

## Evidence-based Practice Initiative – Eccentron

### “Eccentric versus traditional resistance exercise for older adult fallers in the community: a randomized trial within a multi-component fall reduction program.”

LaStayo P, Marcus R, Dibble L Wong B, Pepper G: Eccentric versus traditional resistance exercise for older adult fallers in the community: a randomized trial within a multi-component fall reduction program. BMC Geriatrics. 2017;17:149 DOI 10.1186/s12877-017-0539-8

#### ABSTRACT:

**Background:** Addressing muscle deficits within a multi-component exercise fall reduction program is a priority, especially for the highest risk older adults, i.e. those who have fallen previously. Eccentric resistance exercise with its high-force producing potential, at a low energetic cost, may be ideally suited to address muscle impairments in this population. The purpose of this study was to compare the effects of resistance exercise via negative, eccentrically-induced, work (RENEW) versus traditional (TRAD) resistance exercise on mobility, balance confidence, muscle power, and cross-sectional area, as well as the number of days high fall risk older adults survived without a fall event over a 1 year period.

**Methods:** Randomized, two group, four time point (over 1 year) clinical trial testing RENEW versus TRAD as part of a 3 month multi-component exercise fall reduction program (MCEFRP). Primary outcomes of mobility, balance confidence, muscle power output, and cross-sectional area were analyzed using mixed effects modeling. The secondary outcomes of days to fall and days to near-fall were analyzed using survival analysis.

**Results:** The MCEFRP did have an effect on fall risk factors considered reversible with exercise interventions though there was no differential effect of RENEW versus TRAD ( $p = 0.896$ ) on mobility, balance confidence, muscle power, and cross-sectional area. There were also no group differences in the number of days survived without a fall ( $p = 0.565$ ) or near-fall ( $p = 0.678$ ). Despite 100% of participants having at least one fall in the year prior to the MCEFRP, however, after 3 months of exercise and 9 months of follow-up <50% had experienced a fall or near fall.

**Conclusions:** There were no differential effects of RENEW or TRAD as components of a MCEFRP on the primary or secondary outcomes. The two modes of resistance exercise had identical effects on fall risk and fall -free survival.

*Use of Eccentron: neuromuscular strength eccentric training with visual feedback to improve lower extremity strength, mobility, and balance in adults 65 years and older who experienced at least one fall in the previous 12 months.*

### “The effect of virtual reality-based eccentric training on lower extremity muscle activation and balance in stroke patients.”

Park SK, Yang DJ, UHM YH, Heo JW, Kim JH: The effect of virtual reality-based eccentric training on lower extremity muscle activation and balance in stroke patients. J Phys Ther Sci. 2016;28:2055-2058.

#### ABSTRACT:

**Purpose:** The purpose of this study was to examine the effect of virtual reality-based eccentric training on lower extremity muscle activity and balance in stroke patients.

**Subjects and Methods:** Thirty stroke patients participated, with 15 patients allotted to each of two eccentric training groups: one using a slow velocity (group I) and one using a fast velocity (group II). The virtual reality-based eccentric training was performed by the patients for 30 minutes once a day, 5 days a week, for 8 weeks using an Eccentron system. Surface electromyography was used to measure the lower extremity muscle activity, while a BioRescue was used to measure balancing ability.

**Results:** A significant difference in lower extremity muscle activation and balance ability was observed in group I compared with group II.

**Conclusion:** This study showed that virtual reality-based eccentric training using a slow velocity is effective for improving lower extremity muscle activity and balance in stroke patients.

*Use of Eccentron: neuromuscular strength eccentric training with visual feedback to improve lower extremity strength and balance in patients post-stroke.*

## **“A systematic review and meta-analysis of strength training in individuals with multiple sclerosis or Parkinson disease.”**

Cruikshank TM, Reyes AR, Ziman MR: A systematic review and meta-analysis of strength training in individuals with multiple sclerosis or Parkinson disease. *Medicine*. 2015;94:e411. doi:10.1097/MD.0000000000000411.

### **ABSTRACT:**

Strength training has, in recent years, been shown to be beneficial for people with Parkinson disease and multiple sclerosis. Consensus regarding its utility for these disorders nevertheless remains contentious among healthcare professionals. Greater clarity is required, especially in regards to the type and magnitude of effects as well as the response differences to strength training between individuals with Parkinson disease or multiple sclerosis.

This study examines the effects, magnitude of those effects, and response differences to strength training between patients with Parkinson disease or multiple sclerosis.

A comprehensive search of electronic databases including Physiotherapy Evidence Database scale, PubMed, EMBASE, Cochrane Central Register of Controlled Trials, and CINAHL was conducted from inception to July 2014.

English articles investigating the effect of strength training for individuals with neurodegenerative disorders were selected. Strength training trials that met the inclusion criteria were found for individuals with Parkinson disease or multiple sclerosis.

Individuals with Parkinson disease or multiple sclerosis were included in the study. Strength training interventions included traditional (free weights/machine exercises) and nontraditional programs (eccentric cycling).

