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Evaluation of Electromyographic Biofeedback for the Quadriceps Femoris: A Systematic Review

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Objective: To critically review evidence for the effectiveness of electromyographic biofeedback (EMGB) of the quadriceps femoris muscle in treating various knee conditions.

Data Sources: Databases used to locate randomized controlled trials included PubMed (1980–2010), Cumulative Index of Nursing and Allied Health Literature (CINAHL, 1995–2007), Web of Science (1986–2010), SPORTDiscus (1990–2007), and Physiotherapy Evidence Database (PEDro). Key words were *knee* and *biofeedback*.

Study Selection: The criteria for selection were clinical randomized controlled trials in which EMGB of the quadriceps femoris was used for various knee conditions of musculoskeletal origin. Trials were excluded because of research designs other than randomized controlled trials, articles published in a non-English language, inclusion of healthy research participants, inability to identify EMGB as the source of clinical improvement, and lack of pain, functional outcome, or quadriceps torque as outcome measures.

Data Extraction: Twenty specific data points were abstracted from each clinical trial under the broad categories of attributes of the patient and injury, treatment variables for the EMGB group, treatment variables for the control group, and attributes of the research design.

Data Synthesis: Eight trials yielded a total of 319 participants with patellofemoral pain syndrome (n = 86), anterior cruciate ligament reconstruction (n = 52), arthroscopic surgery (n = 91), or osteoarthritis (n = 90). The average methodologic score of the included studies was 4.6/10 based on PEDro criteria. Pooled analyses demonstrated heterogeneity of the included studies, rendering the interpretation of the pooled data inappropriate. The EMGB appeared to benefit short-term postsurgical pain or quadriceps strength in 3 of 4 postsurgical investigations but was ineffective for chronic knee conditions such as patellofemoral pain and osteoarthritis in all 4 studies. Because the findings are based on limited data, caution is warranted until more randomized controlled trials are conducted to support or refute the general trends observed in this report.

Key Words: exercises, knee, rehabilitation

Key Points

- Electromyographic biofeedback of the quadriceps femoris muscle demonstrated potential improvements in knee extensor torque and functional outcome after anterior cruciate ligament reconstruction or meniscectomy.
- Chronic knee conditions, such as patellofemoral pain and osteoarthritis, did not benefit from electromyographic feedback.
- However, the number of included studies was small; variability in patient populations, interventions, and outcomes was large; and methodologic problems were identified. Therefore, further investigation is warranted.

Musculoskeletal conditions such as anterior cruciate ligament (ACL) ruptures, meniscal lesions, patellofemoral pain syndrome, and osteoarthritis of the knee are associated with a loss of quadriceps muscle force production and cross-sectional area.[1–4] A combination of limb disuse,[5] arthrogenic muscular inhibition,[6] and pain avoidance behaviors[7] may contribute to quadriceps impairment. Strong evidence indicates that functional outcome of the knee and recovery of the quadriceps are associated[8–12] and that knee extensor exercise may improve these outcomes.[12–15]

Electromyographic biofeedback (EMGB) is a tool for detecting and amplifying the electric activity of muscles and providing the patient with visual or auditory information about the magnitude of muscular tension. The EMGB may be used to modulate muscle contraction by bringing the muscular tension to the level of consciousness, such that a patient may adjust motor output accordingly. This tool has been used therapeutically for incontinence and constipation,[16] tension headaches,[17] facial paralysis,[18] motor function after stroke,[19] phonatory performance,[20] and temporomandibular joint disorders.[21] In general, these reviews demonstrated mixed levels of effectiveness, but a beneficial trend was observed when EMGB was used to decrease muscular tension.

In the domains of orthopaedics and sports medicine, knee conditions have drawn the most attention from authors of clini-

cal trials investigating the effectiveness of EMGB. Perhaps this is the case because quadriceps function is related to knee outcomes[8–12]; knee dysfunction may cause a neuromuscular imbalance between the heads of the vastus medialis (VM, or more specifically the vastus medialis oblique [VMO]) and the vastus lateralis (VL),[22] and this imbalance may be a causative factor for patellofemoral pain.[23] Quadriceps atrophy and inhibition are present in various knee conditions, so EMGB may be used as an adjunct to progressive resistive exercises of the quadriceps. Despite common use of biofeedback in knee rehabilitation, we did not find any summaries of its use as an adjunct to therapeutic exercise. Thus, the purpose of our investigation was to answer the following clinical question: Does EMGB of the quadriceps improve patient-oriented outcomes and quadriceps strength after knee dysfunction? Until recently, a critical mass of trials on EMGB had not been published.

