RESEARCH STUDY

Effects of Electrical Stimulation or Voluntary Contraction for Strengthening the Quadriceps Femoris Muscles in an Aged Male Population

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Since musculoskeletal impairment increases with age, it is important to determine if exercise changes age-related muscle weakness. This study compared the training effects of electrical stimulation and voluntary isometric contraction, the traditional exercise, on the quadriceps femoris in males 65 years and older. Eighteen informed, nondisabled males, 72 ± 4 years of age, participated in 12 training sessions over 4 weeks. Maximal voluntary isometric contraction (MVIC) torque was measured with a Cybex II dynamometer prior to and following training. An interclass correlation coefficient (3,1) of 0.982 demonstrated repeated reliable torque measurement. The electrical stimulation group trained at an average of 36% of pretest MVIC; the traditional exercise group trained at an average of 42% MVIC. Average ($F = 14.06$, $p = 0.004$) and peak ($F = 14.32$, $p = 0.004$) torque values were increased with both modes of training. Both methods of training using a low training load were effective in increasing torque in this older male sample. Electrical stimulation has the same potential as traditional exercise to provide improved strength for aged males. Future research should examine electrical stimulation in older persons with compromised ability to exercise using traditional methods.

Key Words: *electrical stimulation, geriatric, training*

The geriatric population has been the fastest-growing segment of the US population in recent years; hence, it has had a major impact on the health care system. Persons age 65 and older are estimated to comprise more than 20% of the US population by the year 2035 (32). Since musculoskeletal symptoms and impairments are reported to increase with age (28), many recent studies have investigated mechanisms underlying aging human skeletal muscle (2,4,8,10–14,20–24,26–28,33). Such research provides an increased awareness of age-associated changes in skeletal muscle and proposed benefits for strengthening techniques to prevent or correct musculoskeletal impairment, subsequent dysfunction, and loss of independence.

Both structural and functional changes of human skeletal muscle are reported with increased age. Clinical impairments associated with age-related changes in muscle include a decrease in muscle volume and muscle strength (12,14,21,26,33). Strength is defined as the ability to generate torque. Mechanisms suggested to account for the loss of torque-generating capability include replacement of muscle mass with fat and connective tissue, changes in endocrine activity, reduction in intramuscular blood flow, and protein alteration (2,10). Collective information from studies of neural integrity in aged human skeletal muscle describes a breakdown in the denervation/reinnervation process (8,20,23,24). Other age-related neural alterations proposed to account for reduced ability to generate torque are a decrease in the number of functional motor neurons (20,23), loss of integrity of peripheral nerve axons and the myelin sheath (23), muscle fiber damage, and neuromuscular junction dysfunction (13). Regardless of the mechanism that leads to decreased strength among the elderly, the loss of strength has been associated with an increased risk of two or more falls per year (28). Falls are cited as the number one source of injury-related deaths in adults 75 years and older (28).

Recent research indicates, however, that people 65 years and older are capable of increasing strength

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(1,9,11,14). Moreover, the reported increased strength results in improved functional ability, suggesting that appropriate strength training may decrease the incidence of falls. The results of these studies support the clinical assumption that aged muscle is mutable and has the ability to increase strength. To date, only traditional methods of volitional exercise have been reported in the literature for the aged population. Alternative methods of strengthening, such as electrical stimulation, may also be useful in this population.

During recent years, investigators have examined the efficacy of neuromuscular electrical stimulation for strength augmentation in young, healthy knee extensor musculature as well as in the rehabilitation of injured or surgically repaired tissues (7,16,30). Results among studies are difficult to compare, however, due to methodological inconsistencies. In addition to differences in training periods and training intensities, differences in calculating training intensity also exist. Many studies utilize maximal tolerated contraction for each individual (4,5,15,17,22,25,29). A more consistent method that allows comparison is studies that use percentage of voluntary maximal contraction (% MVIC) (6,19).

Despite methodological discrepancies in the cited results, it is generally concluded that in healthy, young subjects, neuromuscular electrical stimulation has effectively increased strength (15,19,29,31). In addition, neuromuscular electrical stimulation has been shown to be as effective as traditional muscle strengthening exercises (5,6,17,18,22,25).

