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The Use of Electrical Stimulation to Increase Quadriceps Femoris Muscle Force in an Elderly Patient Following a Total Knee Arthroplasty

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The Use of Electrical Stimulation to Increase Quadriceps Femoris Muscle Force in an Elderly Patient Following a Total Knee Arthroplasty

Background and Purpose. Persistent residual quadriceps femoris muscle force deficits after total knee arthroplasty (TKA) are commonly reported and can prevent patients from returning quickly and fully to functional activities. Neuromuscular electrical stimulation offers a potentially more effective means of increasing muscle force than current rehabilitation protocols. **Case Description.** The patient was a 66-year-old man. Neuromuscular electrical stimulation for increasing quadriceps femoris muscle force was initiated 3 weeks after TKA for 11 sessions to supplement stretching exercises and a high-intensity volitional strengthening program. **Outcome.** The patient's isometric quadriceps femoris muscle force increased from 50% (involved/uninvolved) at 3 weeks after surgery to 86% at 8 weeks after surgery. A concurrent increase in his uninvolved quadriceps femoris muscle force concealed the patient's true increase in his involved quadriceps femoris muscle force in a side-to-side comparison. The patient's final involved quadriceps femoris muscle force (10 weeks after surgery) was 93% of the initial uninvolved quadriceps femoris muscle force. **Discussion.** Our patient was able to return to independent activities of daily living and recreational activities, with force gains that surpassed those reported in the literature. [Lewek M, Stevens J, Snyder-Mackler L. The use of electrical stimulation to increase quadriceps femoris muscle force in an elderly patient following a total knee arthroplasty. *Phys Ther.* 2001;81:1565–1571.]

Key Words: *Geriatrics, Neuromuscular electrical stimulation, Quadriceps femoris muscle, Strength training, Total knee arthroplasty.*

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Over 200,000 total knee arthroplasties (TKAs) are performed annually in the United States.¹ Reports of persistent residual quadriceps femoris muscle force deficits after TKA are common in the literature, although virtually all patients with TKA undergo rehabilitation with a physical therapist.²⁻⁴ Researchers have attributed quadriceps femoris muscle weakness to disuse as a result of osteoarthritis, a problem that is compounded by decreased activity immediately after surgery.^{5,6} In addition, quadriceps femoris muscle weakness has been cited as a potential cause of osteoarthritis.⁷ Persistent quadriceps femoris muscle weakness following TKA can prevent patients from returning quickly and fully to functional activities, including ambulating, rising from a low chair, or ascending or descending stairs.^{4,8,9}

In 1995, the average age of patients undergoing TKA was 68.3 years.¹ Examination of morphological alterations of aged human quadriceps femoris muscles with and without injury can provide some insight into the cause of the force weakness observed prior to and following TKA. Aging contributes to a decrease in the size of the fast glycolytic, type II muscle fibers,¹⁰⁻¹² with osteoarthritis increasing the extent of these changes.⁶ A decrease in the total number of type I and II muscle fibers as well as atrophy of type II muscle fibers may be largely responsible for the decreased force-producing ability of elderly individuals¹² and, therefore, may be an effective target of rehabilitation protocols. Following TKA, an elderly patient may need not only to overcome age-related deficits in force production but also to counter muscular weakness attributable to the osteoarthritic disease process.

Traditionally, strength training programs have been used to counter morphological changes in muscles attributable to injury, aging, or surgery.¹³⁻¹⁵ Patients with knee osteoarthritis and TKA are able to increase their

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quadriceps femoris muscle force production with traditional strength training programs 3 times a week for 3 months.¹⁴ Although strength training regimens do increase quadriceps femoris muscle force production in people with TKA, force deficits continue to exist. Berman et al² reported that the involved quadriceps femoris muscles of patients following TKA were able to generate

only 83% of the uninvolved quadriceps femoris muscle force measured isokinetically at more than 2 years after surgery.

Neuromuscular electrical stimulation (NMES) is an alternative and potentially more effective means than volitional exercise alone of increasing the force of muscles in appropriate patients.¹⁶ However, the use of NMES for increasing muscle force production has not been widely investigated in older adults,¹⁷ although NMES has the potential for effectiveness because it targets a greater proportion of type II fibers than volitional exercise alone.¹⁸ Electrical stimulation has been used for muscle re-education (ie, to enhance muscle recruitment) in the acute, postoperative management of TKA at low intensities that do not allow for clinically meaningful gains in muscle force.^{11,19} Most NMES programs reported in the literature for younger patients (<50 years of age) tend to mimic traditional training programs with 8 to 15 maximum contractions, 3 to 5 times per week. There appears to be a direct relationship between the intensity of the electrically stimulated contraction and the resulting gains in force production.^{16,20}

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All authors provided writing. Mr Lewek and Ms Stevens provided concept/project design, and Dr Snyder-Mackler provided consultation (including review of manuscript before submission).