METHODS

Data Sources

We performed a search of clinical trials in the following databases: PubMed (1980–2010), Cumulative Index of Nursing and Allied Health Literature (CINAHL, 1995–2007), Web of Science (1986–2010), Sport DISCUS (1990–2007), and the Physiotherapy Evidence Database (PEDro) to gather evidence relating to quadriceps exercise with EMGB for knee rehabilitation. Search terms were limited to *knee* and *biofeedback*. For the CINAHL and PubMed searches, we used a sensitive clinical query as advocated by Haynes et al.[24] A hand search was used to identify additional trials, particularly those outside the database time frames.

Study Selection

Included in this review were clinical randomized controlled trials in which EMGB of the quadriceps femoris was used for various knee conditions. Exclusion criteria consisted of research designs other than randomized controlled trials, articles published in a non-English language, inclusion of healthy research participants, research designs in which EMGB treatment effects could not be distinguished from other treatment effects, and investigations that did not include pain, functional outcome, or quadriceps torque as outcome measures. We initially screened references by viewing the article title and abstract. If we could not clearly determine that an article met at least one of the criteria for exclusion, we obtained the full-text article for further review. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram[25] for the selection of trials for this review is illustrated in Figure 1.

Methodologic Assessment

The PEDro criteria were used to identify possible biases in the included research. Eight criteria assess internal validity, and 2 criteria evaluate external validity for each trial. These criteria include participant eligibility criteria, random allocation, concealed allocation, baseline similarity, participant blinding, therapist blinding, assessor blinding, adequate follow-up, intention to treat, statistical comparison, and point estimate.[26] The cumulative PEDro score demonstrated high intertester reliability (intraclass correlation = 0.91).[27]

Data Extraction

A priori, we compiled a list of specific data to be drawn from each included article. Abstracted characteristics of the patients and injuries included the type of knee dysfunction, number of patients, age, sex, and duration of symptoms or time since surgery. Data pertinent to the EMGB treatment included location and alignment of the electrodes, feedback type, and patient instructions. Information pertaining to the control group treatment (ie, exercises performed, exercise variables, nonexercise care, and treatment period) was also recorded. Lastly, attributes of the research design were extracted, including follow-up periods, methods for strength testing, functional outcome or pain measures, mean and SD values, and statistical significance among treatment groups.

Consistency of Findings

Study selection, methodologic assessment, and data extraction were independently evaluated by each author. Discrepancies among the findings were discussed until a consensus was reached.

Pooled Analysis

Pooled analyses were performed on all included studies that provided pain-related outcome or quadriceps strength measures. Data necessary for inclusion in the pooled analyses included group sizes, means, and standard deviations collected immediately after the end of the intervention period. When multiple variables were used to assess pain-related outcome, we placed the highest priority on disease-specific, then joint-specific, and lastly global pain or outcome measures. Similarly, quadriceps strength measures were assessed in numerous ways that were prioritized for the analyses. Priority went to isokinetic dynamometry at the slowest velocities, then isometric dynamometry, followed by isotonic tests of maximal intensity. When bilateral dysfunction was present, data from the right limb were analyzed. For each pooled analysis, only one value from each group could be entered into the calculation. The dependent variables were prioritized to ensure "appropriateness"[28] of functional outcomes and a greater reflection of maximal torque production capacity with low-velocity isokinetic tests.

Data from the included studies were entered into RevMan Software (version 5.0; The Nordic Cochrane Centre, The Cochrane Collaboration, Copenhagen, Denmark). The analyses were performed across all included data and across subgroups defined by the type of knee dysfunction. A fixed-effects model was used to determine standardized mean differences and 95% confidence intervals. Because the software does not correct for differences in the direction of the scale, the group means had to be multiplied by –1 when higher scores were of clinical benefit.[29]

RESULTS

Study Selection

The database search yielded 161 citations specific to the search terms used, 50 of which were duplicates. A hand search found an additional 7 publications that had not been identified by the database search. A total of 118 citations were screened by title and abstract, which eliminated 91 of the studies. Each

