the main factor for strength performance is CSA of the active muscle. Considering that this is simple single joint movement, high level of correlation (r=0.93) was expected. Previous researches on this topic generally showed that maximum arm strength was associated with the increase in arm CSA (Ikai & Fukunaga, 1970; Schantz et al. 1983) as well that level of correlation between biceps brachii CSA and biceps curl exercise strength is medium high to high (Lustosa et al. 2019).

Barbell back squat, as a multi joint knee dominant exercise, require total body effort for maximum performance. This is the reason why total and lower-body muscle mass have higher correlation with squat 1RM (r=0.82) than isolated quadriceps cross-sectional area (r=0.718). This is in line with previous reports who showed that thigh muscle cross-sectional area has weak correlation with back squat strength in the Olympic lifters (r = 0.42) and power lifters (r = 0.12) and moderate correlation in the sample of bodybuilders (r = 0.70) (Cadore et al., 2012; DiNaso et al. 2012; Ferland, St-Jean Miron, Laurier, & Comtois, 2020). As well, numerous previous reports assessed quadriceps performance in different single joint conditions. Trezise & Blazevich (2019) reported that maximum isometric torque during knee extension was most strongly associated with the change in quadriceps muscle size (r = 0.36-0.45), while Trezise et al (2016) showed that around 72% of peak quadriceps torque can be explained by cross-sectional area, agonist and antagonist EMG muscle activity, and percent voluntary activation during knee extension. Interstingly, altough body height showed positive correlation with leg 1RM, further analysis revealed that this relationship reverses and that longitudinal dimensions have negative impact on squat perfomance. It has been shown that participants who are taller (or have longer segment lenghts), have longer resistance moment arms (Vigotsky et al., 2019). In line with this, we found that height have important role in determining squat strenght and that body height may indeed have a negative impact on squat proficiency.

Conclusion

In conclusion, all previously discussed issues support the fact that multi joint strength exercises require and produce high neuromuscular stimulus on the body, and that muscle cross-sectional area is just part of the puzzle in strength manifestation. Therefore, strength in single joint exercises for both arms and legs are more dependent on muscle cross-sectional area, while strength performance in multi-joint movements is much more complex phenomenon.

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