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The purpose of our case report is to describe the use of NMES for producing increases in quadriceps femoris muscle force in combination with a high-intensity volitional strengthening program in an elderly patient following TKA surgery.

Case Description

Patient

The patient was a 66-year-old man diagnosed with left tibiofemoral osteoarthritis. Three weeks prior to our initial evaluation, a TKA was performed to alleviate the patient's pain from the osteoarthritis. The surgeon used a cemented, posterior cruciate ligament-sparing knee prosthesis, which included a femoral component, a tibial base plate with a polyethylene articular surface, and a biconvex patellar component.

Past medical history included a myocardial infarction 20 years previously, high blood pressure controlled by an angiotensin-converting enzyme inhibitor (ramipril [Altace*]), and a degenerative tear of the left medial meniscus, resulting in a partial meniscectomy of both the medial and the lateral menisci 1 year prior to the TKA. Following the TKA, the patient received inpatient physical therapy for 5 days and then had home physical therapy for 2 weeks, for which he was instructed in therapeutic exercises for his left leg; these included quadriceps femoris muscle setting exercises, straight leg raises, supine heel slides to increase knee flexion, and hamstring muscle stretches.

The patient was initially evaluated in our clinic approximately 3 weeks after surgery. At that time, he rated his pain as 2 on a pain rating scale (0–10) while going up and down stairs and while lowering himself into his car. The patient was able to ascend and descend stairs despite his discomfort, although he said that foot-over-foot stair ascents and stair descents were not possible. He required the use of his arms when rising from sitting, but he was able to walk without an assistive device and without pain, although discomfort in the anterior portion of his knee often woke him up at night. The patient wanted to return to recreational activities, such as golf, in which he said he had been unable to participate because of pain, fear of injury to his knee, and muscle weakness. His goal was to return to pain-free golf. At the time of the initial evaluation, he was taking oxycodone-acetaminophen for pain control at night and a non-steroidal anti-inflammatory medication (diclofenac [Voltaren[†]]).

Examination

The patient's knee girth measurements were 47.4 cm on the left and 46.0 cm around the right knee at the level of the midpatella, although we acknowledge that this measurement lacks reliability. The left knee had a closed incision, which was adherent to the subcutaneous tissue when palpated. We assumed that the swelling, pain, and diminished activity following surgery had caused the patient to lose some of his knee range of motion (ROM). Knee flexion ROM was measured in the supine position with the hip flexed and with the knee flexed maximally and the foot flat on the table.²¹ The goniometer axis was placed at the lateral femoral condyle, the proximal arm was positioned along the longitudinal axis of the femur, pointed toward the greater trochanter, and the distal arm was aligned with the long axis of the tibia, pointed toward the lateral malleolus. Knee active ROM was 2 to 71 degrees on the left and 3 to 94 degrees on the right. Passive ROM was 1 to 81 degrees on the left and 2 to 100 degrees on the right. Intratester reliability of goniometric measurements of flexion and extension taken in a way similar to ours has demonstrated that these measurements are reliable for both knee flexion (intraclass correlation coefficient [ICC]=.99) and extension (ICC=.98).²² We determined that the patient had soft tissue approximation end feels for both knee flexion and extension, suggesting either swelling or soft tissue restriction. His limited knee flexion was one factor that appeared to limit his ability to carry out functional activities, such as ascending and descending stairs in foot-over-foot fashion; therefore, a program of active-assisted and passive ROM exercises was implemented to address these deficits (Fig. 1).

We also expected to see quadriceps femoris muscle force deficits as a result of the osteoarthritic disease process^{5,23,24} and his recent surgery and subsequent inactivity.⁵ Isometric quadriceps femoris muscle force was tested with the patient seated on a Lido dynamometer[‡] with his knee flexed 60 degrees. During the best of 3 maximal contractions, his left quadriceps femoris muscles produced 70 ft-lb of force, or 50% of the right quadriceps femoris muscle force. Isometric measurements of quadriceps femoris muscle force have been shown to be reliable at 60 degrees of knee flexion in adults without known pathology or limitations using techniques similar to ours.²⁵ Manual muscle testing of the gluteus medius muscles revealed grades of 4+ /5 on the left and 5/5 on the right.²⁶ The strength of the gluteus medius muscle was tested because, in our experience, this muscle is commonly weak following TKA and this muscle weakness can contribute to altered gait mechanics. Manual muscle test grades at this level, however, have often been shown to lack reliability.