The purpose of this study was to determine if MVIC in older subjects could be changed with minimal training. A low training level of 40% MVIC was selected to compare the torque gains achieved using volitional isometric training and electrically induced isometric contraction. Our hypotheses were as follows: subjects trained using volitional contraction at 40% MVIC would demonstrate no increase in MVIC and subjects trained using an electrically elicited contraction that was 40% MVIC would demonstrate a significant increase in MVIC.

METHODS

Subjects

Eighteen healthy males, mean age 72 ± 4 years, with no reported history of right knee pathology participated in the study. A questionnaire was used to screen candidates for medical contraindications, including prior myocardial infarction, stroke, hypertension, and deafness. A list of medications currently taken was recorded. Participants were given a copy of the procedure and were urged to talk to their physicians about participating in this study. Each subject read and signed an informed consent document. Medical history, resting heart rate, and blood pressure were also obtained.

> ***Collective information from studies of neural integrity in aged human skeletal muscle describes a breakdown in the denervation/reinnervation process.***

All subjects were socially active within the community and lived independently or with a spouse. A questionnaire was used to classify individual activity into one of the three following categories: community active, moderate exercise, or heavy exercise. Criteria for classification as community active was light exercise two times per week. Moderate exercise subjects exercised three times per week for at least one-half hour per exercise session. The heavy exercise group participated in exercise more than three times per week for at least one-half hour per session.

Instrumentation

Isometric torque was measured on the Cybex II isokinetic dynamometer (Cybex, A Division of Lumex, Inc., Ronkonkoma, NY), which was attached to the Humac software system (Computer Sports Medicine Inc., Waltham, MA). The dynamometer was calibrated prior to each testing and training session according to manufacturer's specification. A pen recorder (General Scanning Inc., Recorded Products Division, Arlington, MA) was used periodically throughout the study to record the torque output and the shape of the contraction achieved during the training session. The pen recorder was calibrated prior to each session using standardized weights. A standard universal goniometer (G. E. Mill, Inc., Yonkers, NY) was used to standardize the position of the subject's knee, and skin markers were used to standardize electrode placement. Electrically stimulated isometric contractions were induced by the Intelect VMS II (Chattanooga Corporation, Chattanooga, TN), which was examined prior to the pilot study and weekly throughout the training session. The output of the stimulator was displayed on an oscilloscope to ensure consistency between the current reading on the stimulator dial and actual current output. No adjustments were necessary. During training sessions, standardized wooden blocks were used to support the right foot to ensure 60° of knee flexion. Three sizes of flexible carbon rubber electrodes (Empi, Inc., St. Paul, MN) were used with conduction gel, including 4.5 × 10 cm, 7.5 × 12 cm, and 7.5 × 15.5 cm. The electrode size was selected based on the size of the quadriceps muscle group.

Procedure

Prior to beginning the training period, each subject was pretested to determine an MVIC. The subjects warmed up by pedaling at a comfortable speed on a stationary bicycle or by walking up and down the hall for 5 minutes prior to testing. The radial pulse was recorded prior to warm-up as well as during and after the pretest.

Following warm-up, the subjects were positioned on the Cybex II testing table with the back rest in an upright position and the right knee placed in 60 ± 5° of flexion (Figure 1). This knee position was selected to mimic the posture used in the classic studies that have investigated the difference between electrical stimulation and traditional isometric strengthening of the quadriceps (5,6,22). The shin pad of the Cybex lever arm was adjusted to 2–3 inches above the malleoli, and the axis of the dynamometer head was aligned through the tibiofemoral joint. Knee position was assured by measuring the knee angle with a goniometer. The axis of the goniometer was through the tibiofemoral joint. The stationary arm was aligned with the greater trochanter of the femur, and the movable arm was aligned with the lateral malleolus. The lever arm of the Cybex and the lower extremity were moved to a position of 60° of knee flexion. The Cybex speed was set at 0°/sec, and the angle of the knee was remeasured. Standardized wooden blocks were placed beneath the foot for support to ensure the fixed 60° knee flexion position. The length of the lever arm and the number of blocks were kept constant for each individual subject throughout training. The blocks were used to ensure reproducible knee position. Goniometric data collected over three trials of four subjects indicated that measurements of knee position demonstrated intrarater reliability [ICC (3,1) = 0.997]. The subject's position was standardized by using a pelvic strap and thigh strap on the Cybex. A crossed-arms position was maintained throughout each session to minimize substitution of unwanted muscles during the training.

