Brief report

Effects of once weekly NMES training on knee extensors fatigue and body composition in a person with spinal cord injury

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Study design: Single-subject case (male, 33 years of age, T6 SCI AIS A).

Objectives: To determine the effect of surface neuromuscular electrical stimulation (NMES) training conducted once weekly on improving fatigue resistance as well as regional and whole body composition in an individual with spinal cord injury (SCI).

Setting: Laboratory setting within a SCI Center.

Methods: Surface NMES resistance training (RT) of the paralyzed knee extensors was conducted once weekly for 12 weeks using ankle weights. Knee extensor fatigue index was determined by the number of repetitions (reps) achieved out of 30 reps. Total and regional body composition including percentage body fat (%BF), fat mass (FM), lean mass (LM) were conducted before the first session and one week after the last training session using whole-body dual-energy X-ray absorptiometry.

Results: The participant had a compliance rate of 83% and he was able to lift 6 and 2 lbs on the right and left legs, respectively. Right knee extensors showed greater fatigue resistance compared to the left one. Leg LM increased by 6% accompanied with decrease in arm, trunk and total body LM by -4.7%, -13%, -5%, respectively. The %BF increased by 8%, 7.3%, 15.5%, 11.5% for arm, legs, trunk and total body.

Conclusion: Once weekly of NMES RT evokes local positive changes in leg LM without reciprocating the continuous loss in LM or gain in FM in other regions and total body. Training was effective in increasing strength as well as fatigue resistance of the trained knee extensors.

Keywords: Neuromuscular electrical stimulation, Resistance training, Exercise, Spinal cord injuries, Body composition

Neuromuscular electrical stimulation (NMES) training dosages targeting lean mass (LM) and skeletal muscle hypertrophy range from twice to seven times weekly after spinal cord injury (SCI).¹ Twice weekly of NMES evoked resistance training (RT) has previously been shown to evoke skeletal muscle hypertrophy, improving glucose, insulin tolerance, and mitochondrial functional capacity.²⁻⁵ Moreover, this training paradigm has been shown to induce a modest improvement in increasing leg LM accompanied with a decrease in leg fat mass (FM) and increasing strength and muscle fatigue resistance.³⁻⁴

The cessation of NMES training is likely to reciprocate the gains in body composition and metabolic profile. A successful strategy guaranteeing long-term compliance may be reducing the training frequency in half and reducing the number of training sets. It is unclear, however, whether training once a week may lead to positive body composition changes and increase fatigue resistance similar to that noted following twice weekly of training. The purpose of the current case study was to investigate the impact of 12 weeks of NMES RT protocol that was conducted once weekly on knee extensors fatigue resistance as well as total body and regional LM and FM in a person with chronic complete SCI.

Methods

A 33-year-old man with a complete SCI (T6, AIS A) secondary to a motor vehicle accident participated in

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the study. The participant (weight: 63 kg, height: 177 cm; body mass index: 20 kg/m²) had no previous history of orthopedic, cardiovascular, or metabolic conditions. A consent form that was approved by local ethical committee was signed before the study.

The training protocol was conducted once a week for 12 weeks using surface NMES and ankle weights.²⁻⁵ For the initial two weeks, there were no ankle weights until 30 repetitions were achieved of full knee extension against gravity.⁴ The weights were progressively increased by 2 lbs. on a weekly basis after achieving 3 sets × 10 repetitions of full knee extension. A Theratouch NMES unit (Richmar, Inola, OK, USA) was used along with large conductive adhesive gel electrodes (8 × 10-cm) and parameters were set at 30 Hz and 450-μs pulse duration.²⁻⁵ The current was adjusted manually to activate knee extensors to move the leg and ankle weights dynamically into a concentric (against gravity)/eccentric (with gravity) paradigm. After full knee extension was maintained for 3 seconds, the current was slowly decreased and the leg was returned to the starting position. The Theratouch stimulator offers a manual adjustment of the current by gradually dialing the current knob in a clockwise direction to achieve the desired knee extension, followed by a gradual dialing of the knob in a counter clockwise direction to decrease the current and to move the leg with the gravity. Knee extensor fatigue was determined by the number of repetitions out of 30. A repetition is counted for each leg movement above 75% of the knee extension full range of motion (ROM). The progression of current amplitude was also used as an index of knee

extensors fatigue over the course of the training. Failure of the leg to extend above 25% of the knee's ROM resulted in termination of the training set. A rest period of 2 minutes was allowed between right and left legs.