* Monarch Pharmaceuticals, 355 Beecham St, Bristol, TN 37620.

[†] Novartis Pharmaceuticals Corp, 50 Route 10, East Hanover, NJ 07936.

[‡] Loredan Biomedical Inc, 3650 Industrial Blvd, West Sacramento, CA 95691.

Range of Motion → Exercise bicycle (5-10 min) started with forward and backward pedaling with no resistance until enough range of motion (ROM) for full revolution (second treatment); progression: lowered seat height to produce a stretch with each revolution; added resistance. → Supine, active-assistive wall slides for knee flexion ROM. → Knee extension stretch with manual pressure over knee to increase extension.
Strength (weights at 70% of 1-repetition maximum; 3 sets of 8 repetitions for all strengthening exercises) → Initial exercises: straight leg raises (started with 15 lb, progressed to 20 lb), hip abduction (started with 10 lb, progressed to 15 lb), standing terminal knee extension with Thera-Band ^a for resistance from 0°-45°-0°, lateral step-ups (started with 5.08-cm [2-in] block and progressed to 10.16-cm [4-in] and 15.24-cm [6-in] blocks). → Criteria for progression: exercises were progressed (eg, weights, step height) when the patient could complete the exercise and maintain control through 3 sets of 8 repetitions. → Additional exercises: Non-weight-bearing full ROM, seated knee extension (added during session 6 with 10 lb of resistance, progressed to 25 lb); partial ROM (0°-45° knee flexion) wall squats (added at session 12); unilateral toe raises (added at session 13).
Pain and Swelling → Ice and elevation daily after exercises.
Incision Mobility → Soft tissue mobilization to entire length of incision with greater emphasis on distal one third of incision.
Functional Activities → Ambulation training with emphasis on heel-strike, push-off at toe-off, and normal knee joint excursions. → Stair ascending and descending step over step (initiated at session 10).
Monitoring Vital Signs → Blood pressure and heart rate were monitored at regular intervals throughout treatment.

^a The Hygenic Corp, 1245 Home Ave, Akron, OH 44310.

Figure 1.

Exercise program: exercises were performed 5 times a week (either in the clinic or at home).

We assumed that the patient's quadriceps femoris muscle force deficit was another important factor in his inability to successfully perform functional activities. In order to enhance functional performance, we believed that we needed to optimize the patient's quadriceps femoris muscle force, so we chose to use NMES in conjunction with a high-intensity volitional strengthening program. The use of NMES for increasing muscle force in younger patients has resulted in greater force gains than those obtained with volitional exercise alone,¹⁶ so we believed that NMES had the same potential to optimize force gains in our patient.

Intervention

Three times per week, treatment included warm-up for 5 to 10 minutes on a stationary bicycle, NMES, stretching, and volitional exercises. The patient performed the exercises as part of his home exercise program an additional 2 times per week, for a total of 5 times per week. The home exercise program, consisting of the volitional exercises, was modified as needed to adjust the amount of weight lifted and the number of repetitions and sets as well as to make appropriate corrections in technique (see Fig. 1 for criteria).

For NMES, the patient was seated and stabilized on a Lido dynamometer. His knee was flexed to 60 degrees, and the lateral joint line was aligned with the axis of rotation of the dynamometer. Self-adhesive gel elec-

trodes[§] were placed longitudinally over the distal vastus medialis muscle and the proximal vastus lateralis muscle (Fig. 2). The patient performed 3 maximum volitional isometric contractions (MVICs), the best of which (Table) was used as the measure of maximum to determine the NMES dose. Prior to each NMES treatment, we obtained and documented verbal informed consent to remain confident that our patient remained tolerant of the high-intensity NMES that our treatment provided. A Versa-Stim 380 electrical stimulator^{||} was programmed (alternating current at 2,500 Hz, triangle wave, 10 seconds on, 50 seconds off, 3-second ramp time) for 10 contractions. Comparable settings were shown to be successful for regaining quadriceps femoris muscle force in patients following anterior cruciate ligament reconstruction.²⁷ Stimulation amplitude was increased to the maximum tolerated by the patient above 35% of MVIC and was maintained at the maximum tolerated level throughout each treatment.

