Video Article

Adapted Resistance Training Improves Strength in Eight Weeks in Individuals with Multiple Sclerosis

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Abstract

Hip weakness is a common symptom affecting walking ability in people with multiple sclerosis (MS). It is known that resistance strength training (RST) can improve strength in individuals with MS, however; it remains unclear the duration of RST that is needed to make strength gains and how to adapt hip strengthening exercises for individuals of varying strength using only resistance bands. This paper describes the methodology to set up and implement an adapted resistance strength training program, using resistance bands, for individuals with MS. Directions for pre- and post-strength tests to evaluate efficacy of the strength-training program are included. Safety features and detailed instructions outline the weekly program content and progression. Current evidence is presented showing that significant strength gains can be made within 8 weeks of starting a RST program. Evidence is also presented showing that resistance strength training can be successfully adapted for individuals with MS of varying strength with little equipment.

Video Link

The video component of this article can be found at https://www.jove.com/video/53449/

Introduction

In MS, compromised neural function typically leads to motor dysfunction, resulting in weakness. It is known that muscle weakness contributes to reduced daily activity in people with MS and inactivity further compromises functional ability[1;2]. Our lab has shown that weak hip flexor muscles in individuals with MS affect walking speed[3], particularly in the weakest individuals[4]. The significance of weak proximal hip muscles to walking has been shown in MS as well as in other neurodegenerative conditions[4;5]. This vicious cycle contributes to increased disability and reduced quality of life[6;7]. Regular exercise can improve daily activity[8], cardiovascular fitness[8;9], muscle strength[10], and fatigue[8;11] in people with MS[12]. Strength training is known to promote neural adaptations that can lead to favorable functional outcomes in MS participants[13-16]. Since physical rehabilitation is often the only treatment offered to individuals with MS for recovery of function, it is critical to determine what is the most efficient way to improve strength.

Resistance strength training has been evaluated with no clear consensus on the minimal amount of time needed to see significant changes in muscle strength or the best method for optimizing strengthening. A current review reports that resistance training studies have varied in length from 3 to 26 weeks, mainly targeting the lower extremities in persons with MS suffering from low to moderate impairments (with an Expanded Disability Status Scale of 0-6.5)[14;17;18]. These studies primarily use isokinetic devices for training with direct supervision in a gym location. The use of isokinetic equipment is one way to isolate and strengthen single muscles, but it limits a person's ability to complete the exercises without use of expensive equipment that is not always accessible. Resistance bands offer the advantage of controlling the direction of resistance as well as the placement of the resistance on the limb, thereby avoiding stresses to distal joints. Resistance bands also offer the opportunity to grade the resistance in finer increments then with other equipment such as with cuff weights.

Alignment and movement patterns are carefully addressed in the training of athletes, yet little attention is given to these factors in individuals with chronic degenerating conditions, in part because their limitations are so complex (*e.g.*, sensory, motor control, cognition). The need to address alignment in exercises, as well as in everyday activities is critical[19]. Simple, but well-selected exercises that are precisely performed aid in the resolution of musculoskeletal syndromes in individuals with intact nervous systems[19]. Although many generic exercise programs are available, they do not address the specific impairments in MS that affect mobility and modifications necessary, given the progressive nature of the disease. For this program, we emphasize postural alignment, as well as specific exercises that are done in a position that is most optimal for how the muscle is used functionally.

The goal in this study was to create an accessible, inexpensive, resistance training program for the hip muscles that is generalizable to individuals with variable degrees of disability. Simple but precisely described hip strengthening exercises are adapted here emphasizing the strengthening of isolated muscles and guidelines are provided for individuals to further adapt the exercises depending on their current muscle strength. Recommendations are made so individuals can exercise with resistance bands in a systematic way that is easily adaptable to the home and details needed to replicate the program are specified.

Protocol

NOTE: The institutional review boards at Johns Hopkins University School of Medicine and Kennedy Krieger Institute approved this work. All participants provided written consent before participating.

1. Training

1. Ensure that the instructor is adequately trained in the use of hand held dynamometry and specifics of exercise details prior to initiating this protocol.
   NOTE: Test a mix of individuals with varying strength levels to assure competence and consistency following the specifics of testing and exercise details as described in in Sections 6 and 8.2.

