EMG feedback-assisted postoperative rehabilitation of minor arthroscopic knee surgeries

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This study assessed the effectiveness of surface integrated electromyographic (EMG) biofeedback in the rehabilitation of 51 patients undergoing minor arthroscopic knee surgery. Prior to surgery, both control (n=23) and treatment (n=28) groups received verbal and written explanations of postoperative isometric exercises; the treatment group received additional instruction in the use of ambulatory biofeedback equipment during exercise. Isokinetic tests of strength at approximately two weeks post-surgery revealed that patients given EMG biofeedback during postoperative exercise demonstrated significantly greater extensor torque and quadriceps muscle fiber recruitment than controls. Implications for the use of EMG biofeedback in long-term postoperative rehabilitation are discussed.

KEY WORDS: Biofeedback - Rehabilitation - Arthroscopy - Knee.

A variety of intra-articular conditions may cause anterior knee pain. These include abnormalities of osseous and cartilaginous tissue such as the presence of loose bodies, chondral lesions, subchondral cysts, subluxation of the patella, or avascular necrosis. Patellofemoral pain also may arise from soft tissue pathologies, such as meniscal or synovial disorders.

All of the aforementioned conditions are frequently corrected arthroscopically. Treatment may involve the removal of loose bodies, debridement of articular surface anomalies, meniscectomy, synovectomy, or lateral retinacular release.

Rehabilitation following arthroscopic surgery typically includes an exercise program. Continuous passive motion (CPM) exercise is sometimes employed in a clinical setting when considered medically necessary for optimal rehabilitation. In other cases, patients are prescribed a home regimen of isometric quadriceps contractures, or quad sets, to reduce anterior knee pain. Quad sets also strengthen the knee musculature and enable the affected joint to recover the optimal range of motion.

Several studies indicate that electromyographic (EMG) biofeedback can be a valuable adjunct to such exercise, enhancing motivation as well as muscle strength, tolerance, and flexibility. In a study by Croce, undergraduate volunteers received EMG feedback during isokinetic exercise of the quadriceps muscle group. After five weeks of thrice-weekly conditioning, these subjects demonstrated significantly higher peak torque values when compared to controls who exercised without EMG-feedback. Another study with undergraduates, conducted by Lucca and Recchiuti, examined the effects of EMG-feedback on isometric contraction of knee extensors. Upon completing a 19-day exercise program, experimental subjects displayed significantly

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greater gains in average peak torque than groups that were not given biofeedback.

Both psychological and neurophysiological models have been used to explain these observed increases in performance and strength. Biofeedback may evoke greater interest in the prescribed exercise protocol, thereby increasing subject motivation, compliance, and participation. Alternatively, it may facilitate the firing of motor units and/or the recruitment of new units through enhanced proprioceptive information processing.\(^9\)

Studies of clinical populations support the findings of research using healthy volunteers. For example, a study by Draper\(^3\) found that biofeedback-assisted exercise following anterior cruciate ligament (ACL) reconstruction was superior to exercise alone. Eleven patients in this study received EMG biofeedback during quad sets and straight leg raising exercises, while a control group of equal number received the regular post-operative protocol for ACL injuries. After completing the 12-week program, the biofeedback group exhibited significantly greater strength acquisition. In addition, patients in this group achieved full range of motion in significantly less time than patients in the control group.

Another study\(^10\) demonstrated that surface integrated EMG feedback-assisted exercise was superior to electrical stimulation in promoting recovery following ACL reconstruction. Fifteen patients received EMG-feedback during quad sets and straight leg-raising exercises, while an equal number of controls exercised with electrical stimulation (ES) substituted for EMG-feedback. Post-tests upon completion of the 12-week program indicated that biofeedback group displayed significantly greater strength acquisition than controls, as tested by a Biodex II isokinetic dynamometer.

The efficacy of EMG feedback in promoting recovery following ACL reconstruction has implications for other post-operative rehabilitation programs. Biofeedback techniques have been shown effective in recovering both neural and muscular elements rehabilitation by facilitating voluntarily initiated contractions, as opposed to artificial activation with ES.\(^3\)\(^9\) Given the above, it is reasonable to assume that the use of EMG feedback-assisted exercise can successfully be applied to less complicated knee surgeries and incorporated into conservative rehabilitation for acute and chronic knee pathologies. The purpose of this study is to evaluate the effects of EMG feedback training on patients who have undergone minor arthroscopic procedures.

Wise, Fiebert, and Kates\(^11\) suggested that achieving a VMO:VL EMG ratio of approximately 1:1 facilitated pain reduction in the knee, and that biofeedback assisted exercise promoted the attainment of this optimal VMO:VL ratio. Therefore, a secondary focus of the present study is to examine the ratio of EMG output from the VMO and VL following arthroscopic knee surgery.

