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SPECIAL ISSUE

Surface Electromyography Biofeedback Training to Address Muscle Inhibition as an Adjunct to Postoperative Knee Rehabilitation

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Following a knee injury and surgery, pain-related and fear-related muscle inhibition can interfere with rehabilitation and may contribute to the development of chronic pain. Surface electromyography biofeedback can help patients identify and overcome muscle inhibition during physical therapy exercises, so that normal muscle strength and range of motion can be regained.

Typical Surgical Procedures

Surgery is often performed to repair knee damage after an injury. The following three surgical procedures are common.

Arthroscopy involves washing out debris and removing or shaving down damaged structures by use of mechanical devices. Following a knee injury, arthroscopy may be recommended for damaged cartilage and/or bone, inflamed synovia, torn or degenerated ligaments and/or menisci, uneven chondral flaps, and loose bodies and osteophytes. Arthroscopy also may be suggested for a misaligned patella or to remove a Baker cyst (Laupattarakasem, Laopaiboon, Laupattarakasem, & Sumananont, 2008; Phillips, 2007). (Readers will find a brief glossary of anatomical terms at the end of this article.)

For anterior cruciate ligament (ACL) ruptures, ACL reconstruction is widely used to repair an unstable knee, especially for active persons. This surgery may be recommended for a knee that ''gives way'' during activities. The procedure involves replacing the ACL with an autograft (the individual's own tissue, usually from the patellar tendon or the hamstring tendon) or allograft (a donor's tissue) (Linko, Harilainen, Malmivaara, & Seitsalo, 2005; Phillips, 2007). Figure 1 shows the ligaments of the knee, including the ACL.

For more severe forms of osteoarthritis, a total knee replacement may be performed. Although various materials and procedures exist, the process involves implanting a prosthesis, most commonly via an incision through the quadriceps femoris muscle (Meier et al., 2008; National Institutes of Health, 2003).

Deconditioning and Chronic Knee Pain

Although arthroscopy, ACL reconstruction, and/or total knee replacement may result in reduced pain and improved function, there is often diminished quadriceps strength, increased stiffness, and decreased knee range of motion (ROM) postsurgery that can limit functional activities like walking and climbing stairs. Postsurgical weakness can be even more pronounced if the knee was deconditioned prior to surgery (Akima, Hioki, & Furukawa, 2008; Meier et al., 2008; National Institutes of Health, 2003). With physical therapy exercises and a gradual return to normal activity levels, most postsurgical knee patients can regain strength, ROM, and normalized function. Sometimes, however, postsurgical patients will develop chronic pain and physical disability.

It has been suggested that the development of chronic pain and disability can begin with fear of pain and reinjury, leading to activity avoidance and physical disuse (Lethem, Slad, Troup, & Bentley, 1983), thus resulting in deconditioning syndrome. Deconditioning syndrome is characterized by progressively decreased muscle strength, increased muscle stiffness, decreased ROM of joints, weakness of the cardiovascular system, and impairment of normal healing (Bortz, 1984; Mayer, 2000; Mayer, Polatin, & Gatchel, 1998).

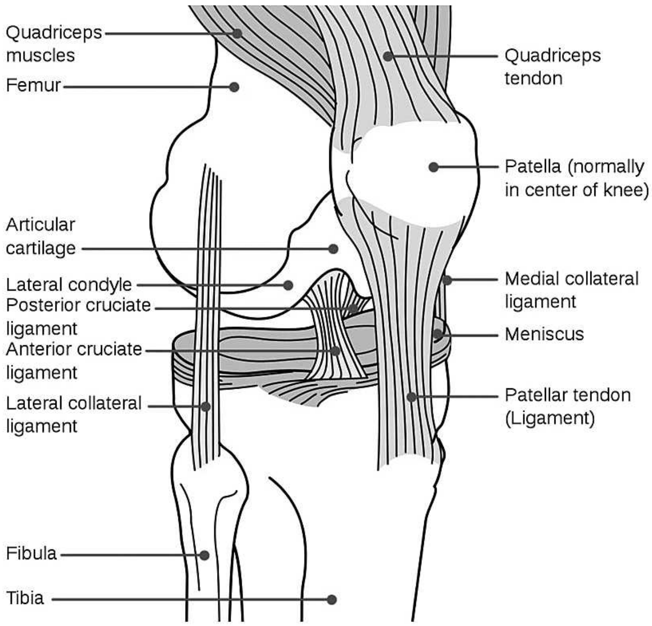

Figure 1. Bones and ligaments of the knee. From Wikipedia Commons.

