

Vastus Medialis Electrical Stimulation to Improve Lower Extremity Function Following a Lateral Patellar Retinacular Release

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Study Design: A single-case study design.

Objectives: To examine the effect of electrical stimulation of the vastus medialis muscle on stiffness, pain and function for a patient with delayed functional progress following a lateral patellar retinacular release.

Background: Five months after an arthroscopic lateral patellar retinacular release, the patient, although highly motivated, had made little progress using routine exercises and taping.

Methods and Measures: An electrical stimulation program producing approximately 300 contractions daily of the vastus medialis muscle was implemented. The electrical stimulation applied for 33 of the 36 days was a rectangular and balanced biphasic pulse of 625- μ s duration, 70-Hz frequency, 8-second peak on-time, 3-second off-time, 1-second ramp-up, and 0.5-second ramp-down. Objective measures of stair climbing and hopping, together with the subjective measure of therapist-palpated superomedial patella displacement force, were recorded for each treatment visit. Other subjective measures were the patient's daily recordings of knee pain and stiffness.

Results: Patient-reported stiffness reduced rapidly as the actual and cumulative number of daily contractions of the vastus medialis muscle increased. After 8 days of electrical stimulation, the patient was able to ascend stairs unassisted and after another 21 days to hop unsupported.

Conclusions: Stiffness rapidly reduced and function started to improve once the electrical stimulation program was implemented. Recovery during the 36 days of treatment with electrical stimulation was greater than during the previous 5 months using other methods. Compliance was not an issue, nor was muscle soreness. *J Orthop Sports Phys Ther* 2002;32:437-446.

Key Words: knee, patella, patellofemoral, quadriceps

This case study presents details of treatment with electrical stimulation to strengthen the vastus medialis (VM) muscle following an arthroscopic lateral patellar retinacular release. Treatment using solely electrical stimulation was introduced 5 months after the lateral patellar retinacular release as the patient was making little progress despite being highly motivated.

Details of the usual physical therapy treatment regimes following arthroscopic lateral retinacular release surgery were sought using the Medline and Cinahl databases covering the period 1990 to May 2001. The studies identified included those reporting the types of surgery and outcomes following recurrent patella dislocations,^{1,2,4,5,7,10,15} methods of measuring patella mobility,⁶ of classifying patellofemoral pain,⁹ or treating^{12,19} and examining the patellofemoral joint.¹⁶ No reports of strengthening programs with or without electrical stimulation following a lateral patellar retinacular release were identified. Details of the usual clinical pathway for a lateral retinacular release of the patella suggest, however, that the patient should aim to achieve a return to activity and do a full rehabilitation program with an emphasis on sports-specific activities in 6 weeks.¹³ Despite being highly motivated, the patient in this study was, 5 months after the lateral patellar retinacular release, unable to do any of her sports-specific activities.

The present case study describes why and how we used electrical stimulation to return the patient to functional and sport-specific

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This study was approved by the Institutional Review Board, Faculty of Health Sciences Human Ethics Committee, La Trobe University.

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activities and suggests a possible explanation of why this method of treatment was successful. As with all case studies, the present example has limited generalizability.¹⁴ We believe, however, that this case study offers valuable insights to clinicians who use electrical stimulation and treat conditions related to the one described here.

Case Description

The patient is a 57-year-old fit, active woman, a bushwalker, skier, kayaker, and mountain climber. In October 2000, she developed pain, swelling, and a decreased range of movement (ROM) of her left knee after commencing a new exercise routine at the gym. Her knee did not improve with physical therapy treatments provided 3 times a week for 4 weeks and she was referred to an orthopaedic surgeon for evaluation. She underwent exploratory arthroscopy of the left knee in December 2000. Arthroscopy showed some superficial longitudinal splitting of her left medial meniscus that did not warrant repair, a Baker's cyst, and the wearing (mostly grade 3, some grade 2) of articular cartilage on the posterior surface of the patella, in the trochlear groove, and on the lateral femoral condyle. A lateral release of the patellar retinaculum was performed arthroscopically at this time.

The postoperative period was uneventful and the patient regained full ROM quickly. She planned to return to her previous outdoor sporting activities and exercise program as soon as possible. In this period, prior to her involvement with us, her physical therapy was aimed at stabilizing the patella by strengthening the VM muscle with an exercise program and later by the application of tape.⁸ She was encouraged to swim. The patient had limited success in obtaining voluntary contractions of her VM muscle, was unable to tolerate taping, and swimming was not practical as the pool was not easily accessed and she did not have the amount of time swimming required. Electrical stimulation was suggested by her physical therapist and she contacted us in May 2001 (5 months following her surgery) to see if it would expedite the strengthening of her left VM muscle. Approval was obtained from the La Trobe University Faculty of Health Sciences Human Ethics Committee in the event this intervention was published.

