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Original Research

Body Composition and Maximal Strength of Powerlifters: A Descriptive Quantitative and Longitudinal Study

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ABSTRACT

International Journal of Exercise Science 16(4): 828-845, 2023. The purpose of this study was to present the relationships between maximal strength and body composition and to conduct yearly follow-ups presenting the chronic effects of maximal strength training on body composition. Thirty-four (age = 28.8 ± 8.7 yrs) classic powerlifters (M = 21; F = 13) completed at least one Dual-Energy X-Ray Absorptiometry (DXA) 43.97 ± 23.93 days after a sanctioned international powerlifting federation affiliate competition (Squat + Bench Press + Deadlift = Total (kg)). In addition, thirteen subjects (n = 13) completed at least one yearly follow up. Paired sample T-Tests and simple linear regressions were performed to determine significant effects on body composition and maximal strength measures. Prediction formulas were obtained as follows: Bone Mineral Content (BMC) (g) = 3.39 * Total (kg) + 1494.78 (r = 0.84; p < 0.000; SEE = 348.05); Bone Mineral Density (BMD) (g/cm^3) = 0.000390 * Total (kg) + 1.115 (r = 0.71; p < 0.000; SEE = 0.062); Total (kg) = 10.84 * Lean Body Weight (LBW) (kg) – 154.89 (r = 0.90; p < 0.000; SEE = 70.27); Total (kg) = 22.74 * Relative LBW (kg/m) – 306.66 (r = 0.92; p < 0.000; SEE = 64.07). Significant differences were observed in BMD (+1.57 ± 1.55%; p = 0.018; ES = 0.22), between measures one and two (333.7 ± 36.3 days apart) as well as LBW (-2.95 ± 3.82%; p = 0.049; ES = 0.16), and Body Fat Percentage (+2.59%; p = 0.029; ES = 0.20) between measures two and three (336 ± 13.3 days apart). Thus, maximal strength can be used to predict BMC and BMD, while LBW can be used to predict maximal strength. As well, consistent powerlifting practice can increase BMD in adults.

KEY WORDS: Back squat; flat bench press; conventional deadlift; sumo deadlift; skeletal muscle mass; bone remodeling

INTRODUCTION

The sport of powerlifting tests Absolute Maximal Strength (AMS) expressed as one repetition maximum (1RM) in kg of its participants during three events: the back squat, the bench press and the deadlift (14, 28, 29). Participants are assigned to the official weight class of their respective division. The participant with the highest obtained total calculated from his/her highest successful attempt in each of the three events wins the weight class (14, 28, 29). Participant bodyweight and total mass lifted are then entered into a formula to determine their Relative Maximal Strength (RMS) and the champion of champions (pound for pound), regardless of bodyweight (14, 28, 29). At the time this study was conducted, the International Powerlifting Federation (IPF) presented two distinct divisions: classic and equipped (13, 14, 28, 29). The main difference between the two divisions is that the equipped division allows additional supportive equipment such as, squat knee wraps, a squat suit, a deadlift suit and a bench-shirt (14, 29) allowing powerlifters to lift more weight (13, 14, 44). On the other hand, the classic division allows basic supportive equipment such as, a singlet, an up to a 13mm thick powerlifting belt, wrist wraps and knee sleeves (28, 29).

To this day, several investigators have presented relationships between physical characteristics of powerlifters and maximal strength. These physical characteristics are presented here from the most to the least relevant and listed as such: Bone Mineral Content (BMC) (18, 17), Bone Mineral Density (BMD), Lean Body Weight (LBW) (6, 19, 15-17), skeletal muscle mass (24, 51) and anthropometry (15, 16, 33, 34, 37). Moreover, previous research studies have shown that sportsmen have a greater BMC (32, 47) and BMD (9, 10, 48) than controls and that athletes participating in impact sports (volleyball) had higher BMD than the ones participating in non-impact sports (swimming) (12) and aged matched controls (4). Furthermore, a previously published longitudinal study showed that sports related physical activity favors BMC in men (40). Additionally, significant BMD improvements has been shown in men practicing regular sports related physical activity (40), in young males practicing badminton and ice-hockey regularly (23) as well as young gymnasts (39). Ultimately, the physiological adaptation benefits from regular participation in physical activity during the teenage years are maintained in young adulthood (39). Given all the previously stated information, one could expect that this study population (mature adult powerlifters) represents the higher end (least probability for significant changes) of what can be expected regarding the long-term effects of powerlifting training on bone remodeling. As of today, analysing BMD scores is the method most used worldwide to identify and predict an individual's risk of bone fracture (11, 36).

On the other hand, it is well documented that osteoporosis is a degenerative disease characterized by a decrease in BMD leading to a decrease in bone strength and an increase in risk of bone fracture (20) that can be prevented with a regular physical activity practice (4, 5, 9, 10, 48). In fact, *Wolff's Law* states that bones adapt to the loads applied on them (12). A recent systematic review specified that load magnitude is more important than training frequency when aiming to increase BMD (3, 17) thus, making powerlifting practice (maximal strength training) an interesting activity for bone remodeling since it is the weight lifting activity where the participants lift the heaviest weight relative to their BW and level of strength (highest magnitude) (17).