Treatment Setting

The authors provide treatment within an interdisciplinary functional restoration chronic pain management treatment program that treats all forms of postinjury chronic pain and disability, including knee injuries. The primary treatment goal is to help patients maximize their physical and psychosocial functioning so that they can more successfully participate in activities of daily living, including employment.

The treatment program addresses both disability-related psychosocial issues (including anxiety, depression, and fear of pain and reinjury) and whole-body physical conditioning, with special emphasis on the injured ''weak link'' body part. As patients regain normal strength, normal ROM, and normal cardiovascular functioning, and as depression, anxiety, and fear are reduced, they then usually report decreased pain and are able to function more normally.

Physical Therapy Treatment of the Postsurgery Knee

A typical knee strengthening protocol begins with isometric contractions of the quadriceps muscle, often referred to as quad sets. When performing quad sets, the patient lies or sits on a flat surface (such as an exercise mat) with the injured leg lying flat and the opposite knee bent. The patient is asked to tighten the muscle on top of the thigh by pushing the knee into the mat.

After the patient has demonstrated success with quad sets, he or she will then progress to straight leg raise (SLR) exercises. For SLRs, the patient is asked to produce a quad set, and then lift the leg 6–8 in. (approximately 15 to 20 cm) off the exercise mat while maintaining the knee contraction. SLRs can be performed as single contractions, resting between each contraction, or as a series of contractions, bringing the leg up and down for sequential repetitions without touching the mat. The patient is shown how to do the SLR in three positions: supine (see Figure 2), sitting up slightly while resting on the elbows, and sitting up completely while resting on the hands. This progression from lying down to sitting up adds difficulty to the SLR exercises.

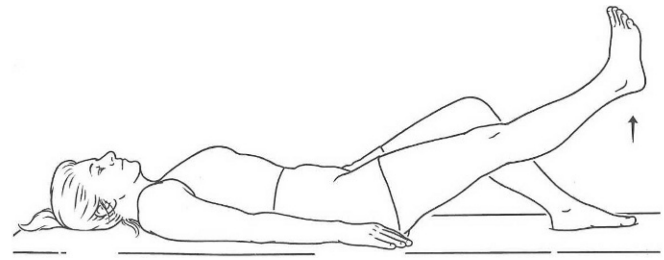

Figure 2. Supine straight leg raise exercise for strengthening the knee. Reproduced with permission of VHI (http://www.vhikits.com, © 2009, VHI).

Recommended hold times for both quad sets and SLRs can be between 1 and 5 seconds or more, depending on the level of deconditioning of the knee. Training frequency varies, though three times a day is common, usually with one to three sets of 10 to 20 repetitions each (Meier et al., 2008). For patients with patellofemoral syndrome (in which the patella does not track smoothly during knee movements), it is common to specifically promote vastus medialis oblique (VMO) contraction. In this condition, the VMO tends to have a less intense and greater delay in contraction compared with the vastus lateralis (VL) (Santos et al., 2008). Figure 3 shows the VL, VMO, and other muscles of the knee and leg. Though it is not covered in this present article, SEMG biofeedback has been used effectively to specifically address the timing dysfunction of VMO muscle firing commonly seen in patellofemoral syndrome (Felder & Leeson, 1997; Ng, Zhang, & Li, 2008).

To help improve mobility, bicycling, active-assist ROM, and active ROM activities, including knee flexion and extension stretches, are most commonly prescribed.