2. Select Location and Equipment Required for Exercise Class

1. Recruit 2-5 individuals to do the exercises at a delegated time.
2. Ensure there is room for a weighted plinth that is able to safely support a person in lying and that rests solidly on the ground, with one long side against a wall. Ensure there is floor area clearance on the ground perpendicular to the long side of plinth legs of at least 2.5 m and 1 m on the short sides of the plinth.
3. Ensure there is adequate space with the following equipment to be available: two chairs that have a seat height of at least 18 inches from the ground and do not have wheels or arms; two padded 'yoga' mats; an adjustable height bench (approximately 90 cm x 30 cm x 45-60 cm). Make sure there is adequate space for people to move safely around the room allowing for device (walkers; canes) use as necessary. More space is needed for groups that have more impaired participants.

3. Resistance Bands

1. Obtain resistance bands from a commercial source (see material and equipment list).
   NOTE: The different color bands represent different amounts of resistance. Check the packaging for the bands you purchase to determine the amount of resistance. In this study example, five latex-free bands ranging 13 to 40 Newtons (N) of force at 100% elongation were used (specifically: level one: 13, level two: 20, level three: 27, level four: 33, level five: 40). Use additional resistance tubing for stronger participants with forces of level six: 45 N, level seven 67 N and level eight: 89 N.
2. Use 160 centimeters (cm) lengths of each band color. Mark 20 cm sections on each respective band. Knot the band at each 20 cm juncture around a looped plastic zip-tie. Use this to individualize the intensity of the resistance. Do this for each level/color of the resistance bands.
3. Using an 8 cm carabiner, combine one level of each resistance band to make at least 4 sets. This will be important for individualizing the resistance at each station.
   NOTE: Carabiner and zip ties need to have a minimum pound tensile strength to resist tension adequately and ensure safe performance. Zip ties of 225 N and carabiners of 667 N strength have been used reliably in this set up. To anchor the bands, the following may be needed: rope (length will depend on other equipment selected); squared 'S' hooks; door anchors.

4. Participant Recruitment

1. Recruit adults with MS through word of mouth, flyers, physician or friend referral, MS newsletters, MS support groups, and websites.
2. Ensure that individuals with MS are: stable on their medications and have been for ~6 months, medically stable, able to follow 2-step directions independently, have functional passive range of motion at the hips, knees, ankles, and minimal pain.

5. Phone Screening

NOTE: This is essential to explain to the interested person what participation requires and to assess the participant's eligibility.

1. Draft a document that can be followed by the person making the call so no details are missed.
   NOTE: In the phone screening, be sure to include demographic information, a review of inclusion and exclusion criteria, disability level, and the structure of the exercise program (*i.e.*, days, length of time) and what to expect from the exercise program.
2. Contact interested participant and schedule a phone screening.
   NOTE: If there is a question of someone's health for safely participating in an exercise program, have the participant ask his or her physician for a note approving an exercise program.

6. Participant Pre-test

NOTE: Conduct pre-tests within 2 weeks before starting the resistance-training program.

1. Schedule each participant for an initial testing session (pre-test) at a participant preferred time of day, and document the time so that all testing sessions can be during this preferred time.
2. Obtain written informed consent from each participant prior to their participation.
3. Obtain strength measures for hip flexor, hip extensor, and hip abductor muscles using a hand held dynamometer to assess for baseline strength status, using a break test. Ensure that the tester overpowers the participants' muscle effort, as described by Bohannon *et al.*
   NOTE: The break test is complete once the participant is no longer able to maintain maximal resistance and the limb begins to move out of the starting position. For all tests ensure that the participants do not use their arms to hold on or brace themselves[20].
   1. Perform all tests alternating sides of the body and repeat to obtain two consistent measures for each side within 45 N of each other. Ask the participant to hold each position for 4-5 sec at maximal effort. Record each measure and the tester performing the measure. Average the two measures for each side to use in results.
      NOTE: Before each test explain to the participant the procedure before each muscle group.
   2. For hip flexion, instruct the participant to lie supine on a mat, legs extended, body relaxed and head resting on a pillow. Instruct the participant to bend one knee and hip, and hold the hip at 90 degrees.
      1. Place the dynamometer on the distal femur. Instruct the participant to pull knee toward nose and hold as strongly as possible. The knee should not move lateral or medial during this movement. Pull dynamometer in the direction of the participant's toes slowly and evenly

