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Skeletal muscle is a dynamic tissue that responds adaptively to both the nature and intensity of muscle use. This phenotypic plasticity ensures that muscle structure is linked to patterns of muscle use throughout the lifetime of an animal. The cascade of events that result in muscle restructuring – for example, in response to resistance exercise training – is often thought to be initiated by muscle damage. We designed this study to test the hypothesis that symptomatic (i.e. detectable) damage is a necessary precursor for muscle remodeling. Subjects were divided into two experimental populations: pre-trained (PT) and naïve (NA). Demonstrable muscle damage was avoided in the PT group by a three-week gradual ‘ramp-up’ protocol. By contrast, the NA group was subjected to an initial damaging bout of exercise. Both groups participated in an eight-week high-force eccentric-cycle ergometry program (20 min, three times per week) designed to equate the total work done during training between the groups. The NA group experienced signs of damage, absent in the PT group, as indicated by greater than five times higher levels of plasma creatine kinase (CK) and self-reporting of initial perceived soreness and exertion, yet muscle size and strength gains were not different for the two groups. RT-PCR analysis revealed similar increases in levels of the growth factor IGF-1Ea mRNA in both groups. Likewise, the significant (P<0.01) increases in mean cross-sectional area (and total muscle volume) were equal in both groups. Finally, strength increases were identical for both groups (PT 25% and NA 26% improvement). The results of this study suggest that muscle rebuilding – for example, hypertrophy – can be initiated independent of any discernible damage to the muscle.
Muscles operate eccentrically to either dissipate energy for decelerating the body or to store elastic recoil energy in preparation for a shortening (concentric) contraction. The muscle forces produced during this lengthening behavior can be extremely high, despite the requisite low energetic cost. Traditionally, these high-force eccentric contractions have been associated with a muscle damage response. This clinical commentary explores the ability of the muscle-tendon system to adapt to progressively increasing eccentric muscle forces and the resultant structural and functional outcomes. Damage to the muscle-tendon is not an obligatory response. Rather, the muscle can hypertrophy and a change in the spring characteristics of muscle can enhance power; the tendon also adapts so as to tolerate higher tensions. Both basic and clinical findings are discussed. Specifically, we explore the nature of the structural changes and how these adaptations may help prevent musculoskeletal injury, improve sport performance, and overcome musculoskeletal impairments.
Do Muscles Function as Adaptable Locomotor Springs?