Many of our knee patients demonstrate inhibition with their exercises. For the purpose of this article, *inhibition* refers to both (a) failure to recruit an adequate level of muscle activity to effectively strengthen the knee and (b) failure to derecruit and relax the knee muscles to effectively stretch the knee. This inhibition is often related to (a) increased pain with mobility and/or strengthening exercises; (b) fear of anticipated pain with increased effort

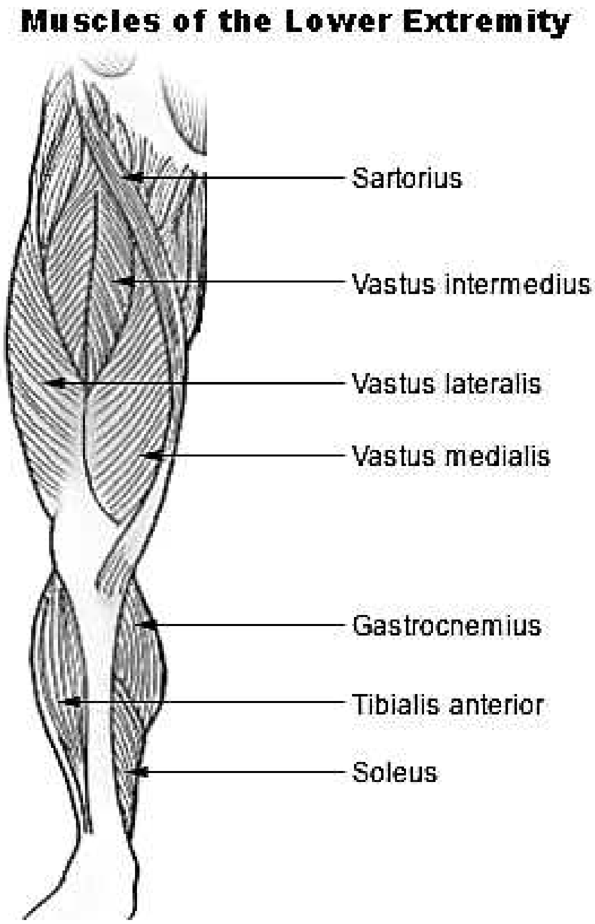

Figure 3. Muscles of the knee and leg. From Wikipedia Commons.

during exercises; and (c) fear of reinjury with knee exercises. Pain-related and fear-related inhibition can limit the ability of patients to exercise effectively, which can then slow or prevent physical progress. SEMG biofeedback can be used to identify and to address muscle inhibition.

SEMG Assessment Protocol

A standard SEMG knee placement is shown in Figure 4. Though other similar protocols have been reported (Draper, 1997), the first author's SEMG protocol for evaluating knees generally involves four measures. This protocol is performed after the patient has been in treatment for several days or weeks and has been instructed already in quad sets and SLR exercises by the physical therapist. First, the patient is positioned in a straight-backed chair and asked to extend the knee, straighten the leg, and produce a maximum knee contraction. This is repeated a few times to get a consistent measure. The patient then lies on a mat on the floor with a pillow for head support. The injured leg rests flat on the floor and the opposite leg is bent at the knee. The patient is asked to produce a few quad sets, to

Figure 4. Surface electromyography (SEMG) placement for vastus medialis oblique (VMO) and vastus lateralis (VL). Reproduced from *The Biofeedback Tutor* with permission of Biosource Software.

demonstrate SLR exercises ''just the way you've been doing them on your own'' for 10 or 15 seconds, then to raise the injured knee, hold the leg with both hands, and allow the knee to bend and relax.