Included articles were critically appraised using the Physiotherapy Evidence Database scale. Of the 507 articles retrieved, only 20 articles met the inclusion criteria. Of these, 14 were randomized and 6 were nonrandomized controlled articles in Parkinson disease or multiple sclerosis. Six randomized and 2 nonrandomized controlled articles originated from 3 trials and were subsequently pooled for systematic analysis. Strength training was found to significantly improve muscle strength in people with Parkinson disease (15%–83.2%) and multiple sclerosis (4.5%–36%). Significant improvements in mobility (11.4%) and disease progression were also reported in people with Parkinson disease after strength training. Furthermore, significant improvements in fatigue (8.2%), functional capacity (21.5%), quality of life (8.3%), power (17.6%), and electromyography activity (24.4%) were found in individuals with multiple sclerosis after strength training.

The limitations of the study were the heterogeneity of interventions and study outcomes in Parkinson disease and multiple sclerosis trials. Strength training is useful for increasing muscle strength in Parkinson disease and to a lesser extent multiple sclerosis.

*Use of Eccentron: 2 articles by Dibble, et al, 2006 and 2009 were included in this systematic review and meta-analysis. Eccentron was used for strength training of individuals with Parkinson disease.*

### **“Exercise and medication effects on persons with Parkinson disease across domains of disability: a randomized clinical trial.”**

Dibble LE, Foreman KB, Addison O, Marcus RL, LaStayo PC: Exercise and medication effects on persons with Parkinson disease across domains of disability: a randomized clinical trial. JNPT. 2015; 39:85-92.

#### **ABSTRACT:**

**Background and Purpose:** Hypokinesia and bradykinesia as movement deficits of Parkinson disease are thought to be mediated by both basal ganglia dysfunction and a loss of muscle mass and strength commensurate with aging and decreased levels of physical activity. For these reasons, we sought to utilize resistance training as a means to increase muscle force and minimize hypokinesia and bradykinesia in persons with Parkinson disease and examine the effects of exercise and medication on Body Structure and Function (muscle force production and muscle cross-sectional area), Activity (mobility), and Participation (Health Status) outcomes.

**Methods:** Forty-two participants were enrolled in a 12-week randomized clinical trial that compared 2 active exercise interventions: a standard care control group (Active Control) and an experimental group that underwent Resistance Exercise via Negative Eccentric Work (RENEW).

**Results:** Participants in both groups improved in muscle force production and mobility as a result of exercise and medication ( $P < 0.02$ ). There were no significant interaction or between-group differences and no significant changes in muscle cross-sectional area or health status were observed. Effect sizes for exercise and medication combined exceeded the effect sizes of either intervention in isolation.

**Discussion and Conclusions:** Taken together, these results point to the complementary effects of exercise and medication on the Body Structure and Function and Activity outcomes but little effect on Participation outcomes.

*Use of Eccentron: neuromuscular strength training targeted at bilateral lower extremity extensor musculature. A high-intensity eccentric resistance exercise program (Resistance Exercise using Negative Eccentric Work [RENEW] was used.*

### **“Effects of age and acute muscle fatigue on reactive postural control in healthy adults.”**

Papa EV, Foreman KB, Dibble LE: Effects of age and acute muscle fatigue on reactive postural control in healthy adults. Clin Biomech. 2015;6 pgs. <http://dx.doi.org/10.1016/j.clinbiomech.2015>.

#### **ABSTRACT:**

**Background:** Falls can cause moderate to severe injuries such as hip fractures and head trauma in older adults. While declines in muscle strength and sensory function contribute to increased falls in older adults, skeletal muscle fatigue is often overlooked as an additional contributor to fall risk. The purpose of this investigation was to examine the effects of acute lower extremity muscle fatigue and age on reactive postural control in healthy adults.

**Methods:** A sample of 16 individuals participated in this study (8 healthy older adults and 8 healthy young persons). Whole body kinematic and kinetic data were collected during anterior and posterior reproducible fall tests before (T0) and immediately after (T1) eccentric muscle fatiguing exercise, as well as after 15-min (T15) and 30-min (T30) of rest.

**Findings:** Lower extremity joint kinematics of the stepping limb during the support (landing) phase of the anterior fall were significantly altered by the presence of acute muscle fatigue. Step velocity was significantly de-creased during the anterior falls. Statistically significant main effects of age were found for step length in both fall directions. Effect sizes for all outcomes were small. No statistically significant interaction effects were found.

**Interpretation:** Muscle fatigue has a measurable effect on lower extremity joint kinematics during simulated falls. These alterations appear to resolve within 15 min of recovery. The above deficits, coupled with a reduced step length, may help explain the increased fall risk in older adults.

*Use of Eccentron: in the context of the study, the Eccentron was utilized to induce quadriceps and hip extensor fatigue.*

### **“Resistance exercise with older fallers: its impact on intermuscular adipose tissue.”**

Jacobs JL, Marcus RL, Morrell G, LaStayo PC: Resistance training with older fallers: its impact on intermuscular adipose tissue. *Biomed Res Intl.* 2014;7pgs. <http://dx.doi.org/10.1155/2014/398960>.