Doses ranged from 35% to 50% of MVIC. Frequencies ranging from 40 to 75 bursts per second were used²⁸ to attempt to find a frequency that would create the greatest force while minimizing any patient discomfort. The patient's hypertension, although controlled by medication, necessitated monitoring of his blood pressure before, during, and after NMES by one of the authors (ML or JS), with changes remaining within $\pm 5\%$ of the pre-NMES measurement.

The patient performed volitional strengthening exercises following each NMES treatment (Fig. 1). Exercises with weights were performed at 70% of the patient's 1-repetition maximum. A 1-repetition maximum is the maximum amount of weight that can be lifted one time. All strengthening exercises were completed in 3 sets of 8 repetitions both in the clinic and at home.²⁹ The patient was able to report all of the exercises and weights for his home program, which suggested that he did do the exercises at home.

Outcomes

By session 12 (8 weeks after surgery), the patient was able to meet his goal of returning to pain-free golf, which he participated in several times per week, although continu-

[§] ConMed Inc, 310 Broad St, Utica, NY 13501.

^{||} Electro Med Health Industries Inc, 11601 Biscayne Blvd, Ste 200A, North Miami, FL 33181.

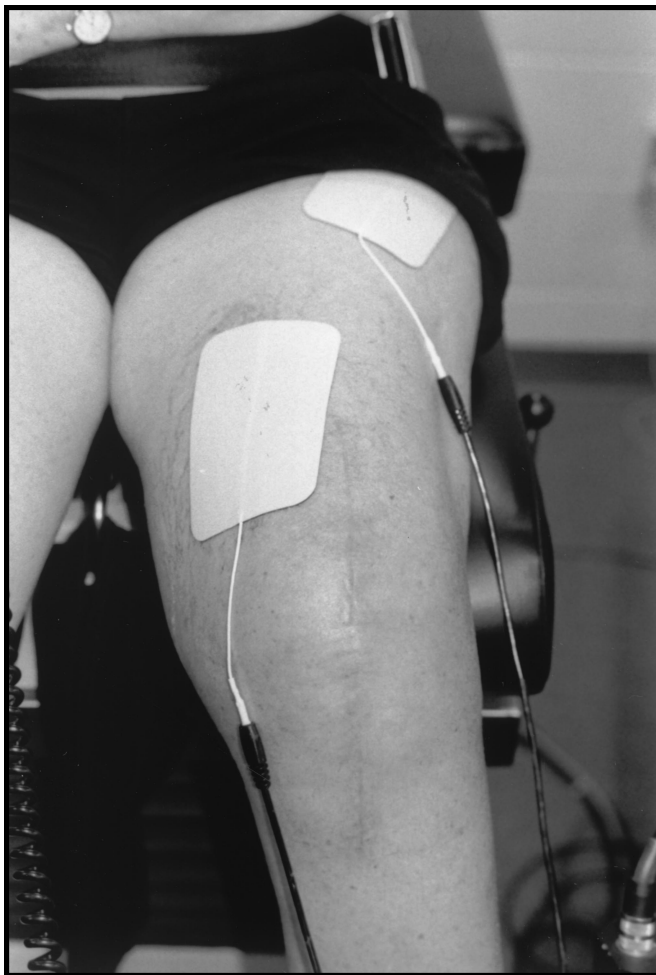


Figure 2.
Electrode placement for neuromuscular electrical stimulation.

ing to use a golf cart. Although he achieved his pretreatment goal, the patient was seen for 6 additional treatments in an effort to eliminate the persistent posterior knee pain that occurred with deep knee flexion. During these 6 treatments, we continued his volitional strengthening program and encouraged flexibility and soft tissue work. Following session 17 at our clinic, the physician attributed the patient's posterior knee pain to a small, bony spicule in the posterior distal femur, observed on a radiograph. The patient was discharged from physical therapy following his next treatment because he had met his initial goal and his surgeon believed that additional physical therapy would be unsuccessful in resolving the patient's posterior knee pain.

At the conclusion of the patient's 18 treatment sessions (7 weeks of treatment, 10 weeks after surgery), he was able to descend small (ie, 10.2-cm [4-in]) stairs and ascend all stairs foot over foot without support and without complaints of pain. He continued to have posterior knee pain with descending a standard staircase foot over foot. At treatment 18, the patient's left knee

active ROM was 0 to 106 degrees, and his passive ROM was 0 to 108 degrees.