Lindstedt SL, Reich TE, Keim P, LaStayo PC

During normal animal movements, the forces produced by the locomotor muscles may be greater than, equal to or less than the forces acting on those muscles, the consequences of which significantly affect both the maximum force produced and the energy consumed by the muscles. Lengthening (eccentric) contractions result in the greatest muscle forces at the lowest relative energetic costs. Eccentric contractions play a key role in storing elastic strain energy which, when recovered in subsequent contractions, has been shown to result in enhanced force, work or power outputs. We present data that support the concept that this ability of muscle to store and recover elastic strain energy is an adaptable property of skeletal muscle. Further, we speculate that a crucial element in that muscle spring may be the protein titin. It too seems to adapt to muscle use, and its stiffness seems to be ‘tuned’ to the frequency of normal muscle use.
Our view of muscle is usually that of a tension-producing machine that, when shortening, provides the work necessary for organisms to move about. However, movement also requires that muscles function to absorb kinetic energy, fluctuations that are inevitable during locomotion. Any time the force acting on the muscle exceeds the force produced by the muscle, the muscle will lengthen while producing force. During normal locomotion, these eccentric contractions function in two capacities: 1) they dissipate absorbed energy as heat, to function as a damper or shock absorber, reducing the kinetic energy via braking, and 2) conversely, the energy absorbed in stretched muscle (and tendon) may be stored as elastic recoil potential energy and subsequently recovered, allowing the muscle to effectively function as a spring. This “spring property” of muscle is both time dependent, which may be the rule that sets stride frequency among mammals, and adaptable, the muscle spring becoming stiffer in response to chronic eccentric loading. Two unique properties of eccentric contractions are physiologically fundamental. The energy cost for eccentric contractions is unusually low and the magnitude of the force produced is unusually high. As a consequence, muscles exposed to chronic eccentric training respond with significant increases in strength and size as well as alterations in the spring properties of the muscle. These predictable responses have both clinical and physical performance consequences. Loss of muscle mass and strength are thought to be nearly inevitable consequences of aging, accelerated by both heart and respiratory disease. Chronic eccentric exercise, which requires minimal energy and thus oxygen support, may be ideally suited for both rehabilitation for this population as well as increasing both strength and power in all individuals. Finally, while the muscle spring properties are often attributed to collagen and tendons (structures outside the muscle fiber), evidence suggests that the gigantic protein titin may contribute significantly to these important and adaptable functions of skeletal muscle inside the fiber.
During locomotion, major muscle groups are often activated cyclically. This alternate stretch-shorten pattern of activity could enable muscle to function as a spring, storing and recovering elastic recoil potential energy. Because the ability to store and recover elastic recoil energy could profoundly affect the energetics of locomotion, one might expect this to be an adaptable feature of skeletal muscle. This study tests the hypothesis that chronic eccentric (Ecc) training results in a change in the spring properties of skeletal muscle. Nine female Sprague-Dawley rats underwent chronic Ecc training for 8 wk on a motorized treadmill. The spring properties of muscle were characterized by both active and passive lengthening force productions. A single “spring constant” (Dforce/Dlength) from the passive length-tension curves was calculated for each muscle. Results from measurements on long heads of triceps brachii muscle indicate that the trained group produced significantly more passive lengthening force ($P < 0.0001$) as well as more active lengthening force ($P < 0.0001$) at all lengths of muscle stretch. In addition, the spring constants were significantly different between the Ecc (1.71 N/mm) and the control (1.31 N/mm) groups. A stiffer spring is capable of storing more energy per unit length stretched, which is of functional importance during locomotion.
Eccentric ergometry: increases in locomotor muscle size and strength at low training intensities

LaStayo PC, Pierotti DJ, Pifer J, Hoppeler H, Linstedt SL

Lengthening (eccentric) muscle contractions are characterized by several unusual properties that may result in unique skeletal muscle adaptations. In particular, high forces are produced with very little energy demand. Eccentrically trained muscles gain strength, but the specific nature of fiber size and composition is poorly known. This study assesses the structural and functional changes that occur to normal locomotor muscle after chronic eccentric ergometry at training intensities, measured as oxygen uptake, that do not influence the muscle when exercised concentrically. Male subjects trained on either eccentric or concentric cycle ergometers for 8 wk at a training intensity starting at 54% and ending at 65% of their peak heart rates. The isometric leg strength increased significantly in the eccentrically trained group by 36%, as did the cross-sectional area of the muscle fiber by 52%, but the muscle ultrastructure remained unchanged. There were no changes in either fiber size, composition, or isometric strength in the concentrically trained group. The responses of muscle to eccentric training appear to be similar to resistance training.
Chronic eccentric exercise: improvements in muscle strength can occur with little demand for oxygen. Eccentric contractions, the lengthening of muscle while producing force, are a common part of our everyday movements. This study presents a challenge to the accepted notion that eccentric work causes obligatory muscle injury while demonstrating that an increase in muscle strength, via eccentric work, can occur with little demand for oxygen. Nine healthy subjects, ages 18–34, were randomly placed in either an eccentric or a concentric training group. Both groups trained for 6 wk while progressively increasing training frequency and duration. Significant gains in isometric leg strength were seen in the eccentrically trained subjects only. While training, the oxygen consumption required to do the eccentric work was equal to or less than that required to do the concentric work. The results demonstrate that by progressively increasing the eccentric work rate, significant isometric strength gains can be made without muscle injury and with minimal increase in metabolic demand for oxygen. The potential clinical implications of an eccentric training program that uncouples skeletal muscle strength improvements from the demand for oxygen are alluring.
An Eccentrically Biased Rehabilitation Program Early after TKA Surgery