Thus, the goal of the current study was to present relationships between maximal strength and body composition and to conduct yearly follow-ups to present the chronic effects of maximal strength training on body composition. The hypotheses was that LBW can be used to predict maximal strength, that maximal strength can be used to predict BMC and BMD, and that chronic powerlifting practice will significantly increase LBW, BMC and BMD. The present results may serve practitioners and scientists tending in the fields of performance/strength gain research or in a prevention/rehabilitation setting as previous research shows that there is a relationship between LBW and maximal strength (6, 19, 15-17), and that regular physical activity practice is related to better bone health (4, 9, 10, 12, 23, 32, 39, 40, 47, 48).

METHODS

Participants

Ethics approval was obtained through the university's institutional review board committee (2790_e_2018). Participants were asked to read and sign two copies of the consent form before proceeding into data collection. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (38). Female participants suspecting or being pregnant were not eligible to participate in this study due to the potential health related risks associated with radiations coming from a Dual-Energy X-Ray Absorptiometry (DXA) scan directed either to the embryo or fetus.

Thirty-four (n = 34) classic powerlifters (M = 21; F = 13) from different age categories (Juniors = 7 (18-23 yrs old); Open = 25 (23-39 yrs old); Masters = 2 (39-49 yrs old)) coming from most federated weight classes (-59 kg = 1; -66 kg = 0; -74 kg = 3; -83 kg = 3; -93 kg = 7; -105 kg = 5; -120 kg = 1; 120 kg+ = 1 for men and -47 kg = 0; -52 kg = 3; -57 kg = 1; -63 kg 2; -72 kg = 4; -84 kg = 0; -84 kg+ = 3 for women) participated in this study and completed at least one DXA scan (2018-2019 = 8M, 6F; 2019-2020 = 10M, 6F; 2020-2021 = 3M, 1F) 43.97 ± 23.93 days after a regional or provincial sanctioned powerlifting competition. Participants' characteristics are presented in Table 1.

Furthermore, 13 powerlifters (8M; 5F) completed at least one baseline DXA scan and a yearly follow-up (repeated measure) one year after the baseline scan, with 9 participants completing one yearly follow-up (data collection 1 and 2: 4M, 1F; and data collection 2 and 3: 1M, 3F) and 4 participants completing two yearly follow-ups (data collections 1, 2 and 3: 3M, 1F). Groups 1 and 2 could not be combined as some participants would be duplicated. The first scan was completed between November 2018 and January 2019, the second between November 2019 and January 2020, and the third between November and December 2020.

The 9 participants (28.2 ± 4.5 years of age) that completed data collection 1 and 2 (333.7 ± 36.3 days apart) trained on average 4.1 ± 0.6 days a week with each training session averaging 110 ± 17mins per session. Participants trained for multiples sets the squat 1.9 ± 0.6 times a week, the bench press 2 ± 0.9 times a week and the deadlift 1.9 ± 0.6 times a week. The rest of the training session was dedicated to warm up exercises, warm up sets and complementary resistance training exercises. Training intensity for the three powerlifting movements was reported to be at an average of 86.6 ± 5.5% of their 1RM and at 8.4 ± 0.3 Rating of Perceived Exertion (RPE) based on the RPE scale for repetitions in reserve (14, 25, 26). Participants presented an average of 2.4 ± 4.2 weeks of convalescence between repeated measures as three participants reported being injured between scans 1 and 2 (injury duration: 4 weeks, 6 weeks and 4 months), but none of them stopped training as they remained active and only modified their training accordingly as it is common for powerlifters to train injured (14, 43).

Table 1. Participants' Characteristics

	All (n = 34)	Men (n = 21)	Women (n = 13)
Squat (kg)	182.4 ± 57.6	216.9 ± 42.7	126.6 ± 25.0
Bench Press (kg)	114.0 ± 41.9	141.3 ± 26.0	70.0 ± 17.0
Deadlift (kg)	206.8 ± 59.7	244.9 ± 38.8	145.2 ± 25.6
Total (kg)	503.2 ± 156.0	603.1 ± 101.2	341.8 ± 64.4
Squat Wilks (pts)	136.4 ± 20.6	140.5 ± 22.1	129.9 ± 16.8
Bench Wilks (pts)	84.0 ± 16.9	91.6 ± 14.0	71.7 ± 14.1
Deadlift Wilks (pts)	155.7 ± 22.7	159.4 ± 24.2	149.6 ± 19.4
Total Wilks (pts)	376.1 ± 54.8	391.5 ± 55.3	351.2 ± 45.8
Squat %	36.3 ± 2	36.8 ± 2	37 ± 1.9
Bench %	22.2 ± 2.5	23.4 ± 2	20.3 ± 2
Deadlift %	41.5 ± 2.5	40.7 ± 2.2	42.7 ± 2.6
Age (yrs)	28.8 ± 8.7	29.7 ± 10.1	27.4 ± 5.7
RT Exp (yrs)	6.1 ± 3.8	7.5 ± 4.1	3.9 ± 1.6
PL Exp (yrs)	2.8 ± 2.3	3.2 ± 2.8	2.0 ± 1.1
Weight (kg)	84.1 ± 19.8	92.2 ± 15.9	71.0 ± 19.0
Height (m)	1.70 ± 0.08	1.74 ± 0.06	1.63 ± 0.04
BMI (kg/m^2)	29.0 ± 5.8	30.4 ± 4.8	26.8 ± 6.7
LBW (kg)	60.7 ± 12.9	69.2 ± 8.3	47.1 ± 4.0
Relative LBW (kg/m)	35.6 ± 6.3	39.7 ± 4.0	29.0 ± 2.0
BF (kg)	20.7 ± 13.2	19.7 ± 10.8	22.4 ± 16.8
BF%	22.9 ± 10.2	20.4 ± 8.5	27.0 ± 11.7
BMC (kg)	3.20 ± 0.63	3.55 ± 0.48	2.63 ± 0.35
BMD (g/cm^3)	1.31 ± 0.09	1.35 ± 0.07	1.24 ± 0.06