#### **ABSTRACT:**

**Objective:** Greater skeletal muscle fat infiltration occurs with age and contributes to numerous negative health outcomes. The primary purpose was to determine whether intermuscular adipose tissue (IMAT) can be influenced by an exercise intervention and if a greater reduction in IMAT occurs with eccentric versus traditional resistance training.

**Methods:** Seventy-seven older adults (age  $75.5 \pm 6.8$ ) with multiple comorbidities and a history of falling completed a three-month exercise intervention paired with either eccentric or traditional resistance training. MRI of the mid-thigh was examined at three time points to determine changes in muscle composition after intervention.

**Results:** No differences in IMAT were observed over time, and there were no differences in IMAT response between intervention groups. Participants in the traditional group lost a significant amount of lean tissue ( $P = 0.007$ ) in the nine months after intervention, while participants in the eccentric group did not ( $P = 0.32$ ). When IMAT levels were partitioned into high and low IMAT groups, there were differential IMAT responses to intervention with the high group lowering thigh IMAT.

**Conclusions:** There is no decrease in thigh IMAT after a three-month exercise intervention in older adults at risk for falling and no benefit to eccentric training over traditional resistance training for reducing IMAT in these individuals.

*Use of Eccentron: neuromuscular progressive eccentric-negative work strength training targeted at bilateral lower extremity extensor musculature.*

### **“Eccentric exercise in rehabilitation: safety, feasibility, and application.”**

LaStayo PC, Marcus RL, Dibble LE, Frajacomo F, Lindstedt S: Eccentric exercise in rehabilitation: safety, feasibility, and application. *J Appl Physiol.* 2014; 1426-1434.

#### **ABSTRACT:**

This non-exhaustive mini-review reports on the application of eccentric exercise in various rehabilitation populations. The two defining properties of eccentric muscle contractions - a potential for high muscle-force production at an energy cost that is uniquely low - are revisited and formatted as exercise countermeasures to muscle atrophy, weakness, and deficits in physical function. Following a dual-phase implementation, eccentric exercise that induces rehabilitation benefits without muscle damage, thereby

making it both safe and feasible in rehabilitation, is described. Clinical considerations, algorithms of exercise progression, and suggested modes of eccentric exercise are presented.

*Use of Eccentron: neuromuscular progressive eccentric-negative work strength training targeted at bilateral lower extremity extensor musculature.*

### **“Effect of eccentric strengthening after anterior cruciate ligament reconstruction on quadriceps strength.”**

Lepley LK, Palmieri-Smith RM: Effect of eccentric strengthening after anterior cruciate ligament reconstruction on quadriceps strength. *J Sport Rehabil.* 2013;22:150-156.

#### **ABSTRACT:**

**Clinical Scenario:** Interventions aimed at safely overloading the quadriceps muscle after anterior cruciate ligament (ACL) reconstruction are essential to reducing quadriceps muscle weakness that often persists long after the rehabilitation period. Despite the best efforts of clinicians and researchers to improve ACL rehabilitation techniques, a universally effective intervention to restore preinjury quadriceps strength has yet to be identified. A muscle’s force-producing capacity is most optimal when an external force exceeds that of the muscle while the muscle lengthens. Hence, the potential to improve muscle strength by overloading the tissue is greater with eccentric strengthening than with concentric strengthening. Traditionally, the application of early postoperative high-intensity eccentric resistance training to the ACL-reconstructed limb has been contraindicated, as there is potential for injury to the ACL graft, articular cartilage, or surrounding soft-tissue structures. However, recent evidence suggests that the application of early, progressive, high-force eccentric resistance exercises to the involved limb can be used to safely increase muscle volume and strength in ACL-reconstructed individuals. As a result, eccentric strengthening may be another attractive alternative to traditional concentric strengthening to improve quadriceps strength after ACL reconstruction. **Focused Clinical Question:** In patients who have undergone ACL reconstruction, is there evidence to suggest that eccentric exercise positively affects postoperative quadriceps strength?

*Use of Eccentron: neuromuscular eccentric strength training post-ACL reconstruction is an effective therapy for increasing quadriceps muscle strength.*

### **“Muscle damage and muscle remodeling: no pain, no gain?”**

Flynn KL, LaStayo PC, McClain DA, Hazel M, Lindstedt SL: Muscle damage and muscle remodeling: no pain, no gain? *J Exper Biol.* 2011;214:674-679.

#### **ABSTRACT:**

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.

*Use of Eccentron: neuromuscular strength training to increase lower extremity muscle volume/hypertrophy and muscle strength of healthy university students.*

### **“Effects of high-intensity resistance training on strength, mobility, balance, and fatigue in individuals with multiple sclerosis: a randomized controlled trial.”**

Hayes HA, Gappmaier E, LaStayo P: Effects of high-intensity resistance training on strength, mobility, balance, and fatigue in individuals with multiple sclerosis: a randomized controlled trial. *J Neurol Phys Ther.* 2011;35. doi:10.1097/NPT.0b013e31820b5a9d.

#### ABSTRACT:

**Background and Purpose:** Resistance exercise via negative, eccentrically induced work (RENEW) has been shown to be associated with improvements in strength, mobility, and balance in multiple clinical populations. However, RENEW has not been reported for individuals with multiple sclerosis (MS).