Marcus RL, Yoshida Y, Meier W, Peters C, LaStayo P

Rehabilitation services are less-studied aspects of the management following total knee arthroplasty (TKA) despite long-term suboptimal physical functioning and chronic deficits in muscle function. This paper describes the preliminary findings of a six week (12 session) eccentrically-biased rehabilitation program targeted at deficits in physical function and muscle function, initiated one month following surgery. A quasiexperimental, one group, pretest-posttest study with thirteen individuals (6 female, 7 male; mean age 57 ± 7 years) examined the effectiveness of an eccentrically-biased rehabilitation program. The program resulted in improvements in the primary physical function endpoints (SF-36 physical component summary and the six-minute walk test) with increases of 59% and 47%, respectively. Muscle function endpoints (knee extension strength and power) also increased 107% and 93%, respectively. Eccentrically-biased exercise used as an addition to rehabilitation may help amplify and accelerate physical function following TKA surgery.
The Use of Eccentrically Biased Resistance Exercise to Mitigate Muscle Impairments Following Anterior Cruciate Ligament Reconstruction: A Short Review

Gerber JP, Marcus RL, Dibble LE, LaStayo PC

Background: Novel interventions that can safely and effectively overload muscle early following anterior cruciate ligament reconstruction are needed to minimize atrophy and weakness that often becomes longstanding.

Evidence Acquisition: Eccentrically induced forces can be safely applied during the early stages of rehabilitation following surgery and serve as a potent stimulus for increasing muscle size and strength.

Results: Compared to a standard rehabilitation program, adding an early 12-week eccentric resistance-training program 3 weeks after anterior cruciate ligament reconstruction induces improvement in quadriceps and gluteus maximus volume at 15 weeks and at 1 year after surgery. Likewise, those who performed an eccentrically biased rehabilitation program also achieved greater improvements in quadriceps strength and hopping ability measured at 15 weeks and at 1 year after surgery.

Clinical Relevance: There is potential to safely and feasibly perform eccentric contractions as part of a formal rehabilitation program following anterior cruciate ligament reconstruction.
The number of total knee arthroplasty (TKA) surgeries performed each year is predicted to steadily increase. Following TKA surgery, self-reported pain and function improve, though individuals are often plagued with quadriceps muscle impairments and functional limitations. Postoperative rehabilitation approaches either are not incorporated or incompletely address the muscular and functional deficits that persist following surgery. While the reason for quadriceps weakness is not well understood in this patient population, it has been suggested that a combination of muscle atrophy and neuromuscular activation deficits contribute to residual strength impairments. Failure to adequately address the chronic muscle impairments has the potential to limit the long-term functional gains that may be possible following TKA.

Postoperative rehabilitation addressing quadriceps strength should mitigate these impairments and ultimately result in improved functional outcomes. The purpose of this paper is to describe these quadriceps muscle impairments and to discuss how these impairments can contribute to the related functional limitations following TKA. We will also describe the current concepts in TKA rehabilitation and provide recommendations and clinical guidelines based on the current available evidence.
Safety, Feasibility, and Efficacy of Negative Work Exercise via Eccentric Muscle Activity Following Anterior Cruciate Ligament Reconstruction

Gerber JP, Marcus RL, Dibble LE, Greis PE, Burks RT, LaStayo PC

Study Design: Randomized, matched design.

Background: Optimal rehabilitation following anterior cruciate ligament reconstruction (ACLR) requires safe and effective interventions. Negative work exercise (via eccentric muscle activity) has the potential to be highly effective at producing large quadriceps size and strength gains early after ACL-R. The purpose of this investigation was to evaluate the short-term safety and efficacy of adding a progressive negative work exercise program via eccentric (ECC) ergometry early after ACL-R.

Methods and Measures: Beginning 3 weeks after ACL-R, 32 participants were randomly assigned into either a 12-week traditional (TRAD) or ECC exercise program. Safety was assessed by measuring knee pain, thigh pain, knee effusion, and knee stability prior to surgery and at 3, 15, and 26 weeks after surgery. Efficacy was assessed by measuring negative work output during the 12-week training program and by measuring functional ability (i.e., quadriceps peak torque, hopping distance, self-reported functional ability and activity level scales) prior to surgery and 26 weeks after ACL-R.

Results: There were no significant differences between groups in measures of knee and thigh pain, effusion, or stability at any period after surgery. Negative work output increased systematically throughout training, while knee and thigh pain remained at relatively low levels. A significant group-by-time interaction was observed for quadriceps peak torque, hopping distance, and activity level (P < .02). Quadriceps strength and hopping distance of the involved limb improved by a significantly greater amount in the ECC group compared to the TRAD group (P < .01). Activity level decreased to a lesser extent in the ECC group compared to the TRAD group (P = .02).