Note: Squat %: Percentage of the Squat on the Total, Bench %: Percentage of the Bench Press on the total, Deadlift %: Percentage of the Deadlift on the Total, RT Exp: Resistance Training Experience (yrs), PL Exp: Powerlifting Experience (yrs), BMI: Body Mass Index, LBW: Lean Body Weight, BF: Bodyfat, BF%: Bodyfat percentage, BMC: Bone Mineral Content, BMD: Bone Mineral Density

The 8 participants (26.5 ± 3.82 years of age) that completed data collections 2 and 3 (336 ± 13.3 days apart) trained on average 3.8 ± 0.6 times a week with each training session averaging 112 ± 22mins per session. Participants trained for multiples sets the squat 2.2 ± 0.8 times a week, the bench press 2.3 ± 1.1 times a week and the deadlift 2 ± 0.8 times a week. The rest of the training session was dedicated to warm up exercises, warm up sets and complementary resistance training exercises. Training intensity for the three powerlifting movements was reported to be at an average of 79.1 ± 7.6% of their 1RM and at 7.8 ± 0.5 RPE. Participants presented an average of 16.2 ± 11.5 weeks of convalescence between repeated measures as six participants reported that their training regimen was affected by Covid-19 government gym shut down measures (3 participants switched to cardiovascular training, one to bodyweight training, one stopped completely and one stopped squats and bench presses and added bodyweight and cardiovascular training). Finally, one participant was injured for 4 weeks but remained active and only one subject reported that his training was not affected.

Powerlifting lifts' frequency does include powerlifting lifts variations, ex: high bar squat, closer grip bench press, paused deadlifts, etc. Repetition Maximum (RM) based on the powerlifter's 1RM combined with the RPE Scale based on the RPE scale for repetitions in reserve (repetitions that the powerlifter did not execute during his set) is presented in Table 2.

Table 2. Percentage (%) of Repetition Maximum Chart Combined with the Rating of Perceived Exertion (RPE) Scale for Repetitions in Reserve

		Repetitions											
Description	RPE	1	2	3	4	5	6	7	8	9	10	11	12
Max Effort	10	100	95	90	88	85	83	80	78	76	75	73	70
Could increase load	9.5	97	92	89	86	84	81	79	77	75.5	74	71	69
1 Rep Remaining	9	95	90	88	85	83	80	78	76	75	73	70	68
1-2 Reps Remaining	8.5	92	89	86	84	81	79	77	75.5	74	71	69	67.5
2 Reps Remaining	8	90	88	85	83	80	78	76	75	73	70	68	67
2-3 Reps Remaining	7.5	89	86	84	81	79	77	75.5	74	71	69	67.5	66.5
3 Reps Remaining	7	88	85	83	80	78	76	75	73	70	68	67	66
3-4 Reps Remaining	6.5	86	84	81	79	77	75.5	74	71	69	67.5	66.5	65.5
4 Reps Remaining	6	85	83	80	78	76	75	73	70	68	67	66	65

Protocol

The experimental approach of the descriptive quantitative part of this study was designed to quantify relationships that exist between maximal strength (independent variables) and body composition (dependent variables) in classic powerlifters. The experimental approach of the longitudinal part of this study was designed to quantify the chronic effects of powerlifting practice on body composition measurements using a repeated measures analysis.

Recruitment was made through an announcement and a yearly recall of the research project through the Quebec Powerlifting Federation's Facebook page. Every year, participants who already had participated in at least one DXA scan would receive an e-mail invitation and a recall for their yearly scan (repeated measure). These announcements were made to inform the potential participants of the research project, inviting them to the university's exercise science department for a DXA scan (DXA Prodigy Advance, model #8743, GE Healthcare, Madison, Wisconsin USA) for research purposes until January 31st of each year. The DXA scan is considered as one of the most reliable piece of equipment employed to analyze human body composition for lean mass, body fat and bone mass, and is recognized as a Gold standard to assess the validity and reliability of other body composition analysis devices (27, 30, 31, 50).

Volunteers had to send an e-mail to the designated researcher to receive an instructional e-mail with a copy of the consent form and schedule an appointment. Participants were asked to stop eating 4 hours and to stop drinking 2 hours prior to their DXA scan and were asked to empty their bladder before the scan. They were instructed to present themselves wearing comfortable clothing without any metal pieces (belt, buttons, etc.) and were asked to remove all other metal objects (piercings, etc.) before the scan. Females were recommended (but not obliged) to get evaluated between the 10th and the 14th day of their menstrual cycle.

