A Home-Based Protocol of Electrical Muscle Stimulation for Quadriceps Muscle Strength in Older Adults with Osteoarthritis of the Knee

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ABSTRACT. ***Objective***. To determine whether home-based neuromuscular electrical stimulation (NMES) applied to the quadriceps femoris (QF) muscle increases strength, physical activity, and physical performance in older adults with knee osteoarthritis (OA).

Methods. Thirty-four adults (> 60 yrs) with radiographically confirmed symptomatic knee OAwere randomized to NMES plus education or education only (EDU). The primary outcome was isometric QF peak torque (PT_{Iso}), with secondary outcomes of daily step counts, total activity vector magnitude, 100-foot walk-turn-walk, timed stair climb, chair rise, and pain. The NMES group used a portable electrical muscle stimulator 3 days a week for unilateral QF training with incremental increases in the intensity of isometric contraction to 30–40% of maximum over 12 weeks. Both groups received the 12-week Arthritis Self-Management course and were followed an additional 12 weeks.

Results. The stimulated knee-extensor showed a 9.1% increase in 120° PT_{Iso} compared to a 7% loss in the EDU group (time × group interaction for 120° PT_{Iso}; p = 0.04). The chair rise time decreased by 11% in the NMES group, whereas the EDU group saw a 7% reduction (p = 0.01, time; p = 0.9, group). Similarly, both groups improved their walk time by ~7% (p = 0.02, time; p = 0.61 group). Severity of pain reported following intervention did not differ between groups.

Conclusion. In older adults with knee OA, a home-based NMES protocol appears to be a promising therapy for increasing QF strength in adults with knee OAwithout exacerbating painful symptoms. (J Rheumatol 2003;30:1571–8)

Key Indexing Terms:
ELECTRICALMUSCLE STIMULATION MUSCLE STRENGTH PHYSICALACTIVITY FUNCTIONALPERFORMANCE KNEE OSTEOARTHRITIS

Osteoarthritis (OA) of the knee is a common, often progressive, and frequently disabling condition[1] that is highly prevalent in late life[2]. Loss of knee extensor muscle strength often accompanies OA of the knee[3,4] and appears to be an important determinant of mobility, independent of radiographic severity[5]. Although painful symptoms and disuse are likely contributors[6], quadriceps femoris (QF) weakness has been observed in adults with early and also asymptomatic radiographic OA[7]. Given its close association with knee OA and the lack of joint-directed disease modifying therapies, interventions focused upon strengthening knee extensor muscle offer a means to maintain mobility despite the ongoing presence of disease. Ettinger and colleagues[8] provide evidence that resistive and aerobic exercise training are feasible and effective means of reducing knee pain severity and disability. Although few of their subjects suffered injury, studies by Roth and colleagues[9] raise the possibility that in sedentary adults who engage in resistive strength training skeletal muscle damage can occur — particularly in women. Hence alternative strategies to strengthen muscles, which might be better tolerated than conventional dynamic exercises, should be explored.

The purpose of this unmasked randomized control study was to test the feasibility of a home-based intervention of neuromuscular electrical stimulation (NMES) to increase QF muscle strength in older adults with symptomatic OAof the knee. A low training level of up to 40% maximal voluntary contraction (MVC) was selected to promote a safe and practical home management program that would decrease the discomfort of hard muscle contractions associated with high training levels. Our hypothesis was that older adults with OA of the knee using electrically elicited muscle contractions of up to 30–40% MVC would demonstrate a significant improvement in isometric peak torque as compared to the education control group. In addition, we

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examined the secondary outcome measures of physical activity, functional performance, and pain.

MATERIALS AND METHODS

Study population. Participants were recruited from local senior centers or responded to advertisements in the local newspaper. All participants were evaluated by physical examination and a standing anterior-posterior knee radiograph. Criteria for inclusion in the study were (1) age 60 years or older; (2) pain in one or both knees; (3) self-reported difficulty in walking, stair climbing, or rising from a chair; and (4) radiographic evidence of knee OA(grade ≥ 1) based on the criteria of Kellgren and Lawrence[10]. Exclusion criteria included (1) recent participation in an exercise program to increase strength; (2) medical condition in which NMES training is contraindicated, i.e., reduced sensory perception in the lower extremity; (3) cognitive impairment that precluded the provision of informed consent; and (4) implanted cardiac pacemaker or defibrillator.

From a pool of 64 individuals with OAof the knee, a total of 43 individuals met the screening criteria and volunteered to participate in the study (Figure 1). Five individuals dropped out following baseline assessments (3 for lack of interest and 2 for health conditions unrelated to the study). Four were disqualified because of incomplete data (2 from each group). Thirty-four subjects made up the final study sample. Before taking part in the study, participants were asked to read and sign an informed consent form approved by the Johns Hopkins University Institutional Review Board.

Design. A 2 (group) × 3 (time) experimental design was used to test the feasibility of an NMES intervention delivered 12 weeks and its subsequent duration of improvement 12 weeks after training. Participants were randomly assigned to one of 2 groups: the NMES group (n = 18) and the education attention-control group (n = 16). The primary outcome was isometric QF peak torque, with secondary outcomes of daily step counts, total activity vector magnitude, 100-foot walk-turn-walk, timed stair climb, timed chair rise, and self-report of pain.