**Methods:** Nineteen individuals with MS (8 men, 11 women; age mean =  $49 \pm 11$  years; Expanded Disability Status Scale [EDSS] mean =  $5.2 \pm 0.9$ ) were randomized into either standard exercise (STAND) or standard exercise and RENEW training (RENEW) for 3x/week for 12 weeks. Outcome measures were lower extremity strength (hip/knee flexion and extension, ankle plantar and dorsiflexion, and the sum of these individual values [sum strength]); Timed Up and Go (TUG), 10-m walk, self-selected pace (TMWSS) and maximal-pace (TMWMP), stair ascent (S-A) and descent (S-D) and 6-Minute Walk Test (6MWT), Berg Balance Scale (BBS), Fatigue Severity Scale (FSS).

**Results:** No significant time effects or interactions were observed for strength, TUG, TMWSS, TMWMP, or 6MWT. However, the mean difference in sum strength in the RENEW group was 38.60 (representing a 15% increase) compared to the sum strength observed in the STAND group with a mean difference of 5.58 (a 2% increase). A significant interaction was observed for S-A, S-D, and BBS as the STAND group improved whereas the RENEW group did not improve in these measures.

**Discussion and Conclusions:** Contrary to results in other populations, the addition of eccentric training to standard exercises did not result in significantly greater lower extremity strength gains in this group of individuals with MS. Further this training was not as effective as standard exercise alone in improving balance or the ability to ascend and descend stairs. Following data collection, reassessment of required sample size indicates we were likely underpowered to detect strength differences between groups.

*Use of Eccentron: neuromuscular strength training to improve lower extremity strength, mobility, and balance of individuals with MS.*

### **“Eccentric exercise versus usual-care with older cancer survivors: The impact on muscle and mobility – an exploratory pilot study.”**

LaStayo PC, Marcus RL, Dibble LE, Smith SB, Beck SL: Eccentric exercise versus usual-care with older cancer survivors: The impact on muscle and mobility – an exploratory pilot study. *BMC Geriatrics.* 2011;11:5. <http://www.biomedcentral.com/1471-2318/11/5>.

**ABSTRACT:**

**Background:** Resistance exercise programs with high compliance are needed to counter impaired muscle and mobility in older cancer survivors. To date outcomes have focused on older prostate cancer survivors, though more heterogeneous groups of older survivors are in-need. The purpose of this exploratory pilot study is to examine whether resistance exercise via negative eccentrically-induced work (RENEW) improves muscle and mobility in a diverse sample of older cancer survivors.

**Methods:** A total of 40 individuals (25 female, 15 male) with a mean age of 74 ( $\pm 6$ ) years who have survived ( $8.4 \pm 8$  years) since their cancer diagnosis (breast, prostate, colorectal and lymphoma) were assigned to a RENEW group or a non-exercise Usual-care group. RENEW was performed for 12 weeks and measures of muscle size, strength, power and mobility were made pre-and post-training.

**Results:** RENEW induced increases in quadriceps lean tissue average cross sectional area (Pre:  $43.2 \pm 10.8$  cm<sup>2</sup>; Post:  $44.9 \pm 10.9$  cm<sup>2</sup>), knee extension peak strength (Pre:  $248.3 \pm 10.8$  N; Post:  $275.4 \pm 10.9$  N), leg extension muscle power (Pre:  $198.2 \pm 74.7$  W; Post  $255.5 \pm 87.3$  W), six-minute walk distance (Pre:  $417.2 \pm 127.1$  m; Post  $466.9 \pm 125.1$  m) and a decrease on the time to safely descend stairs (Pre:  $6.8 \pm 4.5$  s; Post  $5.4 \pm 2.5$  s). A significant ( $P < 0.05$ ) group x time interaction was noted for the muscle size and mobility improvements.

**Conclusions:** This exploration of RENEW in a heterogeneous cohort of older cancer survivors demonstrates increases in muscle size, strength and power along with improved mobility. The efficacy of a high-force, low perceived exertion exercise suggests RENEW may be suited to older individuals who are survivors of cancer.

*Use of Eccentron: neuromuscular strength training to improve muscle and mobility in older cancer survivors.*

**“An eccentrically biased rehabilitation program early after TKA surgery.”**

Marcus RL, Yoshida Y, Meier W, Peters C, LaStayo PC: An eccentrically biased rehabilitation program early after TKA surgery. *Arthritis*. 2011;10 pages. doi:10.1155/2011/353149.

**ABSTRACT:**

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 quasi-experimental, one group, pretest-posttest study with thirteen individuals (6 female, 7 male; mean age  $57 \pm 7$  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.

*Use of Eccentron: neuromuscular strength training to improve physical function and muscle function of patients post-TKA surgery.*

**“The feasibility and efficacy of eccentric exercise with older cancer survivors: A preliminary study.”**

LaStayo PC, Larsen S, Smith S, Dibble L, Marcus R: The feasibility and efficacy of eccentric exercise with older cancer survivors: A preliminary study. *J Geriatr Phys Ther*. 2010;33(3):135-140.