Participants were first asked to read the consent form, while feeling free to ask any questions, and upon agreeing to participate, sign two copies of it. They were then asked about their resistance and powerlifting training experience as well as their training regimen for the returnees.

The following questions were asked about their training regimen:

1. On average, how many powerlifting training sessions per week did you complete since your last scan?
2. On average, what was the duration of those training sessions?
3. Have you injured yourself since your last scan and, if so, how long was the convalescence? Was it active or passive?
4. How many times per week did you perform each of the three powerlifting lifts (Squat, Bench Press and Deadlift), including variations?
5. On average, at what intensity did you train the three powerlifting lifts (in %RM and RPE)?

The participants' height (m) was measured with a stadiometer (Seca GmbH, model 217, Hambourg, Germany) to the nearest cm (± 1 cm) by having the participants stand still with their arms to their side, feet together, heels touching the wall, with their back and their head against the wall at the end of a full inspiration. Bodyweight (kg) was measured to the nearest decimal point (± 0.1 kg) with a digital scale (Adam, model GFK660, Milton Keynes, United Kingdom).

The previously mentioned measurements were also used to create the participant's profile within the DXA's computer software (Encore Version 12.30.008, 2008, GE Healthcare, USA). All DXA measurements were performed with the same apparatus (GE Lunar Prodigy model 8743, USA). The participants were then asked to lay down prone on the DXA mat. The participant's back was aligned with the mat's center line (nose and pubis over the center line) and both arms were placed to the side of the body. If both of the participant's arms could not fit within the mat's limits, participants were positioned so that their entire right side would fit within the limits of the mat and only the right side would be measured. If the participant was too tall, there could be a possibility that his feet were not included in the scan (this was the case for 3 male participants). Once participants were properly placed, the scan would start with them remaining still during the entire time (6 mins).

After the DXA scan completion, the lab assistant would start body segmentation on the computer system along the participant's body profile, so that every region of interest (ROI, body parts) would be correctly divided (i.e., positioning chin height line, separate arms from trunk section with a separation between the clavicula/acromion and humerus, spine, iliac crest height line, between ischium and humeral head identification of center of pubis area etc.) to compile body composition results per region. When having the possibility to only fit the participant's right arm or leg for the DXA scan, then the software would automatically duplicate the participant's right arm or leg composition for the left side.

All three data collections were executed by a different lab assistant. To standardize data analysis and limit human errors, the body segmentation was completely redone for the first and second data collections and revised for the third. This was done to eliminate the inter-tester reliability effect since previous investigations recommend that anthropometric intra-reliability should be above 95% (45) and that measurements should be carried out, when possible, by one observer (45) because the number of observers increases unreliability (35) and in contrast intra-observer reliability is above 95% (21).

Powerlifting competition (meet) results came from the Quebec Powerlifting Federation (QPF). Thus, subjects were all competing under strict drug-testing regulations from the QPF as it serves as the provincial affiliate to the Canadian Powerlifting Union (CPU) which falls under the IPF (8, 28, 42). The CPU's anti-doping program is run by the Canadian Center for Ethics in Sports (CCES), which follows the World Anti-Doping Agency (WADA) regulations (2, 7).

Statistical Analysis

Participants' characteristics coming from the powerlifting meet closest to their first DXA scan are presented in Table 1 as mean ± SD. Participants' percentage of each event on their total (Squat + Bench Press + Deadlift = Total) were calculated from these results. Participants' Wilks points for each of the three powerlifting events was then calculated from these percentages. Subject's relative maximal strength (Wilks points) was calculated from the validated (46) and more efficient (13) Wilks formula (constants differ between men and women) in order to compare maximal strength gains regardless of bodyweight.

Wilks formula (13, 46):

$$\text{Wilks Points} = \text{Weight lifted in kg} * \left(\frac{500}{a + bx + cx^2 + dx^3 + ex^4 + fx^5}\right)$$

Where x is the powerlifter's bodyweight in kg, the other variables (a-f) are constants.

The Wilks formula allows to compare powerlifters' RMS between weight classes and compensate the curvilinear relationship between body weight and maximal strength as a world record squat in the superheavyweight 120+ kg weight class would have about a 2.5 Weight Lifted (WL)/ Bodyweight (BW) ratio, but for the smaller weight class -59 kg it would be around 4.0 WL/BW ratio (13, 46). Thus, the WL/BW ratio formula is unfair to higher weight class powerlifters since as the weight classes go up in each of the events, the RMS ratios goes down (13, 46, 49). To this day, the International Powerlifting Federation (IPF) has modified the formula twice (28), but the Wilks formula remains the only one that has been validated (46) and it has been shown to be more efficient than the IPF formula at comparing powerlifter RMS between men weight classes for both divisions (13).