Interventions. All participants attended the Arthritis Self-Help Course once a week for 12 weeks. The education program taught disease etiology, self-management of symptoms, and techniques of problem solving, goal setting, contracts and feedback to accomplish individual goals. Leaders for the educational program were 2 registered nurses with 16 h of training. During these weekly meetings participants were asked about their activities during the week. This time provided an opportunity for both groups to discuss any difficulties with either program.

Home-based NMES program. Subjects in the NMES group stimulated the QF muscle of the knee with the greatest disease (index knee) using a portable electrical muscle stimulator with preset parameters for home use. The index leg was determined prior to testing and was identified as the knee with the most severe OA based on radiographic evidence and physical examination. The contralateral leg was the opposing lower extremity.

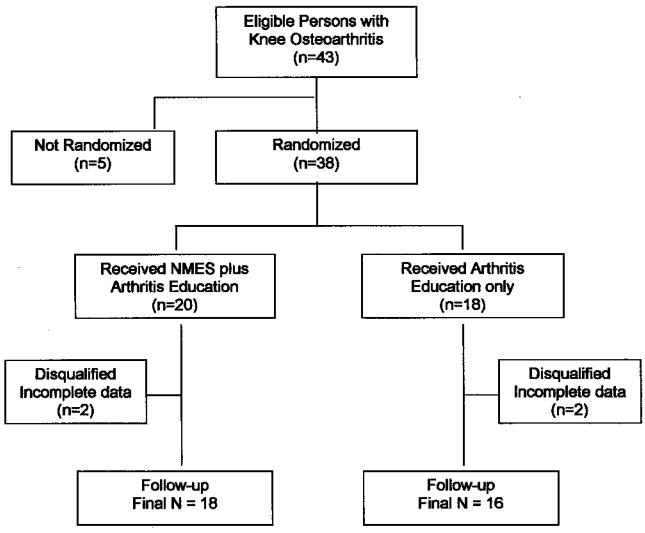

Figure 1. Progression of participants during the study.

Participants performed at home 3 training (or stimulation) sessions per week for 12 weeks. A log was maintained specifying date, time, and amplitude dial setting participants used during stimulation. At 4-week intervals, the intensity of the stimulator was increased a maximum of 10% of MVC or to a current that could be tolerated by each participant. The overall goal was to have participants train for 4 weeks at between 10% and 20% of MVC, then for 4 weeks at 20–30% of MVC, and finally 4 weeks of 30–40% of MVC.

The electrical impulse was generated by a battery-operated device, Respond Select (Empi, St. Paul, MN, USA), that delivered a pulsed current with symmetrical biphasic rectangular waves. Two 4 × 5 inch high-impedance stimulation electrodes (Stympac™; EMHI, Miami, FL, USA) were placed over the QF muscle group of the index leg. The phase width was 300 µs at 50% amplitude. Electrical pulse rate was maintained at 50 pps. The pulsed current was delivered with a ramp-up time of 3 s and a ramp-down time of 1.5 s. The duty cycle was set to 10 s on and 50 s off during stimulation. The current intensity (amplitude) was adjusted and maintained at the appropriate percentage of MVC or to tolerance during each contraction. The treatment protocol was for 15 min sessions of 15 stimulations to the index leg, 3 times per week. For a more consistent intervention, a specified percentage of MVC was used for determining the intensity of the training contraction. The intensity levels used to achieve the percentage of MVC were determined for each participant prior to the start of the trial and at each 4-week increase in training intensity. The progressive increases in force levels occurred every 4 weeks: (1) weeks 1–4 at 10–20% of MVC; (2) weeks 5–8 at 20–30% MVC; (3) weeks 9–12 at 30–40% of MVC. Participants received personal instruction on the use of the portable Respond Select, written instructions, and performed returned demonstrations. Every 4 weeks, when training intensity was adjusted, the trainer verified their technique of applying and using the stimulator. Adherence to using the NMES unit was defined as (1) the amount of time accrued on the Respond Select timer and (2) the minutes reported on the logs provided by the participants.

Attention-control group. The arthritis education group was used to control for time, measurement effects, staff attention, and seasonal influence that might influence the outcome variables independent of the NMES protocol. Individuals randomized to the attention-control group attended the Arthritis Self-Help course. Additionally, participants in the attention-control group received strength testing every 4 weeks to control for time spent adjusting the stimulation intensity of the NMES group.

Upon completion of the 12-week training sessions, all participants had strength measurements, physical activity monitoring, function performance assessments, and self-report of pain, which were repeated at 12-week followup. Attendance for the weekly Arthritis Self-Management Program group sessions was the number of sessions attended divided by the total number of group classes conducted based on the attendance records (once a week for a 1 h session).

