

Crescent pyramid and drop-set systems do not promote greater strength gains, muscle hypertrophy, and changes on muscle architecture compared with traditional resistance training in well-trained men

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Abstract

Purpose The aim of this study was to compare the effects of crescent pyramid (CP) and drop-set (DS) systems with traditional resistance training (TRAD) with equalized total training volume (TTV) on maximum dynamic strength (1-RM), muscle cross-sectional area (CSA), pennation angle (PA), and fascicle length (FL).

Methods Thirty-two volunteers had their legs randomized in a within-subject design in TRAD (3–5 sets of 6–12 repetitions at 75% 1-RM), CP (3–5 sets of 6–15 repetitions at 65–85% 1-RM), and DS (3–5 sets of ~50–75% 1-RM to muscle failure) protocols. Each leg was trained for 12 weeks. Participants had one leg fixed in the TRAD while the contralateral leg performed either CP or DS to allow for TTV equalization.

Results The CSA increased significantly and similarly for all protocols (TRAD: 7.6%; CP: 7.5%; DS: 7.8%). All protocols showed significant and similar increases in leg press (TRAD=25.9%; CP=25.9%; DS=24.9%) and leg extension 1-RM loads (TRAD=16.6%; CP=16.4%; DS=17.1%). All protocols increased PA (TRAD=10.6%; CP=11.0%; DS=10.3%) and FL (TRAD=8.9%; CP=8.9%; DS=9.1%) similarly.

Conclusion CP and DS systems do not promote greater gains in strength, muscle hypertrophy and changes in muscle architecture compared to traditional resistance training.

Keywords Resistance training · Total training volume · Muscle cross-sectional area · Muscle strength · Pennation angle · Fascicle length

Abbreviations

1-RM	One-repetition maximum
CP	Crescent pyramid
CSA	Muscle cross-sectional area
DS	Drop-set
FL	Fascicle length
PA	Pennation angle
PI	Principal investigator
RT	Resistance training
TRAD	Traditional resistance training
TTV	Total training volume
US	Ultrasound
VL	Vastus lateralis

Introduction

Resistance training (RT) is considered as the most effective method to increase muscle strength and mass (i.e., muscle hypertrophy), and to change muscle architecture parameters (e.g., increases in pennation angle and fascicle length) (Aagaard et al. 2002; ACSM 2002, 2009, 2011; Ades et al. 2005; Blazevich et al. 2007; Kraemer and Ratamess 2004; Seynnes et al. 2007). To maximize, or to prevent the stagnation of gains in muscle strength and mass, coaches and well-trained lifters have used advanced RT systems (Charro et al. 2010; Fleck and Kraemer 2014; Kraemer and

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Ratamess 2004; Ribeiro et al. 2016; Schoenfeld 2011). RT systems encompass a variety of training techniques that emphasize different RT variables (e.g., intensity, volume, muscle action, type and order of exercises, and repetition velocity) aiming to maximize specific training-induced adaptations (e.g., muscle strength or muscle hypertrophy). Albeit RT systems are recommended for trained individuals (Fleck and Kraemer 2014; Schoenfeld 2011), little is known if these systems indeed produce superior muscle adaptations when compared to traditional RT (TRAD) protocol.

Crescent Pyramid (CP) is a very popular RT system among RT practitioners. CP requires increasing intensity and decreasing the number of repetitions after each exercise set (ACSM 2009; Charro et al. 2010; Delorme and Watkins 1948; Fish et al. 2003; Fleck and Kraemer 2014; Zinovieff 1951). It is suggested that CP induces high mechanical tension in the muscle due to increments in exercise intensity and total training volume (TTV – sets \times repetitions \times load [kg]), increasing the recruitment of fast motor units and, therefore, inducing greater gains in muscle strength compared to TRAD (Fleck and Kraemer 2014; Mangine et al. 2015; Schoenfeld 2010). However, to the best of our knowledge, there are no studies comparing training-induced gains in muscle strength and mass between CP and TRAD protocols.

Besides the CP system, Drop-set (DS) is another popular RT system among bodybuilders. This system is characterized by sets performed to muscle failure; after failure exercise load is immediately reduced (e.g., ~20%), allowing individuals to perform additional repetitions to muscle failure on each set (Bentes et al. 2012; Fleck and Kraemer 2014). In this regard, it is suggested that DS produces a high metabolic stress due to a high number of repetitions performed on each set, and, therefore TTV, which may promote greater increases in muscle mass than TRAD (Goto et al. 2004; Mangine et al. 2015; Schoenfeld 2010, 2011, 2013b). Similar to CP, there are no studies that have compared training-induced adaptations between DS and TRAD protocols.