Conclusions: Negative work via an ECC intervention was implemented safely after ACLR. The addition of negative work exercise also induced superior short-term results in strength, performance, and activity level after surgery.
Background: Thigh muscle atrophy is a major impairment that occurs early after reconstruction of the anterior cruciate ligament and persists for several years. Eccentric resistance training has the potential to induce considerable gains in muscle size and strength that could prove beneficial during postoperative rehabilitation. The purpose of this study was to evaluate the effects of progressive eccentric exercise on thigh muscle structure following reconstruction of the anterior cruciate ligament.

Methods: Beginning three weeks after reconstruction of the anterior cruciate ligament, forty patients were randomly assigned to a program involving either twelve weeks of eccentric exercises or a standard rehabilitation protocol. Patients were matched by surgical procedure, sex, and age. The final series consisted of two cohorts of twenty patients each who had been treated with one of two types of graft (semitendinosus-gracilis or bone-patellar tendon-bone), with ten patients treated with each of the two rehabilitation protocols in each graft cohort. To evaluate changes in muscle structure, magnetic resonance images of the involved and uninvolved thighs were acquired before and after training. The volume and peak cross-sectional area of the quadriceps, hamstrings, and gracilis and the distal portion of the gluteus maximus were calculated from these images.

Results: The volume and peak cross-sectional area of the quadriceps and gluteus maximus, in both the involved and the uninvolved thighs and in the patients treated with each type of graft, improved significantly more in the eccentric exercise group (p < 0.001). The magnitude of the volume change was more than twofold greater in that group. No significant differences in any hamstring or gracilis structural measurements were observed between the rehabilitation groups. However, the volume and peak cross-sectional area of the gracilis were markedly reduced, compared with the pretraining values, in the patients who had undergone reconstruction with the semitendinosus-gracilis graft.

Conclusions: Eccentric resistance training implemented three weeks after reconstruction of the anterior cruciate ligament can induce structural changes in the quadriceps and gluteus maximus that greatly exceed those achieved with a standard rehabilitation protocol. The success of this intervention can be attributed to the gradual and progressive exposure to negative work through eccentric exercise, ultimately leading to production of high muscle force.
Objectives: To present a progressively increasing negative-work exercise program via eccentric ergometry early after anterior cruciate ligament reconstruction (ACL-R) and to suggest the potential of negative work to amplify the return of quadriceps size and strength.

Case Description: The patient was a 26-year-old highly active recreational athlete who sustained an ACL tear while skiing in January 2004 and then again while skiing in February 2005. This individual underwent an arthroscopically assisted ACL-R with a double-loop semitendinosus-gracilis autograft initially, then a patellar tendon autograft following his ACL graft rupture. Beginning within 3 weeks after surgery, a progressive negative-work exercise program was initiated using an eccentric ergometer. The patient completed 31 training sessions of 5 to 30 minutes in duration over a 12 week period following the ACL-R and 33 training sessions of the same frequency and duration following the ACL revision.

Outcomes: Following ACL-R, quadriceps volume increased 28% (involved lower extremity) and 14% (uninvolved lower extremity) during the 12-week training program. Following revision, quadriceps volume returned to similar levels at the same postoperative period as those achieved after the initial surgery (2% less on the involved side and 2% greater on the uninvolved side). Quadriceps strength, 15 weeks after ACL-R, exceeded preoperative measures by an average of 20% (involved) and 14% (uninvolved). Quadriceps strength after ACL revision exceeded all previous measures.

Discussion: This case report suggests that if gradually and progressively applied, negative work via eccentric ergometry can be both safe and efficacious early after ACL-R. Eccentric exercise may mitigate the prevalent muscle size and strength deficits commonly observed after ACL-R. The results of this case suggest a need for continued research with early negative work interventions following ACL-R.
Elderly Patients and High Force Resistance Exercise – A Descriptive Report: Can an Anabolic, Muscle Growth Response Occur Without Muscle Damage or Inflammation?


