PARTIAL COMPARED WITH FULL RANGE OF MOTION RESISTANCE TRAINING FOR MUSCLE HYPERTROPHY: A BRIEF REVIEW AND AN IDENTIFICATION OF POTENTIAL MECHANISMS

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ABSTRACT

Newmire, DE and Willoughby, DS. Partial compared to full range of motion resistance training for muscle hypertrophy: A brief review and an identification of potential mechanisms. J Strength Cond Res 32(9): 2652–2664, 2018—Resistance training promotes skeletal muscle hypertrophy; there are specific recommendations of intensity, volume, and duration that appear to facilitate hypertrophy the greatest. However, currently, there is not a definitive consensus on optimal range of motion. It appears that the partial range of motion (pROM) mode of exercise may have some similar benefit on muscle hypertrophy as the conventional full range of motion (fROM). Because of the dynamic and multiplanar movement pattern of a multijoint resistance exercise, there may be variation in human force–length and strength-curve theories, which may influence optimal muscle force production at differing portions of a fROM. This suggests specific muscle groups may potentially be optimally recruited during a specific portion of the exercise. The majority of previous research has primarily focused on strength outcomes opposed to muscle hypertrophy. The purpose of this brief review is to highlight the limited and relative pROM literature on muscle hypertrophy and some potential pROM mechanisms that require investigation to assess any plausible relationships. Some potential mechanisms and outcomes of interest are muscle time under tension, muscle activation, and nonuniform hypertrophy. This mode of resistance exercise requires further evaluation on hypertrophic responses; if proven efficacious, it may be employed to those in rehabilitative environments and those that seek more specific regional, local hypertrophic responses such as physique competitors.

KEY WORDS partial range of motion, training specificity

INTRODUCTION

Skeletal muscle hypertrophy is normally expressed as an increase in cross-sectional area or a gain in muscle protein mass as an adaptation to exercise training stress such as resistance training (RT). The increase in muscle protein mass is predominantly due to the accretion of contractile (myosin, actin) and non-contractile (titin, nebulin, etc.) proteins (25,52,59). Muscle hypertrophy is often expressed in a practical form by an increase in anatomical cross-sectional area or functional cross-sectional area (fCSA) by way of an anabolic effect of protein accretion of sarcomeres in a muscle group, which is augmented by RT.

Resistance training protocols are directed to promote muscular strength, hypertrophy, power, and endurance. It has been well documented that there are specific RT intensities and repetition schemes that primarily promote these specific muscular adaptations with some relative crossover (34). The SAID principle (specific adaptations to imposed demands) states that the training effects are specific to the muscle groups recruited during training bouts and the type of training program implemented (24). However, the range of motion (ROM) is not a factor that is normally manipulated when participating in RT (22). The suggested ROM for optimal muscular adaptations and performance outcomes is proposed to be a full range of motion (fROM); however, currently, there is not a definitive consensus on this statement (22).

The American College of Sports Medicine (ACSM) suggests to optimize muscle hypertrophy, the training protocol should be prescribed to an intensity between 70-85% of a one-repetition max (1RM), 7–12 repetitions per set, and 1–3 sets per resistance exercise (2). However, the ACSM position stand does not identify a ROM as a functional factor that may influence muscular adaptations.
Range of motion is defined as the amount of movement about a joint, which is dependent upon the joint articulation, classification, and the plane or axis the action takes place. The ROM related to skeletal muscle has been termed “functional excursion” which is defined as a muscle from a position of a full stretch to a position of maximal concentric contraction that is directly influenced by the joint it crosses (14,32). For multijoint muscles, their range goes beyond the limits of any one joint that may cross. These muscle groups normally function in the midportion of their functional excursion, where ideal length–tension relations exist (32). In comparison, partial range of motion (pROM) would be defined by as a specified ROM within the fROM spectrum. Additionally, this specified ROM may be a muscular movement about a joint that may potentially be within the spectrum of the optimal length–tension and strength relationship curve (35), which may subjectively and or objectively recruit a particular muscle group to optimize a specific muscular movement or action during a multijoint resistance exercise.

The force–length (also referred to as length–tension) curve was first observed by Blix in 1894 looking at isometric forces of isolated frog skeletal muscles increased as a function of muscle length, plateaued, and then decreased. This was later supported by Gordon et al. (26), looking at single muscle fibers showing similar results. These seminal studies indicated that there is a length-dependent muscle–force relationship, which is directly related to the extent of overlap between the myosin and actin filaments in the sarcomere. There is limited work investigating the force–length relationship in individual human skeletal muscles in vivo. Previous research has focused on moment-angles related to differing joints and joint angle known as strength-curves (35,39).

The strength-curve theory suggests that the maximum force that can be produced may vary as a function of the joint angle. However, this observation is also limited in that the resistance exercise is (a) isolated to a single-joint exercise, (b) the muscle of interest appears to be the primary mover, and (c) the joint is limited to 1° of rotational freedom (35). Additionally, the assumption that the strength-curves are an accurate representation of force–length relationships may be flawed in that net force outcome may be a component of both synergistic and antagonistic muscle groups acting on the joint and the dynamic muscle fiber and tendon lengths about the joint angle during contraction (39). With the understanding that numerous multijoint exercises, and potentially single-joint exercises (pending the factors listed above), may recruit individual muscle groups, with differing optimal force–length curve, at differing portions of the joint angle or ROM (Figure 1).