The presence of muscle inhibition is determined in several ways. Inhibited patients will demonstrate very low SEMG readings during quad sets and SLRs (<10 μV root mean squared [RMS]), and the VMO readings will typically be lower than the VL. Baseline SEMG levels during sitting knee extensions will often be several times higher than during quad sets and SRLs, implying that the knee is capable of a stronger contraction during quad sets/SLRs than the patient is demonstrating. During knee flexion stretches, inhibition is indicated by lack of flexion-relaxation, suggested that the knee muscles are ''guarding'' and may not have reached the end range of the stretch. The flexion-relaxation phenomenon is usually associated with muscles of the low back. In a normal flexion-relaxation pattern, the lumbar muscles activate as one bends toward the floor, then relax as one reaches maximal flexion (Neblett et al., 2003c). This same phenomenon can be observed with other joints, including knees, during gravity-assisted stretching.

When evaluating SEMG readings, it is important to understand that inhibition does not imply malingering. Inhibited knee patients often demonstrate a great deal of effort during strengthening and stretching exercises, but due to increased pain during exercises, fear of increased pain, and/or fear of reinjury, they will often develop habits, consciously or unconsciously, of protecting the knee from harm.

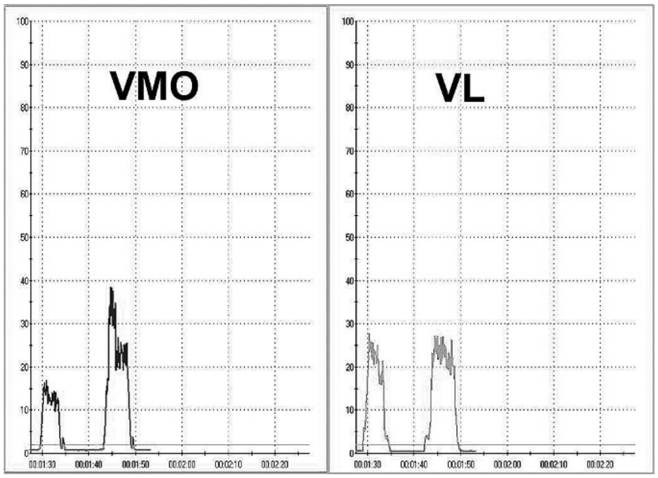

Figure 5. Baseline surface electromyography (SEMG) measure of the right knee with vastus medialis oblique (VMO) and vastus lateralis (VL) placements. While in an upright sitting position, Case Example 1 was asked to extend her knee, straighten her leg, and produce a maximal knee contraction two times.

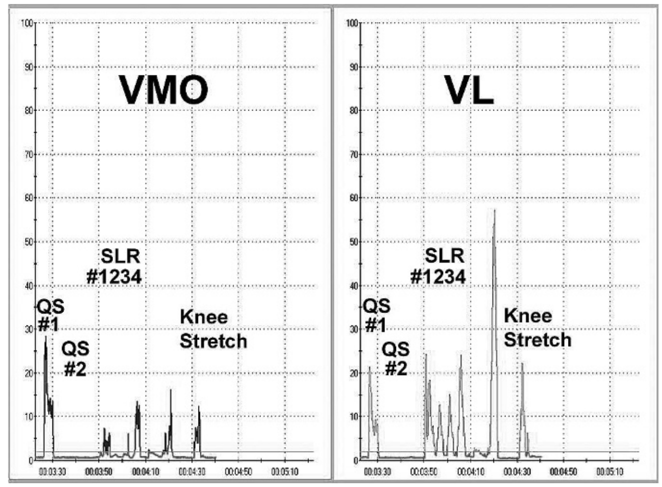

Figure 6. Baseline surface electromyography (SEMG) measure of the right knee with vastus medialis oblique (VMO) and vastus lateralis (VL) placements. While lying supine on the floor (as in Figure 2), Case Example 1 was asked to produce two quad sets (notice that the second one was so weak that it did not register), to produce four straight leg raises (notice minimal VMO activation), and to point the knee toward the ceiling, interlace the fingers beneath the knee (as in Figures 8 and 9), and allow the knee to bend and stretch (notice good flexion-relaxation during the knee bend).