FIGURE 1. *Positioning of subjects on the dynamometer for pretesting and training.*

Forty percent maximal voluntary isometric contraction was considered a low training dose clinically, but the results obtained in this study suggest a relationship between lifestyle and training dose.

During initial testing, each subject performed three MVICs. The subjects were instructed to gradually build the strength of the contraction to maximum in 2 seconds and to maintain maximum contraction for 10 seconds. Coaching and verbal cueing for motivation were standardized. The same tester gave verbal cues which included "begin to push;" "push a little more;" "now push as hard as you can;" "push, push, push;" and "relax." A rest period consisting of several minutes was taken between test trials. If the third attempt yielded the highest torque value, the subject was asked to repeat the contraction sequence until the last torque recorded was less than the previous one. Data collected at two sessions over 1 day of testing from four subjects demonstrated reliable maximal torque measurements with an ICC (3,1) of 0.982.

Training

Subjects were randomly assigned to one of two groups. Four subjects dropped out after the first week of training. Seven subjects in the traditional exercise group trained with voluntary isometric contraction. Eleven subjects in the electrical stimulation group trained with electrical stimulation. Both modes of training consisted of three sessions per week for 4 consecutive weeks. The goal of each treatment session was to achieve 40% of the pretest MVIC for each of the 10 contractions. Pen recordings monitored the quality of the contraction; the training goal was a smooth curve at the target training level. The pen recordings were used to ensure that the investigators turned the current to the target level quickly and did not adjust it during the maintained contraction. The pen recordings were also used to ensure that the traditional-exercise-trained subjects maintained the target level contraction throughout the training period. Pulse was recorded pretraining, during the training session, and posttraining. During the training, a pillow was placed over the subjects' legs to prevent viewing the muscle contraction, and music was offered to increase relaxation and decrease any anxiety. This was done because some of the subjects in the electrical stimulation group expressed alarm when they saw their quadriceps contract involuntarily. It was hoped that this method would enable training to achieve target level. After training sessions, subjects were offered ice to minimize muscle soreness.

The traditional exercise training involved 10 voluntary isometric contractions produced for 15 seconds at the specified training intensity. The contractions were gradually increased to the training intensity over a 5-second period and were held constant for 10 seconds. Subjects maintained appropriate training intensity by monitoring a computer screen or dynamometer and by verbal coaching. Each contraction was followed by a 50-second rest period.

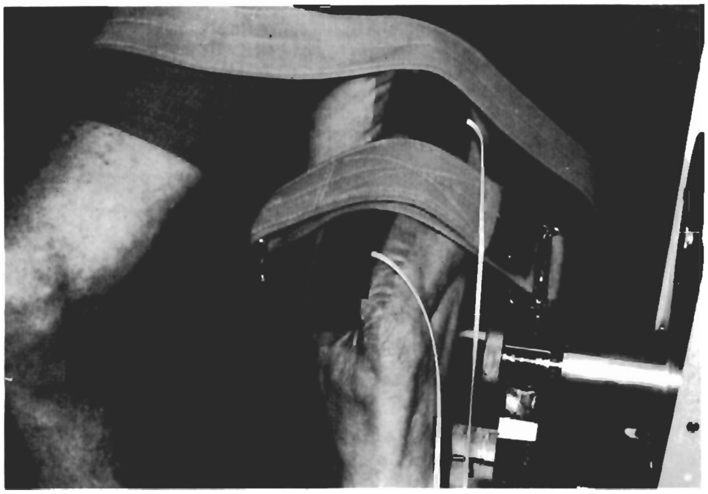

FIGURE 2. *Electrode placement used to elicit an electrically evoked muscle contraction in the quadriceps femoris muscle group.*

Future studies should examine ways to ensure a maximal voluntary contraction and design performance tests that do not mimic the training sessions.