Partial range of motion is a training mode that is not entirely novel and has been investigated in research showing some positive outcomes and efficacy. However, overall, it has been suggested by researchers, clinicians, and athletes that this mode of training has little muscular benefit when compared to fROM. Most research has investigated and compared strength outcomes (Table 1) when assessing the ROM and more often than not, fROM is the mode most often promoted over pROM, yet both have shown to improve strength outcomes (7). The fROM advocacy is most likely attributed to the potential for a greater amount of mechanical stress placed equally about the whole length of the muscle (8,16,29,41,44). Additionally, it has been suggested that pROM may negatively influence joint flexibility more so than using the traditional fROM (23,40). However, there are some studies that have shown multiple benefits by using pROM during resistance exercises for strength outcomes, hypertrophy, and rehabilitative protocols (27,50,51).
## Table 1. Partial range of motion (pROM) resistance training and skeletal muscle adaptations.*

<table>
<thead>
<tr>
<th>Study</th>
<th>pROM angle</th>
<th>Duration</th>
<th>pROM RT exercise</th>
<th>Outcome measures</th>
<th>Authors interpretations</th>
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<tbody>
<tr>
<td>Bazyler et al. (7)</td>
<td>Full squat (F)</td>
<td>2 d·wk⁻¹, block periodized, 12 wk</td>
<td>Barbell back squat</td>
<td>1RM for full squat: F: ↑5.1 ± 4.5%, FP: ↑8.2 ± 2.1%</td>
<td>1RM squat and partial squat in both groups with a 3.1 and 4.7% greater improvement in the F and FP groups</td>
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<td>F group improved isometric strength at 90° by 5.3%</td>
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<td></td>
<td>Full squat + partial (FP): 100° of knee flexion</td>
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<td>And the FP group improved at 120° by 8.9%</td>
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<tr>
<td>Bloomquist et al. (8)</td>
<td>A) 45°—shallow squat (SS)</td>
<td>3 d·wk⁻¹, 12 wk</td>
<td>Barbell back squat</td>
<td>1RM for DS ↑20 ± 3% in both squat ranges</td>
<td>Regardless of range of motion, resulted in ↑ in 1RM strength and pennation angle</td>
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<td>DS group ↑LBM of the legs, isometric strength, and front thigh muscle CSA at all measured points</td>
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<td>B) 90°—deep squat (DS)</td>
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<td>The SS group elicited front thigh muscle CSA ↑ at the 2 most proximal sites</td>
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<td>Clark et al. (13)</td>
<td>100% (fROM), 75, 50, and 25% of ROM, variable ROM (VROM)</td>
<td>4 wk</td>
<td>Smith machine bench press</td>
<td>Peak force (N): 25 and 50% &gt; 75 and 100%</td>
<td>Peak force levels &gt; than those that occur during fROM training may be produced throughout a considerable segment of the midrange of the movement</td>
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<td>Resistance training (RT) throughout different phases of the ROM with various loads, may optimize performance by enhancing the true movement specificity of training</td>
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Legend: F = full squat, FP = full squat + partial squat, SS = shallow squat, DS = deep squat.
<table>
<thead>
<tr>
<th>Study</th>
<th>ROM/Condition</th>
<th>ISO</th>
<th>Training</th>
<th>Exercise</th>
<th>Post-Training</th>
<th>Notes</th>
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<tr>
<td>Graves et al. (27)</td>
<td>A) 120–60°</td>
<td>2–3 d·wk⁻¹, 10 wk</td>
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<td>Variable resistance knee extensions</td>
<td>Post-training isometric strength: A, B, AB &gt; C: 35–80°, 110°; B, AB &gt; C: 9°, 20°; A, AB &gt; C: 95°; B, AB &gt; A: 20°; B &gt; A: 35°, 50°; A &gt; B: 80°; A, AB &gt; B: 95°.</td>
<td>Group B (60–0°) trained QC in contracted position showed to have the greatest improvement in weight after 10 wk of training</td>
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<td>B) 60–0°</td>
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<td>Hypertrophy was not assessed Some benefit observed from limited ROM resistance exercise. However, fROM should be attained when conditions allow for maximum strength improvements</td>
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<td>AB) 120–0°</td>
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<td>C) Control</td>
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<td>Massey et al. (42)</td>
<td>pROM vs. fROM vs. mixed: 2–5 in from full extension of elbows</td>
<td>2 d·wk⁻¹, 10 wk</td>
<td>Traditional bench press</td>
<td>Post-training: fROM similar to pROM in ↑ 25 and 24.33 lb Combination style 16.5 lbs</td>
<td>pROM and combination ranges of motion effects on strength outcomes were found to be similar as fROM pROM is not found to be any more beneficial than fROM. Advocate fROM based on joint flexibility and ↓ susceptibility to injury Advocate pROM as additive to fROM for training plateaus</td>
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<td>McMahon et al. (44)</td>