It has been shown that increases in muscle strength and mass are strongly dependent on TTV of RT. Accordingly, studies have shown greater increments in muscle strength and hypertrophy for high TTV protocols when compared to low TTV ones, regardless of the type of manipulation of RT variables (e.g., intensity and volume) (Candow and Burke 2007; Gentil et al. 2015; Kelly et al. 2007; Krieger 2009, 2010; Mitchell et al. 2012; Ronnestad et al. 2007; Schoenfeld 2013a; Schoenfeld et al. 2016b; Sooneste et al. 2013). Conversely, equalized TTV RT protocols have not shown differences in muscle strength and hypertrophy responses in spite of distinct manipulations of RT variables (Ahtiainen et al. 2003, 2005; Candow and Burke 2007;

Chestnut and Docherty 1999; Gentil et al. 2015; Kok et al. 2009; Moore et al. 2012). Thus, it is reasonable to suggest that when TTV is equalized, the manipulation of training variables when using CP and DS systems would not promote additional increases in muscle strength and hypertrophy when compared to TRAD.

Therefore, the aim of this study was to compare the effects of CP and DS systems with TRAD RT with equalized TTV on muscle strength and hypertrophy in well-trained young men. As a secondary aim, we compared the effects of these protocols on some muscle architecture parameters. Our hypothesis was that CP, DS, and TRAD promote similar increases in muscle strength and hypertrophy when TTV is equalized between RT protocols.

Methods

Participants

Thirty-two men (age: 27.0 ± 3.9 years, height: 1.79 ± 0.0 m, body mass: 84.6 ± 8.6 kg, RT experience: 6.4 ± 2.0 years) volunteered to participate in this study. Participants had trained their lower limbs for at least 4 years with a frequency of two times per week, and were able to squat with at least 130% of their body mass to be deemed as resistance trained (ACSM 2009; Baker et al. 1994; Brandenburg and Docherty 2002; Gibala et al. 1994; Ostrowski et al. 1997). Besides being deemed as resistance trained, participants had to: (1) be free from using anabolic steroids; (2) be free from musculoskeletal disorders or risk factors as assessed by the PAR-Q Questionnaire; (3) perform 45° leg press and leg extension exercises in their RT routines. All of the assessments were performed at the same time of the day, and participants were oriented to have a light meal 2 h prior to each testing session. Additionally, participants were advised to maintain their eating habits, and to consume only the nutritional supplement provided by the P.I., after each RT session (i.e., 30 g Whey Protein–Whey Select–3VS Nutrition–Brazil). Participants signed a consent form, the study was conducted in accordance with the Declaration of Helsinki, and ethical approval was granted by the University's ethics committee.

Experimental design

Initially, participants visited the laboratory to perform a familiarization session with the 45° leg press (RT-054–Tonus–Brazil–São Paulo) and leg extension (RT-068–Tonus–Brazil–São Paulo) exercises 1-RM test. They completed the first 1-RM test 48 h after the familiarization session. 1-RM was re-tested 72 h after the first 1-RM test. Seventy-two hours after, cross-sectional area (CSA) of the

vastus lateralis (VL) muscle and muscle architecture variables [i.e., pennation angle (PA) and fascicle length (FL)] were assessed. Self-reported training logs of the 2 weeks prior to the commencement of the study were used to determine the TTV usually performed by each participant. Then, TTV was used to rank each limb of the participants into quartiles to randomly and balanced allocate each of the participants' limbs to the following experimental conditions: (1) Traditional (TRAD); (2) Crescent pyramid (CP); (3) Drop-set (DS). The TRAD condition was defined as a "positive" control for all of the participants. Thus, 32 limbs were allocated to the TRAD protocol (16 dominant and 16 non-dominant limbs). Contralateral limbs were then allocated to either CP ($n=16$, 8 dominant and 8 non-dominant limbs) or DS protocol ($n=16$, 8 dominant and 8 non-dominant limbs). These procedures were adopted to mitigate the influence of previous TTV on training-induced adaptations. Following, participants performed two familiarization sessions with the assigned protocols, and then underwent 12 weeks of RT. 45° leg press and leg extension 1-RM were re-tested at the end of week 6 to adjust training load. Additionally, muscle CSA and architecture, 45° leg press and leg extension 1-RM loads were re-assessed 72 h after the last RT session at post-training.

Equalization and progression of the total training volume

As TTV can greatly affect muscle strength and hypertrophy gains (Candow and Burke 2007; Gentil et al. 2015; Kelly et al. 2007; Krieger 2009, 2010; Mitchell et al. 2012; Ronnestad et al. 2007; Schoenfeld 2013a, 2016b; Sooneste et al. 2013), we utilized RT records to determine initial training load for each participant. Initial TTV was defined as 120% of the TTV that each participant performed in the 2 weeks prior to the commencement of the study. This procedure ensured the absence of abrupt increases or decreases in TTV at the beginning of the study. The TTV performed on each CP or DS session was equalized to the TTV performed on the TRAD session (i.e., trained first). 70 and 30% of the TTV was performed in the 45° leg press, and leg extension exercises, respectively. The TTV was increased by ~7% every 3 weeks (i.e., 6 RT sessions) for all of the participants.