Correlations between maximal strength (independent variables) and body composition (dependent variables) were calculated using a 2-tailed Pearson correlation analysis. Correlations were calculated from the baseline DXA scan as 20 of the 34 participants only participated in one DXA scan. Simple linear regression analyses were performed with the most significant correlations to establish prediction formulas. Simple linear regression equations are presented with their *R*-values (correlations), *P*-values and Standard Error of Estimate (SEE). Paired sample *T*-Tests were performed to determine if chronic powerlifting practice had a significant effect on the various body composition measurements. Paired sample *T*-Tests were retained instead of an ANOVA analysis since the number of participants in paired samples was different for the separate time points measures (M1, M2 and M3). Thus, paired sample *T*-tests were used to compare two separate time points measures at the time (M1 and M2; M2 and M3 or M1 and M3). Statistical significance was set at $p < 0.05$ for all analyses. No statistical power calculation was executed as it was considered unnecessary as this experimental design was not directed towards presenting differences between groups but rather towards reporting changes in time. Effect size (ES) were calculated using Cohen's *d* (0.2 = small, 0.5 = medium and 0.8 = large). All statistical analyses were conducted using IBM SPSS Statistics for Windows version 25.

RESULTS

Correlations between maximal strength and body composition are presented in Table 3. The simple linear regression formulas to predict BMC and BMD from AMS as well as to predict AMS from LBW and RLBW are presented in Table 4. As well, Fig. 1 illustrates linear regressions for the quantity of weight (kg) lifted as a function of LBW or RLBW (Fig1. A and C, respectively) and of bone mass (BMC and BMD) according to the amount of weight lifted (Fig. 1 B and D, respectively). Paired sample *T*-test repeated measures results between M1 and M2 and between M2 and M3 are presented in Table 5. The repeated measures analysis shows a significant difference ($p < 0.05$) for BMD (+1.57 ± 1.55%; $p = 0.018$; ES = 0.22) between measures M1 and M2 as well as for LBW (-2.95 ± 3.82%; $p = 0.049$; ES = 0.16) and BF% (+2.59%; $p = 0.029$; ES = 0.20) between measures M2 and M3.

Table 3. Correlations Between Characteristics and Maximal Strength Measures for All Participants (n = 34)

	Squat (kg)	Bench (kg)	Deadlift (kg)	Total (kg)	Squat Wilks	Bench Wilks	Deadlift Wilks	Total Wilks	Squat %	Bench %	Deadlift %
RT Exp (yrs)	.33	.42*	.53**	.44**	.09	.36*	.38*	.30	-.57**	.28	.18
PL Exp (yrs)	.35*	.37*	.51**	.42*	.37*	.44**	.58**	.51**	-.32	.13	.13
Weight (kg)	.73**	.69**	.62**	.69**	.19	.32	-.12	.12	.16	.45**	-.57**
Height (m)	.65**	.70**	.69**	.70**	.10	.40*	.06	.19	-.25	.54**	-.34*
BMI (kg/m^2)	.59**	.52**	.44**	.53**	.18	.21	-.17	.06	.30	.30	-.54**
LBW (kg)	.87**	.91**	.87**	.90**	.35*	.62**	.21	.41*	-.17	.62**	-.49**
Relative LBW (kg/m)	.89**	.92**	.88**	.92**	.40*	.66**	.24	.45**	-.14	.62**	-.51**
BF (kg)	.22	.11	.07	.14	-.02	-.12	-.33	-.18	.39*	.02	-.34
BF (%)	-.02	-.13	-.18	-.11	-.14	-.29	-.44*	-.32	.45**	-.11	-.25
BMC (kg)	.82**	.81**	.83**	.84**	.37*	.54**	.22	.40*	-.09	.51**	-.44**
BMD (g/cm^3)	.68**	.65**	.74**	.71**	.41*	.50**	.40*	.47**	-.15	.32	-.20

Squat %: Percentage of the Squat on the Total, Bench %: Percentage of the Bench Press on the total, Deadlift %: Percentage of the Deadlift on the Total, RT Exp: Resistance Training Experience (yrs), PL Exp: Powerlifting Experience (yrs), BMI: Body Mass Index, LBW: Lean Body Weight, BF: Bodyfat, BF%: Bodyfat percentage, BMC: Bone Mineral Content, BMD: Bone Mineral Density

* indicates significant correlations at $p < 0.05$; ** indicates significant correlations at $p < 0.01$

Table 4. Linear Regression Analysis Formulas for Predicting Absolute Maximal Strength, Bone Mineral Content and Bone Mineral Density (n = 34)