<td>Isoenertial: A) (SR) ROM 0–50° knee flexion. B) (LR) ROM 0–90° knee flexion</td>
<td>3 d·wk⁻¹ for 8 wk; 4-wk detraining</td>
<td>Free weights, machine, Sampson chair, and body weights</td>
<td>CSA at 25, 50, 75%: LR &gt; SR at 75% (8 wk) only; Fascicle pennation angle at 25, 50, 75% for each group, with no significant effect of group Muscle strength (MVC): there were no differences between MVC in SR and LR at baseline or after training</td>
<td>Muscle adaptations were observed in both SR and LR training groups Significant main effect of training: strength, VL fascicle length, VL aCSA ↑ Major finding: ↑ in fascicle length at all sites in the LR group compared with SR group, although only significant at 50 and 75% of total femur length (continued on next page)</td>
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<tr>
<td>Study</td>
<td>Comparison</td>
<td>Duration</td>
<td>Exercise</td>
<td>Data</td>
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<tr>
<td>Massey et al. (41)</td>
<td>pROM vs. fROM vs. mixed</td>
<td>2 d·wk⁻¹, 10 wk</td>
<td>Traditional bench press</td>
<td>Post-training: the fROM group mean 25.39 lbs whereas the pROM 16.88 lbs and mixed 16.25 lbs groups</td>
<td>Hypertrophy was not measured. Lifting fROM is superior; also suggests that the pROM technique can have a positive effect on overall ROM strength with female subjects.</td>
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<td>Paoli et al. (50)</td>
<td>3 ROMs with elbow angles: (R1) 90°; (R2) 135°; (R3) 180°</td>
<td>2 sessions: A) 1RM for all 3 elbow angles, B) 3 sets (0, 30, and 70% of 1RM) of 10 reps with elbow angle R1, R2, R3.</td>
<td>Seated military DB press</td>
<td>EMG of all 8-selected muscles increased in proportion with the increase of the load.</td>
<td>The greater the ROM the greater the EMG response. Specific activation in varying the ROM of the trapezius and the deltoid were the most involved muscles in this exercise with each of the 3 ROMs. Hypertrophy was not measured. In strength development with heavy loads, the choice of an incomplete ROM might reduce the involvement of the trapezius without the deltoid activity.</td>
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<td>Pinto, et al. (51)</td>
<td>FULL: 0–130°</td>
<td>2 d·wk⁻¹ for 10 wk</td>
<td>Elbow flexion exercise</td>
<td>1RM significantly †FULL 25.7% &gt; PART 16.0% above baseline</td>
<td>Some musculature may produce their respective maximal force, whereas other musculature is not optimal force producing lengths at a specific joint angle. Muscle thickness †FULL 9.52%, PART 7.37% above baseline. The force produced when RT at differing ROMs may vary according to the angle chosen.</td>
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*1RM = 1-repetition max; † = increased; LBM = lean body mass; CSA = cross-sectional area; fROM = full range of motion; VROM = variable range of motion; ROM = range of motion; QC = quadriceps; ↓ = decrease; SR = short range; LR = long range; MVC = maximal voluntary contraction; VL = vastus lateralis; aCSA = anatomical cross-sectional area; EMG = electromyography.
rationale for the usage of pROM as a possible training mode is that during a multijoint resistance exercise, the strength-curve for any given muscle group at any given point of the ROM may not be at an optimal joint angle or muscle length for maximal myosin and actin cross-bridge formation, and therefore optimal force production and recruitment. An optimal ROM for any multi-joint exercise has not been established and requires much more research to more appropriately and accurately define (35). In contrast, single-joint exercises have been more well defined using “strength-curve” assessments. However, if the single-joint exercise does not meet the criteria listed (single-joint muscle is the primary mover, 1° of rotation), the optimal ROM may be open to interpretation. Furthermore, only a handful of studies have compared fROM to pROM (7,16,41,42,44,47,51) and even fewer investigating hypertrophy (8,44,45,51). Our definition of pROM is suggested to be an undefined ROM used during a resistance exercise bout within the spectrum of a normal fROM exercise (Figure 2).

The purpose of this review is to highlight the previous, relative, and very limited research that has investigated pROM on muscle hypertrophy and to highlight some potential mechanisms during pROM that could be the factors that may influence hypertrophy, thereby prompting future investigations to assess the feasibility of promoting the use of pROM in RT. To complete this review, English-language literature searches of the PubMed, EBSCO, and Google Scholar databases were conducted for all time periods up to March 2017. Combinations of the following keywords were used as search terms: “pROM,” “variable range of motion,” “fROM,” “hypertrophy,” “RT,” “electromyography (EMG),” “fCSA,” and “muscle thickness.” The articles retrieved in the search were then screened for any additional articles that had relevance to the topic. Given the small number of articles related to this topic, a narrative approach was chosen as the best way to convey applicable information, and inclusion criteria was based on relevancy to the particular area of discussion.