**ABSTRACT:**

**Introduction:** Older individuals who have survived cancer, and the commensurate treatment, often experience a reduced quality of life in part due to their impaired muscular abilities and deficits in mobility. The purpose of this preliminary study was to determine the feasibility and preliminary efficacy of resistance exercise via negative, eccentrically-induced work (RENEW) with older cancer survivors.

**Methods:** Older cancer survivors with a perception of moderate muscle weakness and fatigue participated in 12 weeks of RENEW. Measures of feasibility included: 1) the participant's ability to progress the total amount of work of RENEW; 2) whether peak knee extension torque production became impaired; and 3) whether RENEW induced leg muscle pain as measured on a visual analog scale. The preliminary measure of efficacy included: the performance of a timed up and go mobility test.

**Results:** The participants significantly increased the total average work per week over the 12 weeks of RENEW. Participants increased ( $p < 0.001$ ) their work ~3-fold from week 3 ( $7.6 \pm 5.1$  kJ) to week 12 ( $22.1 \pm 14.8$  kJ) without muscle pain over the 12-week RENEW training period. Knee extension peak torque production improved (11%) significantly ( $p = 0.02$ ) (pretest:  $248 \pm 92$  N; posttest:  $275 \pm 99$  N) after 12 weeks of RENEW. The time to perform the TUG test improved (14%) significantly ( $p < 0.001$ ) (pretest:  $8.4 \pm 2.7$ ; posttest:  $7.2 \pm 2.3$  s) after 12 weeks of RENEW, suggesting preliminary efficacy.

**Conclusion:** Collectively, RENEW appears feasible and potentially efficacious for older, weak and fatigued cancer survivors.

**Implications for Cancer Survivors:** The use of eccentric muscle exercise may be ideally suited for older cancer survivors due to its high force and low energetic cost capabilities.

*Use of Eccentron: neuromuscular strength training to improve muscle function and mobility of older cancer survivors.*

## **“High intensity eccentric resistance training decreases bradykinesia and improves quality of life in persons with Parkinson’s disease: a preliminary study.”**

Dibble LE, Hale TF, Marcus RL, Gerber JP, LaStayo PC: High intensity eccentric resistance training decreases bradykinesia and improves quality of life in persons with Parkinson’s disease: a preliminary study. *Parkinsonism Related Disord.* 2009;15:752-757. doi:10.1016/j.parkreldis.2009.04.009.

**ABSTRACT:**

Persons with Parkinson disease (PD) often demonstrate bradykinesia during mobility tasks. Bradykinesia combined with other PD-related movement deficits may contribute to self-reported reductions in quality of life. At this time, no studies have examined the effects of resistance exercise as an intervention to reduce bradykinesia and improve self-reported quality of life. Therefore, we examined changes in muscle force production, clinical measures of bradykinesia, and quality of life following 12 weeks of a high intensity eccentric resistance exercise program in persons with mild to moderate PD. Twenty individuals with idiopathic PD were matched into an experimental or an active control group. All participants were tested prior to and following a 12-week intervention period. The experimental group performed high intensity quadriceps contractions on an eccentric ergometer 3 days a week for 12 weeks. The active control group participated in an evidence based exercise program of PD. The outcome variables were quadriceps muscle force, clinical bradykinesia measures (gait speed, timed up and go) and disease specific quality of life (Parkinson’s disease questionnaire-39 [PDQ-39]). Data was analyzed using separate 2 (group) x 2 (time period) ANOVAs. Results demonstrated significant time by group interaction effects for gait speed, timed up and go, and the composite PDQ-39 score ( $p < 0.05$ ). Muscle force, bradykinesia, and QOL were improved to a greater degree in those that performed high intensity eccentric resistance training compared to an active control group. Additional research is needed to determine if this type of training has long-term impact and if it results in an alteration of the natural history of the mobility and QOL decline in persons with PD.

*Use of Eccentron: neuromuscular training using high intensity resistance to increase lower extremity strength and improve mobility and quality of life in persons with PD.*

**“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: The use of eccentrically biased resistance exercise to mitigate muscle impairments following anterior cruciate ligament reconstruction: a short review. Sports Health. 2009;1:31. doi:10.1177/1941738108327531.

**ABSTRACT:**

**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.

*Use of Eccentron: neuromuscular strength training to improve lower extremity muscle volume, strength, and hopping ability of patients post-ACL reconstruction.*

**“Effects of early progressive eccentric exercise on muscle size and function after anterior cruciate ligament reconstruction: a 1-year follow-up study of a randomized clinical trial.”**

Gerber JP, Marcus RL, Dibble LE, Greis PE, Burks RT, LaStayo PC: Effects of early progressive eccentric exercise on muscle size and function after anterior cruciate ligament reconstruction: a 1-year follow-up study of a randomized clinical trial. Phys Ther J. 2009;89:51-59.

**ABSTRACT:**

**Background and Purpose:** The authors previously reported that focused eccentric resistance training during the first 15 weeks following anterior cruciate ligament reconstruction (ACL-R) induced greater short-term increases in muscle volume, strength, and measures of function relative to standard rehabilitation. The purpose of this study was to evaluate the effects of early progressive eccentric exercise on muscle volume and function at 1 year after ACL-R.