**Background and Purpose:** Elderly individuals participate in resistance exercise to induce an anabolic response and grow muscle to help overcome functional deficits. It is thought that a muscle damage and inflammatory response to resistance exercise is a necessary prerequisite for an anabolic and muscle growth response.

**Methods:** This is a descriptive study of 11 elderly individuals in rehabilitation who underwent a 2-3x/week high force resistance exercise that used eccentric contractions. Serum measures of muscle damage, inflammation, and an anabolic response are reported along with changes in muscle mass as measured with dual energy X-ray absorptiometry.

**Results:** Negative work increased >3-fold during the 11 weeks of resistance exercise. There were no significant changes in the damage measure of serum creatine kinase (pretraining: 18.5 ± 1.2 Sigma units/ml; post-training: 19.2 ± 1.1 Sigma units/ml). Proinflammatory tumor necrosis factor-1 values remained within normal range (<4.0 pg/ml) throughout the 11 weeks of training. A nonsignificant trend for an anabolic increase (65%) in insulin like growth factor-1 was noted along with a significant increase (6%) in thigh muscle mass.

**Conclusions:** Neither damage, nor inflammation appear to be prerequisites for inducing anabolic and muscle growth responses in elderly individuals undergoing a high force resistance exercise with eccentric contractions.
The Positive Effects of Negative Work: Increased Muscle Strength and Decreased Fall Risk in a Frail Elderly Population

LaStayo PC, Ewy GA, Pierotti DD, Johns RK, Lindstedt SL

Background. The objective of this study was to determine if a chronic eccentric training intervention, i.e., negative work, could limit or even reverse sarcopenia and its related impairments and functional limitations. Is high-force eccentric training tolerable by elderly people and will it result in improved muscle size, strength, balance, and fall risk?

Methods. 21 frail elderly subjects (mean age, 80 years) experienced 11 weeks of lower extremity resistance training. The experimental eccentric (ECC) group (n=11) performed negative work while exercising on a high-force eccentric ergometer. The active “controls” performed traditional (TRAD) (n=10) lower extremity resistance exercises (weight training). Muscle fiber cross-sectional area and strength, balance, stair descending abilities, and fall risk were assessed prior to and following this intervention.

Results. All ECC subjects who started the negative work intervention completed the study and reported the training to be relatively effortless; they experienced minimal and transient muscle soreness. Both groups experienced a significant increase in muscle fiber cross-sectional area (ECC ¼ 60%, TRAD ¼ 41%). Only the ECC group experienced significant improvements in strength (60%), balance (7%), and stair descent (21%) abilities. The timed up and go task improved in both groups, but only the ECC group went from a high to a low fall risk.

Conclusions. These data demonstrate that lower extremity resistance exercise can improve muscle structure and function in those with limited exercise tolerance. The greater strength increase following negative work training resulted in improved balance, stair descent, and fall risk only in the ECC group. Because low energy cost is coupled to high force production with eccentric exercise, this intervention may be useful for a number of patients that are otherwise unable to achieve high muscle forces with traditional resistance exercise.
Increased Strength and Physical Performance with Eccentric Training in Women with Impaired Glucose Tolerance: A Pilot Study

Marcus RL, LaStayo PC, Dibble LE, Hill L, McClain DA

Background: Menopause is associated with both a loss of muscle mass and a worsening of insulin sensitivity (IS). Although eccentric resistance exercise (ECC) can effectively improve muscle mass over time, a single bout of ECC can worsen IS. This study assessed the effect of repeated ECC on IS, muscle mass, and function in postmenopausal women with impaired glucose tolerance (IGT).

Methods: Sixteen PM women (aged 56 years ± 6.4) with IGT were randomly assigned to a 12-week, knee extensor ECC program (n = 10) or a nonexercise control group (CON) (n = 6). Participants underwent hyperinsulinemic-euglycemic clamps, dual-energy x-ray (DEXA) absorptiometry, quadriceps strength assessment, 6-minute walk (6MW) tests, and an assessment of steps taken per day before and after training.