In addition, one must be aware of the effects of adipose (fat) tissue impedance on the SEMG signal. The more adipose tissue between the sensor and the knee muscle, the lower the SEMG signal will appear during contractions. For an average healthy knee, with minimal adipose, VMO contractions will typically exceed 100 μV RMS, and the VMO SEMG signal will typically be higher than that of the VL. Flexion-relaxation of the knee will typically be below 2 μV RMS.

SEMG Training Protocol for SLR Exercises

The patient remains supine with a pillow under the head to be able to observe the SEMG display. One must first familiarize the patient with SEMG display using some test contractions.

The treatment goal is then clarified. ''We want to evaluate how well your muscles are contracting during your SLRs, and then we will use the muscle biofeedback to maximize your SLR technique so that these exercises will be most effective for strengthening your knee.''

Review the baseline assessment graphs with the patient, pointing out evidence of inhibition. ''If your knee only contracts to this level during your SLR exercises, it's probably not going to work very well to strengthen your knee. We need to get stronger contractions for this exercise to work effectively.''

Demonstrate how the VMO and VL muscles work together during quad set contractions to straighten the knee and pull the kneecap upward. Some practice quad sets with the healthy knee are often helpful. While sitting up, with the healthy knee extended on the floor, one can see that a strong quad set will push the knee down into the floor and bring the foot up slightly.

Begin SEMG training with quad set contractions. Encourage the patient to produce a firm quad set with the injured knee while observing the SEMG feedback display, with the goal of producing the highest reading. Auditory feedback can be added to enhance learning. Adding a round lumbar pillow or rolled-up towel, or placing the therapist's hand underneath the knee for tactile cuing, can sometimes help the patient find the correct technique. ''As you contract, your knee will push down into the floor (pillow/towel/my hand).'' One must be observant of muscle substitution in hip and other muscles during training. ''Focus your muscle energy directly into the VMO. You don't need to tighten your whole leg and hip.''

If, after education and encouragement, the patient has difficulty producing an effective quad set, one should open a dialogue about fear of pain and/or reinjury. ''What do you think makes your knee not want to contract very much? Does it cause pain when you do it? Are you afraid that you might reinjure your knee if you contract harder?'' One must be empathetic about fear of pain and reinjury and be willing to address the patient's concerns. Educate the patient that some level of pain during knee rehabilitation is normal and expected. ''This pain is uncomfortable, but it does not mean that your knee is being harmed. As your knee gets stronger, then the pain that you experience during your exercises will gradually lessen.'' If fear of reinjury is an issue, then use of logical analysis is often

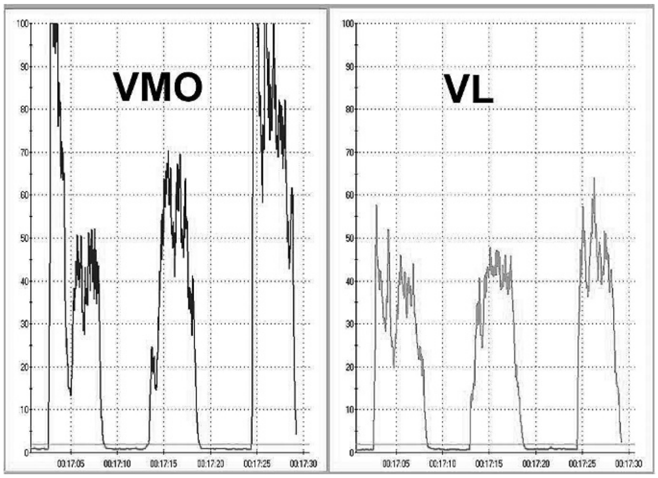

Figure 7. Surface electromyography (SEMG) measure of the right knee during straight leg raise (SLR) exercises, with vastus medialis oblique (VMO) and vastus lateralis (VL) placements. While lying supine on the floor (as in Figure 2) and receiving visual SEMG feedback and verbal instruction, Case Example 1 is practicing a two-part SLR strategy of "quad set, then raise and hold." Notice the first contraction "dies" somewhat in the VMO upon raising the leg. By the third attempt, this patient was demonstrating better success with maintaining the contraction during the SLR.

helpful. ''Your doctor and your therapists wouldn't ask you to do these exercises if they had any concerns at all that it will be harmful to your knee. They believe that these exercises are safe and that they will help your knee get better.''