METHODS

Visit 1, Day 1

Weight-Bearing Examination The patient walked a maximum of 200 to 300 m with a minimal limp, favoring her left leg, without assistance, and before pain commenced. She needed a single-point cane for walking longer distances, negotiating uneven surfaces, and carrying anything. She climbed stairs with

a step-to gait pattern, ascending leading with her right leg and descending leading with her left leg. She was unable to jump or hop on her left leg, with or without assistance. Her left knee ached and was stiff particularly in the mornings.

Non-Weight-Bearing Examination Signs of chronic swelling were apparent in both the infrapatellar and suprapatellar areas of the left knee with the patient in the supine position and with her legs extended. No limitations in patella mobility were palpated. (Girth measurements were not made as we could not reliably differentiate changes in swelling in the peripatellar region from those changes in the VM muscle bulk.) With the hip flexed to 45°, she had a full and pain-free range of knee flexion. With her hip in a neutral position, the patient had some anterior knee and rectus femoris muscle tightness as her knee was flexed.

The strength of her quadriceps muscle was tested isometrically when sitting with her knee extended and her lower leg supported by the therapist. She was unable to maintain the knee fully extended against gravity. During the isometric quadriceps contractions with the knee in full extension there was a noticeable lateral displacement of the patella. No further quadriceps testing was done at this stage. VM muscle strength was examined subjectively, using visual observation and palpation, with the patient's left leg supported and her knee extended. The patient could initiate with difficulty a barely visible contraction of the VM and produce a just palpable patellar movement that could be felt at the medial border of the patella during the first few attempts only.

Outcome Measures Following our examination, our initial aims were to selectively strengthen the VM muscle using electrical stimulation to produce strong repeated contractions and to measure the outcomes both objectively and subjectively. The 2 objective functional outcome measures were the ability to ascend and descend stairs unassisted by handrails or a gait aid and to hop on the left leg unassisted. The subjective outcome measures were an assessment of superomedial patellar movement as palpated by the therapist during a quadriceps contraction and the daily levels of pain and stiffness as reported by the patient using separate 10-cm visual analogue scales. The visual analogue scales for both pain and stiffness were anchored with the words "none" on the left side and "max possible" on the right side. In addition, the patient was to keep a purpose-designed daily diary in which she reported the distance walked, cane use, stairs climbed, details of each electrical stimulation session, and any adverse events affecting her knee.

Intervention Following examination, the possible benefits and risks of electrical stimulation as a means of strengthening muscle were explained to the pa-

tient¹⁸ and her written informed consent was obtained. Throughout the study, her rights were protected.

The skin was checked and cleaned using an alcohol swab. Figure 1 shows an outline of the placement of the 2 small Dermatode C electrodes (American Imex, Irvine, CA) used with equal-sized 38 × 44-mm Dermatode A skin mounts (American Imex, Irvine, CA) placed over the VM muscle. The output (constant current) of the Respond-Select stimulator (Medtronic Nortech Division, San Diego, CA) used had been tested immediately prior to this case study. The settings selected and stored were as follows: an asymmetrical balanced biphasic pulse duration of 300 μ s, frequency of 55 Hz, peak on-time of 6 seconds, off-time of 3 seconds, a separate ramp-up of 1 second, and a ramp-down of 0.5 seconds.

To check the accuracy of the electrode placements and patient tolerance of electrical stimulation one of the investigators carefully increased the output using the constant stimulation option. The quality and specificity of the VM muscle contraction confirmed the appropriateness of the electrode placement and the patient tolerated the current comfortably. The constant stimulation option was turned off and the stored program implemented. A palpable superomedial patellar movement occurred while the stimulator cycled on. The placements of the electrodes were marked with an indelible pen.

The patient was advised to leave the electrodes on between sessions each day and to change the gel pads daily. She was also advised that if the stimulation became uncomfortable or the skin became irritated she was to contact us immediately. Otherwise, she was to use the stimulator as set and with a pulse amplitude of approximately 45 mA for 3 10-minute sessions daily (ie, approximately 57 contractions per session for a total of 171 contractions per day, 7 days per week). Electrical stimulation was to be applied while she sat in a chair with her knee extended and heel touching the floor or in long sitting with her legs supported. Electrical stimulation was performed

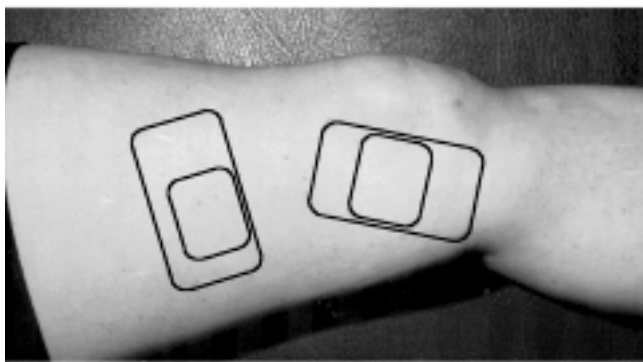


FIGURE 1. The locations of the 2 sets of electrodes used to stimulate the vastus medialis muscle: 2 small electrodes days 2 to 8, 2 larger electrodes days 9 to 37.

without the patient actively contracting the quadriceps.