   3. For hip extension, instruct the participant to lie prone on a plinth, legs extended and body relaxed. Provide a pillow under the chest if the participant is uncomfortable lying completely flat or has limited hip extension range of motion. Instruct the participant to bend one side knee to 90 degrees flexion and hold.
      1. Place the dynamometer on the distal femur. Instruct the participant to use buttocks to lift knee off mat, hold and do not twist. Push dynamometer down in the direction of the mat.
         NOTE: The instructor can rest the hand not holding the dynamometer on the mat to assure that the leg does not reach the mat while the dynamometer is being used.

   4. For hip abduction, instruct the participant to lie side-lying on a mat with shoulders, back, and hips resting against a wall. Provide a pillow for the participant to rest if needed. Optionally ask the participant to rest their head on the bottom arm or hand. Explain to the participant to bend the bottom leg knee, and extend the top leg with the heel touching the wall and the toes pointing slightly upward. Instruct the participant to keep the top leg straight and heel against the wall, and to lift his or her leg up to ~45 degrees and hold.
      1. Place the dynamometer on the side of the leg (*i.e.*, the distal femur) and push down.

7. Program

NOTE: Instruct the participants in introductory material and specifics of the exercises as detailed in sections 7 and 8. 7.1 – 7.8 need to be explained in the first session and reviewed as necessary. Instruct exercises one at a time and no more than three per day for optimal participant training. Instruct one-on-one whenever possible for optimal supervision and performance. Anticipate 1-2 weeks for higher functioning individuals to learn the basics of exercise performance and 2-3 weeks for more impaired individuals. Anticipate need for supervision and assistance to decrease over the course of the program. However, instructors will continue to provide direct observation and cuing as needed throughout the program as increasing resistance often results in increased effort and more difficulty attending to alignment.

1. Instruct the participant on the principles and goals of the program.
   1. Instruct the participant that the main goal of the program is to strengthen key leg muscles to maximize walking.
   2. Instruct the participant on the importance of isolated muscle strengthening. Strengthening an isolated muscle may look easy, but positioning, controlling movement, and adding resistance can make the effort high. If a muscle is not strengthened in isolation, the strong will get stronger and the weak will get weaker.
   3. Instruct the participant that the goal of the functional training exercise is to incorporate the isolated muscle strengthening into whole body movements. Emphasize correct alignment is necessary for optimal muscle performance. Explain to the participant that the functional exercise demonstrates a way to apply the exercises to daily activities.

2. Instruct the participant on program expectations of the participant.
   1. Offer group exercise participation three times per week for twelve weeks, for a total of 36 sessions. Include a rest day among the three weekday sessions. For example, a Monday, Tuesday, Thursday format is appropriate.
   2. Require the participant to complete a minimum of 33 group sessions within 14 weeks.
      1. Offer a monthly make up session to allow participants to meet this objective.

   3. Provide and require participants to perform a one-day home program of three exercises each weekend.

3. Instruct the participant in the group exercise setting for safety and timeliness.
   NOTE: Include in the instruction the following: Important to start on time and end on time as a group. When arriving early wait for instructor to begin. When arriving late it may not be possible to finish all the exercises on that day. Attention to time is necessary due to space availability. Respect the center location for safety and courtesy.
4. Instruct the participant in attention to safety.
   1. Ensure participants use care when moving about the room by attending to the "set up" of the exercise equipment and the other people in the room. Ask the participants to use, as necessary, a walking device to move about the room to ensure the safety of the group. Emphasize the importance that the instructor be able to focus the class on the exercises without having to interrupt the session to address the individual safety issues that arise due to inattention.

5. Inform the participant of exercise equipment usage and care

NOTE: As appropriate, instructors set up and take down equipment before and after each class.
1. Ensure instructors clean equipment according to hospital guidelines. Instruct participants to use a personal towel to cover the mats to maintain the integrity of the equipment and for infection control.