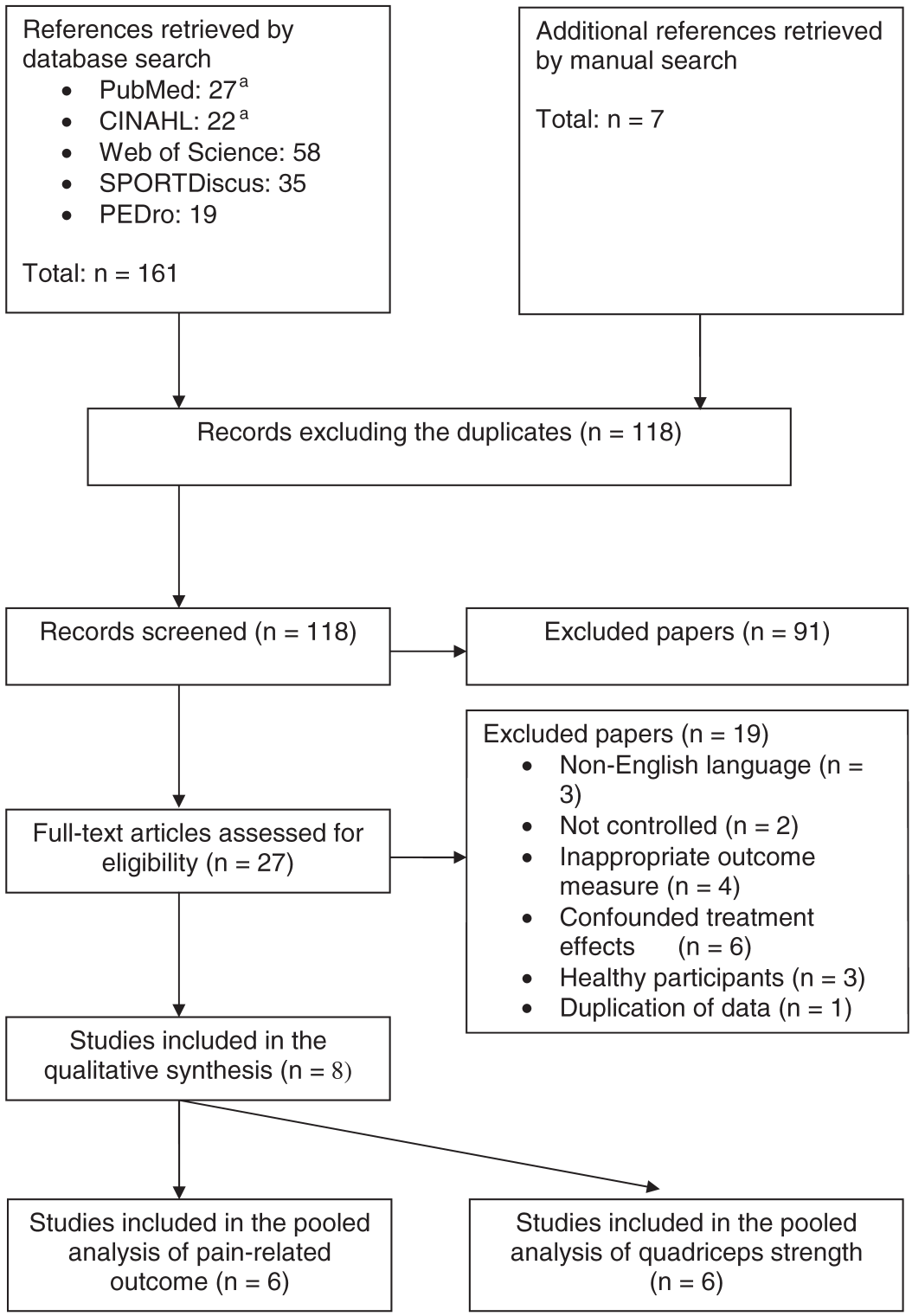


Figure 1. PRISMA flow diagram demonstrating the selection of trials. [a] A high-sensitivity clinical query was used to filter the results.[24] Abbreviations: CINAHL, Cumulative Index of Nursing and Allied Health Literature; PEDro, Physiotherapy Evidence Database.

of the remaining 27 articles was examined in full text to determine suitability for inclusion. After the review, additional trials were excluded on the basis of non-English language (n = 3),[30–32] no control group (n = 2),[33,34] inappropriate outcome measures (n = 4),[35–38] confounded treatment effects (n = 6),[39–44] inclusion of healthy participants (n = 3),[45–47] and duplication of data between studies (n = 1).[48] The duplicate trials[48,49] shared functional outcome data, but one also provided isokinetic testing of the knee, making it the appropriate choice for inclusion.[49] Two trials that were excluded on the basis of inappropriate outcomes investigated quadriceps strength with noninstrumented manual muscle testing[36] and while pressing the knee against a sphygmomanometer.[38] Eight articles met the criteria for inclusion in this systematic review. Six of these provided the quantitative data for a pooled analysis on pain-related outcomes, and another combination of 6 trials included data for a pooled analysis on quadriceps strength. The selection process is reflected in the PRISMA flow diagram[25] in Figure 1.