**Materials and methods**

**Subjects**

Participants consisted of 35 male and 16 female patients between the ages of 18 and 65 referred to South Miami Hospital. Patients with the following knee conditions were included: meniscal tears (n=27), loose bodies within the knee complex (n=2), patellar chondromalacia (n=10), synovitis (n=5), or some combination of these (n=7). Prospective patients were excluded on the basis of either ligament tears or severe, chronic arthritis. All diagnoses were confirmed with arthroscopy. No significant differences occurred in the distribution of these diagnostic categories between control and experimental groups (\(\chi^2=4.72\), df=4, p=0.32).

Table I displays the subject demographics by group. Subjects were randomly assigned to control and treatment groups based on whether the year of their birth was an odd or even year.

Group composition was evaluated in order to check for randomization. The control and treatment groups were similar in gender composition (\(\chi^2=0.61\), df=1, p=0.44), with the control group consisting of 14 males and 9 females and the treatment group containing 21 males and 7 females. No significant between-group differences were obtained for age (t=0.83), height (t=−1.32), weight (t=−1.07), body mass index (t=1.97), or pre-operative pain rating (t=−40), all df’s=49, all p’s>0.05.

In addition, no differences between groups were found for average EMG units measured during 10 presurgical quad setting exercises without biofeedback, from either the vastus lateralis (VL; t=−1.44), or the vastus medialis obliquus (VMO; t=−1.89), both df’s=43, both p’s>0.05.
TABLE I—Demographics.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Biofeedback</th>
<th>±SD</th>
<th>Control</th>
<th>±SD</th>
</tr>
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<tr>
<td>Age (years)</td>
<td>45</td>
<td>15</td>
<td>48</td>
<td>15</td>
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<tr>
<td>Height (m)</td>
<td>1.7</td>
<td>0.2</td>
<td>1.7</td>
<td>0.1</td>
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<tr>
<td>Weight (kg)</td>
<td>81</td>
<td>0.2</td>
<td>85</td>
<td>14</td>
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<tr>
<td>BMI (kg/m²)</td>
<td>27</td>
<td>3</td>
<td>31</td>
<td>12</td>
</tr>
<tr>
<td>Presurgery average EMG for VL channel</td>
<td>67</td>
<td>38</td>
<td>51</td>
<td>40</td>
</tr>
<tr>
<td>Presurgery average EMG for VMO channel</td>
<td>45</td>
<td>25</td>
<td>31</td>
<td>22</td>
</tr>
<tr>
<td>Presurgery pain rating</td>
<td>6.6</td>
<td>3</td>
<td>6.3</td>
<td>3</td>
</tr>
<tr>
<td>Number of subjects</td>
<td>28</td>
<td>23</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

No significant differences: Age, height, weight, BMI=Body Mass Index, presurgery average EMGs, presurgery pain rating. Range of Presurgery Pain Rating 1 to 10, with 1=most severe pain, pain medication frequently required, and 10=no pain, no pain medication required.13

Isometric quad setting exercise

Patients were instructed to perform the quad setting exercises while seated, with knees in zero degrees of extension. If necessary, they were instructed to place a pillow beneath the affected knee to support and protect the joint, as well as to reduce hyperextension to zero. Next, patients maximally contracted the quadriceps muscles, holding this contraction for five seconds; the subsequent relaxation phase was ten seconds long.

Isokinetic knee extension exercise

Isokinetic post-testing of strength was conducted with a Biodex II (Shirley, NY) isokinetic dynamometer. This isokinetic torque measurement device is utilized frequently for research, clinical assessments, and therapeutic exercise in orthopedic physical therapy and sports medicine. The device allowed stabilization of the subject in a seated position via chest, thigh, and leg stabilizers. A lever arm extended from a precision dynamometer parallel to the lower leg at the axis of the knee. A padded bar extended from the lever arm perpendicular to the leg, so that the bottom of the pad abutted the superior border of the medial malleolus while still allowing full range of motion at the ankle. The bar fastened across the calf with an adjustable belt.

For the tests, each subject was instructed to extend and flex the knee, thereby forcing the lever arm with consistent effort at a constant speed of 120 degrees per second. Subjects were tested throughout their maximal range of motion (ROM), typically from 0 degrees to 90 degrees, for up to 15 repetitions. Biodex II software computed average torque, work, and ROM.

Electromyography

Surface integrated EMG was recorded from both the VL and the VMO with silver imbedded cloth electrodes sewn onto a spandex belt. Cloth electrodes have been demonstrated to have a 0.98 correlation with standard disposable silver/silver chloride electrodes, as shown by within-subject correlations. Electrode placement was according to Basmajian and Blumenstein,13 and was consistent during feedback assisted home exercise and isokinetic post tests of strength. Patients were trained regarding proper electrode placement for home use, with instructions to correct for excessive impedance.