To ensure sufficiently strong contractions of the VM muscle daily, 2 patient-controlled variables were to be adjusted over time: the number of contractions daily and the pulse amplitude. To achieve this, the patient was advised that the future aim was to complete 5 15-minute sessions daily. The pulse amplitude was always to be as high as she could comfortably tolerate and adjusted within a session if necessary. At this stage, the patient was not to do any exercise beyond the electrical stimulation program and her daily level of function was to remain unchanged. To monitor her progress she was asked at this visit to start keeping the daily purpose-designed diary.

Visit 2, Day 4

Stimulation was well tolerated but the patient reported experiencing some stiffness near her medial patella on day 2. The skin under the electrodes was not irritated. On examination, the findings were as follows: no visible change in the suprapatellar or infrapatellar swelling or in her functional activities (distance walked, stair climbing, or hopping capabilities). She still had a limp and required a cane when walking more than 200 to 300 m.

She had already increased her daily electrical stimulation program to 5 15-minute sessions, and the current to an intensity of just over 50 mA, with no adverse effects. To increase the strength of each muscle contraction, 2 changes were made to the stored program: the longer duration waveform was selected (a 625- μ s symmetrical biphasic balanced pulse, which consists of a 300- μ s negative phase, a 25- μ s interphase interval, and a 300- μ s positive phase) and the peak on-time was increased to 8 seconds. The off-time remained at 3 seconds, and the ramping remained as previously adjusted. She was again advised to adjust the intensity to as high a level as was comfortable, which was approximately 52 to 53 mA. A strong VM muscle contraction was palpable during stimulation.

Visit 3, Day 9

The patient continued to tolerate stimulation well and developed no skin or muscle problems. On this visit we collected her daily records of pain and stiffness for later analysis. On examination, the previously noted swelling around her knee remained unchanged. She was able to produce a palpably stronger, albeit weak, voluntary contraction of the VM muscle than when initially examined. She was also able to ascend 4 stairs (step-through) without using a hand rail, but descended with a step-to pattern, leading with her left leg. The patient was unable to hop on her left leg with or without assist-

ance. Her gait pattern was not assessed, nor was an isometric manual muscle test of her quadriceps conducted at this visit.

Her program was changed to further increase the amount of force generated by electrical stimulation. To do this, the pulse frequency was increased to 70 Hz, and the size of electrodes to 50 × 90 mm. Figure 1 shows how the larger electrodes (American Imex, Irvine, CA) were arranged. The strength of the isolated VM muscle contraction was subjectively assessed by manually resisting the superomedial movement of the patella during electrical stimulation. Considerably more patellar displacement force was produced, using a commensurably increased current of approximately 75 mA. The patient reported that this setup was comfortable and she could continue the existing treatment schedule of 5 15-minute daily sessions (approximately 72 contractions per session for a total of 360 contractions per day, up to 7 days per week, using the built-in stimulator timer). Her program continued to exclusively utilize electrical stimulation.

Visit 4, Day 16

During pretreatment tests the patient ascended 12 stairs unassisted and used alternate legs (step-through), but was unable to descend in the same manner. On examination, no changes were apparent in the chronic swelling noted earlier in her knee region. The force produced by the VM muscle was manually tested by resisting the superomedial movement of the patella during an isometric voluntary contraction. Resistance against the patella was now possible, as it was previously not. Isometric manual muscle testing of the quadriceps muscle showed that it could now produce a grade 5/5 contraction with the knee fully extended and the patient sitting. Testing concentrically or in flexion was not attempted.

The patient's daily diary at this stage indicated no increase in pain or stiffness, suggesting that the level of electrical stimulation applied was not aggravating the condition and she could now increase her level of functional activity, particularly in walking. Inspection of the skin under the proximal electrode showed an irritated area of approximately 1 mm in diameter. She was advised to cover it directly with a slightly larger piece of dry adhesive dressing sheet and to continue her electrical stimulation program unchanged, along with her daily checks of the skin under the electrodes. Daily rectus femoris stretches, with her lying prone with a towel over her ankle and using it to assist knee flexion, were added to her program.

Visit 5, Day 23

The patient ascended 22 stairs using alternating lower extremities with minimal hesitation and was also able to descend the same way, albeit more hesi-

tantly. Throughout she did not use hand rails or any other form of assistance. She was still unable to hop on her left leg but no longer needed a cane when walking. There was no change to the swelling initially observed around her knee. The patient had continued her rectus femoris stretching program, as discussed. We decided to continue with her current program of electrical stimulation as she continued to tolerate it well and to continue her rectus femoris stretches unchanged.

Visit 6, Day 30

Initial testing indicated an improvement in function. The patient was better able to ascend and descend the set of 22 stairs using both legs alternately (step-through pattern) and without the hesitancy of the previous session. She had no limp when walking. When asked to hop on her left leg, she managed to rise 2 to 3 cm off the ground without assistance, but with difficulty (graded 0.5 hop). At this stage, her program was changed to incorporate EMG biofeedback (The Prometheus Group, Dover, NH) to increase her awareness of the VM muscle activity relative to the other parts of the quadriceps muscle. The electrodes were attached over her VM and vastus lateralis (VL) muscles with the aim of increasing her VM/VL muscle activity ratio. This was initially done in standing or in sitting with her knee extended for periods of 10 minutes or until she had signs of fatigue. The patient was advised that the progression would incorporate weight-bearing activities. She was to continue to use electrical stimulation as previously during the day and start using biofeedback in the evening.