Results: ECC participants experienced greater increases in leg lean soft tissue mass (ECC, 0.41 kg; CON, 0.53 kg; p = 0.03), quadriceps strength (ECC, 9.3 kg force; CON, 2.9 kg force; p = 0.02), and 6MW distance (ECC, 56.4 meters; CON, 3.3 meters; p = 0.03) than CON participants and demonstrated a trend toward more steps taken per day posttraining (ECC, 1747 steps; CON, 339 steps; p = 0.10). IS was unchanged.

Conclusions: This novel exercise improves muscle mass and function without worsening IS in postmenopausal women with IGT. Because it can be performed at low levels of exertion and improves muscle mass and function without impairing IS, ECC should be used to ameliorate muscle loss in physically inactive postmenopausal women. The impact of longer-term ECC on IS should be investigated. Demonstrating that ECC does not worsen IS in this population is significant because it has promise to combat the muscle-mediated impairments common in aging women.
Background and Purpose: The purpose of this study was to compare the outcomes between a diabetes exercise training program using combined aerobic and high-force eccentric resistance exercise and a program of aerobic exercise only.

Subjects and Methods: Fifteen participants with type 2 diabetes mellitus (T2DM) participated in a 16-week supervised exercise training program: 7 (mean age=50.7 years, SD=6.9) in a combined aerobic and eccentric resistance exercise program (AE/RE group) and 8 (mean age=58.5 years, SD=6.2) in a program of aerobic exercise only (AE group). Outcome measures included thigh lean tissue and intramuscular fat (IMF), glycosylated hemoglobin, body mass index (BMI), and 6-minute walk distance.

Results: Both groups experienced decreases in mean glycosylated hemoglobin after training (AE/RE group: "0.59% [95% confidence interval (CI)=1.5 to 0.28]; AE group: "0.31% [95% CI=0.60 to 0.03]), with no significant between-group differences. There was an interaction between group and time with respect to change in thigh lean tissue cross-sectional area, with the AE/RE group gaining more lean tissue (AE/RE group: 15.1 cm² [95% CI=7.6 to 22.5]; AE group: 5.6 cm² [95% CI=10.4 to 0.76]). Both groups experienced decreases in mean thigh IMF cross-sectional area (AE/RE group: 1.2 cm² [95% CI=2.6 to 0.26]; AE group: 2.2 cm² [95% CI=3.5 to 0.84]) and increases in 6-minute walk distance (AE/RE group: 45.5 m [95% CI=7.5 to 83.6]; AE group: 29.9 m [95% CI=7.7 to 67.5]) after training, with no between-group differences. There was an interaction between group and time with respect to change in BMI, with the AE/RE group experiencing a greater decrease in BMI.

Discussion and Conclusion: Significant improvements in long-term glycemic control, thigh composition, and physical performance were demonstrated in both groups after participating in a 16-week exercise program. Subjects in the AE/RE group demonstrated additional improvements in thigh lean tissue and BMI. Improvements in thigh lean tissue may be important in this population as a means to increase resting metabolic rate, protein reserve, exercise tolerance, and functional mobility.
High-Intensity Negative Work Reduces Bradykinesia while Improving Balance and Quality of Life in Persons with Parkinson’s Disease

Dibble LE, Hale TF, Marcus RL, Droge J, Gerber JP, LaStayo PC

**Purpose/Hypothesis:** Bradykinesia associated with Parkinson’s Disease (PD) is considered a strong contributor to disability and strength deficits have been implicated as a contributor to PD bradykinesia. Despite clear discussions of the rationale for strength training in PD, and the dramatic improvements in strength and function seen in healthy and frail elders exposed to strength training, research that examines the effect of resistance training on bradykinesia or overall quality of life is sparse. The purpose of this study was to examine, in persons with PD, the changes in bradykinesia, balance, and self reported quality of life as a result of participation in a 12 week high intensity strength training program. NUMBER OF SUBJECTS: Eight individuals with idiopathic PD (mean age = 61; mean Hoehn and Yahr on medication= 2.5) participated.

**Materials/Methods:** The focus of the exercise program was performing high intensity negative work on an eccentric ergometer 3 days a week for 12 weeks. Participants were tested prior to and following a 12 week intervention period with testing and training conducted at standardized times in their medication cycle. Clinical bradykinesia and balance measures (10 meter walk, TUG, BBS, and FR), and a self report quality of life measure (PDQ-39) were utilized as outcomes. Pre to post intervention differences were tested using separate Wilcoxon matched pairs tests with an alpha level set at .05. To determine strength of effect, percent improvement and Cohen’s effect sizes were also calculated.