Electrical stimulation was used to elicit a similar muscle contraction for the electrical stimulation group. Positioning on the Cybex II was identical to that of the voluntary isometric group. A hand-held probe was used to identify the motor points for the rectus femoris and the vastus medialis. One stimulating electrode was placed over the motor point of the rectus femoris, and the second electrode was placed over the motor point of the vastus medialis (Figure 2). A 4.5 × 10-cm electrode was placed over the vastus medialis motor point. A 7.5 × 15.5-cm electrode was placed over the rectus femoris, unless the two electrodes overlapped because the thigh was too small. If this occurred, a 7.5 × 12-cm electrode was substituted for the 7.5 × 15.5-cm electrode. Electrode placement was marked with a semipermanent skin marker to standardize placement. The electrodes were covered with gel, and the electrode perimeters were taped to the skin. A biphasic symmetrical square waveform was delivered by the Intelect VMS II. The phase duration ranged from 100–113 μsec. Frequency was maintained at 25 pps unless additional current was needed to maintain the appropriate MVIC percentage; frequency was increased up to 50 pps as needed. The pulsed current was delivered with a ramp time of 5 seconds, a total on time of 15 seconds, and an off time of 50 seconds. The current intensity was adjusted and maintained at the appropriate percentage of MVIC or to tolerance during each contraction.

Posttest

After completing the training period, each subject completed a posttest. The procedure for the posttest was the same as the procedure for the pretest.

Data Analysis

Two-way analyses of variance with one repeated measure were used to compare the torque, in Nm, from the two training groups. The highest MVIC peak torque achieved pretest and posttest was the repeated measure in one analysis. The average of three peak MVIC torques was the repeated measure in the second analysis. A least significant difference multiple range post hoc test examined any group differences.

Subjects were classified based on their self-reported activity level as community active. A linear regression, using Pearson's product moment coefficient, was used to examine the relationship between activity level and the percentage change in peak torque following training.

Ancillary measurement of radial pulse was examined using a nonparametric Wilcoxon Sign test to explore any trends between groups.

RESULTS

Peak and average MVIC torque for each subject are found in Tables 1 and 2, respectively. Training pro-

Subjects	Pre MVIC	Post MVIC	% Change	% Training Intensity
ES				
1	178	203	15	38
2	130	149	15	33
3	146	153	5	38
4	127	150	18	43
5	180	175	−3	41
6	88	98	11	37
7	123	130	5	23
8	179	163	−9	40
9	169	184	9	40
10	195	195	0	26
11	137	174	27	41
TE				
1	182	229	26	41
2	163	164	1	42
3	121	148	22	45
4	156	165	6	42
5	193	183	−5	41
6	165	172	4	40
7	178	207	17	43

TABLE 1. *Average of the peak torque (Nm) from three maximal voluntary isometric contractions (MVIC) was used prior to and following training to compute the change score. The results for each subject in the electrical stimulation (ES) group can be compared with each subject in the traditional exercise (TE) group. Training intensity is the average dose over sessions based on pretest peak torque MVIC.*

duced a significant difference in pretest compared with posttest peak and average MVIC torque (Tables 3 and 4). There was no difference, however, in the torque values between the two exercise groups.

A Sign test was used to assess any difference in radial pulse rate between the electrical stimulation and voluntary exercise groups (Table 5). The test revealed a trend for an increase in pulse rate during training for the voluntary exercise group compared with the electrical stimulation group. There was a decrease in pulse rate posttraining for both groups ($p < 0.05$).

Since there was no significant difference in torque between groups, the data from subjects in both groups were pooled and grouped according to physical activity level (Figure 3). There was a significant correlation between activity level and percent peak torque achieved following training ($N = 18$, $r = 0.57$, $p = 0.01$). The relationship between activity level and percent peak torque achieved accounted for 33% of the variance between these two variables ($r^2 = 0.33$).