Study Quality

The 8 included studies had an average PEDro score of 4.625/10, as illustrated in Table 1. These scores represent multiple sources of bias that may skew the results. The most common shortcomings were lack of blinding (patient, therapist, or assessor), concealed allocation, and intention-to-treat analyses. One trial was quasirandomized by birth date, which met the criteria for inclusion in this review but was not considered randomized by PEDro criteria.[55] Another trial was described as double blind, but only the assessors were blinded.[49]

Two trials failed to meet the "baseline comparability" criterion of PEDro; the postsurgical studies used a posttest-only design when the outcome of interest was quadriceps strength testing.[50,51] A third postsurgical study met the baseline comparability PEDro criterion because of the preintervention and postintervention assessment of functional outcome but limited the assessment of quadriceps strength to after the EMGB intervention period.[55] This scenario produced uncertainty about the equality of the groups before the intervention with respect to important outcome measures in the study. Therefore, one cannot affirm that differences between groups at follow-up were exclusively due to the study intervention.

Data Synthesis

The 8 studies consisted of a total of 319 participants with patellofemoral pain syndrome (2 trials,[49,53] n = 86), ACL reconstruction (2 trials,[50,51] n = 52), arthroscopic surgery (2 trials,[54,55] n = 91), and osteoarthritis (2 trials,[52,55] n = 90). For the trials that used EMGB after arthroscopy[54,55] the largest number of patients had a meniscectomy (73.6%), followed by patellar chondromalacia (11.0%), synovitis (5.5%), loose bodies (2.2%), or a combination of the aforementioned conditions (7.7%). The ages of the patients varied according to the knee dysfunction, with ACL reconstruction, patellofemoral pain, arthroscopy, and osteoarthritis representing a spectrum of ages from youngest to oldest, respectively. The respective proportions of female and male patients varied by condition: patellofemoral pain syndrome (74.4% versus 25.6%), ACL reconstruction (40.4% versus 59.6%), arthroscopy (17.6 versus 82.4%), and osteoarthritis (94.4% versus 5.6%). See Table 2 for additional demographic details.

The EMGB treatment of the quadriceps was not uniform among studies. Two channels were used to elicit feedback in

Table 1. Methodologic Assessment of Included Studies With Physiotherapy Evidence Database (PEDro) Scores

Author	Random Allocation?	Concealed Allocation?	Baseline Comparability?	Blind Participants?	Blind Therapists?	Blind Assessors?	Follow-Up?	Intention-to-Treat Analysis?	Group Comparisons?	Point and Variability Measures?	Cumulative Score (Maximum = 10)
Draper[50]	Yes	No	No	No	No	No	Yes	No	Yes	Yes	4
Draper and Ballard[51]	Yes	No	No	No	No	No	Yes	No	Yes	Yes	4
Durmus et al[52]	Yes	No	Yes	No	No	No	Yes	No	Yes	Yes	5
Dursun et al[53]	Yes	No	Yes	No	No	No	Yes	No	Yes	Yes	5
Kirnap et al[54]	Yes	No	Yes	No	No	No	Yes	No	Yes	Yes	5
Levitt et al[55]	No	No	Yes	No	No	No	No	No	Yes	Yes	3
Yilmaz et al[56]	Yes	No	Yes	No	No	No	Yes	No	Yes	Yes	5
Yip and Ng[49]	Yes	No	Yes	No	No	Yes	Yes	No	Yes	Yes	6
Cumulative score	7/8	0/8	6/8	0/8	0/8	1/8	7/8	0/8	8/8	8/8	4.625

Table 2. Demographic Characteristics of Patients in the Included Studies

Authors	Condition or Procedure	Patients, No.	Duration of Dysfunction	Age, y	Sex (Women/Men)
Dursun et al[53]	Patellofemoral pain	60	E: 10.8 ± 7.7 mo C: 9.7 ± 8.1 mo	E: 36.9 ± 9.2 C: 36.6 ± 10.6	48/12
Yip and Ng[49]	Patellofemoral pain	26	NA	T: 32.5 ± 8.8	16/10
Draper[50]	Acute anterior cruciate ligament reconstruction	22	1 wk postoperatively	T: 23	7/15
Draper and Ballard[51]	Acute anterior cruciate ligament reconstruction	30	Immediately postoperatively	E: 25 ± 8.1 C: 24 ± 7.7	14/16
Kirnap et al[54]	Arthroscopic meniscectomy	40	3 d postoperatively	T: 34.5 ± 10.3	0/40
Levitt et al[55]	Arthroscopy: Meniscectomy, n = 27 Patellar chondromalacia, n = 10 Synovitis, n = 5 Loose bodies, n = 2 Combination, n = 7	51	Immediately postoperatively	E: 45 ± 15 C: 48 ± 15	16/35
Durmus et al[52]	Osteoarthritis (grade I–II)	50	NA	E: 54.7 ± 1.8 C: 54.8 ± 2.0	50/0
Yilmaz et al[56]	Osteoarthritis (grade I–III)	40	E: 17.5 ± 9.1 mo C: 15.6 ± 8.5 mo	E: 55.6 ± 7.2 C: 59.4 ± 5.6	35/5
8 Trials	4 General knee conditions	319			186/133