Measurements. Demographic and clinical information. Demographic information such as age, sex, race, marital status, education, and income were self-reported using standardized instruments. Bilateral knee radiographs were obtained for each participant. Radiographic grade was assigned for each knee using the Kellgren and Lawrence grading system[10,11] by a rheumatologist blinded to participant assignment. Arthritis pain was assessed using 2 questions from the Arthritis Impact Measurement Scale 2[12]. Participants were asked to describe their arthritis pain (1 = very severe to 5 = none) and the frequency of severe pain (1 = all days to 5 = no days). Disability was assessed by 4 questions from the Functional Performance Inventory[13] in which participants rated their difficulty in (1) walking one block, (2) walking several blocks, (3) climbing one flight of stairs, and (4) moving in and out of a chair.

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Muscle strength. All participants had strength measurements every 4 weeks for 12 weeks and a followup strength measurement at 24 weeks. Maximal isometric QF force was measured using the dynamometer, Kinetic Communicator (Kin-Com125E, Chattecx, Chattanooga, TN, USA). Prior to testing, a 5-minute warmup on a stationary bicycle was performed by all participants. Isometric torque values for the knee extensors were tested at angles of 120° and 140° (where 180° = full extension) at a fixed speed (0°/s) with a fixed resistance ensuring no joint motion. With verbal encouragement, participants performed a maximal voluntary contraction of a 3 s duration. Each participant performed 3 trials with each leg at each angle and a 1 minute or greater rest between trials. Isometric peak torque was the best of the 3 maximal efforts performed.

Physical activity monitoring. Daily physical activities were measured pre-, post-, and followup using the Tritrac R3D accelerometer (Tritrac R3D Research Ergometer; Professional Products, Madison, WI, USA) and the electronic pedometer (New Lifestyles Digi-Walker, Model SW-200; Yamax, Kansas City, MO, USA). The accelerometer was worn at the waist, close to the body, secured in the pouch of a fanny pack with the pedometer attached to the exterior of the fanny pack. Both devices were worn in the front with the pouch aligned with the pants crease on the right side. The accelerometer measured movement in 3 dimensions [X (anteroposterior), Y(vertical), and Z (mediolateral) vectors] and then calculated to denote motion as velocity over time or total vector magnitude units. The expression

$$\sqrt{\quad}$$

was used to calculate total vector magnitude units. The pedometer measured steps walked per day. Participants were instructed to wear the fanny pack for 3 consecutive days except when bathing or sleeping, and to maintain a log indicating when the fanny pack was worn and removed.

Functional performance. Three measures of functional performance were administered to all participants, plus an assessment of arthritis pain. All timed functional performance tasks were measured with an electronic LCD stopwatch and recorded in seconds to the nearest one-hundredth.

The 100-foot timed walk-turn-walk[14,15] was conducted in a 50-foot section of corridor that was premeasured and marked with tape on the floor; a second evaluator confirmed the distance. A large plant was placed about 1 foot beyond the endpoint to provide a more obvious indicator of the distance limit. Each participant was positioned behind the start line and instructed to walk at his or her usual pace down a marked 50-foot hallway, turn around, and return to the starting point for a total distance of 100 feet. Participants were then instructed to walk at a fast pace down the same marked hallway.

The timed stair climb test[13,16] began with participants ascending 4 steps (6-inch rise, 11.5-inch run) to a 30 inch square platform, turning around, and returning to the bottom of the stairs, with instructions to climb as quickly as possible, with handrail use as needed. Time to complete one flight was registered.

The timed chair rise test[13,17,18] was administered using a straight-back chair (Model DPZY6E, Hon Company, Muscatine, IA, USA) with height adjustment to ensure a perpendicular angle at the knees for proper form. From a sitting position, participants were instructed to come to a full standing position as quickly as possible and then return to the initial seated position. The use of chair arms was permitted only if the participant was unable to stand without the use of their arms. Time to complete 3 full stands was logged.

Pain. Arthritis pain was assessed using the Pain Rating Index – Total from the McGill Pain Questionnaire[19]. Participants were asked to describe their pain over the last week using 20 groupings of 78 descriptive pain words that were ordered by pain intensity. The total pain score was the sum of pain intensity for each word grouping. The McGill Pain Questionnaire has demonstrated reliability and validity[20,21].

Statistical methods. Statistical analyses were completed using SPSS version 10.1. Baseline demographics (age, sex, race, income, education, class attendance, and grade of OA) between treatment groups were compared using an independent sample t test for normally distributed variables. To examine associations between group assignment and categorical variables, the Pearson chi-square or Fishers'exact test was used. A repeated measures analysis of variance (ANOVA) was used to test for main effects of the intervention (a home-based electrical muscle stimulation protocol vs attention-control) over time (pretest, post-test, and followup), and the intervention by time interaction. The Geisser-Greenhouse procedure was used if the statistical assumption of sphericity was not met. Linear regression was used to determine the relationship between the percentage change in isometric peak torque and the highest training intensity achieved during the 12-week treatment period. Statistical significance (α) was set to 0.05 for all statistical tests.

Change in QF muscle strength was defined as the percentage difference between the pretest and post-test MVC. Training intensity was the maximum percentage of MVC obtained by the participant trained over any 4-week period. This was calculated using the percentage of MVC at baseline, week 4, or week 8, with parameters based on the force of the electrically induced isometric contraction divided by the MVC for the current session (i.e., baseline, week 4, or week 8). The highest training intensity achieved was the peak intensity of these 3 calculations. In general this would be at weeks 9–12; however, it is possible that earlier weeks had a higher training intensity if the participant could not tolerate an increase in intensity.