Resistance training protocols

Traditional resistance training (TRAD)

The TRAD protocol trained with an intensity corresponding to 75% of the 1-RM load in the unilateral 45° leg press and leg extension exercises. Overall, participants performed 3–5 sets of 6–12 repetitions on each exercise. As we used

75% of the 1-RM load on both exercises, a couple participants could not be close to failure in the first or second set, but all of them were very close to, or reached, failure in the last sets. The number of sets and repetitions were adjusted every time that the TTV was increased. A 2-min rest was allowed between sets and exercises.

Crescent pyramid system (CP)

In CP protocol, load (kg) was increased and repetitions were reduced after each exercise set. Participants performed the CP protocol with a similar TTV to the contralateral leg. In this regard, the number of sets each participant performed varied from 3 to 5 and the number of repetitions performed on each set was ~15 in the first set (65% 1-RM), ~12 in the second set (70% 1-RM), ~10 in the third set (75% 1-RM), ~8 in the fourth set (80% 1-RM), and ~6 in the fifth set (85% 1-RM). Similarly to the TRAD protocol, a couple participants could not be close to failure in the first or second set, but all of them were close to, or reached, failure in the last sets. Similar to the TRAD protocol, the number of sets and repetitions were adjusted every 3 weeks, when TTV was increased. A 2-min rest was granted between sets and exercises.

Drop-set system (DS)

The DS protocol used the same initial TTV and exercises as the TRAD and CP protocols. Each set was conducted to muscle failure. Then, participants performed up to two drops after the initial failure on each set (e.g., initial load—repetitions to muscle failure—short pause—reduction of 20% of the load—repetitions to muscle failure—short pause—reduction of 20% of the load—repetitions to failure). If the predetermined TTV for each exercise was reached before the end of the second drop (e.g., the first drop of the second set), the exercise was terminated to ensure the equalization of the TTV with the TRAD protocol. A 2-min rest interval was granted between sets and exercises.

Maximum dynamic strength test (1-RM)

Unilateral 1-RM test in the 45° leg press and leg extension exercises was performed following the recommendations described by Brown and Weir (2001). Initially, participants performed a general warm-up in a cycle ergometer at 20 km h⁻¹ for 5 min, followed by two sets of specific warm-up. The first set consisted of 8 repetitions with 50% of the estimated 1-RM, and the second set comprised 3 repetitions with 70% of the estimated 1-RM with a 2-min rest between warm-up sets. After the warm-up, the 1-RM test was initiated. Participants had up to 5 attempts

to reach their 1-RM load on each exercise, with a rest of 3 min between attempts. The greatest load lifted was considered as the 1-RM load. The coefficient of variation and the typical error for the 45° leg press and leg extension 1-RM tests were 1.31% and 2.89 kg, and 1.38% and 1.05 kg respectively.

Muscle cross-sectional area (CSA)

The CSA was obtained through an ultrasound imaging (US) unit following the procedures described in our previously published validation study (Lixandão et al. 2014). Participants were instructed to abstain from vigorous physical activities for at least 72 h prior to each CSA assessment (Damas et al. 2016b; Newton et al. 2008). Prior to the acquisition of images, participants laid in a supine position for 20 min to ensure fluid redistribution. A B-mode US, with a linear probe set at 7.5 MHz (Samsung, MySono U6, São Paulo, Brasil), was used to acquire the images. Transmission gel was applied in the area where the images were obtained, ensuring acoustic coupling, without compressing the epidermis. The point corresponding to 50% of the distance between the greater trochanter and the lateral epicondyle of the femur was used for the acquisition of CSA images. Images were acquired in the sagittal plane. To guide the displacement of the probe, the skin was transversely marked at intervals of 2 cm. Sequential images of the VL muscle started at the point of alignment of the upper edge of the probe with the most medial skin mark (over the rectus femoris muscle) and ended at the lateral aspect of the thigh. Images were recorded every 2 cm. Then, the sequence of images were opened in Power Point (Microsoft, USA), manually rotated to reconstruct the entire fascia of VL muscle, and saved as a new figure file. Figure files were opened in the ImageJ software and the “polygonal” function was used to determine VL CSA. ImageJ “polygonal” functional was calibrated using a known distance marked in the US unit. The CV and the TE of CSA measures was 1.05% and 0.33 cm², respectively.