RANGE OF MOTION AND MUSCLE HYPERTROPHY

Within the last few decades, there have only been a handful of research training studies assessing muscular adaptations in response to pROM versus the traditional fROM. Recently, researchers have begun to observe additional measurable factors such as muscle hypertrophy concurrent with muscle activation and strength outcomes.

Pinto et al. (2012) compared 2 RT groups, untrained, using elbow flexion (seated machine bicep curls), for a 10-week training period. The fROM group performed elbow flexion with (0–130° of elbow flexion, where 0° is full elbow extension), whereas the pROM group performed elbow flexion (50–100°). Both groups showed the same muscle thickness (MT) increase over the training period. The fROM group showed an increase of 9.7%, comparatively to pROM which had 7.8%; no significant difference between groups was observed ($p = 0.07$). Consistent with other literature (Table 1) observing strength outcomes, fROM showed a greater 1RM increase (25.7%) than did pROM (16.0%) when compared to baseline values. The use of fROM during RT showed to be a better form of ROM for strength changes, yet in regard to hypertrophy, the both modes of ROM seem to be equal. Interestingly, Pinto et al. (2012) made a unique suggestion in regard to pROM usage during multijoint resistance exercises, stating that different muscles contract at differing lengths throughout the full ROM, each of these muscle groups may not be at optimal lengths for force production. Hence, for any given joint angle, some musculature may produce their maximal force, whereas others may be at a less than optimal length to do so (51).

McMahon et al. (2014) investigated the differences between pROM vs. fROM over 8 weeks of RT. They
compared muscle activation via surface electromyography and MT (muscle width) changes using the B-mode ultrasound (US) at 25, 50, and 75% sites of femur length during barbell back squat training. They assessed knee flexion angles of 0–50° (shorter ROM) and 0–90° (longer ROM). Interestingly, after the cessation of 8 weeks of training, all ROM groups showed an increase of MT at all sites ($p < 0.001$). Additionally, the 40–90° and 0–90° ROM groups maintained MT gains at all 2 sites (50 and 75% of vastus lateralis [VL]) for the duration of 4-week detraining period (8–12-week) ($p < 0.01$). There were no differences ($p > 0.05$) found in mean relative changes between ROM training groups post-training or after detraining at 25 and 50% femur length (0–50°; 12 ± 13%, 40–90°; 11 ± 7%, 0–90°; 13 ± 11%). The 0–50° and 0–90° ROM groups had a greater ($p < 0.05$) relative increase in MT 2 weeks into detraining (week 10; 0–50°; 26 ± 13%, 0–90°; 21 ± 9%) compared with 0–50° (13 ± 8%) at 75% femur length. This was also the case the last week of detraining (week 12); however, at the 8-week time point, the 0–90° ROM group showed a greater ($p < 0.05$) MT than 0–50° ROM group at 75% femur length site. In relation to muscle activation, changes were observed preand post-training at a knee angle of 70°. No differences were found between any of the tested weeks nor between the groups (45).

Bloomquist et al. (2013) investigated how the ROM of a squat affected strength, lean body mass (LBM), and hypertrophic outcomes using differing methodologies to observe hypertrophy using US to measure MT and MRI to assess CSA. They investigated 17 untrained males who trained 3 d-wk$^{-1}$ for 12 weeks using periodized and progressive loads in conjunction with the barbell back squat exercise. The authors did not express a prescribed intensity used during the training study. However, the repetition range implemented was varied daily and weekly from a traditional “3 × 10” hypertrophic range (67–85% of 1RM) and a lower rep range of “3 × 6” (≥85% of 1RM). The squat exercise groups consisted of a fROM or a deep squat 0–120° of knee flexion where participant descends to ~120° or parallel to the floor and the pROM or shallow squat, which was 0–60° of knee flexion. Both groups maintained a 2–4-second eccentric descent followed by a maximal concentric effort. To assess the pre- and post-CSA change between groups, they used 9-slice MRI (9 being the most proximal) of the front and back thigh, LBM was assessed with dual X-ray absorptiometry (DXA), and they used US to measure MT and architectural differences. The MT measure was taken midway (50%) between the greater trochanter and the lateral condyle. They found some conflicting results between hypertrophic measures. Their MRI assessment showed a significant difference between the 0–120° and 0–60° group in CSA. The 0–120° had a much more pronounced effect on CSA on the anterior thigh (sartorius, quadriceps [QC], and adductors in the most proximal sections) in all slices except the most proximal area, which was similar to 0–60°. However, the US measures of MT of the right VL showed no difference between training groups along with a similar pre-change and post-change in the pennation angle (PA). DXA measures supported the use of 0–120° with an increase in leg (~1.7 kg) mass, whereas 0–60° showed no difference (8).