6. Instruct the participant in exercise station format
   1. Ensure instructor assigns starting station and order of stations. Refer participants to use white columns of weekly log sheet (see Appendix) to indicate the specific exercises by day.
   2. Instruct participants that timeliness is essential for everyone to get through all the exercises at each session. Instruct participants to attend to the instructions to change between legs and between stations. Encourage participants to ask for help with set up as needed

7. Instruct participants in daily format
   1. Provide participants a sign in sheet for instructors to monitor compliance with attendance.
   2. Ensure instructors post a sign with the following list for reference: Sign in (Date and Initials); Warm up with instructor; Get clipboard and exercise packet; Put on appropriate ankle strap or thigh strap; Move to first station; Change stations as indicated; Enter effort and repetitions on log sheets after each exercise; Complete all strengthening and functional exercises; Please put logs, straps and pens back in bag and leave with instructor at end of session (see Appendix for Exercise Log).

8. General Considerations

1. Instruct participants in the routine for each exercise:
   1. Refer to exercise log for the appropriate strap and hook placement. Perform on one leg, holding for 3-5 sec at the end range before returning to starting position. Perform each movement slowly and with good alignment. Perform each exercise for two sets of repetitions with a 60 sec rest between sets.
   2. Refer to the first page of the participant's log for the number of repetitions per set. Repeat the exercise on the other side. Instruct participant to record performance as indicated for each exercise before moving on to the next on the provided exercise log (see instructions in 6.19).
   3. Provide adequate training and supervision for the specific exercises. Instruct exercises one at a time and no more than three per day for optimal participant training. Instruct one-on-one whenever possible for optimal supervision and performance.
   4. For higher functioning individuals anticipate to use weeks 1-2 to learn the basics of exercise performance and weeks 1-3 for more impaired individuals.
   5. Provide decreasing amount of supervision and assistance over the course of the program as the participants become more independent. However, provide direct observation and cuing as needed throughout the program as increasing resistance often results in increased effort and more difficulty attending to alignment.

2. Warm Up Exercise
   1. Select the most appropriate warm up for the group at each session.
      NOTE: Recommended warm up options include: forward walking or marching; backward walking; sidestepping or skipping for 30 meters each. Vary as needed based on abilities of the group.

3. Hip Flexion
   1. Instruct participant to lie supine with both hips straight. Instruct participant to slowly lift one knee towards chest to end range of hip flexion, keeping knee close to midline. Instruct participant to lower leg with control to starting position. Ask the participant to tighten their abdominal muscles to keep the pelvis stable if necessary.
   2. For weaker individuals, instruct participant to perform this side-lying with the top leg supported on a low bench placed in front of the participant.

4. Hip Abduction
   1. Instruct the participant to lie side-lying with the bottom leg slightly bent and the top leg straight. Instruct the participant to lift the top leg toward the ceiling, keeping the leg in line with the trunk and the knee facing straight ahead or slightly turned up toward the ceiling. Instruct the participant to lower the leg to starting position. Use the wall behind the participant to ensure the shoulders, hips and ankles are all in proper alignment and as a cue to keep the moving leg from coming forward.
   2. For weaker individuals, instruct the participant to bend the top leg at the knee more to decrease the effort; keep the heels in contact and only move the knee by rolling up and out; or perform in supine.

5. Hip Extension
   1. Instruct the participant to lie face-lying with one leg straight and one leg bent. Instruct the participant to raise the bent thigh off the support surface, keeping the knee bent.
   2. For optimal alignment: Instruct the participant to tighten abdominal muscles to keep the pelvis stable if necessary.
   3. For weaker individuals, instruct the participant to perform in side-lying with the top leg supported on a low bench placed behind the participant. For stronger individuals (modification), instruct the participant to perform the exercise on the floor starting from a hands and knees position. Ensure back and pelvis remain stable throughout the movement.

6. Knee Flexion
   1. Instruct the participant to lie face-lying with both legs straight. Instruct the participant to bend the knee as far as possible, keeping the pelvis and thigh still and keeping the hips on the support surface
   2. For optimal alignment, instruct the participant to tighten abdominal and/or buttocks muscles to keep the pelvis still.
   3. For weaker individuals, instruct the participant to perform in side-lying with leg supported on a bench or in sitting.