Visit 7, Day 37

The patient was able to complete 5 consecutive hops, without assistance, on her left leg. She could ascend and descend 22 stairs using alternate legs (step-through pattern) without assistance or hesitation. The aims of her program at this stage were to continue to increase her level of functional activity and use of EMG biofeedback. She was advised to continue to monitor her functional use of the left leg, checking for any signs of overuse, such as an increase in the size of her Baker's cyst or in morning pain and stiffness. The swelling in the infra- and suprapatellar regions of her knee remained unchanged. On this visit we again collected the daily records of pain and stiffness completed since visit 3 for later analysis.

Data analysis

The length of each VAS line (patient-recorded pain and stiffness morning and night) was measured (mm) and the data recorded. After visit 7 (day 37), daily averages were calculated for each visit, the data

were graphed to show change over time, and the correlation between pain and stiffness was calculated.

The number of contractions performed with electrical stimulation per day for each of the 36 days was calculated. To account for changes in the duty cycle and intensity, electrical stimulation dosage (mA·min) was calculated as follows: intensity (mA) by treatment time (sessions per day × session duration [minutes]), by duty cycle, and by the daily total between each visit averaged. The number of stairs climbed without assistance or hesitation and the number of independent hops were graphed with the averaged electrical stimulation dosage.

RESULTS

Figure 2 shows that patient-recorded pain and stiffness both decreased from the first recording (day 2) until the final recording (day 37). Stiffness (Figure 2A) increased on day 3, the day after the commencement of the electrical stimulation program, then systematically decreased with an abrupt increase on day 25, followed by a continuing progressive decline over the next 4 days. Figure 2B shows that the patient's

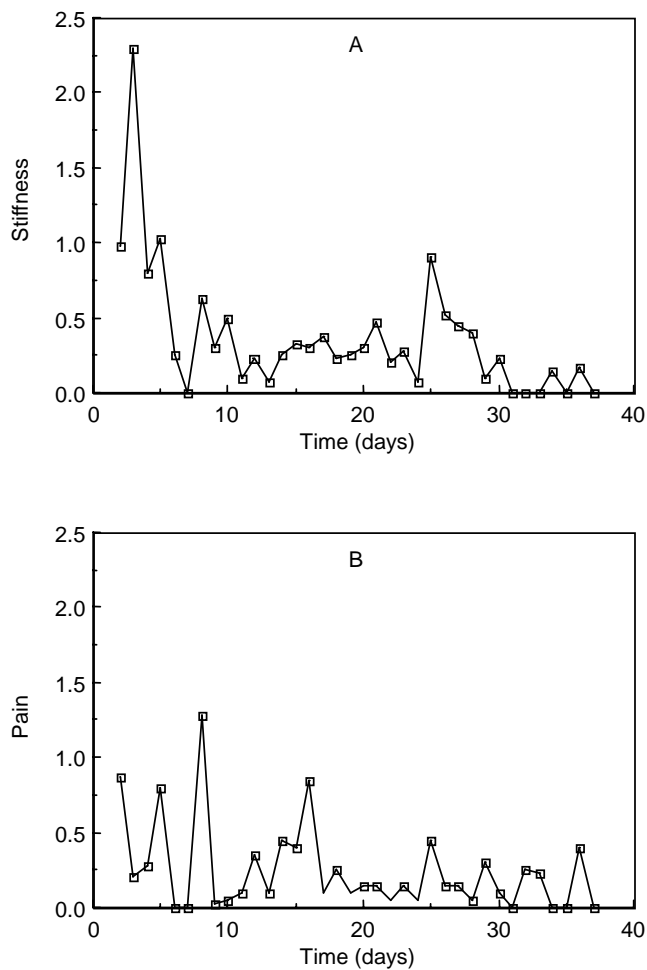


FIGURE 2. The daily changes in (A) stiffness and (B) pain from day 2 after the initial visit on day 1.

pain levels were not high, varied less than those of stiffness, and consistently decreased over the period investigated. The correlation between pain and stiffness was positive but weak ($r = 0.35$).

The average daily number of contractions (days 2 to 37 inclusive) was 282 (range = 0–437). Figure 3 shows the averaged electrical stimulation dosage. The dosage increased from 860 mA·min/d at the start to an average of 2,800 mA·min over the 36 days. From days 16 to 37 the daily average dosage was 2,990 mA·min. Figure 3 also shows that the number of stairs climbed without support or hesitation increased from day 9 after commencing electrical stimulation. Independent hopping became possible after 30 days of electrical stimulation.