Magnetic resonance imaging is considered the most accurate approach for in vivo quantification of body composition (36); Bloomquist et al. (2013) observed a true difference between these forms of RT on overall CSA measures. However, because of the similar group pre- and post-MT measurement by US and the similar proximal area CSA change (slice 9) by MRI between 0–120° and 0–60°, it could be argued that there is some discrepancy among muscle hypertrophy measures. Furthermore, the 0–60° of knee flexion during squat exercise was chosen by these authors based on previous work suggesting that angle placed the greatest stress on patella tendon to promote patella tendon hypertrophy. The angle chosen may not be an optimal ROM for a pROM technique to promote recruitment of a particular regional muscle group during the bout assuming that the forces of the patella tendon and the QC muscle forces are similar (38). Nonetheless, there was evidence of a pROM training effect on regional muscle adaptations seen in CSA changes in the proximal portion of the front thigh, which responded equally between groups per MRI assessed CSA measures (8). Based on the positive proximal CSA changes in the anterior thigh that would consist of the adductors, and predominantly the VL and RF of the QC, it may be plausible to suggest that pROM use during a squat exercise may be beneficial for specific regional muscle adaptations for those who desire regional or specific hypertrophy of the proximal area or by those who may have limited passive ROM of the knee or hip because of injury or conditions such as osteoarthritis.

**Potential Mechanisms to Isolate and Investigate**

Training volume is dictated by a prescribed goal, training status, the intensity or load, rest time, and time under tension (TUT) (54). Another factor of training volume is the work performed via the mechanical work, which is configured by multiplying the force required to move the load by the distance traveled. The assumption is that the force generated is equal to the load being lifted and that all repetitions are performed with the same ROM. The work may be better quantified by multiplying the load by the number of sets and repetitions, commonly referred to as “volume load” (5,31,56). Moreover, another assumption is that the repetition rate and distance also remain consistent, which would maintain equal work during each repetition and therefore set. However, during a dynamic concentric or eccentric action, there may be a differing time from start to finish that may affect the muscular TUT. To more accurately quantify volume, the TUT during dynamic RT protocols, the load, repetitions, and contraction velocities of the concentric and eccentric phases (along with the duration of any isometric phase if used) of
the repetitions should be controlled and remain consistent to maintain equality of the work load. Lastly, the assumption that the joint action during a resistance exercise repetition has completed its full joint action or a full ROM muscle action. If this does not take place, it may be deemed volitional muscular failure, which could be categorized as an incomplete ROM (12,19). Comparatively, the difference in muscular work between pROM and fROM should be minimal when controlling for the total value of work, assuming the displacement is similar. However, when further comparing the distance of the repetition, pROM should be less than fROM being it displaces less distance, assuming that precautions have been taken to control for repetition rate and number. In theory, the total amount of mechanical work (force \times distance) done during a pROM should be always less if all factors are controlled. If less distance is being displaced and therefore less total mechanical work during a pROM resistance exercise bout, how would less work augment muscular hypertrophy? If individual muscle groups where recruited more so during a specific portion of a ROM during a resistance exercise and assessed to show a greater amount of contraction and therefore work than accompanying synergists, this may potentially lead to a greater stimulus relative to the working musculature, suggesting that more volume and stimulus would ideally promote hypertrophy. This work over time has been categorized as “TUT.”

**Muscle Time Under Tension**

Kulig et al. (35) proposed that a multi-joint exercise strength-curve is difficult to assess due to the joint configuration changes during the exercise and the muscle groups acting upon the joints during the movement have relative associated strength-curves. Furthermore, multi-joint exercises (bench, squat) operate in multiple degrees of freedom (flexion/extension, adduction/abduction, internal/external rotation), which further convolutes the ability to assess an accurate strength-curve. The length-tension curve relationship (1) suggests that an optimal muscle length will normally evoke a greater force outcome through greater myosin and actin interaction. Similar to the length-tension curve theory, it may be feasible that, during a multi-joint exercise, differing agonist muscle groups may have individual and relative optimal lengths for force production during differing portions of a given ROM (35).

A distinct muscle group that is under tension or is contracted during a specified amount of time during a resistance exercise bout is referred to as muscle TUT (55). Tran et al. (55) controlled TUT as a possible factor that influences the total volume and work done in a resistance exercise bout. It was observed that when manipulating TUT or volume load, it influenced acute markers of fatigue when normalized for volume (either by the TUT or volume load method). Increased concentric TUT resulted in significantly greater neuromuscular fatigue. Greater decrements to twitch force suggest that more significant training stresses are placed on localized skeletal muscle recruited rather than the central nervous system component with a longer TUT. The authors concluded that an increase in TUT or volume load resulted in greater localized muscular fatigue that seems to be a result of impairments in muscle contractile properties. Furthermore, a greater TUT may lead to optimal stimuli for hypertrophic adaptations as long as the training load is maintained within ranges that have shown to support these outcomes (56).

Burd et al. (10) investigated the impact of TUT on intramuscular protein metabolism they compared unilateral leg extensions contracted for 6 seconds with a load of 30% of 1RM until failure. Their results showed that 6-second TUT during resistance exercise did not stimulate an immediate rise in myofibrillar protein synthesis (MPS) rate. However, it did result in a delayed stimulation at 24–30 hours post-exercise determined by a 2.3-fold increase in MPS above-fasted rates ($p < 0.001$). Additionally, the longer TUT increased the acute (0–6 hours) magnitude of sarcoplasmic protein synthesis rates that were stimulated 1.8-fold above-fasted levels ($p = 0.001$); however, it had no significant impact on extending the time course of this response (10). This further suggests that an increase in TUT may influence a greater relative muscular adaptation. More simply stated, the longer the TUT, the more overall work and volume the muscle group has engaged in, which may lead to greater adaptations. Potentially, if muscle fibers are recruited under a longer TUT because of a reduced ROM, it may be plausible to suggest this as a possible factor to explain hypertrophic responses.