Pennation angle (PA) and fascicle length (FL)

PA and FL of VL were measured at the same time and site of the CSA acquisition, with the probe oriented longitudinally to the muscle belly. The PA was defined as the angle formed between the intersection of a fascicle and the deep aponeurosis. FL was defined as the distance from fascicle origin in the deep aponeurosis to insertion in the superficial aponeurosis. The mean value of three images was used to determine PA and FL using the “Angle” tool (Scanlon et al. 2014) and “Straight” tool (Erskine et al. 2009), respectively, of the ImageJ software (1.50b). The coefficient of

variation and typical error for PA and FL assessments were 1.35% and 0.35°, and 1.05% and 0.05 cm, respectively.

Statistical analysis

After visual inspection, data normality and variance homogeneity were confirmed by Shapiro–Wilk Levine’s tests, respectively. As the TRAD condition had 32 “legs” (i.e., positive control condition), while the CP and DS conditions (i.e., experimental conditions) had only 16 “legs”, we performed 10 simulations in which 16 legs were randomly removed from the TRAD condition. These simulations were performed to test if different samples of 16 “legs” in the TRAD condition would change the statistical findings when compared to the situation in which the TRAD condition had 32 “legs”. As none of the simulations produced different statistical findings, for any of the dependent variables, we performed the actual analyses having 32 “legs” in the TRAD condition and 16 “legs” in the CP and DS conditions. To compare baseline values of the dependent variables between-protocols (TTV, 1-RM, CSA, PA and FL) a repeated measures one-way ANOVA was implemented. As there were no significant differences between protocols at baseline, a mixed model having protocols and time as fixed factors and subjects as random factor was performed for each dependent variable to compare training effects over time. In case of significant *F*-values, a Tukey adjustment was implemented for pairwise comparisons. Statistical analyses were performed in the software SAS 9.2 and *P* values was set as *P* < 0.05.

Results

Total training volume (TTV)

No significant differences in TTV (*P* > 0.05) were detected between protocols TRAD, CP, and DS (Fig. 1).

Maximum dynamic strength

All of the protocols showed significantly greater 1-RM values from pre- to post-training for 45° leg press (TRAD = 25.9%, CP = 25.9%, and DS = 24.9%; main time effect, *P* < 0.0001) (Fig. 2a) and leg extension (TRAD = 16.6%, CP = 16.4% and DS = 17.1%; main time effect, *P* < 0.0001) exercises (Fig. 2b). Compound 1-RM values (unilateral 45° leg press plus unilateral leg extension) significantly increased from pre- to post-training (TRAD = 24.1; CP = 24.6; DS = 22.9; main time effect, *P* < 0.0001) (Fig. 2c). No significant differences were detected between protocols (*P* > 0.05). Individual

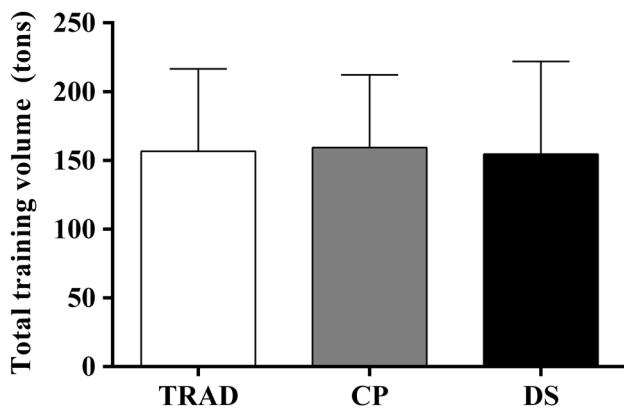
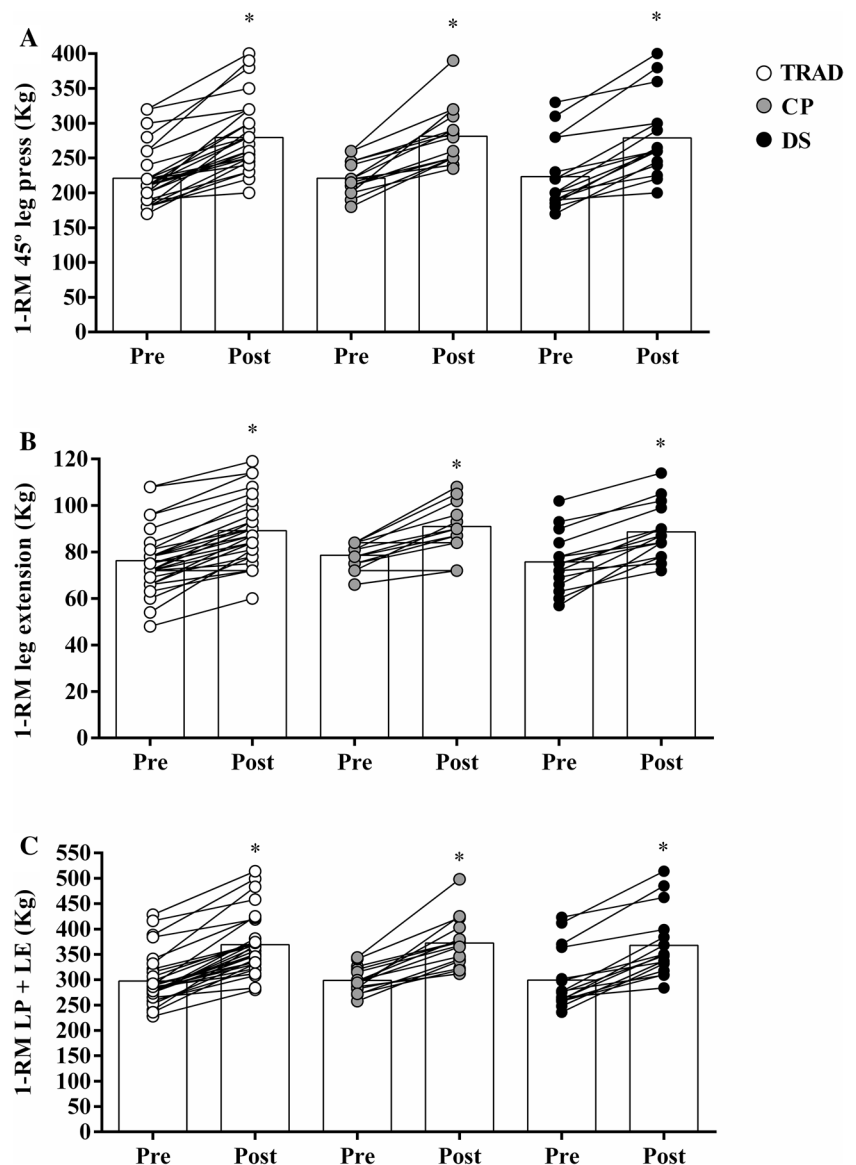