DISCUSSION

The present case study describes the outcome of an intensive program designed to strengthen the VM muscle using electrical stimulation. We first examined this patient 5 months after she had an arthroscopic lateral patellar retinacular release. Prior to her first examination, the patient had experienced little change in function despite having regular physical therapy treatment consisting initially of exercises aimed to strengthen her VM muscle and, later, patellar taping.

We implemented a program of solely electrical stimulation and advised that she maintain her current functional level. Within days, her levels of pain and stiffness had reduced and soon after an increased level of function became possible for her. That this change occurred so soon after commencing the electrical stimulation program, and following 5 months of little change, strongly suggests that her outcome was a direct consequence of the intervention and not merely a coincidence. As with all case

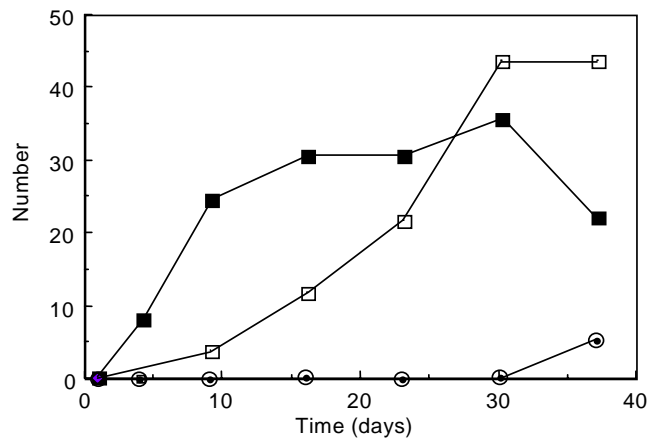


FIGURE 3. Number of stairs climbed unassisted (□) and hops (⊙) performed at each visit and the average daily dosage of electrical stimulation in mA·min (■). (Electrical stimulation dosage values were divided by 100 before plotting, to allow comparison.)

studies, to confirm this would require further research.¹⁴

The question for us as researchers concerned the extent of improvement following the implementation of the electrical stimulation program alone. We initially expected that the electrical stimulation would strengthen her VM muscle and any changes would occur more slowly than they did. To facilitate rapid strengthening, the electrical stimulation program was particularly intense in terms of the number of daily contractions and strength of the stimulus. At its most intense (days 5 to 37) a long duration biphasic pulse (625 μ s) was applied for a long peak on-time (8 seconds), a short off-time (3 seconds), and ramping (1.5 seconds), at a frequency of 70 Hz, which is well above that required for tetany. The program was usually repeated daily for 5 15-minute periods (timed by the stimulator). This meant an average of 282 contractions daily for 36 consecutive days. The initial electrical stimulation programs (days 2 to 4 inclusive) used combinations of fewer and shorter sessions as well as lower frequencies, pulse durations and amplitudes. Starting this way enabled us to ensure patient tolerance of electrical stimulation, compliance with the program, and examination of her skin tolerance to the current over time. The patient's response to the electrical stimulation and her rate of improvement suggested that we could make the changes in current parameters and numbers of daily contractions necessary to increase the intensity of her program.

Two findings suggest that the outcome was due to more than strengthening alone: the rate and timing of the decrease in patient-reported knee stiffness, and the rate of functional improvement. A stretching effect produced by the electrical stimulation would possibly explain both findings. The number of daily contractions using high-intensity-producing parameters (high amplitude, frequency, and pulse duration) would have effectively mobilized or stretched tissues attaching to the lateral and inferolateral aspects of the patella. That is, the repeated electrically induced contractions of the VM muscle would have gradually produced a plastic deformation of tissues on the contralateral aspects of the patella. For a patient, this would be perceived as less stiffness in her knee and should have commenced soon after the implementation of the electrical stimulation program.

This explanation would also account for the rapid increase in functional improvement. As early as day 9 (electrical stimulation commenced on day 2), the patient was able to use a step-through gait ascending stairs for the first time since the arthroscopy 5 months earlier. After that she continued to improve rapidly. While an increased strength in the VM muscle may have aided this progress, which is possible given the expected percentage of fast-twitch fi-

bers (VM deep, mean = 38.5%, 95% CI = 28.5–48.5; VM surface, mean = 43.7%, 95% CI = 48.9–63.6),¹¹ this would not account for the rapid reduction in patient-reported stiffness. Stretching of tight contralateral tissues by virtue of the number of stretches per day would also have decreased any compressive pressures during weight-bearing flexion on the more damaged lateral patella facets and the femoral trochlear groove noted during the arthroscopy. This would have enabled the greater range of weight-bearing flexion required for stair climbing.

The number of repetitions per day used in this case study was high but is markedly less than that reported as required for mobilizing soft-flexion contractures in hemiplegic wrists.¹⁷ The study by Pandyan and Granat¹⁷ used approximately 1200 contractions per day for 14 days, with a frequency between 35 and 55 Hz. Pulse details, including amplitude and duration, were not provided but the emphasis appeared to be on the number of contractions rather than the torque each produced. The focus of the present study was on increasing strength, but 282 (average) contractions per day for 36 consecutive days is more than the 200 per day reported as necessary to increase range of movement.³

One expected side effect of the high number of daily electrical stimulation contractions was soreness of the VM muscle. The patient recorded a marked increase in stiffness on day 3, consistent with delayed onset muscle soreness. This resolved over the next 2 days, even as the number of contractions per day was increased. There were no other problems of soreness related to the electrical stimulation.