**Results:** Significant improvements (% change) were seen in gait speed (14%), balance test performance (TUG 20%; FR 16%) and physical components of perceived quality of life (ADL 15%; bodily discomfort 31%) \(p<.05\). The range of effect sizes was .35-2.13.

**Conclusion:** Persons with PD demonstrate reduced bradykinesia and improvements in their balance function and physical components of quality of life as a result of high intensity lower extremity negative work. This research supports the hypothesis that peripheral muscle force limitations affect movement abilities in persons with PD and that these limitations are subject to change.

**Clinical Relevance:** Lower extremity resistance training may be a critical component of PD rehabilitation and this research provides effect sizes to assist in the design of larger trials to examine this topic more thoroughly. The neurologic, hormonal, and structural adaptations that contribute to the observed improvements are the subject of further research in our laboratory.
The Safety and Feasibility of High-Force Eccentric Resistance Exercise in Persons with Parkinson’s Disease

Dibble LE, Hale T, Marcus RL, Gerber JP, LaStayo PC

Objective: To examine the effect of high-force eccentric resistance exercise on measures of muscle damage and injury in persons with mild to moderate Parkinson’s disease (PD).

Design: Before-after trial.

Setting: Tertiary care center clinical laboratory.

Participants: Ten persons with PD (Hoehn and Yahr Staging Scale, stage 1–3).

Intervention: Participants trained 3 days a week for 12 weeks on an eccentric ergometer, performing high-force eccentric resistance exercise with bilateral lower extremities.

Main Outcome Measures: Serum creatine kinase (CK) concentrations, muscle pain scores, and isometric force production were measured before, during, and after training.

Results: Mean CK levels did not differ and did not exceed the threshold of muscle damage at any time point (P>.17). Muscle visual analog scale scores were low and only differed at week 2 (P=.04). Participants were highly compliant, whereas total negative work and isometric force increased over time (P=.02, P=.006, respectively).

Conclusions: Persons with mild to moderate PD can safely and feasibly participate in high-force eccentric resistance training. The data we present provide a basis for future investigations of the efficacy of this type of training on muscle size, strength, and mobility in persons with PD.
High-Intensity Resistance Training Amplifies Muscle Hypertrophy and Functional Gains in Persons with Parkinson’s Disease

Dibble LE, Hale TF, Marcus RL, Droge J, Gerber JP, LaStayo PC

Abstract: Strength deficits in persons with Parkinson’s disease (PD) have been identified as a contributor to bradykinesia. However, there is little research that examines the effect of resistance training on muscle size, muscle force production, and mobility in persons with PD. The purpose of this exploratory study was to examine, in persons with PD, the changes in quadriceps muscle volume, muscle force production, and mobility as a result of a 12-week high-force eccentric resistance training program and to compare the effects to a standard-care control. Nineteen individuals with idiopathic PD were recruited and consented to participate. Matched assignment for age and disease severity resulted in 10 participants in the eccentric group and 9 participants in the control group. All participants were tested prior to and following a 12-week intervention period with testing and training conducted at standardized times in their medication cycle. The eccentric group performed high-force quadriceps contractions on an eccentric ergometer 3 days a week for 12 weeks. The standard-care group exercise program encompassed standard exercise management of PD. The outcome variables were quadriceps muscle volume, muscle force, and mobility measures (6-minute walk, stair ascent/descent time). Each outcome variable was tested using separate one-way analyses of covariance on the difference scores. Muscle volume, muscle force, and functional status improvements occurred in persons with PD as a result of high-force eccentric resistance training. The eccentric group demonstrated significantly greater difference scores for muscle structure, stair descent, and 6-minute walk ($P < 0.05$). Magnitude of effect size estimators for the eccentric group consistently exceeded those in the standard-care group for all variables. To our knowledge, this is the first clinical trial to investigate and demonstrate the effects of eccentric resistance training on muscle hypertrophy, strength, and mobility in persons with PD. Additional research is needed to determine the anatomical and neurological mechanisms of the observed strength gains and mobility improvements.