7. Hip External Rotation

1. Instruct the participant to start in a seated position. Instruct the participant to rotate the knee/thigh outward.
2. For optimal alignment, avoid moving hip into abduction, adduction or flexion. Heel may slide behind or in front of opposite foot depending on comfort of the participant.
3. For weaker individuals, instruct the participant to perform the exercise in supine with the leg straight.
4. For stronger individuals, instruct the participant to perform the exercise in standing with knee resting on the chair and hip maintained in extension.

8. Knee Extension
    1. Instruct the participant to lie supine with exercise leg straight and resting leg bent. Instruct the participant to raise the leg from the hip, keeping the knee straight and stopping at the height of resting leg knee.
    2. For optimal alignment, if the pelvis rocks, tighten abdominal muscles and/or do not lift the leg as high.
    3. For weaker individuals, instruct the participant to perform in side-lying with leg supported on a bench or in sitting.

9. Functional Exercise
    1. Select the most appropriate functional exercise for the group at each session. Select the functional exercise based on participant abilities incorporating patient safety, cognition and confidence level.
    NOTE: Selected examples of functional exercises include: Planks face-lying and side-lying; Hands and knees leg and/or arm lifts (can support trunk on an exercise ball to decrease difficulty); Step touch to a bench (lower height to decrease difficulty); Step ups to a bench (lower height to decrease difficulty); Marching in place (heel raises only to decrease difficulty); Variations of standing on one leg (one foot on a low bench to one foot on block of foam to using light touch of a finger on a wall to standing on one leg to moving the free leg in space); Sit to stand (lower height chair to increase difficult; put one foot forward of the other to increase the difficulty); Standing to/from squat (smaller range or wall slide to decrease difficult); Walk wide stepping with resistance band loop at level of ankles.

10. Home Exercise
    1. Provide each participant an individualized home program each weekend.
    2. Instruct participants in the following structure: perform two sets of ten repetitions of hip flexion in supine using provided resistance band; perform sit to stand for 3 min duration; perform selected functional exercise for 3 min duration; perform each exercise once over the weekend.

11. Exercise Log
    1. Instruct participants to fill out the exercise log (see Appendix) as described in this section. Instruct participants to do so immediately following each exercise on the respective page.
    2. Instruct the participant to enter today's date and repetitions performed on log sheets. Instruct the participant to enter effort as defined using the rating of perceived exertion (RPE) scale of 0-10 (see Appendix).
    3. Instruct the participant to enter the color of the resistance bands and the length used.
    NOTE: The length is equals the loop number of the resistance bands. Example: If using the loop closest to the secured object, write in "1 loop".
    4. Have the instructors fill in the band goal for tomorrow and that participants know to use this color and length at the next session. Print a new log sheet weekly for each participant and enter the number of repetitions according to the following schedule: Weeks 1-3 do 10 repetitions per set; Weeks 4-6 do 12 repetitions per set; Weeks 7-9 do 15 repetitions per set; Weeks 10-12 do 18 repetitions per set.

12. Exercise intensity
    1. Progress through each participant individually through performance evaluation of each exercise for proper form and participant safety according to the following guidelines and in accordance with the trained instructor's clinical judgment.
    2. Advance the resistance level according to the 'perceived exertion rating' ranges if alignment is correct: Rating of zero through three — advance at the next session; Rating of four through seven — advance in the next week; Rating of eight through ten — maintain at same level, if form is correct and participant has no complaints (*i.e.,* pain, too much effort, *etc.*).
    3. Continue to cue the participant in the proper form if alignment is not correct.
    NOTE: Complaints of pain or very, very strenuous effort (*i.e.,* a rating of 10) should take precedence to determine resistance level and whether to maintain or decrease resistance.
    4. Advance the resistance bands each week by either the color or the length as follows:
        1. Color of band, use next intensity level band and keep the same length or add another band at the same or longer length of the current band.
        2. Length of band: Shorten band by 1 loop.
        NOTE: Limitation is based on amount of stretch to band through given range of motion. Typical band stretch limits are of two-three times the resting length.