After 5 weeks of intervention with NMES and volitional exercises, our patient achieved an 86% quadriceps femoris muscle index [(force of involved leg/force of unininvolved leg) $\times$ 100]. This is currently an ongoing area of research in our laboratory for this patient population; to date, no information that we are aware of is available regarding what the index predicts or its reliability. At discharge, 10 weeks after surgery, the patient's involved quadriceps femoris muscle force was 81% of the unininvolved muscle force when tested isometrically at 60 degrees.

Discussion

The patient achieved greater force gains in a shorter period of time than has been generally reported in the literature, allowing him to return quickly to independent activities of daily living and recreational activities.^{2,4,5,15,30} Berman et al² reported isokinetic quadriceps femoris muscle force (involved/uninvolved) at 3 to 6 months and 7 to 12 months to be 58.5% and 71.1%, respectively, when tested at 60°/s. Lorentzen et al⁵ tested isometric knee extension force at 75 degrees of knee flexion in 30 patients at 3 and 6 months following TKA. The subjects generated quadriceps femoris muscle indexes of 60% and 71% at the 3- and 6-month follow-up examinations, respectively.⁵ The investigators in both of these studies measured both the involved and unininvolved quadriceps femoris muscle force during each testing session, rather than using comparisons with an initial baseline measurement. This approach is similar to the measurement strategy that we used for our patient. Our patient's actual force gains were greater than the 86% quadriceps femoris muscle index reported because of late force gains in his unininvolved quadriceps femoris muscles. We are encouraged by the outcomes for our patient and believe that the combination of NMES with a high-intensity volitional strength training program could be effective in terms of magnitude of improvement and the time it takes to reach goals in an elderly patient after TKA. However, effectiveness can be determined only through controlled studies.

Neuromuscular electrical stimulation offered a safe addition to a traditional, high-intensity volitional strengthening program. The patient's prior heart problems were a source of concern for us in developing our intervention, so his blood pressure was closely monitored until we felt confident that it presented no threat to his health. Because of the potential Valsalva maneuver resulting from a sustained isometric contraction, we were concerned about increases in the patient's blood pressure.

Table.

Maximum Voluntary Isometric Force at 60 Degrees of Knee Flexion and Frequencies Chosen for Neuromuscular Electrical Stimulation (NMES) Application Throughout the Course of Treatment

Session	Weeks After Surgery	Force (Involved Limb) (ft-lb)	Force (Uninvolved Limb) (ft-lb)	Frequency (Bursts/s)
IE ^a	3	70	140	
1	3	70	130	75
2	4	100		50
3	4	100		75
4	4	90		75
5	5	110		75
6	5	115		50
7	6	110		50
8	6	120		50
9	6	105		40
10	7	110		40
11	7	100 ^b	130	40
12	8	120	140	NMES D/C ^c
18	10	130	160	Physical therapy D/C

^a IE=initial examination.

^b After performing therapeutic exercise.

^c D/C=discontinued.

A limitation of our case report was that we measured our patient's force at the same angle of knee flexion that we used for his NMES treatments. Although isometric training will produce the greatest gains at the exercised angle, evidence suggests that force improves through the rest of the ROM.³¹ To help ensure force improvements throughout the ROM, our patient's volitional training program was devised to emphasize force improvements throughout his available knee ROM. In addition, force measurements are measurements of impairment, and their use as outcome measurements can be questioned.

The quadriceps femoris muscle force of our patient following strength training with NMES and volitional exercises increased faster than what appears to be typical for patients following TKA, but we examined only one patient without controls. For this reason, we believe that the use of NMES with a high-intensity volitional training protocol may result in greater force gains than volitional exercises alone. Research with multiple subjects and a control group is needed to adequately determine the impact of NMES on quadriceps femoris muscle force following TKA and carryover to functional activity.

Conclusion

This case report describes the use of NMES, in addition to a volitional strength training program, to enhance quadriceps femoris muscle force in an elderly patient following TKA. The patient made faster strength gains than what available research indicates is typical for traditional strength training protocols in similar

patients.^{4,5,15} This patient was chosen for strengthening with NMES because of his desire to return to a high level of function, and this motivation also could have played a role in his rapid rate of improvement. The positive gains of our patient suggest that there is potential value in our approach and in research to determine the effects of NMES in patients following TKA.

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