**Participants and Methods:** Forty patients who had undergone an ACL-R were randomly assigned to 1 of 2 groups: a group that received early progressive eccentric exercise (n=20) and a group that received standard rehabilitation (n=20). Seventeen participants in the eccentric exercise group and 15 participants in the standard rehabilitation group completed a 1-year follow-up. Magnetic resonance images of the thighs were acquired 1 year after ACL-R and compared with images acquired 3 weeks after surgery. Likewise, routine knee examinations, self-report assessments, and strength and functional testing were completed 1 year after surgery and compared with previous evaluations. A 2-factor analysis of variance for repeated measures (group x time) was used to analyze the data.

**Results:** Compared with the standard rehabilitation group, improvements in quadriceps femoris and gluteus maximus muscle volume in the involved lower extremity from 3 weeks to 1 year following ACL-R were significantly greater in the eccentric exercise group. Improvements in quadriceps femoris and gluteus maximus muscle volume were 23.3% (SD=14.1%) and 20.6% (SD=12.9%), respectively, in the eccentric exercise group and 13.4% (SD=10.3%) and 11.6% (SD=10.4%), respectively, in the standard rehabilitation group. Improvements in quadriceps femoris muscle strength and hopping distance also were significantly greater in the eccentric exercise group 1 year post-surgery.

**Discussion and Conclusions:** A 12-week focused eccentric resistance training program, implemented 3 weeks after ACL-R, resulted in greater increases in quadriceps femoris and gluteus maximus muscle volume and function compared with standard rehabilitation at 1 year following ACL-R.

*Use of Eccentron: neuromuscular strength training to improve lower extremity muscle volume, strength, and hopping distance of patients post-ACL reconstruction.*

### **“Comparing eccentric resistance exercise in prostate cancer survivors on and off hormone therapy: a pilot study.”**

Hansen PA, Dechet CB, Porucznik CA, LaStayo PC: Comparing eccentric resistance exercise in prostate cancer survivors on and off hormone therapy: a pilot study. *Phys Med Rehabil.* 2009;1:1019-1024. doi:10.1016/j.pmrj.2009.09.016.

#### **ABSTRACT:**

**Objectives:** To determine the feasibility of an eccentric resistance exercise training protocol in with prostate cancer and to assess whether men with prostate cancer who are receiving androgen deprivation therapy (ADT) have a blunted effect from the training as compared with prostate cancer survivors not receiving ADT.

**Design:** Prospective pilot study.

**Setting:** Academic medical center.

**Participants:** Sixteen men with prostate cancer (Gleason scores 3+3 to 4+4) were initially enrolled. Ten men (mean age 66, range 48-86) completed the study, 5 were currently receiving ADT. Analysis was performed on these 10 men.

**Interventions:** Subjects were evaluated at baseline. All men underwent a 12-week resistance training protocol using a recumbent, high-force eccentric, leg cycle ergometer 3 times per week at a “somewhat hard” perceived rate of exertion for 12 to 15 minutes. Pre-exercise and post-exercise training changes were examined within and between groups.

**Main Outcome Measures:** Quadriceps muscle volume (magnetic resonance imaging), isometric knee extension strength, functional mobility (Timed Up and GO Test [TUG] and 6-minute walk [6MW]), health-related quality of life (FACT-P), and fatigue (FACIT-fatigue scale).

**Results:** The ADT group demonstrated significant within-group improvements in the 6MW ( $P = .01$ ) and isometric knee extension strength ( $P = .03$ ). This group also demonstrated a clinically relevant change in FACT-P; however, this did not meet statistical significance. The non-ADT group demonstrated significant within-group improvements in the physical subscale of the FACT-P ( $P = .03$ ) and an increase in muscle volume ( $P = .04$ ). Their improvements in the TUG approached significance ( $P = .08$ ). No between-group differences existed.

**Conclusions:** Eccentric resistance exercise was well tolerated, and both groups derived some benefits in strength and functional mobility. Men receiving ADT did not appear to have blunted response to the exercise as compared with prostate cancer survivors not receiving ADT.

*Use of Eccentron: neuromuscular strength training to improve lower extremity muscle strength and functional mobility of prostate cancer survivors.*

### **“Reversing muscle and mobility deficits 1 to 4 years after TKA. A pilot study.”**

LaStayo PC, Meier W, Marcus RL, Mizner R, Dibble L, Peters C: Reversing muscle and mobility deficits 1 to 4 years after TKA. A pilot study. *Clin Ortho Relat Res.* 2009;467:1493-1500. doi.10.1007/s11999-009-0801-2.