RESULTS

Subject characterization. There were no significant differences at baseline between the groups on all demographic, clinical, and outcome variables ($p < 0.05$) (Tables 1 and 2). The mean age was 70 years for both groups, with the majority being female, married, white, and overweight to obese (body mass index > 29). Nearly one-third of participants were college graduates.

OA of the knee. Both groups reported similar disability and mild to very mild pain, with severe pain present some days during the past month.

Adherence. Class attendance was similar in both groups, with the attendance rate for the NMES group at 85% and the education group at 78% ($p = 0.3$). In the NMES group, participants kept weekly logs indicating the date and time the Respond Select was used. Of 36 possible stimulation sessions, participants reported 29.2 ± 7.15 stimulation sessions or a compliance rate of 81%. The Respond Select was equipped with a hidden compliance monitor that recorded the total number of hours each participant accrued. Out of 9 possible hours, the average number of hours recorded by the Respond Select compliance monitor was 8.43 ± 2.8 hours. This is well above the 7.25 hours participants reported on the logs, indicating participants either underreported stimulation sessions or the device was turned on but not used (the device automatically turns off after 15 min).

Muscle strength. The results of the repeated measures ANOVA for the stimulated (index) knee extensor (IKE) showed a significant time × group interaction for 120° PT_{Iso} ($F(2,64) = 3.40$, $p = 0.04$) (Figure 2A), but not in the 140° PT_{Iso} ($F(2,64) = 1.87$, $p = 0.16$) (Figure 2C). Comparing Figures 1A and 1C reveals a similar trend at both angles of

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Table 1. Baseline participant characteristics.

	NMES Group, n = 18	Education Group, n = 16	p
Age, yrs	70.28 ± 5.58	70.81 ± 4.90	0.77[a]
Female, %	83.3	75.0	0.68[c]
Caucasian, %	77.8	93.8	0.38[b]
Marital status, %			
Married	44.4	50.0	0.16[b]
Widowed	16.7	37.5	
Single (divorced, single)	38.9	12.5	
Annual income < $30,000, %	56.3	71.4	0.47[c]
College graduate, %	33.3	31.3	0.90[b]
Difficulty, %			
Walking one block	44.4	43.7	0.82[b]
Walking several blocks	72.2	75.0	0.24[b]
Climbing one flight of stairs	83.3	62.5	0.20[b]
Moving in/out of a chair	66.7	68.7	0.85[b]
Arthritis Pain			
Severity	4.00 ± 0.77	3.56 ± 1.03	0.18[a]
Frequency	3.33 ± 0.77	2.88 ± 1.26	0.22[a]
Grade of OA			
Index knee, %			
Grade 1	27.8	18.8	0.75[b]
Grade 2	33.3	43.8	
Grade 3	33.3	25.0	
Grade 4	5.6	12.5	
Contralateral knee, %			
Grade 1	22.2	13.3	0.975[b]
Grade 2	33.3	40.0	
Grade 3	33.3	33.3	
Grade 4	5.6	6.7	
Total knee arthoplasty, %	5.6	6.7	
Body mass index (kg*m^2)	29.53 ± 4.12	31.56 ± 5.90	0.25[a]

Values are mean ± SD except where indicated. [a] Independent sample t test. [b] Pearson chi-square. [c] Fisher's exact test.

Table 2. Influence of electrical muscle stimulation on selected physiological variables.

	NMES Group, n = 18			Arthritis Self-Management Group, n = 16		
	Pretest M (SD)	Post-test M (SD)	Followup M (SD)	Pretest M (SD)	Post-test M (SD)	Followup M (SD)
Muscle strength[†]						
Index KE PT_{lso} 120˚	289.17 ± 87.58	315.39 ± 76.42*	266.10 ± 84.20	340.25 ± 98.50	316.38 ± 98.73	307.83 ± 84.90
Contra KE PT_{lso} 120˚	313.50 ± 81.58	299.27 ± 94.04	313.57 ± 113.97	331.25 ± 98.30	312.00 ± 91.83	287.81 ± 101.38
Index KE PT_{lso} 140˚	193.11 ± 64.32	213.38 ± 59.44	153.62 ± 79.68*	227.75 ± 81.67	207.18 ± 68.77	191.12 ± 60.40
Contra KE PT_{lso} 140˚	195.39 ± 50.73	196.50 ± 63.02	201.47 ± 90.50	223.93 ± 90.75	219.75 ± 52.42	183.52 ± 71.87
Physical activity[†]						
Steps per day	4531 ± 3107	4240 ± 2157	4331 ± 2979	4677 ± 2759	3909 ± 2344	4413 ± 2915
Total vector magnitude	82156 ± 30308	82979 ± 25253	78609 ± 34500	88832 ± 41631	88197 ± 29584	99824 ± 44272
Functional performance[†]						
Chair, s	9.80 ± 2.37	8.76 ± 2.40	8.46 ± 2.34	9.86 ± 2.83	9.14 ± 2.64	8.76 ± 2.46*
Stairs, s	8.16 ± 2.97	7.30 ± 2.37	7.29 ± 1.33	7.17 ± 2.86	7.19 ± 2.02	7.03 ± 1.66
WTW normal pace, s	31.50 ± 7.63	29.60 ± 4.78	29.97 ± 4.45	31.57 ± 5.42	30.23 ± 4.83	29.46 ± 4.90*
WTW fast pace, s	24.25 ± 3.77	24.44 ± 4.28	25.61 ± 4.53	24.64 ± 3.92	24.44 ± 3.69	24.02 ± 3.71
Pain[†]						
Pain Rating Index—Total	20.26 ± 11.08	16.33 ± 13.35	16.14 ± 12.03	13.81 ± 10.79	11.12 ± 8.00	12.42 ± 9.66