Fig. 1 Total training volume following 12 weeks of traditional (TRAD), crescent pyramid (CP), and drop-set (DS) protocols. Values presented as mean \pm SD

Fig. 2 Maximum dynamic strength (1-RM) in unilateral 45° leg press (LP) (a), unilateral leg extension (LE) (b) and compound (LP plus LE) (c) measured at baseline (Pre) and after 12 weeks of training (Post) for the traditional (TRAD), crescent pyramid (CP), and drop-set (DS) protocols. *Significantly different from Pre (main time effect, $P < 0.0001$). Values presented as mean \pm SD

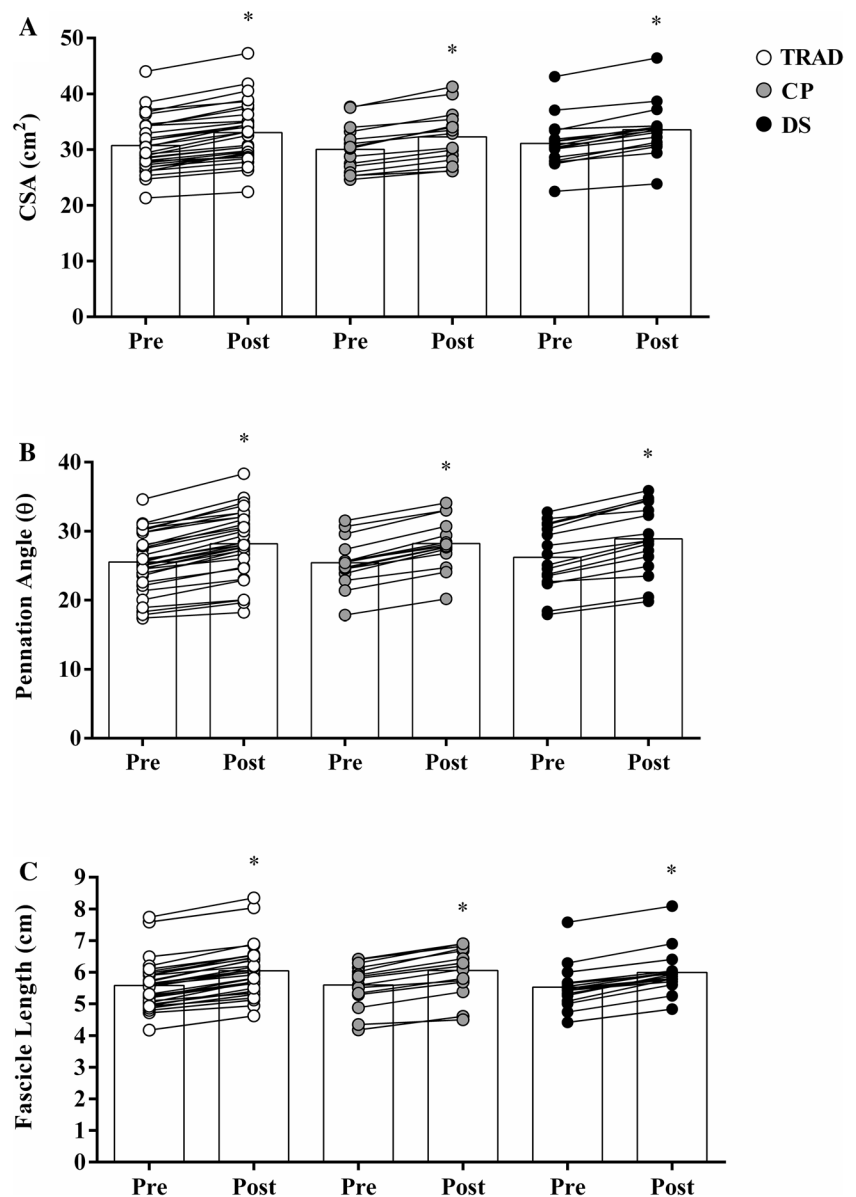


relative changes (%) in compound 1-RM values are shown in Fig. 4a.

Muscle cross-sectional area (CSA) and muscle architecture

In relation to CSA, all of the protocols significantly increased values from pre- to post-training (TRAD=7.6%, CP=7.5%, and DS=7.8%; main time effect, $P=0.01$) (Figs. 3a, 4b). Regarding increases in PA, all of the protocols showed significant and similar increases from pre- to post-training (TRAD=10.6%; CP=11.0%; DS=10.3%; main time effect, $P=0.001$) (Fig. 3b). FL values also increased significantly and similarly from pre- to post-training for all of the protocols (TRAD=8.9%; CP=8.9%; DS=9.1%; main time effect, $P=0.001$) (Fig. 3c). No