#### **ABSTRACT:**

Muscle and mobility deficits can persist for years after a total knee arthroplasty (TKA). The purposes of this study were (1) to determine if 12 weeks of rehabilitation with resistance exercise induces increases in muscle size, strength, and mobility in individuals 1 to 4 years after a TKA; and (2) to compare the muscle and mobility outcomes of a traditional resistance exercise rehabilitation program with a rehabilitation program focused on eccentric resistance exercise. Seventeen individuals (13 women, four men; mean age, 68 years; age range, 55–80 years) with either a unilateral or bilateral TKA (total of 24 knees) were included in this matched and randomized repeated-measures rehabilitation pilot trial. Increases in quadriceps muscle volume and knee extension strength followed 12 weeks of eccentric exercise. Improvements were also noted in four mobility tests. Similar improvements were noted in the traditional group in two mobility tests. An increase in muscle size and strength and an improvement in levels of mobility can occur after 12 weeks of resistance exercise in older individuals 1 to 4 years after TKA. When the exercise mode focuses on eccentric resistance, the muscle growth response is greater as is the improvement in important mobility tasks.

*Use of Eccentron: neuromuscular strength training to improve lower extremity muscle and mobility deficits of patients 1 to 4 years post-TKA.*

### **“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: Increased strength and physical performance with eccentric training in women with impaired glucose tolerance: A pilot study. *J Women’s Health.* 2009;18:253-260.

#### **ABSTRACT:**

**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  $\pm$  6.4) with IGT were randomly assigned to a 12-week, knee extensor ECC program ( $n = 10$ ) or a non-exercise 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 post-training (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.

*Use of Eccentron: neuromuscular strength training to increase lower extremity muscle mass and improve function of postmenopausal women with impaired glucose tolerance.*

**“Comparison of combined aerobic and high-force eccentric resistance exercise with aerobic exercise only for people with Type 2 Diabetes Mellitus.”**

Marcus RL, Smith S, Morrell G, Addison O, Dibble LE, Wahoff-Stice D, LaStayo PC: Comparison of combined aerobic and high-force eccentric resistance exercise with aerobic exercise only for people with Type 2 Diabetes Mellitus. *Phys Ther.* 2008; 88(11):1345-1354.

**ABSTRACT:**

**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 cm<sup>2</sup> [95% CI=7.6 to 22.5]; AE group: -5.6 cm<sup>2</sup> [95% CI=-10.4 to 0.76]). Both groups experienced decreases in mean thigh IMF cross-sectional area (AE/RE group: -1.2 cm<sup>2</sup> [95% CI=-2.6 to 0.26]; AE group: -2.2 cm<sup>2</sup> [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.

*Use of Eccentron: neuromuscular strength training to improve thigh lean tissue, BMI, and physical performance of individuals with type 2 MD.*

**“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: Safety, feasibility, and efficacy of negative work exercise via eccentric muscle activity following anterior cruciate ligament reconstruction. *J Ortho Sports Phys Ther.* 2007;37(1):10-18.

**ABSTRACT:**

**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 (ie, 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.

*Use of Eccentron: neuromuscular strength training to improve lower extremity strength, performance, and activity level in patients post-ACL reconstruction.*

### **“Effects of early progressive eccentric exercise on muscle structure after anterior cruciate ligament reconstruction.”**

Gerber JP, Marcus RL, Dibble LE, Greis PE, Burks RT, LaStayo PC: Effects of early progressive eccentric exercise on muscle structure after anterior cruciate ligament reconstruction. *J Bone Joint Surg.* 2007;89:559-570.

#### **ABSTRACT:**

**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.

*Use of Eccentron: neuromuscular strength training to improve thigh muscle structure in patients post-ACL reconstruction.*

### **“Elderly patients and high force resistance exercise – A descriptive report: can an anabolic, muscle growth response occur without muscle damage or inflammation?”**

LaStayo PC, McDonagh P, Lipovic D, Napoles P, Bartholomew A, Esser K, Lindstedt S: Elderly patients and high force resistance exercise – A descriptive report: can an anabolic, muscle growth response occur without muscle damage or inflammation? *J Geriatr Phys Ther.* 2007;30(3):128-134.

#### **ABSTRACT:**

**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:  $18.5 \pm 1.2$  Sigma units/ml; post-training:  $19.2 \pm 1.1$  Sigma units/ml). Proinflammatory tumor necrosis factor- $\alpha$  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- $\alpha$  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.

*Use of Eccentron: neuromuscular strength training to improve anabolic and muscle growth responses in elderly individuals without muscle damage and inflammation occurring.*

### **“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: The safety and feasibility of high-force eccentric resistance exercise in persons with Parkinson’s disease. *Arch Phys Med Rehabil.* 2006;87:1280-1282.

#### **ABSTRACT:**

**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.

*Use of Eccentron: neuromuscular strength training to safely improve lower extremity muscle strength of individuals with Parkinson's disease without muscle damage and injury.*

### **“High-intensity resistance training amplifies muscle hypertrophy with functional gains in persons with Parkinson’s disease.”**

Dibble LE, Hale TF, Marcus RL, Droge J, Gerber JP, LaStayo PC: High-intensity resistance training amplifies muscle hypertrophy with functional gains in persons with Parkinson's disease. *Movement Disorders*. 2006;21:1444-1452.

#### **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.

*Use of Eccentron: neuromuscular strength training using eccentric resistance to increase lower extremity muscle volume and strength and improve mobility of individuals with Parkinson's disease.*

## “Early application of negative work via eccentric ergometry following anterior cruciate ligament reconstruction: A case report.”