13. Training monitoring
    1. Every four weeks, ensure test hip flexion strength using dynamometer to determine that the progression is ongoing.
    Note: Anticipate maintenance of current strength level at four weeks, with an increase from pre-test at eight weeks.
    2. If a reduction in strength is observed, reassess the resistance levels being used. Consider assessment by physician if symptoms progress.

9. Post-test Evaluation

1. Schedule a testing session with each participant within one week of finishing the required class dose.

2. Repeat strength measures, as described in pre-test. Obtain strength of hip flexor, hip extensor, and hip abductor muscles using a hand held dynamometer.

10. Statistical Analysis

1. Calculate descriptive statistics for baseline variables (*e.g.*, muscle strength for hip flexors, hip extensors, and hip abductor muscles).
2. To determine if there is a group change in strength in pre- to post-resistance training use a t-test, or a Mann-Whitney test in the case of a non-normal population. Evaluate group strength on the summed strength of both sides (left and right) for each muscle group.
3. To determine if there is a change in strength for an individual muscle determine the percent change from baseline. Use this for individual feedback throughout the group. Use a standard statistical package such as Stata.

Representative Results

We show results from 26 individuals with MS who participated in a 12-week lower extremity progressive, resistance training (PRT) at our facility. Our participants have varying levels of disability with a median EDSS of 4.0 (range: 1-6.5), are on average 50.0 (11.3) years of age (youngest is 23 years, oldest is 64 years), 17 are female, and have an average symptom duration of 12.5 (8.7) years.

Figure 1 shows that hip strength improved following 12-weeks of training ($p<0.005$ for all hip muscles). For hip flexion, statistically significant improvements were first made following 8-weeks of training ($p=0.013$), with additional improvement at the end of 12-weeks. Individual muscle groups were compared using paired t-tests with the p-value set at 0.017 to control for multiple comparisons. When we assess each individual's strength change from pre-intervention to post-intervention, we see varied responses with most showing good improvement: more than half improved strength by more than 44 N. To demonstrate this, **Figure 2** shows three examples of participants who improved their strength despite hip muscles having different degrees of weakness to start with. **Figure 2A** shows an example of an individual with asymmetric hip strength (left weaker than right) at baseline, this person presented with a hemi-paretic walking pattern. Following strength training, this person specifically gained hip flexion strength on the weaker, left side. By contrast, hip abductor and extensor muscles were more symmetric and both sides gained strength post intervention. Note: this person (2A) started on the right for hip flexion at 1 level 5 band at loop 3 for a total of 40 N at 100% stretch and progressed to 1 level 5 and 1 level 3 band at loop 2 (1/3 shorter overall length), for a total of 67 N at 100% stretch. **Figure 2B** shows an individual with very weak hip muscles compared to control values (hip flexion: 195 ± 44 N)[5]. This individual gained strength in all three muscles and on both the right and left sides even with profound initial weakness. Note: this person (2B) started on the right for the hip flexion exercise in side-lying without bands and progressed to doing the exercise in supine without bands. **Figure 2C** shows an individual who is relatively strong in his hip muscles at baseline, relative to control values (hip flexion: 304 ± 52 N)[5]. Though this person had only very mild weakness, all muscles show improvements on the order of 22-44 N following the strength training intervention. Note this person (2C) started on the right for hip flexion with 2 level 5 bands and 2 level 3 bands at loop 4 for a total of 146 N at 100% stretch and progressed to 1 level 5 band and 1 level 2 and all three tubes doubled at loop 4 length for a total of 469 N at 100% stretch.