Biofeedback was provided to each patient in the treatment group by a BioPrompt Portable EMG Computer programmed with Bio-Scope Software (Version 9R3, EMPI, Inc., St. Paul, MN). Each unit is 3 3/8" W X 5 1/2" H. The bandwidth was 100 Hz to 540 Hz. Bandpass filtering was done in front of the root mean square conversion, and the time constant for the root mean square conversion was 40 milliseconds. The filtered integrated signal was sampled and stored at 4 Hz. Each BioPrompt was preprogrammed to alarm if impedance levels exceeded 40 Kohms. Weekly compliance rates and EMG amplitude levels during exercise were calculated after downloading the stored data into an IBM-compatible 386 personal computer for further storage and reduction. Bio-Scope software calculated the average EMG during each contract and relax phase in home exercise sessions. Visual feedback was given to patients via a bar graph shown on a liquid crystal display, and auditory feedback was provided with a beeping sound that increased in frequency as muscle activity increased.

EMG data were collected during isometric quad setting exercises at pre- and post-testing with the BioPrompt Portable EMG computers yoked directly to an IBM-compatible 386 personal computer through fiber optic cable and an interface box.

Again, the Bio-Scope software was set to alarm if impedance levels exceeded 40 Kohms, but the units
were silent and did not provide feedback during this phase. Bio-Scope software calculated average EMG during isometric contractions.

Procedure

All subjects were recruited and gave informed consent at the time when surgery was scheduled. On the day of surgery, each subject received verbal and written explanations regarding isometric quad setting exercises. These exercises were used during pre- and post-operative measurement of EMG produced by the quadriceps muscle, as well as being a major component of the home exercise treatment regimen. Prior to surgery, the treatment group also received instruction in the use of ambulatory EMG biofeedback during home exercise. Presurgical practice feedback was provided to insure that patients understood the task. The treatment group was discharged with the portable home units after instructions in proper use. EMG units were pre-programmed to alert patients to scheduled exercise through an auditory alarm plus visual instructions.

Exercises were scheduled for three sessions per day: morning, mid-day, and evening. These units prompted patients for the proper timing (cadence) of contract and relax cycles (contract=five seconds, relax=ten seconds). Electromyographic stored data verified patient compliance and adequate electrode impedance.

Results

The average rate of compliance with home exercise was calculated for subjects in the biofeedback group. Percentage of compliance for each subject was computed by dividing the number of exercise sessions completed by the total number of possible sessions. The mean rate of exercise compliance in the biofeedback group was 54.70% (SD±3.13). No comparable measure of exercise compliance was available for the control group.

The five dependent variables examined in this study were average EMG units measured from the VL during 10 post-surgical quad setting exercises without biofeedback, average EMG units measured from the VMO during same, peak torque and range of motion (ROM) from isokinetic post test exercises, and a postsurgery pain rating. All measures were collected on an average of 14 days after surgery. Factorial analyses of variance (ANOVAs) were performed, with group and gender as independent variables. Table II displays the means and standard deviations of the outcome measures by group and gender.

Results from the ANOVAs for average EMG indicated a significant gender effect for both the VL [F (1, 46)= 19.14, p<0.001] and VMO [F (1,46)= 18.72, p<0.001]. Males generated more microvolts from both the VL and the VMO muscles than females did.

In addition, a main effect for group was revealed when comparing postsurgery average EMG for the VMO. The biofeedback group demonstrated significantly greater microvolts from the VMO than the control group, F (1, 46)=5.38, p=0.025.

When examining peak torque measured at post-test, a significant gender effect was apparent. Males produced more peak torque than females during isokinetic knee extension exercises [F (1, 47)=26.55, p<0.001]. Peak torque data revealed a significant group by gender interaction, F (1, 47)=7.60, p=0.008. Simple main effects tests were performed to compare peak torque values for males and females by group. These analyses indicated that males in the biofeedback group generated more torque than males in the control group, F (1, 34)=21.65, p<0.01. No sig-

### Table II.—Outcome measures.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Combined Biofeedback (±SD)</th>
<th>Combined Control (±SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>Post-surgery</td>
<td>80(54)</td>
<td>47(35)</td>
</tr>
<tr>
<td>Average VL EMG1</td>
<td>96(48)</td>
<td>30(38)</td>
</tr>
<tr>
<td>Post-surgery</td>
<td>55(35)</td>
<td>28(20)</td>
</tr>
<tr>
<td>Average VMO EMG2</td>
<td>76(30)</td>
<td>20(25)</td>
</tr>
<tr>
<td>Peak torque3</td>
<td>43(27)</td>
<td>29(18)</td>
</tr>
<tr>
<td>Maximum range of motion4</td>
<td>88(18)</td>
<td>89(17)</td>
</tr>
<tr>
<td>Post-surgery pain rating5</td>
<td>6.6(3)</td>
<td>6.3(3)</td>
</tr>
</tbody>
</table>

1) Significant gender effect, p<0.001; 2) Significant gender effect, p<0.001; 3) Significant group effect, p<0.025; 3) Significant gender effect, p<0.001. Significant group x gender interaction, p<0.008; 4) Significant gender effect, p<0.028; 5) Significant gender effect, p<0.001; EMG units in microvolts. Peak torque in lb. Range of motion in degrees. Range of post-surgery pain rating 1 to 10, with 1=most severe pain and 10=no pain.18
significant between-group differences in peak torque values emerged for females, F (1, 15)=2.66.