		r	p	SEE
Squat	Squat (kg) = 3.86 * LBW (kg) – 52.35	0.87	< 0.000	29.23
	Squat (kg) = 8.16 * Relative LBW (kg/m) – 108.09	0.89	< 0.000	26.81
Bench Press	Bench Press (kg) = 2.94 * LBW (kg) – 64.42	0.91	< 0.000	18.05
	Bench Press (kg) = 6.17 * Relative LBW (kg/m) – 105.67	0.92	< 0.000	16.22
Deadlift	Deadlift (kg) = 4.03 * LBW (kg) – 38.12	0.87	< 0.000	29.78
	Deadlift (kg) = 8.42 * Relative LBW (kg/m) – 92.90	0.88	< 0.000	28.38
Total	Total (kg) = 10.84 * LBW (kg) – 154.89	0.90	< 0.000	70.27
	Total (kg) = 22.74 * Relative LBW (kg/m) – 306.66	0.92	< 0.000	64.07
Bone Mineral Content	BMC (g) = 9.01 * Squat (kg) + 1554.86	0.82	< 0.000	362.07
	BMC (g) = 12.20 * Bench Press (kg) + 1807.26	0.81	< 0.000	373.84
	BMC (g) = 8.72 * Deadlift (kg) + 1394.66	0.83	< 0.000	358.91
	BMC (g) = 3.39 * Total (kg) + 1494.78	0.84	< 0.000	348.05
Bone Mineral Density	BMD (g/cm^3) = 0.001014 * Squat (kg) + 1.126	0.68	< 0.000	0.068
	BMD (g/cm^3) = 0.001334 * Bench Press (kg) + 1.169	0.65	< 0.000	0.067
	BMD (g/cm^3) = 0.001063 * Deadlift (kg) + 1.092	0.74	< 0.000	0.059
	BMD (g/cm^3) = 0.000390 * Total (kg) + 1.115	0.71	< 0.000	0.062

LBW: Lean Body Weight, BMC: Bone Mineral Content, BMD: Bone Mineral Density

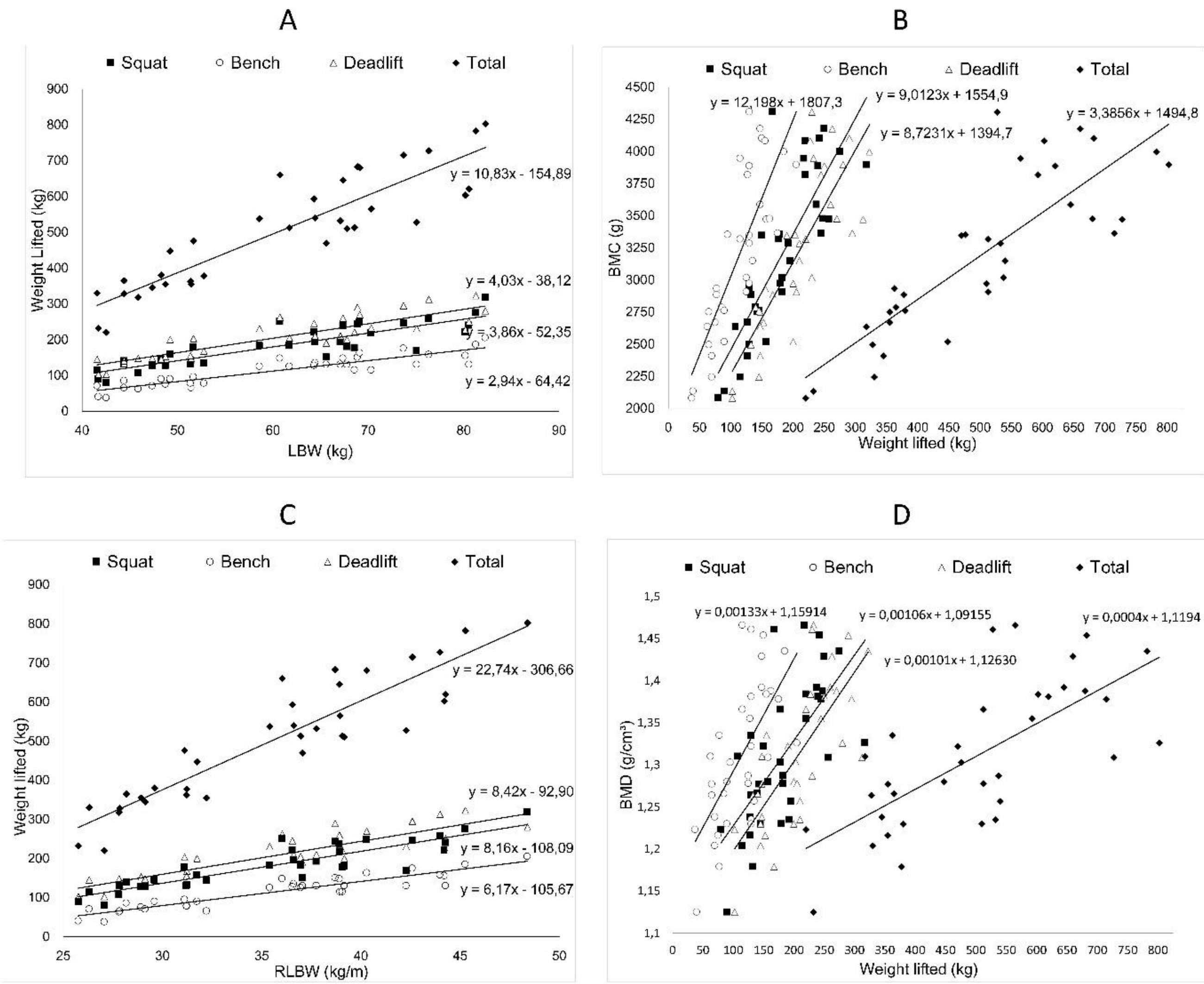

Figure 1. Relationships between body composition characteristics and maximal strength measures. A) Weight lifted as a function of lean body weight (LBW); B) Bone mineral content (BMC) as a function of weight lifted; C) Weight lifted as a function of relative lean body weight (RLBW); and D) Bone mass density (BMD) as a function of weight lifted.