Total body DXA (GE Lunar, Lunar software version 13, Madison, WI, USA) scans were performed and analyzed for LM and FM. Scans were measured before and after the 12 weeks of NMES RT using the same Lunar Prodigy Advance Dual-Energy X-ray by the same trained DXA operator. The coefficient of variability of repeated scans at our facility has been determined to be less than 3%.⁶

Results

Participant completed 10 visits of the scheduled 12 visits for an 83% compliance rate. The final ankle weights lifted were 6 lbs. (2.7 kg) and 2 lbs. (0.91 kg) on the right and the left legs, respectively. Progression of knee extensors strength and the amplitude of the current (mA) over 12 weeks are listed in Table 1. In set 1 following the first 5 repetitions, the average amplitude of the current of the following 5 repetitions (6–10) gradually increased by 17% and 21% for the right and the left legs, respectively. In set 2 following the first 5 repetitions, the average amplitude of the current of the following 5 repetitions (6–10) gradually increased by 24% and 22% for the right and the left legs, respectively. In set 3 following the first 5 repetitions, the average amplitude of the current of the following 5 repetitions (6–10) gradually increased by 17% for the right leg. We could

Table 1 Progression of repetitions (Reps) and the current amplitude (mA) over 12 weeks of NMES RT in a person with SCI

Weeks	Weight (lbs.)	Right Leg				Weight (lbs.)	Left Leg			
		Reps out of 30 (Strength Percentage)*	Set 1 1-5/6-10 (mA)#	Set 2 1-5/6-10 (mA)	Set 3 1-5/6-10 (mA)		Reps out of 30 (Strength Percentage)	Set 1 1-5/6-10 (mA)	Set 2 1-5/6-10 (mA)	Set 3 1-5/6-10 (mA)
1	0	30 (100%)	96/99	94/108	90/111	0	25 (83%)	75/80	76/96	105/122
2	Missed	–	–	–	–	Missed	–	–	–	–
3	0	30 (100%)	102/108	97/114	111/128	0	16 (53%)	95/114	106/113	118/0
4	2	20 (66%)	96/115	107/150	113/0	0	17 (56%)	105/128	116/130	128/0
5	2	27 (90%)	108/124	117/136	122/146	0	25 (83%)	86/100	98/125	106/125
6	4	23 (76%)	109/133	122/149	126/137	2	17 (56%)	108/135	122/137	118/0
7	Missed	–	–	–	–	Missed	–	–	–	–
8	4	17 (56%)	131/150	122/166	165/0	2	14 (46%)	105/135	114/141	123/0
9	4	23 (76%)	119/141	117/149	151/174	2	17 (56%)	110/135	121/164	157/0
10	4	26 (86%)	127/157	130/166	154/178	2	10 (43%)	140/168	140/175	144/0
11	4	30 (100%)	120/142	121/147	134/160	2	21 (70%)	110/142	117/146	128/144
12	6	30 (100%)	100/114	98/110	107/121	2	24 (80%)	105/126	118/149	136/152

*Strength is calculated as the number of repetitions achieved above 75% of target ROM divided by 30 (total number of repetitions in 3 sets) and multiplied by 100.

#The average of the amplitude of the current (mA) of first 5 reps (1–5) and the amplitude of the current of the second 5 reps (6–10) across 3 sets of the right and left legs for 12 weeks. The value 0 assigned in the 3rd set of right and left leg reflects failure of the participants to continue raising his leg above 25% of the target ROM.

not determine the average amplitude for the left leg because of the extreme fatigue in 7 out of the 10 visits.

Over 12 weeks, body weight did not change and remained around 62.7 kg. Fig. 1 showed the percentage changes in the regional and the total body composition before and after training. Following training, LM increased from 5.75 to 6 kg (4%) and from 5.3 to 5.8 kg (9%) for the right and the left legs, respectively. For both legs, LM increased from 11 to 11.8 kg (+0.8 kg; 7%).

Discussion

The case report was undertaken to determine the efficacy of reducing the frequency of NMES RT from twice to once weekly on the regional and the total body composition as well as increasing knee extensors strength and fatigue resistance in a person with a chronic complete SCI. Long-term commitment to a training program is a key to ensure successful compliance in the SCI community. Previously, we and others have shown that twice weekly of 4 sets of NMES RT for 12 weeks has positive adaptations on skeletal muscle size and metabolic profile after SCI.^{2–5} Therefore, testing the efficacy of a follow-up detraining protocol by reducing the frequency per week as well as the number of sets may seem as an attractive strategy to maintain long-term compliance after SCI.