Finally, gender effects were noted for range of motion (ROM) and post-surgery pain ratings. Men exhibited greater post-operative range of motion, F (1, 47)=5.14, p=0.028, and reported less postoperative pain, F (1, 47)=27.17, p<0.001, than women.

To accomplish the secondary purpose of the present study, pre- and post-test VMO:VL ratios were computed for each subject. Next, factorial ANOVAs were calculated, using group and gender as independent variables. No significant differences were noted at pre-test; however, a significant group effect was evident at post-test [F (1, 46)=4.53, p =0.039]. The mean VMO:VL ratio for the group given biofeedback was 1:1.43, while the mean VMO:VL ratio for the control group was 1:1.73.

**Discussion**

This study extends the findings of previous research regarding the use of biofeedback-assisted exercise with both normal and clinical populations. The results demonstrate that EMG feedback-assisted exercise following arthroscopic knee surgery facilitated strengthening of quadriceps muscles, as measured by peak torque during quad setting exercises. Biofeedback-assisted exercise also resulted in significantly greater torque levels postoperatively for males, in comparison to exercise in the absence of feedback, as measured by Biodex II isokinetic testing.

Because feedback-assisted exercise appeared to have greater impact on males than on females, a post hoc investigation of demographic differences between the genders was conducted. These analyses revealed that female subjects were significantly older than male subjects (F=5.70, df=1, p=0.02); the mean age for males was 43.5 years, while for females the mean age was 54.2 years. In addition, significant gender differences were noted regarding the types of diagnoses assigned to subjects (χ²= 9.94, df=4, p=0.04). Male and female subjects were equally likely to receive a diagnosis of a meniscal tear; however, males were given more diagnoses of loose bodies, chondromalacia, or a combination of diagnoses.

Given the above, one possible explanation for gender differences in the effects of biofeedback is that feedback may be less effective with chronic degenerative processes associated with age, as opposed to more acute types of injuries likely to be sustained by younger, more active subjects. Another potential explanation for such differences may relate to cognitive factors (e.g., self-efficacy, outcome expectancies) concerning the perceived benefits of exercise.15

As mentioned earlier, a secondary goal of the present investigation concerned the ratio of VMO:VL EMG output in experimental subjects versus controls. Subjects in the biofeedback group produced a post-operative mean VMO:VL EMG ratio that approached the optimal 1:1 ratio more closely than the VMO:VL ratio achieved by control subjects.

The positive postoperative changes described in this study became apparent within a two-week period. Such differences may be explained by increases in muscle fiber recruitment, exercise compliance, and total exercise performance. The use of ambulatory biofeedback data provides a good indirect measure of patient compliance with post-operative exercise regimens, in addition to promoting more rapid recovery. These benefits, to both patient and physician, suggest that EMG feedback-assisted exercise can be a worthwhile tool for physician-directed post-operative rehabilitation.

Several limitations of this study have implications for future research in this area. First, while male subjects given biofeedback demonstrated significant improvement relative to males in the control group, this same treatment effect was not observed with female subjects. A longer treatment period may be necessary before beneficial effects of biofeedback treatment become apparent in female subjects.

Second, a longer follow-up period is clearly needed, to determine whether treatment gains from the use of biofeedback are maintained over time. Furthermore, repeated assessment of outcome over time may shed light on the mechanism through which biofeedback exerts effects.

Third, based on the results of the present study, future investigations should match subject groups by gender, age, and diagnosis. Such an approach may reveal differences in response to biofeedback on the basis of degenerative versus acute etiologies.

Lastly, future research should incorporate a placebo control group in the experimental design. Several studies in chronic pain and rehabilitation have
used sham feedback with a placebo control group. These studies provided control subjects with carefully prepared false feedback during exercise, while matching treatment on all other aspects. This strategy controls for demand effects without providing components of effective treatment. Such an approach here would have the additional benefit of obtaining automated measures of compliance for control subjects that are equivalent to the compliance measures recorded for subjects given biofeedback. Comparable measures of exercise compliance could be used to verify that experimental effects are the result of biofeedback treatment, and not just a function of exercise performance.

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References