Patient compliance was unusually high. We think this is attributable to the patient's initial motivation, the congruency of the program with her lifestyle, and her relatively rapid improvement after 5 months of little change postsurgery. The patient is a truly dedicated outdoors enthusiast who was willing to cooperate fully once she was aware of what the program would entail. She was able to incorporate up to 5 daily sessions of electrical stimulation into her lifestyle with little adjustment and missed treatment on very few days. Depending on her schedule, some electrical stimulation sessions were completed as she traveled to and from work or during brief work breaks (1 during her lunchtime and 1 or 2 in the evening). Her rapid functional improvement and decrease in stiffness possibly further encouraged her compliance.

Pain was not a major issue in the present case. The gradual change shown in Figure 2 is consistent with both the known gating effect of applying cutaneous electrical stimulation and with the explanation offered above of a gradual stretching of contralateral soft tissues.

CONCLUSION

We devised an electrical stimulation program for the patient to strengthen her VM muscle following 5 months of little change after an arthroscopic patellar retinacular release. At day 16 we introduced passive stretches of her rectus femoris muscle and encouraged an increased level of functional activity. The combined effect of the program was a marked decrease in the patient's daily knee stiffness and an increase in function over the 36 days described in the present case study. Although unable to confirm these facts, we believe the improvement was due to the strengthening of the VM muscle and concurrent passive stretching of the lateral and inferolateral patellar tissues caused by contractions produced by electrical stimulation.

REFERENCES

1. Aglietti P, Buzzi R, De Biase P, Giron F. Surgical treatment of recurrent dislocation of the patella. *Clin Orthop*. 1994;308:8-17.
2. Aglietti P, Pisaneschi A, De Biase P. Recurrent dislocation of patella: three kinds of surgical treatment. *Ital J Orthop Traumatol*. 1992;18:25-36.
3. Baker LL. Electrical stimulation to increase functional activity. In: Nelson RM, Hayes KW, Currier DP, eds. *Clinical Electrotherapy*. 3rd ed. East Norwalk, CT: Appleton and Lange; 1999:355-410.
4. Bellemans J, Cauwenberghs F, Witvrouw E, Brys P, Victor J. Anteromedial tibial tubercle transfer in patients with chronic anterior knee pain and a subluxation-type patellar malalignment. *Am J Sports Med*. 1997;25:375-381.
5. Dandy DJ, Desai SS. The results of arthroscopic lateral release of the extensor mechanism for recurrent dislocation of the patella after 8 years. *Arthroscopy*. 1994;10:540-545.
6. Fithian DC, Mishra DK, Balen PF, Stone ML, Daniel DM. Instrumented measurement of patellar mobility. *Am J Sports Med*. 1995;23:607-615.
7. Ford DH, Post WR. Open or arthroscopic lateral release. Indications, techniques, and rehabilitation. *Clin Sports Med*. 1997;16:29-49.
8. Gillear W, McConnell J, Parsons D. The effect of patellar taping on the onset of vastus medialis obliquus and vastus lateralis muscle activity in persons with patellofemoral pain. *Phys Ther*. 1998;78:25-32.
9. Holmes SW, Jr., Clancy WG, Jr. Clinical classification of patellofemoral pain and dysfunction. *J Orthop Sports Phys Ther*. 1998;28:299-306.
10. Irwin LR, Bagga TK. Quadriceps pull test: an outcome predictor for lateral retinacular release in recurrent patellar dislocation. *JR Coll Surg Edinb*. 1998;43:40-42.
11. Johnson MA, Polgar J, Weightman D, Appleton D. Data on the distribution of fibre types in thirty-six human muscles. An autopsy study. *J Neurol Sci*. 1973;18:111-129.
12. Kowall MG, Kolk G, Nuber GW, Cassisi JE, Stern SH. Patellar taping in the treatment of patellofemoral pain. A prospective randomized study. *Am J Sports Med*. 1996;24:61-66.
13. Mangine RE, Eifert-Mangine M, Burch D, Becker BL, Farag L. Postoperative management of the patellofemoral patient. *J Orthop Sports Phys Ther*. 1998;28:323-335.
14. McEwen I. *Writing Case Reports: A How-to Manual for Clinicians*. 2nd ed. Alexandria, VA: American Physical Therapy Association; 1996.
15. Myers P, Williams A, Dodds R, Bulow J. The three-in-one proximal and distal soft tissue patellar realignment procedure. Results, and its place in the management of patellofemoral instability. *Am J Sports Med*. 1999;27:575-579.
16. Nissen CW, Cullen MC, Hewett TE, Noyes FR. Physical and arthroscopic examination techniques of the patellofemoral joint. *J Orthop Sports Phys Ther*. 1998;28:277-285.
17. Pandyan AD, Granat MH, Stott DJ. Effects of electrical stimulation on flexion contractures in the hemiplegic wrist. *Clin Rehabil*. 1997;11:123-130.
18. Robertson VJ, Chipchase LS, Laakso EL, Whelan KM, McKenna LJ. *Guidelines for the Clinical Use of Electrophysical Agents*. Melbourne, Australia: Australian Physiotherapy Association; 2001.
19. Werner S, Arvidsson H, Arvidsson I, Eriksson E. Electrical stimulation of vastus medialis and stretching of lateral thigh muscles in patients with patello-femoral symptoms. *Knee Surg Sports Traumatol Arthrosc*. 1993;1:85-92.