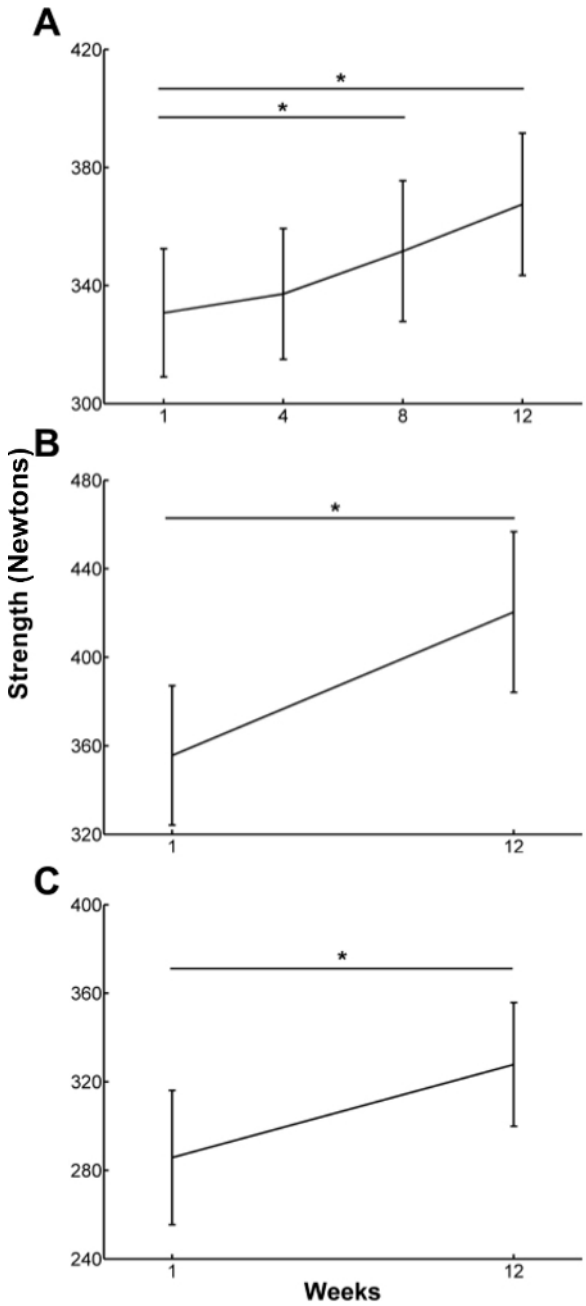

Figure 1. Hip flexion strength. Line graph from 26 individuals with MS showing mean values ± standard deviation for strength of the hip flexor muscles in Newtons. (**A**) summed hip flexion strength. (**B**) summed hip abduction strength. (**C**) Summed hip extension strength. Base: baseline measure; pre-intervention; 4 wk: mean after 4 weeks of the intervention; 8 wk: mean after 8 weeks of the intervention; 12 wk: mean value after 12 weeks of the intervention.