Table 5. Powerlifter's physical characteristic changes overtime (paired sample *T*-Test)

	Measure 1 vs 2 (*n* = 9)				Measure 2 vs 3 (*n* = 8)				Measure 1 vs 3 (*n* = 4)			
	M1	M2	Δ%	ES	M2	M3	Δ%	ES	M1	M3	Δ%	ES
Weight (kg)	91.33 ± 19.21	93.20 ± 19.85	2.08 ± 3.70	0.10	79.75 ± 18.69	80.49 ± 19.29	0.86 ± 2.91	0.04	85.65 ± 13.67	89.35 ± 14.64	4.32 ± 7.07	0.26
Height (m)	1.73 ± 0.07	1.73 ± 0.07	0.00 ± 0.00	0.00	1.68 ± 0.09	1.68 ± 0.09	0.00 ± 0.00	0.00	1.73 ± 0.09	1.73 ± 0.09	0.00 ± 0.00	0.00
LBW (kg)	66.66 ± 10.71	67.02 ± 10.27	0.71 ± 2.61	0.03	56.84 ± 11.42	55.08* ± 10.84	-2.95* ± 3.82	0.16	63.81 ± 8.43	63.15 ± 5.56	-0.53 ± 5.32	0.09
BF (kg)	21.33 ± 15.80	22.89 ± 15.85	0.39 ± 0.32	0.10	19.97 ± 14.80	22.28† ± 15.02	14.15† ± 12.63	0.15	18.41 ± 20.27	22.76 ± 18.53	47.20† ± 36.61	0.22
BF (%)	21.93 ± 12.78	23.08 ± 11.85	1.15	0.09	23.50 ± 12.79	26.09* ± 12.88	2.59*	0.20	19.60 ± 18.59	23.75 ± 15.67	4.15	0.24
BMC (kg)	3.39 ± 0.47	3.46† ± 0.53	1.79† ± 2.67	0.14	3.03 ± 0.60	3.03 ± 0.60	0.10 ± 1.94	0.00	3.32 ± 0.45	3.39 ± 0.54	2.0 ± 2.73	0.14
BMD (g/cm^3)	1.33 ± 0.09	1.35* ± 0.09	1.57* ± 1.55	0.22	1.31 ± 0.08	1.31 ± 0.09	0.20 ± 1.21	0.00	1.36 ± 0.08	1.37 ± 0.08	0.84 ± 2.22	.0125

*Significantly Different Between Repeated Measures at $p < 0.05$
†Nearly Significantly Different Between Repeated Measures at $p < 0.10$
LBW: Lean Body Weight, BF: Bodyfat, BF%: Bodyfat percentage, BMC: Bone Mineral Content, BMD: Bone Mineral Density

DISCUSSION

Results presented in Table 3 show that resistance training experience in years, powerlifting experience in years, weight, height, BMI, LBW, BF, BF%, BMC and BMD were all significantly correlated with AMS and RMS in the squat, the bench press, the deadlift and the total. These results confirm the previously published results that LBW (6, 19, 15-17), RLBW (15-17), BMC (18, 17) and BMD (18, 17) were all significantly correlated with male classic powerlifters' RMS. As expected, weight and height being absolute measures were mostly significantly correlated with AMS outcomes as shown in previously published research (15-17). Meanwhile, LBW and RLW as well as BMD and BMC were also significantly correlated with RMS. Moreover, the results described in this study present a greater number of statistically significant correlations as well as prediction equations than those previously published putting in relation body composition measure by DXA and powerlifting outcomes (18, 19, 17). Ultimately, the prediction formulas presented in Table 4 could be used to predict bone health (BMC and BMD) from maximal strength in all three of the powerlifting events as well as to predict maximal strength from LBW and RLBW. On the other hand, BF and BF% were the body composition measures the least correlated with powerlifting outcomes, as shown in previously published research (15-17).

The results presented in Table 5 show that chronic classic powerlifting practice significantly improved BMD in mature adults (28.2 ± 4.5 years of age) over a 333.7 ± 36.3-day period with 4.1 ± 0.6 training sessions per week, lasting a total of 110 ± 17mins per session performed at 86.6 ± 5.5% of their 1RM and at 8.4 ± 0.3 RPE. As mentioned previously in the introduction, it was somewhat expected that the participants in the present study (adult powerlifters) would show minimal increases in BMC and BMD, when compared to expectations in other population, as the long-term effects of powerlifting training on bone remodeling was affected by their many accumulated years of resistance and powerlifting training. Nonetheless, these results add to previously published longitudinal studies which demonstrated that a regular physical activity practice over time (5years) favors BMC and BMD improvement in men (24.1 ± 0.6 years of age at baseline) (40). Similarly, weekly regular school and local club badminton practice of 5.3 ± 1.4h per week (16.1 ± 0.5 to 19.1 ± 0.4 years of age), or ice-hockey practice of 9.4 ± 2.0h per week (16.1 ± 0.5 to 19.0 ± 0.4 yrs) over the course of three years also significantly increased BMD in young males (23). As well, a significant increase in BMD was shown over a one year span in experienced (7.1 ± 0.6 years of experience) artistic gymnast children (10.0 ± 0.3 to 11.0 ± 0.3 years of age) training 15.7 ± 1.6 hrs per week (39). Thus, in the current study, similar results of increased markers of bone health are presented, but in older subjects with an activity that can be practiced individually in a non-regulated setting, similarly to a practice of regular individual physical activity (ex., running, jumping, etc.). Hence, maximal strength training could be used in order to increase BMD in mature adults by utilising similar general concepts of training modalities, i.e., training frequency, intensity and duration.