**Muscle Activation**

It has been suggested that depending on the electrodes used, muscle observed, and quantification/qualification technique, the EMG activity and muscle tension may have both a linear and nonlinear relationship (33). Therefore, surface EMG amplitude should be interpreted with much caution (15). For the purpose of this article, the term “muscle activation” will be used to describe muscle group recruitment during resistance exercises that are commonly interpreted from EMG amplitude (15,20). Furthermore, during a particular resistance exercise, the recruitment of differing muscle groups to initiate a joint movement during a multijoint exercise may have differing EMG amplitude magnitudes and possible differing muscle activation levels of specific muscle groups during differing points of the ROM. For example, during the ascent phase of multijoint exercise such as the flat barbell bench press, the actions are shoulder protraction prompted by the transverse contraction of the pectoralis major that coincides with elbow extension. Interestingly, with the use of EMG in some unpublished data by Duffey (18), they observed differing muscle activation magnitudes of these same muscle groups during differing portions of the ROM with differing grip widths, possibly suggesting differing
muscle-specific TUT during the exercise. The anterior deltoid (AD) EMG activity tended to be greatest at roughly the midpoint in both the descent and ascent phase. The triceps brachii (TB) maximal activity occurred late in the descent phase and early in the ascent phase. Lastly, the major primary mover of this exercise is the pectoralis major, which exhibited the highest relative EMG activity late in the descent phase and the early portion of the ascent phase (18).

Paoli et al. (50) investigated muscle activation of skeletal muscle groups involved in the seated dumbbell military press at differing ROM. They assessed elbow extension at 90, 135, and 180°. However, the authors did not state the joint angle of the starting position of the exercise; however, from the figure the authors used in the article, it shows dumbbells near or resting on the deltoid (>90° elbow flexion). The range of intensity used was 0, 30, and 70% of IRM. They investigated muscle activation at the clavicular head of pectoralis major (PMCH), AD, medial deltoid (MD), posterior deltoid (PD), upper trapezius (UTr), middle trapezius (MTr), long head of triceps (TBLH), and teres minor. As expected, muscle activation increased with greater amounts of load (0 vs. 70%), and the authors concluded that at 70% of IRM they found no significant differences in all deltoid group muscle activation assessments (AD, MD, PD) between 135 and 180°. However, UTr was more activated with 180° than with 135°. The authors stated that when using 135° (pROM) with 70% of IRM, the deltoid recruitment was similar to 180° during the movement while reducing the participation or the activation of the UTr. Similarly, PMCH, PD, and TBLH showed the highest activation for the 180° portion of the ROM (50). The outcomes of this article suggest that during a dumbbell military press, using pROM with the same intensity (70% of IRM) as fROM, there seems to a reduction of synergistic recruitment pattern and therefore more efficient and more specific recruitment of the deltoid muscle group.

Barnett et al. (6) observed differences in bench press positioning (incline, horizontal, and decline) and grip width on EMG activity. They observed the manipulation of body positioning and grip width effected the EMG activity. Wide-hand grip horizontal bench press had the maximum EMG activity on the sternocostal head of the pectorals major compared with other body positions and narrow grip (6). Similarly, EMG activity was found to be different when observing individual muscle activity of the vastus medialis oblique, VL, and rectus femoris, which were significantly more active during the squat exercise when compared to the activity of the biceps femoris or semimembranosus (28). However, it should be stated that EMG amplitude parallels tension in a human muscle when contracting isometrically, yet there is no quantitative relationship between EMG and tension when a muscle is allowed to change its length (30). Muscle appears to be without uniform EMG activity during a specific joint action, which supports the notion that there may be a regional or more specific response during a bout of resistance exercise. This supports that EMG amplitude and muscle activation are relative to body positioning and may be altered by kinematic changes, thereby recruiting more specific musculature to perform a certain joint action.

In respect to the relationship of muscle activation and muscle TUT (33), it may be plausible to suggest that during a multijoint resistance exercise that the relative TUT for each muscle group may be distinct, concurrent with the suggestion that the maximal activation of these muscle groups may be dependent on differing time points during a specific portion of a traditional ROM. Furthermore, if the TUT and magnitude of muscle activation are different during a certain portion of a ROM, this may influence a greater muscle specific workload and possibly augmented muscular adaptations compared with other muscle groups involved in the same exercise.