Once the patient has demonstrated success with quad set contraction, then begin SLR training. Even after success with quad sets, patients often will revert to inhibition during SLRs. A useful technique for producing the most effective SLR is to do it in two steps. ''First produce a good quad set, and then maintain it as you raise your leg off the floor.'' Allow the patient to practice with visual/auditory feedback and continue to offer encouragement.

During SEMG training, one must be careful to regulate the number of assessment and training knee contractions, regulate the hold times for knee contractions, and be aware of signs of muscle fatigue to prevent overfatigue and pain flare-up. Muscle fatigue is indicated when training contractions appear successively weaker and the patient is unable to sustain contractions at a steady level, even with good effort. It is wise to ice the knee following the biofeedback training session to help control inflammation.

Case Example 1

Example 1 is a 42-year-old flight attendant. She was injured when her knee struck a metal bar during a turbulent flight and then later ''popped'' while she was squatting. A sprain was initially diagnosed, and then a medial meniscus tear was later discovered. She underwent three surgeries, including insertion of, and later removal of, a screw and participated in 36 visits of physical therapy. Upon admission to treatment in our facility, she walked with a significant limp, demonstrated extreme weakness in her knee, and had been unable to work for more than 2 years.

Figure 5 shows her baseline sitting knee extension. Figure 6 shows her baseline supine quad sets, SLRs, and knee flexion stretch. Baseline knee extension SEMG was relatively low (note that she had very little adipose tissue in her knee), and supine quad sets and SLRs were very low. Her knee flexion stretch looked good, with complete flexion-relaxation and good flexion range of motion. She initially had difficulty achieving stronger contractions during biofeedback training. She said that it ''feels like my knee cap is breaking in half'' while contracting the knee and admitted to concern about re-injury. She expressed awareness of habitually favoring and protecting her knee since her injury. We processed her fears (as laid out earlier in this article) and discussed how favoring her knee had probably contributed to deconditioning and continued problems with pain. It was also pointed out that her muscle inhibition had probably limited her success during her 36 sessions of physical therapy that she completed prior to entering our program. With education and encouragement during this treatment session, she was able to overcome her inhibition and began producing very nice quad sets and eventually SLRs. Figure 7 shows a series of SRL training trials. During this training, she reported that the exercises still caused pain, but that she felt more confident the exercises would not harm her knee.

SEMG-Assisted Stretching Biofeedback Training for Knee Flexion

Rationale for SEMG-assisted stretching (SEMGAS) has been detailed elsewhere (Neblett, Gatchel, & Mayer, 2003a; Neblett, Mayer, & Gatchel, 2003b; Neblett, Mayer, Brede, & Gatchel, in press). When performing SEMGAS with a knee, the patient remains supine with a pillow for head support so that the SEMG display can be observed. One must first familiarize the patient with the SEMG display using some test contractions.

The treatment goal is then clarified: ''We want to evaluate how effectively you are stretching your knee, and then we will use the muscle biofeedback to fine-tune your stretch technique so that you can achieve the best range of motion in your knee.''

Review the baseline assessment graphs with the patient, pointing out evidence of inhibition. ''The goal of stretching is to lengthen muscles. It looks like your knee muscles are