KE PT_{lso}: knee extensor isometric peak torque; WTW: walk-turn-walk. * Significant within-group differences from baseline ($p < 0.05$); [†] No significant between-group differences at baseline ($p < 0.05$).

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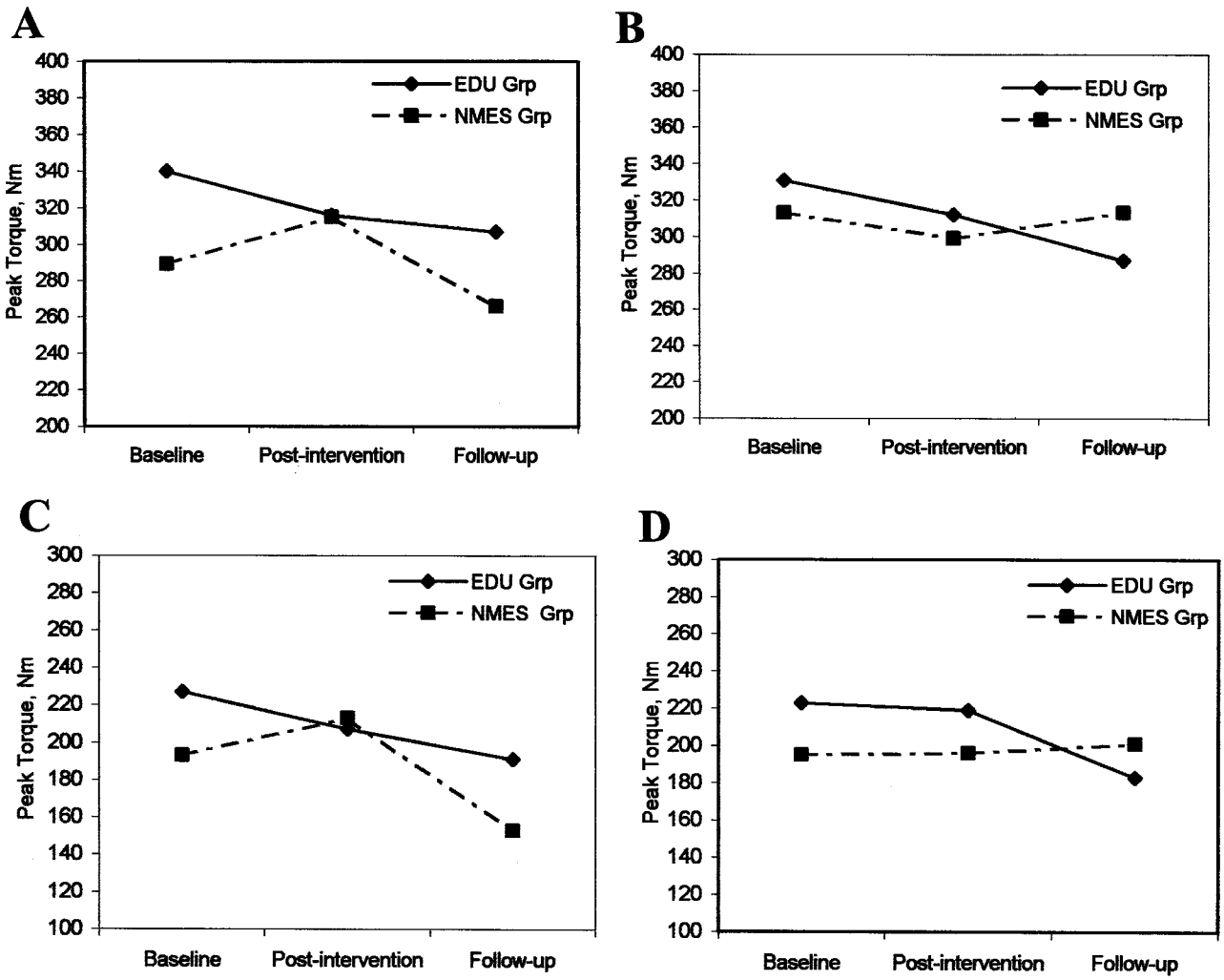

Figure 2. Isometric peak torque at 120° for the (A) index and (B) contralateral leg and 140° for the (C) index and (D) contralateral leg at baseline, postintervention, and followup by treatment group.

testing, with an improvement in strength post-intervention only in the NMES group. This was observed with *a priori* contrasts that identified a baseline to post-test difference in the groups [IKE 120° PT_{Iso}: $F(1,32) = 6.40$, $p = 0.02$; IKE 140° PT_{Iso}: $F(1,32) = 3.65$, $p = 0.06$]. For the NMES group there was a 9.1% increase in isometric QF torque values (IKE 120° PT_{Iso}) post-intervention, whereas the education group saw a 7% loss in isometric QF torque (Table 2).