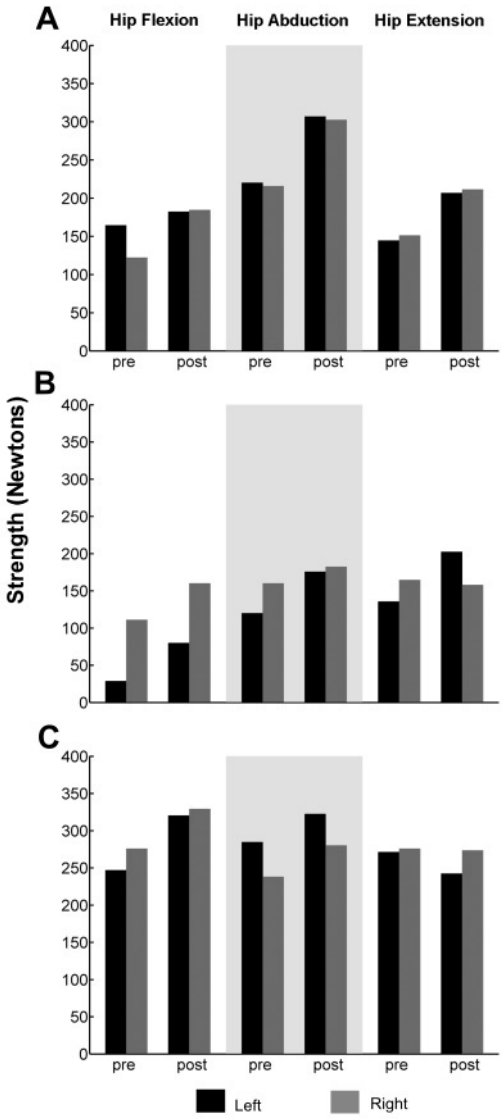

Figure 2. Three representative examples of strength change, before and after the resistance strength training program. The bar graphs show the mean strength measure for the right and left sides of the hip flexor, hip extensor and hip abductor muscles for three MS participants. The dark columns are left hip flexion and the lighter columns are right hip flexion measures. (**A**) participant with notable hip flexor asymmetry at baseline (age: 46, female, symptom duration: 4 yrs, EDSS: 1) (**B**) participant with notably weak hip muscles at baseline (age: 58, female, symptom duration: 34 yrs, EDSS: 6). (**C**) participant with very mild weakness in hip muscles at baseline (age: 37, male, symptom duration: 1 yrs, EDSS: 2). The y-axis is strength, in Newtons. The x-axis indicates the right and left muscle strength for visit 1 and visit 2 for the three hip muscles. Pre, is baseline or pre training; Post, is 12-week or post-training.

Discussion

The protocol describes a progressive resistance training program using isolated muscle strengthening with resistance bands for people with MS. This protocol has unique features for individuals with degenerative conditions whose strength limitations may be compromising their ability to ambulate and maintain their quality of life. The focus is on improving proximal muscle strength in the lower extremities that is important for walking speed in MS[21;4]. One advantage of this protocol is that it emphasizes isolated muscles in appropriate alignment (*e.g.*, hip abduction with hips extended). The protocol can be individualized to accommodate for asymmetric weakness, profound weakness, or individuals with mild weakness. By contrast, traditional gym equipment often allows for substitution of stronger muscles without optimizing muscle alignment for functional performance (*e.g.*, hip abduction with hips flexed). While resistance bands are inexpensive relative to gym equipment they may stretch out over time, losing their resistance. However, we found that one set of bands was effective for the 12-week exercise program, for groups of 4 people. Other advantages of the protocol are that it is inexpensive, feasible to do in a small group setting, and requires minimal equipment. Lastly, we emphasize pre- and post-tests using a quantitative device such as a hand held dynamometer to better evaluate for subtle but significant changes in individuals as well as for group comparisons.

These preliminary results, taken from a larger ongoing study, demonstrate that significant strength improvements occur within 8 weeks of training. This is important because participants often want to know when to expect to see improvements from their rehabilitation efforts. This

information can be valuable in motivating participants and obtaining funding. Participant testimonials were reflective of this, an example is shown in highlighted textbox. Finally, in designing clinical trials testing pharmacologic or rehabilitative interventions, seeing change in 8-weeks allows for expedient results.

MS is characterized by heterogeneous signs and symptoms in which weakness occurs in combination with other symptoms (*i.e.*, cognitive, sensory, spasticity, ataxia). For successful use of this protocol, individualizing the program based on daily performance is essential. Each participant was supervised by a rehabilitation professional within their group, ensuring that: proper alignment was used; the exercises were of adequate intensity; and safety was maintained throughout the program. One modification to the protocol in order to ensure adequate supervision was to enroll participants sequentially (one per week). Professional clinical judgment is valuable for careful attention to skin integrity, safety with ambulation between stations to prevent falls, whole body alignment to prevent secondary pain complications with exercise, and for monitoring adequate environmental temperature control. As with other intervention studies, participant compliance both with frequency and quality of performance is a potential issue so should be addressed proactively. Effective strategies used in this protocol include offering monthly make up sessions and allowing 10%-15% longer duration to complete the required number of training sessions. Direct supervision as well as the group dynamic provides a means for accountability and camaraderie to optimize compliance.

As part of the larger study, we will be assessing for longevity, application to walking, functional performance, and quality of life in a controlled study, which was one of the limitations of the current study. In the future, application of this protocol to home or community environments would provide greater access for participants to benefit from this program. Better access to this protocol could allow the application to rare neurodegenerative disorders that also have leg weakness as a key symptom. Ideally, a program such as this could be optimized for the community under the instruction of non-clinically trained individuals as has been done for interventions in Parkinson's Disease22. More research is needed to generalize this information safely while maintaining the fidelity of the program.

Participant Testimonial: One participant (**Figure 2A**) reports, "I have a step-stool in my kitchen, and I used to have trouble climbing on it to put dishes away. Now it's easy, I just hop right up there!" And, "I went to my granddaughter's birthday party over the weekend and both of my daughters commented on how much better I look. They noticed that I wasn't as tired, didn't need breaks and could walk and move around better. It's nice when other people start to notice!"

Disclosures

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