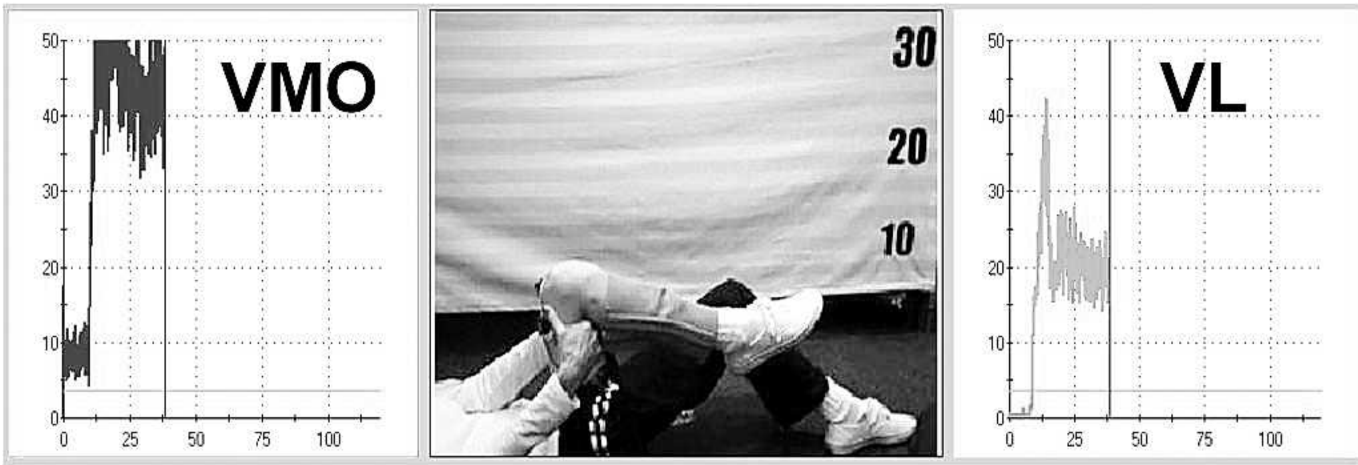

Figure 8. Baseline surface electromyography (SEMG) measure of the right knee, with vastus medialis oblique (VMO) and vastus lateralis (VL) placements. Case Example 2 was asked to hold the leg below the knee and allow the knee to bend and stretch. Notice elevated SEMG readings during the stretch, showing a lack of flexion-relaxation.

contracting and shortening at the same time that you are trying to lengthen them. Let's see if we can teach your knee to relax better during this stretch so that your stretch will be more effective.''

Practice knee flexion trials with visual and/or auditory feedback. While the patient holds the knee, it may be necessary for the therapist to begin by manually supporting the leg in a fixed position until the patient can relax the knee. The leg can then be gradually lowered by the therapist while the patient attempts to maintain relaxation. Because the patient's knee may be sensitive, and fear of increased pain is often an issue, one must be willing to take time during this process. It is essential to build rapport and be willing to process the patient's concerns.

When working on knee flexion stretches, one must regulate the number of training trials and the stretch hold times to help prevent pain flare-ups. Again, it is wise to ice the knee following the biofeedback training session to help control inflammation.

Case Example 2

Example 2, a loan counselor, tore the menisci in both knees when she tripped and landed on them about 8 months before beginning treatment with us. She underwent arthroscopic surgery on both knees. Her right knee surgery was about 2 months prior to this treatment session.

As can be seen in Figure 8, she showed poor flexion-relaxation during her baseline knee stretch. She reported concern about increased pain and possible reinjury while bending her knee. Her concerns were addressed, and education about the safety of stretching her knee was provided. During training, the patient allowed her foot to