Strength gains were not maintained over time, with *a priori* contrasts showing a post-test to followup difference in the groups [IKE 120° PT_{Iso}: $F(1,32) = 4.42$, $p = 0.04$; IKE 140° PT_{Iso}: $F(1,32) = 2.66$, $p = 0.11$]. For the NMES group (Table 2), there was 15.6% (IKE 120° PT_{Iso}) and 28% (IKE 140° PT_{Iso}) decline in isometric QF torque from post-testing to followup, whereas the education group saw a 2.7% (IKE 120° PT_{Iso}) and 7.75% (IKE 140° PT_{Iso}) decrease, which suggests that the strength effect post-stimulation was not maintained over time. When isometric QF torque was compared at baseline to followup, the overall loss in strength seems to be similar for both groups, with a 7.98% (IKE 120° PT_{Iso}) and 20.4% (IKE 140° PT_{Iso}) decrease for the NMES group as compared to a 9.5% (IKE 120° PT_{Iso}) and 16.08% (IKE 140° PT_{Iso}) decrease for the education group.

Analyses were repeated for the contralateral leg using PT_{Iso} 120° and PT_{Iso} 140°. The contralateral isometric QF torque for the NMES group maintained its baseline strength for 24 weeks, whereas the attention-control group saw a nonsignificant decline in isometric QF torque of 12.8% (PT_{Iso} 120°; $p = 0.44$) (Figure 2B) and 17.8% (PT_{Iso} 140°; $p = 0.31$) over the same period (Figure 2D). This suggests that stimulation may have attenuated the progressive decline in strength in the contralateral leg.

Multiple regression analysis was used to determine the

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contribution of training intensity to the change in isometric QF torque. Figure 3 illustrates the positive relationship observed between training intensity and the percentage change in isometric QF torque at IKE PT_{Iso} 120° (r = 0.48, p = 0.04) and IKE PT_{Iso} 140° (r = 0.40, p = 0.10). Based on these regression analyses, the percentage of training intensity needed to increase strength is about 18% of MVC.

Physical activity. The repeated measures ANOVA for total vector magnitude did not show a significant F ratio for the time × group interaction effect (F(2,64) = 2.14, p = 0.13), the main effect for group (F(1,32) = 1.04, p = 0.32), or the main effect of time (F(2,64) = 0.49, p = 0.61). Similarly, the daily steps showed no significant main effect for group (F(1,32) = 0.002, p = 0.97), main effect for time (F(2,64) = 1.04, p = 0.36), or time × group interaction (F(2,64) = 0.25, p = 0.78). The above findings suggest that physical activity by the 2 groups was similar during the duration of the study.

Functional performance. The functional performance variables, timed stair climb and fast-pace 100-foot walk-turn-walk (Table 2), were not significant for main effects for time, main effects for group, or time × group interactions. However, for the normal paced 100-foot walk-turn-walk and the timed chair stand, there was a significant main effect of time (chair, p = 0.01; WTW, p = 0.02). Compared to baseline, both groups had a faster walking pace and were able to stand up quicker from the chair post-training. At followup, both groups continued to stand quicker from a chair, yet the time to complete the 100-foot walk-turn-walk leveled off.