Nonuniform Skeletal Muscle Hypertrophy

It has been suggested that there may be differing strain length dispersal in sarcomeres of differing lengths in differing regions of muscle fibers (11). Additionally, there may also be intermuscle fiber type variation within a muscle group related to orientation. Lexell et al. (37) found a within-subject range of 47–57% variation of type I muscle fiber 200 mm distal from the VL origin. Moreover, one single muscle fiber can have differences in myosin heavy chain isoform expression and diameter size (4). This variation may be potentially explained by heterogenic muscle architecture that may regulate variability in intermuscular adaptations from certain resistance exercise (11,17). The nonuniform hypertrophy theory suggests there may be a local adaptation of muscle and muscle fibers augmented by RT (4). Investigating this possible relationship, Narici et al. (1996) examined the QC muscle activation and CSA changes. They observed 7 healthy males during 6 months of RT on alternate days with 6 series of 8 unilateral leg extensions at 80% of IRM. After the cessation of the training, the CSA of the QC increased by 18.8 ± 7.2% (p < 0.001) and 19.3 ± 6.7% (p < 0.001) in the distal and proximal regions. In comparison, there was an increase in 13.0 ± 7.2% (p < 0.001) in the central area of the muscle. The average increase in muscle CSA of the QC segments was: (a) rectus femoris 27.9%, (b) VL 19.5%, (c) vastus medialis 18.7%, and (d) vastus intermedius 17.4%. Overall, the authors suggested there appeared to be nonuniform intermuscular hypertrophy of the QC in response to the RT. The VL and rectus femoris were observed to have the greatest hypertrophy in the distal region, whereas the vastus intermedius and medialis muscles exhibited the most significant hypertrophic response in the proximal portion. It was reported that hypertrophy was significantly different between and within the 4 segments of the QC. However, no differences were seen in mean muscle fiber CSA via muscle biopsy, and similarly, no differences were found in time to maximum EMG (4,49).
With some similarity and differences when compared to the work done by to Narici et al. (49), Wakahara et al. (58) investigated the CSA and muscle activation responses during a supine dumbbell elbow extension. When observing the figure in this article, the resistance exercise depiction used by the authors resembled a unilateral dumbbell bench press. They found the percentage of the activated area of the TB acutely by transverse relaxation time (T2) weighted MRI. The authors assessed 5 regions of the TB via 4, 10, 16, 22, and 28 cm from the elbow joint. They then investigated the impact of RT (3 d·wk–1 for 12 weeks) on muscle activation and CSA (MRI) changes of the TB. They assessed a portion of each head (long head, medial head, and lateral head) of an area of (~1 cm²) opposed to the entire CSA of the TB. The authors stated that the muscle activation was significantly greater in the 10 and 16 cm positions (midportion) of the TB. The most significant activated muscle portion was at a distance of 16 cm of the lateral and medial head of the TB. Interestingly, the CSA was observed to have the greatest relative increase was found in the middle portion of the TB (10–22 cm). Essentially, this suggests that the areas of greatest activation (10 and 16 cm) coincide with the central regional areas of the greatest hypertrophic (CSA) response (10–22 cm), whereas the least responsive area was found in the proximal region. Based on the authors, MRI scans of the proximal region were almost exclusively inhabited by the long head of the TB, all 3 heads were included in the middle area, and the medial head was found to be predominantly in the distal region. Therefore, they concluded that greater relative increase in CSA in the middle area of the TB than that in the proximal regions which indicates that the extent of hypertrophy of the medial and lateral heads was greater than the long head.

The authors propose that the greater hypertrophic effect may be in part due to greater muscle activation and recruitment in conjunction with a greater mechanical and metabolic stress in the medial and lateral heads of the TB. Moreover, muscle activation of the resistance exercise during the training session may be dependent on the exercise modality and the anatomical feature of each component of the muscle group (57).

In contrast to the work by both Narici et al. (49) and Wakahara et al. (58), Drummond et al. (17) assessed proximal, medial, and distal regions hypertrophic differences of the biceps brachii with MRI during a 12-week training period using the “Scott” preacher curl bench. They found no difference between the CSA of the proximal, medial, and distal regions of the biceps brachii (p = 0.45) assessed. However, the authors did not investigate muscle EMG to determine muscle activation differences which Drummond et al. (17) conceded that might not be an equal comparison with previous study designs.

Inherent muscle architecture may be another factor that assists in explaining nonuniform muscle hypertrophy. Matta et al. (42) investigated muscle thickness (MT) and the PA at 50, 60, and 70% of arm length of the biceps brachii and TB after 12 weeks of strength training in 49 untrained males. They found a regional difference between MT in biceps brachii, with an increase of 12% in the proximal site and a lesser increase at the distal site 5%. Comparatively, the TB showed increases in both MT and PA at the 3 sites assessed, yet no significant variation was seen among them. The authors suggested that the outcome may be explained by the variation of muscle architecture between the 2 distinct muscle groups, being the biceps brachii categorized as a fusiform muscle, whereas the TB has a pennated-fiber arrangement (43).

If differences have been found in muscular activation, recruitment patterns, and contraction type, during traditional fROM resistance exercises that influence differing muscular adaptations, it may be plausible that differing ROM during resistance exercise may also promote differing muscular adaptations.