DISCUSSION

Although many studies have shown increases in torque production following physical training (6), we are among the first investigators to report the use of electrical stimulation in an older population. The volunteers in this study tolerated electrical stimulation well, with no adverse side effects. Minimal training using either voluntary isometric contraction or electrically elicited isometric contraction changed the MVIC produced in knee extension in our sample of men over 65 years of age. The subjects in this study demonstrated a 9% average increase in torque posttraining. Results from Lai et al (19), Laughman et al (22), and Kubiak et al (18), using similar training levels in younger volunteers, reported a 50, 33, and 45% increase in torque, respectively. The results of this study suggest that a higher training level may be indicated for the older person. As indicated in Table 3, there was a 12% gain in peak torque following training of less active subjects who trained at the target level compared with a 5% gain in the subjects who continued a

Subjects	Pre MVIC	Post MVIC	% Change	% Training Intensity
ES				
HE	182	206	13	38
ME	134	150	12	33
CA	148	155	5	38
ME	129	156	21	43
HE	183	183	0	41
ME	91	99	9	37
CA	127	137	7	23
HE	182	164	−10	40
HE	171	190	11	40
ME	201	197	−2	26
ME	152	179	18	41
TE				
CA	193	230	20	41
ME	163	169	4	42
CA	127	149	17	45
CA	160	167	4	42
ME	194	184	−5	41
HE	167	176	6	40
ME	186	214	15	43

TABLE 2. *Subjects are classified based on previous exercise history as community active (CA), moderate exercise (ME), or heavy exercise (HE). The highest peak torque (Nm) collected from three maximal voluntary isometric contractions (MVIC) prior to and following training is listed for all subjects. Electrical stimulation (ES) subjects trained with electrical stimulation; traditional exercise (TE) subjects trained with voluntary isometric contractions. The % change is the difference between the pretest and posttest MVIC divided by the pretest MVIC. Training intensity is the average dose over sessions based on the pretest peak torque MVIC.*

	df	F Ratio	Significance
Training groups	1	14.06	0.004
Strength training effect	1	13.98	0.004
Interaction	1	0.17	0.720

TABLE 3. *Results of a two-way analysis of variance with one repeated measure using average pretest and posttest torque values.*

	df	F Ratio	Significance
Training groups	1	14.32	0.004
Strength training effect	1	16.33	0.002
Interaction	1	0.12	0.759

TABLE 4. *Results of a two-way analysis of variance with one repeated measure using peak pretest and posttest torque values.*

Heart Rate % Change	During Training	Posttraining
ES		
$\bar{X}$	−0.65	−3.17*
SD	±3.91	±3.92
TE		
$\bar{X}$	+3.63	−2.56*
SD	±3.60	±2.49

* $p < 0.05$.

TABLE 5. *Pulse rate data were normalized to pretraining radial pulse rates because of the variability among resting heart rates prior to training. The means and standard deviations of % change during and immediately following training were averaged over subjects and sessions for the electrically stimulated (ES) group and compared with the volitional isometric (TE) group.*