Fig. 3 Muscle cross-sectional area (CSA) (**a**), pennation angle (PA) (**b**) and fascicle length (FL) (**c**) measured at the baseline (Pre) and after 12 weeks of training (Post) for the traditional (TRAD), crescent pyramid (CP) and drop-set (DS) protocols. *Significantly different from Pre (main time effect, $P=0.001$). Values presented as mean \pm SD



significant differences between protocols were detected ($P>0.05$).

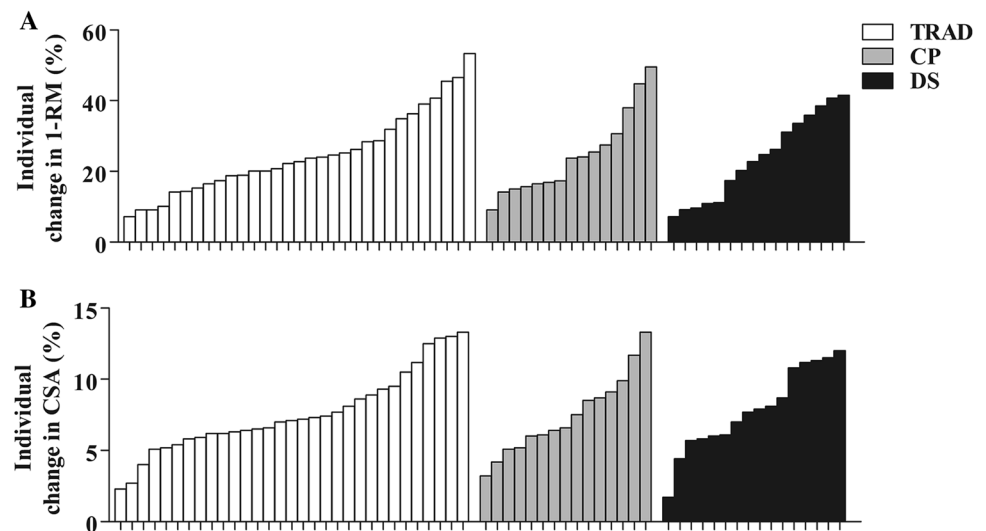
Discussion

To the authors' knowledge, this is the first study comparing the effects of Crescent Pyramid (CP) and Drop-set (DS) RT systems with Traditional (TRAD) RT in a volume-equated program on muscle strength, cross-sectional area (CSA), and architecture parameters in well-trained individuals. Our main finding is that CP and DS systems do not produce additional gains in muscle strength and mass compared to TRAD.

Accordingly, we found similar increases in muscular strength between TRAD, CP, and DS protocols (24.9–25.9% for leg press and 16.4–17.1% for leg extension). The increases in 1-RM values for the 45° leg press and leg extension exercises reported herein are consistent with other studies that performed TRAD in well-trained individuals (~20% after 24 sessions) (Ahtiainen et al. 2005; Schoenfeld et al. 2014b, 2015, 2016a).