Gerber JP, Marcus RL, Dibble LE, Greis PE, LaStayo PC: Early application of negative work via eccentric ergometry following anterior cruciate ligament reconstruction: A case report. *J Ortho Sports Phys Ther.* 2006;36(5):298-307.

### ABSTRACT:

**Study Design:** Case report.

**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.

*Use of Eccentron: neuromuscular training using eccentric resistance to safely and efficaciously increase lower extremity muscle size and strength of patients post-ACL reconstruction.*

## “Eccentric muscle contractions: Their contribution to injury, prevention, rehabilitation, and sport.”

LaStayo PC, Woolf JM, Lewek MD, Snyder-Mackler L, Reich T, Lindstedt SL: Eccentric muscle contractions: Their contribution to injury, prevention, rehabilitation, and sport. *J Ortho Sports Phys Ther.* 2003;33:557-571.

### ABSTRACT:

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.

*Use of Eccentron: neuromuscular training using high negative-work regimes that take advantage of the unique properties of 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: The positive effects of negative work: Increased muscle strength and decreased fall risk in a frail elderly population. *J Gerontol.* 2003;58A(5):419-424.

**ABSTRACT:**

**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 = 60%, TRAD = 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.

*Use of Eccentron: neuromuscular training using eccentric resistance to improve muscle structure and function of the frail elderly.*

**“Eccentric exercise in coronary patients: Central hemodynamic and metabolic responses.”**

Meyer K, Steiner R, LaStayo P, Lippuner K, Allemann Y, Eberli F, Schmid J, Saner H, Hoppeler H: Eccentric exercise in coronary patients: Central hemodynamic and metabolic responses. *Med Sci Sports Exerc.* 2003;35(7):1076-1082.

**ABSTRACT:**

**Purpose:** With lengthening (eccentric) muscle contractions, the magnitude of locomotor-muscle mass and strength increase has been demonstrated to be greater compared with shortening (concentric) muscle contractions. In healthy subjects, energy demand and heart rate responses with eccentric exercise are small relative to the amount of muscle force produced. Thus, eccentric exercise may be an attractive alternative to resistance exercise for patients with limited cardiovascular exercise tolerance.

**Methods:** We tested the cardiovascular tolerance of eccentric exercise in 13 coronary patients (ages 40–66) with preserved and/or mild reduced left ventricular function. Patients were randomly assigned to either an eccentric (ECC;  $N = 7$ ) or a concentric (CON;  $N = 6$ ) training group and trained for 8 wk. Training workload was increased progressively (from week 1 to 5) to an intensity equivalent to 60%  $\text{VO}_2\text{peak}$ .

**Results:** On average, maximum power output achieved with ECC was fourfold compared with CON ( $357 \pm 96$  W vs  $97 \pm 21$  W;  $P < 0.005$ ), whereas measures of oxygen uptake and blood lactate were significantly lower ( $P < 0.05$  each), and ratings of perceived exertion were similar for ECC and CON. During a 20-min session of ECC and CON, central hemodynamics was measured by means of right heart catheterization. During ECC, responses of mean arterial blood pressure, systemic vascular resistance, pulmonary capillary pressure, cardiac index, and stroke work of the left ventricle on average were in the normal range of values and similar to those observed during CON. Compared with baseline, after 8 wk of training, echocardiographic left ventricular function was unchanged.

**Conclusion:** The results indicate uncoupling of skeletal muscle load and cardiovascular stress during ECC. For low-risk patients with coronary heart disease without angina, inducible ischemia, or left ventricular dysfunction, ECC can be recommended as a safe new approach to perform high-load muscular exercise training with minimal cardiovascular stress.

*Use of Eccentron: neuromuscular training to increase strength without cardiovascular stress in patients with coronary heart disease.*

### **“Do muscles function as adaptable locomotor springs?”**

Lindstedt SL, Reich TE, Keim P, LaStayo PC: Do muscles function as adaptable locomotor springs? *J Experiment Biol.* 2002;205:2211-2216.

#### **ABSTRACT:**

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.

*Use of Eccentron: neuromuscular training to improve muscle properties and function.*

### **“Eccentric ergometry: increases in locomotor muscle size and strength at low training intensities.”**

LaStayo PC, Pierotti DJ, Pifer J, Hoppeler H, Lindstedt SL: Eccentric ergometry: increases in locomotor muscle size and strength at low training intensities. *Am J Physiol Regulatory Integrative Comp Physiol.* 2000;278:R1282-R1288.

#### **ABSTRACT:**

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.

*Use of Eccentron: neuromuscular training to increase muscle size and strength in adult males.*

**“Chronic eccentric exercise: improvements in muscle strength can occur with little demand for oxygen.”**

LaStayo PC, Reich TE, Urquhart M, Hoppeler H, Lindstedt SL: Chronic eccentric exercise: improvements in muscle strength can occur with little demand for oxygen. *Am J Physiol Regulatory Integrative Comp Physiol.* 1999;45:R611-R615.

**ABSTRACT:**

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.

*Use of Eccentron: neuromuscular training to increase muscle strength without muscle injury and at low cardiovascular demand in healthy adults.*