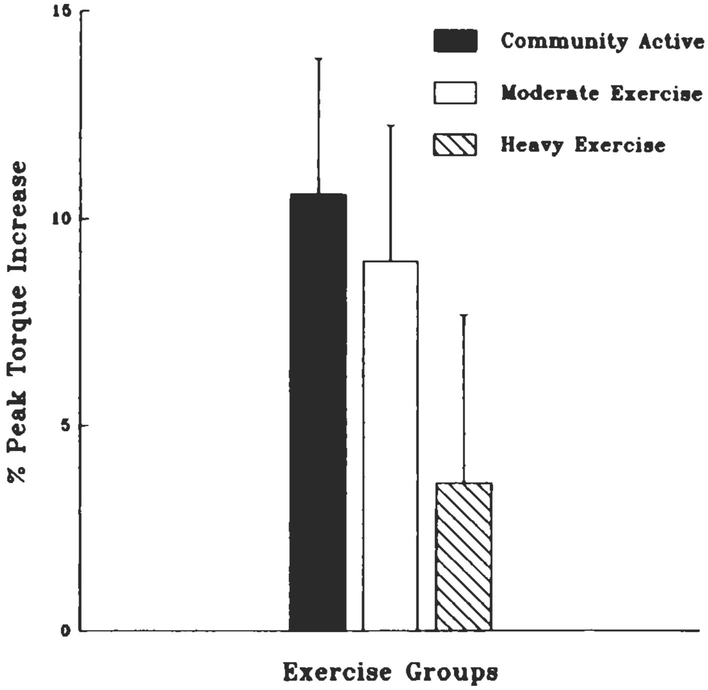

FIGURE 3. *Peak torque change following training is pooled and compared with reported pretest exercise level.*

heavy exercise program outside the training session.

Minimal training was defined in our study as 10 contractions per session, three sessions per week for 4 weeks. Forty percent MVIC was considered a low training dose clinically, but the results obtained in this study suggest a relationship between lifestyle and training dose. A 40% MVIC dose appeared to be a more adequate training level for the sedentary volunteers, but it appeared to be inadequate for the physically active volunteers.

Confounding factors may account for some of the outcomes in our study. Previous studies have used younger subjects, and it is possible that aging muscle responds differently to training. Another factor is the target training achieved for the electrical stimulation group. It took time for three of the subjects in this group to reach their target level. Although the average intensity of the electrical stimulation group was 36%, three of the subjects did not achieve the training level. Moreover, one of the subjects only achieved 26% MVIC, which was the maximal current offered by the machine. Another problem encountered was the inability of several subjects to fully relax the muscles in the thigh. This was evidenced by a contraction of the hamstrings when the quadriceps were stimulated electrically. The cocontraction of the hamstrings affected the torque reading, so the electrical dose was not accurate. This study also demonstrates the importance of remaining flexible with a protocol and changing frequency, pulse duration, or electrode size as needed to ensure subject tolerance and comfort.

We cannot be assured that our subjects demonstrated a maximal volitional effort. Although the technique used to elicit MVIC was reliable, we did not superimpose an electrically elicited twitch to ensure a maximal voluntary contraction (3). In addition, our reliability testing was conducted on the same day with a sample of the subjects. It is possible, therefore, that we did not achieve relative testing between days. Finally, it is possible that our subjects learned to produce a maximal contraction by the posttest. Since we tested on the same device used for training, motor learning may have contributed to enhanced posttraining performance. Future studies should examine ways to ensure a maximal voluntary contraction and design performance tests that do not mimic the training sessions.

Suggestions for future research include increasing the number of training sessions, increasing training doses, and monitoring heart rate and blood pressure under more controlled conditions. The preliminary data collected on radial pulse in this study suggest a trend for increased pulse during exercise for traditional isometric strength training but not for electrical stimulation. These data suggest that an exciting future avenue of research might be investigation of the role of electrical stimulation as a modality for strengthening in patients with cardiac overload precautions for traditional strengthening programs. Future studies should employ an electrical stimulation device that provides adequate current to ensure that subjects reach matched training target levels. It is also important that future studies determine if there is a correlation between changes in torque in the quadriceps femoris and changes in a functional task.

Despite the limitations in sample size, achieved training levels, and lifestyle of the volunteers, results from the current study indicate that both modes of training were effective in producing a significant increase in torque posttraining. This research also suggests that electrical stimulation should be examined as a strengthening technique for older subjects with cardiac conditions.

CLINICAL IMPLICATIONS

Electrical stimulation produces significant strengthening of aged muscle in the absence of volitional effort. Therefore, it may be used as an alternative strengthening technique. The results of this study suggest that it is important to assess the prior physical activities of patients to ensure that the strength training program adequately stresses the muscle to ensure strength gains. Clinical application of electrical stimulation may be an important intervention affecting the rehabilitation outcome of aged persons unable to exert muscular forces due to immobility weakness, orthopaedic surgeries, cardiovascular disease, physical impairment, and dysfunction. JOSPT

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