Regarding the comparison between TRAD, CP, and DS, it is suggested that the CP system may induce greater increases in muscle strength compared to TRAD and DS due to higher training intensity (Fleck and Kraemer 2014), which can increase the recruitment of fast motor units (Schoenfeld et al. 2014a). In fact, authors have suggested that high-intensity RT protocols may promote greater gains in

Fig. 4 Individual relative changes (%) in compound maximum dynamic strength (1-RM, unilateral 45° leg press plus unilateral leg extension) (a) and muscle cross-sectional area (CSA) (b) in relation to baseline values for the traditional (TRAD), crescent pyramid (CP), and drop-set (DS) protocols



muscle strength than low-intensity RT protocols in trained individuals (~20 vs. ~9%) (Mangine et al. 2015; Schoenfeld et al. 2015). In our study, 1-RM increased similarly between TRAD, CP, and DS protocols (24.9–25.9% to 45° leg press and 16.4–17.1% to leg extension). The range of training intensities used in the present study (TRAD=75% 1-RM; CP=65–85% 1-RM; DS=~60–75% 1-RM) may partially explain the similar gains in muscle strength, which may have ensured the recruitment of the motor unit pool (Clamann 1993; De Luca and Contessa 2012). Additionally, TTV equalization may have promoted similar muscle overload between protocols, despite the differences in volume and intensity between protocols, and therefore strength gains (Candow and Burke 2007; Gentil et al. 2015; Kelly et al. 2007; Krieger 2009, 2010; Marshall et al. 2011; Mitchell et al. 2012; Ronnestad et al. 2007; Schoenfeld 2013a; Sooneste et al. 2013). Our data support the hypothesis that RT systems are not needed to maximize muscle strength gains in trained individuals in TTV-equalized conditions.

Increases in VL CSA were also similar between TRAD, CP, and DS protocols (7.5–7.8%). Studies have reported that muscle hypertrophy responses is lower in well-trained individuals (Ahtiainen et al. 2003, 2005; Brandenburg and Docherty 2002) compared to individuals with little or no RT experience (Wernbom et al. 2007). However, in our study, the increase in muscle CSA was higher than in other studies on trained individuals. For instance, Ahtiainen et al. (2003) reported increases in quadriceps CSA of ~5.6% after 21-weeks of RT (5 sets of leg extension carried out twice a week) in bodybuilders and weightlifters. Following, the same group observed an increase of only ~4% in quadriceps CSA after 21-week of RT (3–4 sets of squats and 4–5 sets of leg press of 10-RM carried out twice a week) in resistance-trained individuals (Ahtiainen et al. 2005). Studies

from our group and others have demonstrated that RT-induced changes in muscle CSA have a high between-subject variability (range: –11–30%) (Ahtiainen et al. 2016; Brandenburg and Docherty 2002; Fonseca et al. 2014; Hubal et al. 2005; Laurentino et al. 2012; Libardi et al. 2015; Vechin et al. 2015). In the present study, all of the participants improved muscle CSA, and the between-subject variability was lower than previously reported (range: 1.7–13.3%) (Fig. 4b). It is possible that the following characteristics of our experimental design may have optimized anabolic stimuli and minimized between-subject variability even in trained individuals: (1) individuals had an initial training load that considered training history ensuring an appropriate muscle overload; (2) TTV was frequently increased (i.e., 7% every six training sessions) to ensure a continuous progression and load-equalization between protocols (Krieger 2009, 2010; Schoenfeld et al. 2016b); (3) to warrant maximal elevation in protein synthesis after each RT session and to reduce the diet-induced between-subject variability, all of the participants ingested 30 g of whey protein after each RT session (Burd et al. 2010; Damas et al. 2016a; Hartman et al. 2007; Mitchell et al. 2012); (4) our within-subject experimental design allowed a more precise volume equalization between protocols and minimized the effects of the between-subjects biological variability when comparing training protocols.

Regarding the comparison between TRAD, CP, and DS protocols, it has been suggested that sets performed to failure in DS system, and the associated high TTV, are advantageous for muscle hypertrophy due to a high metabolic stress, and a consequent anabolic milieu compared to TRAD and CP protocols (Mangine et al. 2015; Morton et al. 2016; Schoenfeld 2013b; Schoenfeld et al. 2015). However, our DS protocol did not result in greater increases in CSA when compared to the other protocols. As