The findings revealed that once weekly positively impacted leg LM (>6%) without impacting other regions or total body composition. The person lost in general 5% of LM and gained about 13% of total FM. Four years ago, the same participant was previously engaged in 21 weeks of functional electrical stimulation (FES), 4 times per week.⁷ His body weight increased by 8.5 kg, percentage body FM increased by 5.5% (+8.5 kg) and LM (+1 kg) did not change after training. We have attributed these unanticipated results on body

composition due to stress, pain and failure to adhere to the recommended caloric intake during FES-training. In this study, the body weight remained unchanged and the participant continued to regress in his body composition profile. Despite the continuous gain in %BF, training was effective in maintaining similar changes in percentage of FM between the paralyzed legs and the innervated arms.

Maintaining healthy dietary habits should be highly encouraged during the course of any exercise trial. Failure to account for caloric intake and the quality of macro-nutrients (percentages fat, carbohydrate or protein) may mask the positive outcomes of exercise on body composition variables and may further progress cardiovascular risk factors.⁷ We should acknowledge that our participant maintained healthy dietary habits by consuming low caloric meals with balanced macro-nutrients during the course of the trial. This may explain that despite the low frequency, once a week, body weight did not change.

An interesting finding is that the right knee extensors showed greater strength and fatigue resistance compared to the left knee extensors. Despite the person is a complete SCI, this unilateralism as an outcome of training is not clearly understood. Sabatier *et al.* showed 60% reduction in electrically evoked knee extensors fatigue following 12 weeks of NMES RT in five persons with complete SCI.³ Lifting 2 lbs resulted in fatigue as shown by decrease in repetitions by 34% and 27% of the right (week 4) and the left (week 6) legs, respectively. This could be explained by delayed onset muscle injury as a result of including the eccentric component in the training paradigm.¹ The right knee extensors were able to recover and fatigue resistance increased from 56% at week 8 to 100% at week 11; whereas the left leg slowly progressed from 56% in week 6 and only attained 80% in week 12 (Table 1).

The stimulation parameters including a frequency of 30 Hz and pulse duration of 450 μ s were selected to ensure tetanic contraction, reduction in muscle fatigue and reasonable muscle activation of the knee extensors.^{8,9} During each training set, the amplitude of the current (0–200 mA) was gradually increased to account for the decline in the evoked torque (i.e. fatigue) through the 10 repetitions of moving the trained leg into full knee extension. Anecdotal evidence may support the idea that with training, the amplitude of the current required to perform the same task may gradually decrease, suggesting improvement in the activation properties of the trained knee extensors. The participant may need less current to lift his leg with increasing ankle weights. This may also be related to

Figure 1 Percentage changes in total and regional body composition following 12 weeks of NMES training that was conducted once weekly.

the decrease in the impeding factors similar to intramuscular fat; which is likely to impede the progression of the current in the stimulated knee extensors.¹⁰ However, the data of the current case report cannot support the changes in muscle activation and the increase in the strength can be partially explained by regional increase in leg LM.

Patient's satisfaction relevant to participation was confirmed by his 83% compliance rate and the fact that the training protocol did not interfere with his busy working schedule. We and others have previously highlighted the barriers of exercise to individuals with SCI.^{11,12} Designing an exercise protocol with a manageable frequency that can be easily translated to a home based routine is a key to ensure high compliance and satisfaction among persons with SCI. A frequency of once a week may be used as a desirable dose of maintenance following long-term training for 3 or 6 months. This may prevent regression in body composition to prior training status. However, Mohr *et al.* showed that once a week is not a sufficient dose for maintaining the training effects of FES on insulin sensitivity.¹³ The limitations to the current case report were that magnetic resonance imaging was not acquired, metabolic profile (glucose, insulin or lipid panel) and pain level were not evaluated. These measurements may have provided further insights on the studied frequency.

Conclusion

The current case report documented that once weekly of NMES RT can lead to increased legs LM, strength, as well as fatigue resistance of the trained knee extensors. Unlike twice weekly of training, there are no positive adaptations on other regional and total FM or LM. Considering the limitation of being a single case report, this training paradigm can be adopted for detraining purposes or home based intervention to maintain regional adaptations in legs LM and to ensure long-term commitment after cessation of NMES intervention.

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