Invited Commentary

I enjoyed reading the case report by Drs. Robertson and Ward. The initial approach to treatment for a patient who has undergone a lateral patellar retinacular release should be fairly straightforward and one we would expect any entry-level therapist to be able to plan and implement. But when the patient does not respond to routine plans of care, such as the patient in this case, the ability to recognize that a change in approach is needed and

the tenacity to pursue a viable alternative is what we would expect of our expert clinicians. It is even better when they go one step further and share their ideas and experiences with the rest of us in the form of a published case report. Drs. Robertson and Ward are to be commended on both of these counts.

The report illustrates a number of positive actions that therapists need to consider when approaching a case where the patient appears to be unresponsive

to routine treatment. In the history, the authors keyed in on the patient's complaints of stiffness, pain, and the inability to ambulate on stairs, and used them to develop patient-oriented measures of treatment outcome for the case. They hypothesize from their examination that the patient's inability to adequately contract the quadriceps muscles and the resulting alteration in patellar motion might be key contributors to the patient's problem. They further determined that an intervention to correct these impairments above and beyond voluntary exercise would probably be required. Thus, they developed the electrical stimulation treatment described in this case. The authors also described a method for increasing the dosage of electrical stimulation based on an effect they were attempting to create with the treatment: the superior and medial displacement of the patella during contraction of the quadriceps. Some could question the appropriateness of this selected effect of treatment as its reliability and validity have yet to be established. However, given that the therapists observed little to no patellar movement on voluntary attempts by the patient to contract the quadriceps, and that they believed an important factor in improving the patient's condition was to restore active patellofemoral joint motion, it would seem reasonable that they would attempt to use this type of evaluation to monitor whether the electrical stimulation was having one of the desired treatment effects.

Treatment was initiated using electrical stimulation only, the patient's response to treatment was observed over time, and the progression of treatment was based on the patient's response to treatment. This approach, in my opinion, allowed the authors to conclude that the patient's progress was likely due to the electrical stimulation treatment. However, the plausible mechanism by which the electrical stimulation may have had its effect deserves further comment and debate.

First, the authors indicate that the electrical stimulation treatment was designed to specifically strengthen the vastus medialis muscle. However, it seems possible that the treatment could have elicited force contributions from the other heads of the quadriceps muscles as well, via overflow of the electrical current to other compartments of the quadriceps. I would not argue against the notion that the vastus medialis muscle plays a role in reducing lateral displacement of the patella during quadriceps contraction, but the other portions of the quadriceps would contribute substantially to superior glide of the patella.⁴ Given that the patient did not provide a voluntary effort during the electrical stimulation, it is doubtful that the electrical stimulation only served to contract the vastus medialis muscle to counter a lateral displacement

from the contribution by the other compartments of the quadriceps femoris muscle group. I would argue that if the authors induced a superior and medial displacement with the electrical stimulation treatment, it is likely that other compartments of the quadriceps, along with the vastus medialis, were also likely activated during the treatment.

Second, the electrical stimulation protocol may not have been the most optimal approach for inducing increases in voluntary muscle force output (muscle strength) over time. It is well documented that electrically induced muscle contractions can fatigue a muscle quite rapidly, and the on/off time ratio of stimulation can markedly influence the rate of muscle fatigue.^{1-3,5} On/off time ratios on the order of 1:5 have been recommended for electrical stimulation protocols designed to increase muscle strength so that muscle fatigue during the treatment session is avoided. The on/off time ratios described by Robertson and Ward ranged from 2:1 (6 seconds on, 3 seconds off) to 2.7:1 (8 seconds on, 3 seconds off). Given the on/off time ratios used and that the patient's muscle was subjected to hundreds of contractions per day, it is likely that the patient's muscle may have fatigued early in the treatment, minimizing the potential for significant gains in muscle force output over time.

Robertson and Ward acknowledge that strengthening alone was probably not the only mechanism responsible for the patient's favorable response to treatment. They suggest that the electrical stimulation treatment may have improved the flexibility of soft tissues in the lateral and inferior-lateral aspects of the patella by providing repeated daily mobilizations of the patella through contractions of the quadriceps. I agree that this would be possible, and it seems to me to be a more plausible explanation than specific gains in strength of the vastus medialis muscle.