**Discussion**

Muscular hypertrophy is a dynamic and multifaceted process that may be additionally influenced by the ROM chosen during a resistance exercise. There is recent data to show that using pROM during a RT bout may have some similar hypertrophic benefits when compared to a fROM exercise (8,44,51). In this small area of research, these authors assessed the effect on ROM during multijoint barbell squat and single-joint elbow flexion training. Depending on the method to analyze hypertrophy, there were some similar measures when comparing fROM to pROM. However, the majority of research that has investigated ROM during resistance exercise has primarily focused on strength outcomes.

One of the prominent suggestions to explain how a reduced ROM may potentially influence hypertrophy is a difference in the optimal muscle force–length curve. This theory suggests that when force is developed by a muscle, it is dependent on the length at which the muscle is activated (1,26,39). Additionally, it has been suggested that there may be variation in human strength–curve theory during a multijoint resistance exercise, which may elude to differences in optimal muscle group force production during a multijoint resistance exercise at differing portions of a fROM. Because of the dynamic and multiplanar movement pattern of a multijoint resistance exercise, it is feasible to suggest that differing muscle groups may be more optimally recruited during a specific portion of the exercise which may not be in concert with other agonists at the same point (35,51). Furthermore, pROM may have an impact on force distribution and it may be feasible that differing portions of the ROM may be more optimal for the force–length curve relationship, possible muscle activation, and desired muscle recruitment (11,35). Additionally, another theory that may explain how pROM may assist in muscular adaptations is through the process of TUT. Tran et al. (56) defined TUT as a distinct muscle group that is under tension or contraction of a specified amount of
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Time during a resistance exercise. Taking into consideration the aforementioned force–length curve definition (1) and the suggestion of the strength-curve theory relative to differing muscle groups within a multijoint exercise (35), it may be plausible to suggest that TUT may be increased by way of altering the ROM to place greater TUT on a specific muscle group. Greater TUT may equate to more individual muscle work or volume and potentially greater stimulus resulting in greater hypertrophic potential (56).

Muscle tension is related muscle activation (amplitude), which is defined as a transformation from the neural signal to a measure of muscle activation (9). It has been suggested that there is a difference in muscle EMG amplitude at differing portions of a resistance exercise ROM (18) and there is an association with the area of muscle activated and the area of CSA increase (57,58). It may be feasible that during a pROM resistance exercise bout that if a greater TUT is being placed on a particular muscle group, a greater muscle activation may equate to a more specific recruitment of that particular muscle group during that time.

Lastly, a muscular adaptation to RT that has been observed by some and refuted (17) by others is nonuniform hypertrophy. Based on the architecture, the anatomical difference of the muscle group, resistance exercise, and exercise chosen, hypertrophy may not be heterogeneous throughout each muscle group that is recruited during the training bout (4,43,45,49,57). Intramuscular factors that may explain this regional form of hypertrophy may be related to differences in fiber size and fiber composition. Related to both the relative muscular activation and recruitment patterns of a regional area, evidence has shown differences in hypertrophic responses.

These mechanisms warrant further investigation to identify if they may be a factor in explaining some of the similar hypertrophic responses seen when pROM is used as a mode of resistance exercise. With the common understanding and respect to the limitations of these selected studies, the individualized interpretations, and these selected author’s perceptions; there may be a portion of a ROM during a resistance exercise that may recruit or isolate a favorable muscle group during a specified portion of a fROM resistance exercise. In summation, these studies should lead to further investigations in both trained and untrained populations assessing how a specific ROM about a joint during a multijoint resistance exercise may potentially isolate and recruit a specific muscle group for the purpose of regional or more specific muscle adaptations.

Skeletal muscle hypertrophy is a multifactorial response augmented by RT. Although not a novel mode of resistance exercise, pROM research offers very little data in which to assess how a specific ROM about a joint during a multi-joint resistance exercise may potentially isolate and recruit a favorable muscle group during that time.

A specific muscle group for the purpose of regional or more specific muscle activation during a multijoint exercise, which may specifically stimulate muscle adaptations unique to the muscle group recruited. Some potential mechanisms of interest related to pROM RT may be muscle activation, TUT, and nonuniform hypertrophy. Understandably, further research is needed to observe and elaborate any possible mechanisms and potential benefits of pROM on skeletal muscle hypertrophy by way of differing single and multijoint exercises, their respective optimal ranges, the magnitude of regional muscle activation at differing ranges of motion, and largely compared with traditional fROM. If shown to be similar or beneficial, this may be a novel technique to be employed by populations who have more specific and regional muscle hypertrophic goals or perhaps in an orthopedic rehabilitation setting.

Practical Applications

Recent research has shown that pROM training method may have similar muscular hypertrophic adaptations as traditional fROM RT. This technique requires further exploration to investigate any potential mechanisms that may isolate and explain these similar outcomes. This training regimen may be a useful training technique in some RT populations and be may be used by persons with joint pain or in conjunction with rehabilitative exercise. A reduced ROM is used during rehabilitation to promote greater joint mobility via pain and muscle tension reduction (3). Additionally, this mode of resistance exercise may be beneficial for those who compete in cosmetically judged physique competitions, who are visually judged by their relative muscular size, aesthetic, and symmetrical structure (48).

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References