Although, results show a significant mean increase of +1.57 ± 1.55% ($p = 0.018$) in BMD between repeated measures time points of M1 and M2, Table 5 shows that there was, nonetheless, a lack of a significant increase +0.20 ± 1.21%; $p = 0.671$ of BMD between repeated measures time points of M2 and M3. Of course, a similar increase in BMC would have been expected between repeated measures M2 and M3 due to the similarities in the subjects' training regiments' characteristics, but as shown, BMC remained unchanged between these two time points (M2 vs M3). Herein, the lack of an increase in BMD, the significant decrease in LBW, and the significant increase in BF% between measures M2 and M3 may have been brought upon by the government shut down of gyms/training facilities in order to limit Covid-19 propagation (M2 and M3). In fact, when looking at the convalescence average between measures M1 and M2 compared to measures M2 and M3 (2.4 ± 4.2 weeks vs 16.2 ± 11.5 weeks; respectively) and considering that between measures M2 and M3, six out of the eight subjects' training was affected by gym/training facilities shutdown. It can be hypothesized that these results could be explained by detraining effect having participants lose LBW and gain BF. Furthermore, by examining the BMD results, one can hypothesize that the bone remodeling increase induced by a chronic powerlifting practice is about 3-times slower than its decrease when practice is stopped (16.2 ± 11.5 weeks of convalescence / 336 ± 13.3 days between scans).

The present results related to convalescence are similar to those reported in previous studies, where it has been shown that even minor changes in physical activity practice affects bone formation markers (1). Similarly, stopping ice-hockey practice for a 30-month period causes a BMD loss measured at the femoral head at a significantly greater rate when compared to players continuing ice-hockey practice (16.7 +/- 0.6 years of age at baseline) and controls (16.8 +/- 0.3 years of age at baseline) (22). As well, participating in ice-hockey during childhood and adolescence does not guarantee that osteoporosis of the femoral head will not appear in adulthood if the activity is not maintained (22). Thus, although physical activity practice is associated with a continuous BMD increase in men after puberty, stopping its practice for three years leads to a decrease in BMD, similar to what is observed in detraining (41).

Limitations to this study include the use of the DXA scan as 3 male participants were too tall and their feet did not fit into the scan, some participant's arms could not fit within the mat's limits so that their right arm was duplicated by the software for the body composition analysis. Also, the body sections are divided by the evaluator, which can cause human induced errors, therefore reducing the measurement precision. Additionally, the DXA scan software does not include enough points of division to divide the members and the line from which the body parts are divided are thick, making this process less precise. Furthermore, BMD is measured from a 2-D scan and is expressed in cm^3, although it should be expressed in cm^2. This means that subjects' bone density is measured from the frontal plane, but some body part measurements might be more accurate if they were measured from the sagittal plane (eg. hips) or from the back (eg. spine). Finally, the hand position of the subjects should be standardized, as placing the subjects into an anatomical position (hands supinated) seems to make a more precise reading. In comparison, when the hands are placed in a neutral position, the 2-D scan does not allow a correct measurement since the phalanges and metacarpal bones stack up on one another. Statistical analyses limitations to this this study include that both sexes (men and women) were combined into one group for all analyses (most previously cited research had been conducted on men), that three distinct paired sample t-tests were executed to compare repeated time point measures and that no statistical power calculation was executed. Other limitations of the longitudinal part of the study include the sample size and not monitoring the exact training volume of each training sessions. These limitations were also present in similar previously published research (22, 23, 39, 40).

Ultimately, this study was able to show that maximal strength in the three powerlifting events and the total was able to predict powerlifting experience in years, weight, height as well as BMI, LBW, BF, BF%, BMC and BMD measurements. It was able to present that chronic powerlifting practice significantly improved BMD between measures M1 and M2, that BF% and BF (kg) increased between measures M2 and M3 and that BMC nearly significantly improved between measures M1 and M2. The hypotheses being that LBW could be used to predict maximal strength, that maximal strength from the three powerlifting events can be used to predict BMC and BMD, and that a chronic powerlifting practice would significantly increase LBW, BMC and BMD are valid in part as all predicted results were accurate except for the increase in BMC that failed to reach statistical significance at a $p < .05$.

The results of the present study could serve to predict BMC and BMD from any of the three powerlifting events and the total, as well as maximal strength in all three powerlifting events and the total from LBW and RLBW. Results could also help qualified practitioners prescribe typical individual classic powerlifting/strength training to mature patients in need of reaching a healthy bone mass by having them train 100-120 mins per session, 4 times a week, practicing each of the three powerlifting movements twice a week at 80-90% of their 1RM and at around 8 RPE based on repetitions in reserve.

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