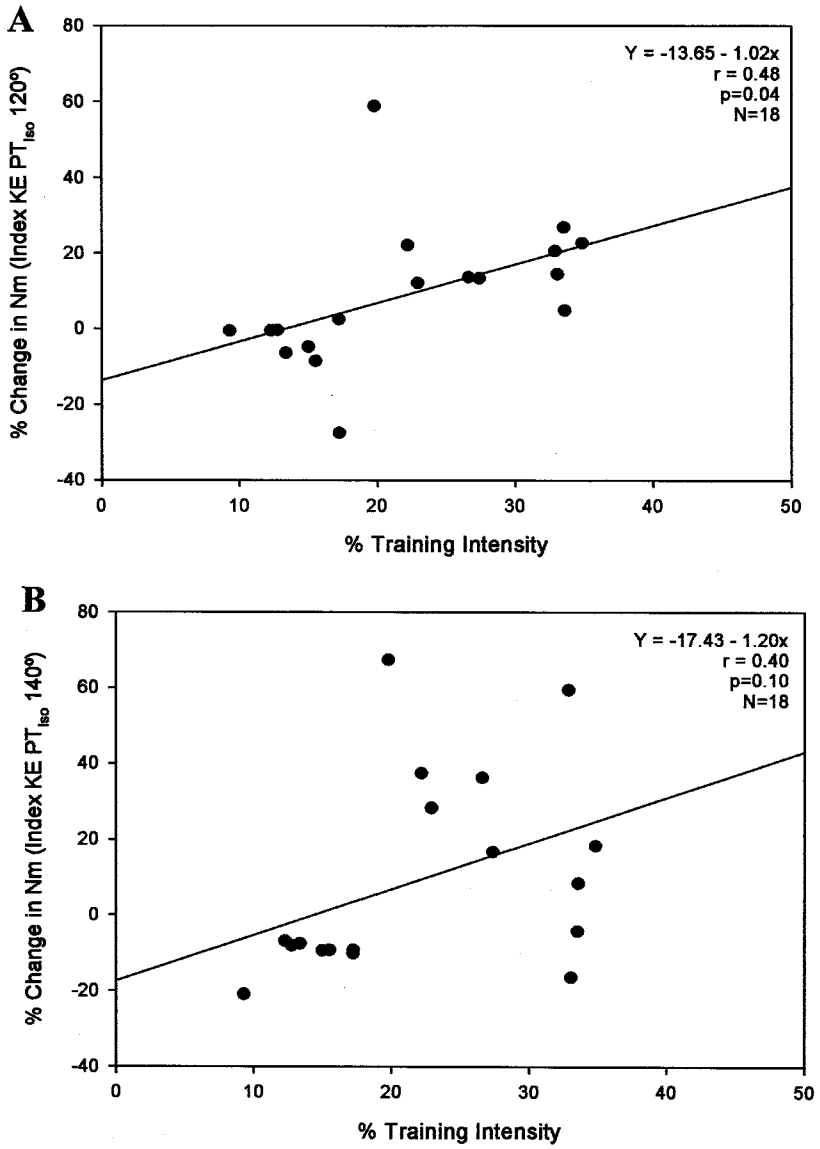

Figure 3. Scatterplot showing the relationship between training intensity and the percentage change in isometric peak torque at (A) 120° and (B) 140°.

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Pain. Using repeated-measures ANOVA, participants' pain scores were compared pretest, post-test, and at followup. The time × group interaction ($F(2, 64) = 0.19$, $p = 0.83$), the main effect of time ($F(2,64) = 1.25$, $p = 0.29$), and the main effect of group ($F(1,32) = 3.42$, $p = 0.07$) were not significant. The pattern of change from pretest to post-test was similar for both groups (19.4% decrease) (Table 2).

DISCUSSION

In this preliminary study we demonstrated that a home-based NMES is feasible and can increase QF muscle strength safely in adults with OA of the knee. We also observed an increase in QF muscle strength following 12 weeks of NMES in individuals with knee OA; the gains in strength were not maintained 12 weeks following cessation of the training. The contralateral leg was not stimulated directly, yet we observed that participants in the NMES group maintained their QF muscle strength over the 6-month period, whereas the control group steadily lost isometric QF muscle strength. This maintenance of strength by the NMES group could be attributed to a combination of factors including a crossover effect.

Participants in our study demonstrated a 9% average increase in knee extensor peak torque postintervention with average training intensities at 22% of MVC, while the EDU-only group saw a 7% loss. In the study by Caggiano, *et al*, a similar 9% increase was found in strength among healthy older men; however, they required a higher level of NMES intensity (36% of MVC)[22]. We found a minimum training dose of 18% MVC was needed to show strength gains in this sample of older disabled adults with knee OA (Figure 2). This suggests that for future studies, achieving or maintaining a higher or more sustained use of NMES (> 18% of MVC) is likely to lead to a larger and more sustained effect of the treatment. Our subjects received training levels above 18% for up to 8 weeks at most. Based on our experience, patients with symptomatic knee OA tolerate 30–40% MVC and all subjects accepted 20% over the course of the study, suggesting 20–30% MVC could be used long term in these patients.

These subjects represent a sedentary group with mean step counts per day (4600 ± 2905) well below the average for healthy adults of similar age (7335 ± 4369)[23]. Over the course of the study, activity level was maintained in both groups. Interestingly, function performance exhibited a trend toward faster walking pace and quicker chair rise immediately after the 12-week intervention, even with modest improvements in strength. The relationship between strength and function has been shown to be nonlinear by Buchner and colleagues, who have suggested that a threshold of strength was needed to perform specific performance tasks[24]. Even small decrements of strength loss below this threshold translate into slower walking speed. Thus, small increases in leg strength may yield substantial gains in performance for weak, disabled older adults, whereas large strength increases have minimal or no effect in stronger older adults[25]. We stimulated only the most involved knee, with the majority of participants having bilateral knee involvement. Even though we saw statistically significant and sustained improvements in walk-turn-walk and timed chair rise, stimulating both knees could potentially improve performance further.

The protocol we followed did not appear to exacerbate participants'symptoms, and in the majority of cases reduced arthritis pain, with both groups reporting a 19% reduction in pain. In a previous analysis using this same protocol[26], we found that electrical muscle stimulation led to a significant decline in pain 15 minutes after the NMES session as compared to before the training ($p < 0.001$). This reduction in pain occurred during 74% of the training sessions; however, no change in pain level was reported at 17% of the training sessions, and a slight increase in pain was reported at 9% of the training sessions.