the TRAD and CP protocols do not require reaching muscle failure on each set (ACSM 2009; Charro et al. 2010, 2012), participants were not instructed to reach it on each set. Despite the fact that achieving failure was not a prerequisite to TRAD and CP, sets were performed with high level of effort and fatigue due to an initial high TTV (i.e., addition of 20% to the previous TTV) and periodical increases in TTV throughout the experimental protocol. Although we should consider that only the DS performed all sets to muscle failure, to the best of our knowledge, there is no data supporting the notion that individuals should reach muscle failure on each set of the training routine (Davies et al. 2016; Nóbrega and Libardi 2016). At last, another unpublished data set from our group (under review) shows that sets performed to muscle failure or volitional interruption (i.e., point in which participants voluntarily interrupted the exercise prior to muscle failure) do not produce acute differences in muscle hypertrophy. In spite of the lack of studies investigating the effects of the standard DS system, some studies compared blood lactate response (Goto et al. 2003) and changes in muscle strength and mass (Goto et al. 2004) between TRAD and a RT protocol that resembles the DS system (i.e., addition of one set with reduced load until muscle failure, which was performed at the end of the session after a short pause). The results of these studies showed greater lactate concentrations immediately after the session (Goto et al. 2003) and greater muscle adaptation after 10 weeks of training (Goto et al. 2004) for the DS system when compared to the TRAD. Importantly, a higher number of repetitions was performed in the “DS system” in both studies, resulting in greater TTVs than in the other protocols, suggesting that the advantages offered by DS may be due to a higher TTV and not to the system per se (Schoenfeld 2011). Recently, Schoenfeld et al. (2016b) demonstrated a graded dose–response relationship in which increases in RT TTV produced greater gains in muscle hypertrophy, highlighting the importance of TTV for muscle hypertrophy. Taken together, it is possible to suggest that DS cannot provide advantages to muscle CSA gains over other RT protocols for resistance-trained individuals when TTV is equalized.

Muscle hypertrophy was accompanied by similar increases in PA and FL between protocols. To the best of our knowledge, this is the first study investigating the effects of RT systems on muscle architecture parameters in resistance-trained individuals. Given that changes in muscle architecture accompany the changes on muscle CSA (Aagaard et al. 2001), one should expect smaller changes in PA and FL in trained individuals than in untrained ones (Wernbom et al. 2007). However, our results showed increases in PA and FL comparable to those observed in recreationally active individuals (~10% to PA and ~8% to FL) (Blazevich et al. 2007; Seynnes et al. 2007). Therefore,

it is possible to suggest that the strategies used herein to ensure adaptive responses in well-trained individuals optimized not only the increases in CSA, but also in PA and FL. The changes in PA and FL allow us to suggest that the increase in CSA was due to increased number of sarcomeres in parallel, and thus maximum force capacity (Aagaard et al. 2001).

Our study provides some practical insights that should be considered. First, as TRAD, CP, and DS produced similar changes in the assessed parameters, it is recommended that the utilization of a RT system should take into account individual preferences. Second, training-induced adaptations seem to be optimized with periodical adjustments in TTV throughout a training period. Finally, the manipulation of intensity or volume does not interfere in muscle strength and hypertrophy gains, at least when the TTV of protocols is equalized and progressively increased.

This study is not without limitations. CSA was measured in a single point, which can limit the ability to assess non-uniform muscle growth. However, non-uniform muscle growth is more likely to occur when exercises are varied throughout the training period (Fonseca et al. 2014), which was not the case in the present study. The unilateral training model employed in the present study may favor the occurrence of cross-education, which may lead to neurally-induced strength gains in untrained contralateral muscles (Lee and Carroll 2007). However, we believe that cross-education effects (at least at the post-training assessment) have been minimized in our design due to the following factors: (a) the occurrence of neurally-induced strength gains usually lasts less than the duration of our experimental period (i.e., 12 weeks); (b) in a meta-analysis, Munn et al. (2004) demonstrated an average strength gain of ~10% when undergoing cross-education in untrained individuals. Our strength gains are 1.5 times greater than the gains induced by cross-education, which may rule out cross-education as a factor driving our training-induced adaptations; (c) the participants of the present study were deemed as strength-trained individuals, as they had 6.4 ± 2.0 years of resistance training experience. Cross-education is less likely to occur in trained individuals than untrained ones; (d) the advantages of using a within-subject design outgain those of a between-subject design. Biological variability (between-subject design) has a greater effect on muscle strength and hypertrophy gains than cross-education; (e) a within-subject design is very effective in controlling biological variability as between-leg responses are equally affected by biological variability; (f) it was of utmost importance to control TTV between protocols. A between-subject design would not allow controlling TTV precisely, as using TTV from one experimental group to another could have produced a sub-par or an excessive overload greatly affecting our findings.

Conclusions

Crescent Pyramid and Drop-set systems do not promote greater strength gains, muscle hypertrophy and changes in muscle architecture compared with resistance training traditionally performed with constant intensities and volumes.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical standard All procedures performed herein were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

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