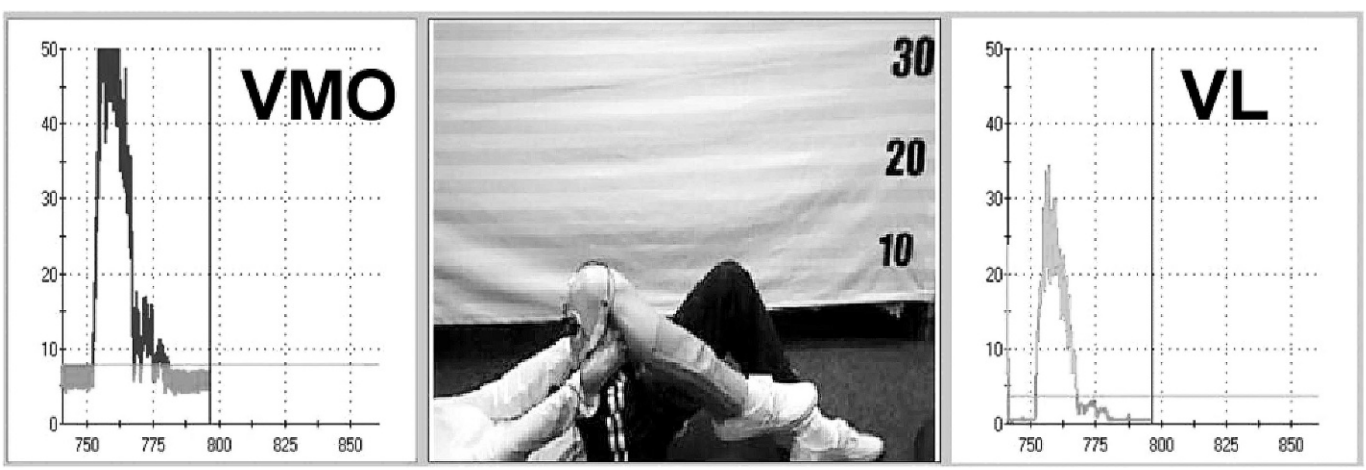

Figure 9. Training surface electromyography (SEMG) measure of the right knee, with vastus medialis oblique (VMO) and vastus lateralis (VL) placements. While receiving visual and auditory SEMG feedback and verbal instruction, Case Example 2 is practicing flexion-relaxation during a gravity-assisted knee stretch. Notice increased range of motion compared with the baseline stretch in Figure 8.

be supported by the therapist and then gradually lowered, while maintaining relaxation of the knee. This was repeated several times until she was able to lower her leg fully and allow flexion-relaxation in a gravity-assisted stretch (see Figure 9). She reported that the pain at the end range of her stretch, while maintaining flexion-relaxation, was less than she had expected, and with increased practice she became less fearful. Being able to see positive changes in flexion-relaxation and ROM with the Webcam pictures shown in Figures 8 and 9 were reinforcing and encouraging to her.

Conclusion

Muscle inhibition (including both inadequate muscle recruitment during strengthening exercises and inadequate muscle relaxation during stretches) often involves fear of pain and reinjury, which can contribute to deconditioning and chronic pain following a knee injury and surgery. SEMG biofeedback training, as an adjunct to postoperative knee rehabilitation, can help to identify and teach patients to reduce or to overcome muscle inhibition (usually in one training session), so that increased strength and ROM can be achieved. After successful training and education, patients will typically report that effective stretches and SLR exercises do cause some pain, but that the pain is significantly less distressing. Regular practice of effective stretches and strengthening exercises can then result in reduced pain, more normal functioning of the knee, and the ability of patients to use the knee more successfully during functional activities of daily living.

Glossary

Baker cyst: Swelling of the bursa behind the knee joint. A *bursa* is a synovial-fluid–filled sac that provides a cushion between bones, tendons, and/or muscles around a joint.

Cartilage: A tough yet flexible connective tissue covering the end of bones in adult joints that helps to protect and support the bones. Cartilage is also found in the ears and nose. It has no blood supply or nerves.

Chondral flap: *Chondral* refers to anything related to cartilage, so this term refers to an unsecured portion of cartilage.

Ligament: Fibrous tissue connecting bone to bone, which provide support and strength for joints.

Meniscus: Crescent-shaped cartilage on the tibia (lower leg bone) used as a shock absorber in the knee. There are two inside each knee. The medial meniscus in on the inner side of the knee and the lateral meniscus is on the outer side.

Osteophyte: Bony projections that usually form along joints. Also known as *bone spurs*.

Patella: The kneecap, whose primary purpose is to provide leverage on the quadriceps and patellar tendons when extending the knee.

Synovia: A clear, thick fluid that lubricates and nourishes joints.

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