I am sure there are other possible mechanisms that could explain why this treatment approach resulted in a favorable outcome. We should keep in mind, however, that a favorable response to a treatment does not necessarily confirm the mechanism by which the treatment had its effect. We should also keep in mind that whatever the mechanism may have been, Drs. Robertson and Ward developed and implemented a treatment approach that solved a difficult clinical problem for their patient. The information in this case will prompt me to consider using this approach when I encounter similar patients in the future.

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REFERENCES

1. Barclay CJ. Effect of fatigue on rate of isometric force development in mouse fast- and slow-twitch muscles. *Am J Physiol.* 1992;263:C1065–C1072.
2. Benton LA, Baker LL, Bowman BR, Waters RL. *Functional Electrical Stimulation: A Practical Clinical Guide.* Downey, CA: Professional Staff Association of the Rancho Los Amigos Hospital; 1981:65–71.
3. Binder-Macleod SA, Snyder-Mackler L. Muscle fatigue: clinical implications for fatigue assessment and neuromuscular electrical stimulation. *Phys Ther.* 1993;73:902–910.
4. Lieb FJ, Perry J. Quadriceps function. An anatomical and mechanical study using amputated limbs. *J Bone Joint Surg Am.* 1968;50:1535–1548.
5. Packman-Braun R. Relationship between functional electrical stimulation duty cycle and fatigue in wrist extensor muscles of patients with hemiparesis. *Phys Ther.* 1988;68:51–56.

Authors' Response

We thank Dr. Fitzgerald for his insightful commentary on our case study and on what became a major issue for us: explaining such a rapid functional improvement following the introduction of electrical stimulation after 5 months of postarthroscopic surgery rehabilitation with little change. Our initial explanations examined 3 possible outcomes of using electrical stimulation: a reduction in pain resulting in inhibition of the quadriceps action, an increase in quadriceps strength, and a change in patella mobility.

A reduction in pain was quickly eliminated because postarthroscopy pain was never a major problem for this patient (Figure 2 of article).

We believe that the apparent change in strength of the quadriceps muscle is the most likely explanation for the rapid effectiveness of our intervention of using electrical stimulation to improve lower-extremity function in this patient. At our initial assessment on day 1 (visit 1) we noted a lateral displacement of the patient's left patella (operated side) during quadriceps contractions. At that time, the patient was also unable to maintain her knee extended against gravity. By day 16 (visit 4), the isometric strength of the patient's quadriceps had increased to grade 5/5, and the subjective palpable force produced by the vastus medialis muscle was higher than previously noted.

The initial lateral patella displacement during contractions suggested to us not only weakness of the vastus medialis muscle, but also some tightness of the lateral and inferior-lateral knee structures not identified during our initial assessment. At the time of arthroscopy, the surgeon had noted considerable wearing (graded 2/3 and 3/3) of the articular cartilage on the posterior surface of the left patella, the lateral femoral condyle, and the trochlear groove. We hypothesized that quadriceps muscle contractions could have been inhibited as a result of increased pressure between articular surface areas covered with very little articular cartilage: the posterior surface of

the relatively immobile patella, the more lateral aspects of the trochlear groove, and the lateral femoral condyle.

The multiple daily contractions produced using electrical stimulation would have repeatedly stretched the lateral and inferior-lateral tissues attaching to the left patella while simultaneously strengthening the vastus medialis muscle. We believe that in time the patella might be positioned in a more optimal (medial) position during knee extension. While we have no direct evidence for this hypothesis, the circumstantial evidence is convincing and entirely consistent with the patient's previous lack of improvement over 5 months despite a very high level of motivation.

Dr. Fitzgerald also proposed that the electrical stimulation might have strengthened other heads of the quadriceps. We doubt this for 2 reasons. First, the location of the electrodes made it improbable that branches of the femoral nerve would be stimulated other than those to the vastus medialis. Consistent with this fact, we saw no contractions of other parts of the quadriceps muscle. Second, we consistently palpated only medial or superomedial patella movement during electrical stimulation, which is consistent with the action of an unopposed vastus medialis muscle.

Having the patient assist during electrically initiated contractions was an option we chose not to pursue. After the patient had regained reasonable strength of her vastus medialis muscle, we introduced biofeedback to try to promote her awareness of vastus medialis activation during weight-bearing and non-weight-bearing activities. By then, the vastus medialis muscle was capable of producing sufficient force and there was adequate patella mobility.

We agree that our dosage was unusual for a strengthening program. The duty cycle and number of repetitions were both very high throughout this patient's rehabilitation. Based on the first visit, we aimed to expedite the strengthening of her vastus

medialis muscle and to test that she would comply with an intensive regime and that skin damage was unlikely. Evidence of the success of this strategy was soon apparent to us, so we increased our demands on the vastus medialis muscle.

We published this case study because we believe that too few clinicians consider the use of electrical stimulation when evaluating treatment options. Also, we believe that more clinicians should report the outcomes of their uses of electrical stimulation, pro-

viding sufficient details to enable the replication of their procedure. After more such clinical reports, we can generate hypotheses regarding a range of uses of this modality and test them more rigorously. There clearly remains much to learn about the clinical uses of electrical stimulation.

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