NMES in older adults with OAof the knee appears to be a promising intervention for maintaining and increasing QF muscle strength, while promoting a faster walking pace and quicker chair rise without exacerbating arthritic symptoms. NMES has clinical application for individuals with knee OA where medications are not tolerated, exercise cannot or will not be performed, or surgical intervention is not viable.

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REFERENCES

1. Fried L, Guralnik J. Disability in older adults: evidence regarding significance, etiology, and risk. J Am Geriatr Soc 1997;45:92-100.
2. Lawrence RC, Helmett CG, Arnett FC, et al. Estimates of the prevalence of arthritis and selected musculoskeletal disorders in the United States. Arthritis Rheum 1998;41:778-99.
3. van Baar ME, Dekker J, Lemmens JAM, Oostendorp RAB, Bijlsma JWJ. Pain and disability in patients with osteoarthritis of hip or knee: the relationship with articular, kinesiological, and psychological characteristics. J Rheumatol 1998;25:125-33.
4. McAlindon TE, Cooper C, Kirwan JR, Dieppe PA. Determinants of disability in osteoarthritis of the knee. Ann Rheum Dis 1993;52:258-62.
5. Hughes VA, Frontera WR, Wood M, et al. Longitudinal muscle strength changes in older adults: influence of muscle mass, physical activity, and health. J Gerontol A Biol Sci Med Sci 2001; 56:B209-17.
6. O'Reilly S, Jones A, Muir KR, Doherty M. Quadriceps weakness in knee osteoarthritis: the effect on pain and disability. Ann Rheum Dis 1998;57:588-94.
7. Slemenda C, Brandt KD, Heilman DK, et al. Quadriceps weakness and osteoarthritis of the knee. Ann Intern Med 1997;127:97-104.
8. Ettinger WH Jr, Burns R, Messier SP, et al. A randomized trial comparing aerobic exercise and resistance exercise with a health education program in older adults with knee osteoarthritis: The Fitness Arthritis and Seniors Trial (FAST). JAMA1997;277:25-31.
9. Roth S, Martel GF, Ivey FM, et al. High-volume, heavy-resistance

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strength training and muscle damage in young and older women. J Appl Physiol 2000;88:1112-8.
10. Kellgren JH, Lawrence JS. Radiological assessment of osteoarthrosis. Ann Rheum Dis 1957;16:494-502.
11. Kellgren JH, Lawrence JS. The epidemiology of chronic rheumatism. Vol II. Atlas of standard radiographs. Oxford, UK: Blackwell Scientific Publications; 1963.
12. Meenan R, Mason J, Anderson J, Guccione A, Kazis L. AIMS 2: The content and properties of a revised and expanded Arthritis Impact Measurement Scales Health Status Questionnaire. Arthritis Rheum 1992;35:1-10.
13. Rejecki W, Ettinger WH Jr, Schumaker S, James P, Burns R, Elam J. Assessing performance-related disability in patients with knee osteoarthritis. Osteoarthritis Cartilage 1995;3:157-67.
14. Kwon I, Schrager M, Talbot L, Fozard J, Metter E. The relationship between muscle strength and the time taken to complete a standardized walk-turn-walk test. J Gerontol A Biol Sci Med Sci 2001;56A:B398-B404.
15. Marks R. Reliability and validity of self-paced walking time measures for knee osteoarthritis. Arthritis Care Res 1994;7:50-3.
16. Fisher N, Kame V, Rouse L, Pendergast D. Quantitative evaluation of a home exercise program on muscle and functional capacity of patients with osteoarthritis. Am J Phys Med Rehabil 1994; 73:413-20.
17. Csuka M, McCarty D. Simple method for measurement of lower extremity muscle strength. Am J Med 1985;78:77-81.
18. Guralnik JM, Simonsick EM, Ferrucci L, et al. A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. J Gerontol 1994;49:M85-94.
19. Melzack R. The McGill Pain Questionnaire: major properties and scoring methods. Pain 1975;1:277-99.
20. Creamer P, Flores R, Hochberg M. Management of osteoarthritis in older adults. Clin Geriatr Med 1998;14:435-51.
21. Davis G. The clinical assessment of chronic pain in rheumatic disease: Evaluating the use of two instruments. J Adv Nurs 1989;14:398-402.
22. Caggiano E, Emrey T, Shirley S, Craik R. Effects of electrical stimulation or voluntary contraction for strengthening the quadriceps femoris muscles in an aged male population. J Orthop Sports Phys Ther 1994;20:22-8.
23. Voorrips L, Ravelli A, Dongelmans P, Deurenberg P, Staveren WV. A physical activity questionnaire for the elderly. Med Sci Sports Exerc 1991;23:974-9.
24. Buchner D, Larson E, Wagner E, Koepsell T, Lateur BD. Evidence for a non-linear relationship between leg strength and gait speed. Age Ageing 1996;25:386-91.
25. Buchner D, Beresford S, Larson E, LaCroix A, Wagner E. Effects of physical activity on health status in older adults II: Intervention studies. Annu Rev Publ Health 1992;13:469-88.
26. Gaines JM. The effects of neuromuscular electrical stimulation on chronic knee pain and functional performance in older adults with osteoarthritis of the knee [dissertation]. Baltimore: The Johns Hopkins University; 2001.

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