Abbreviations: C, control group; E, experimental group; NA, data not available; T, total sample.

nearly all the trials. However, in both postoperative ACL reconstruction trials, a single electrode was placed proximal to the patella and offset slightly to the medial side but not described as being placed over any specific muscle.[50,51] When 2 electrodes were used, the VL always had an electrode placed superficial to it. The second of the 2 electrodes was placed on either the VM[53,56] or, more specifically, the VMO.[49,54,55] In another study, the 2 electrodes were vaguely described as being placed over 3 heads of the quadriceps,[52] leaving uncertainty about their exact location. When the information was provided, all authors indicated that the active electrodes were aligned with the muscle fibers below. In 6 trials, the EMGB devices provided visual and auditory feedback; one investigation each used units with visual[49] or auditory[54] feedback alone. Four groups used a threshold function, in which no feedback was provided until a certain amount of electric activity was detected in the muscle. Three of these groups[50,51,54] vaguely described the EMGB threshold as near maximum isometric contraction, and another[53] clearly described the threshold value as 80% of the average of 3 maximal contractions. Patients treated with EMGB for ACL reconstruction, arthroscopy, or osteoarthritis were encouraged to maximally contract all heads of the quadriceps, whereas those with patellofemoral pain syndrome were instructed to increase the activity of the VM or VMO while maintaining a lower level of activity in the VL.[49,53] See Table 3 for additional details of the EMGB treatment.

Because EMGB functions as an adjunct to quadriceps exercise in those with knee dysfunction, all patients participated in exercise programs. All authors compared quadriceps exercise and EMGB with quadriceps exercise and no EMGB, but in 2 trials electrotherapy was superimposed during the control groups' exercises.[51,52] The exercise programs focused the use of the EMGB device on quadriceps setting and straight-leg–raise exercises, except for one study that used only flexed-knee quadriceps isometric exercises.[52] In that same study, the exercises and exercise variables were slightly different between the EMGB and control groups.[52] Otherwise, the exercise interventions were the same between the EMGB and control groups. Exercise variables were poorly reported by most authors, so that the sets, repetitions, intensity, and recovery after the exercises are largely unknown. Nonexercise treatments were uncommon but consisted of cryotherapy, patellar mobilization, controlled weight bearing, postoperative bracing, and electrotherapy. The exercise programs varied in duration from 10 days to 12 weeks, 2 to 7 days per week, and 1 to 3 times daily. The settings included outpatient therapy, home exercise programs, and group exercise programs. For additional details about the exercise programs of the included studies, see Table 4.

Three groups[50,51,54] found some benefit of EMGB after knee surgery. Two of these were published by the same lead author and demonstrated EMGB as superior for ACL-reconstructed patients in developing quadriceps strength relative to exercise-only[50] and electrotherapy-exercise conditions.[51] Both studies had below-average PEDro scores (4/10 each) and were posttest-only designs. Therefore, one cannot determine whether the differences between the experimental and control groups were, in fact, due to the intervention. These studies are likely to be more prone to bias and confound, so we must interpret them with great caution. The third study[54] that demonstrated positive findings investigated the role of EMGB for 2 weeks after arthroscopic meniscectomy. A disparity in Lysholm knee scores was not present preoperatively or 3 days postoperatively, but at 2 and 6 weeks postoperatively, a difference was noted between the EMGB and exercise-only groups. The methods used in this investigation were slightly above average (5/10) but lacked blinding, concealed allocation, and an intention-to-treat analysis. Despite possible biases, this trial was as sound as any other of the included studies and should be seriously considered as

Table 3. Attributes of Electromyographic Feedback in Included Studies

Authors	Biofeedback Device	Electrode Locations	Electrode Orientation	Feedback Type	Threshold Level	Electromyographic Feedback Instructions
Dursun et al[53]	Myomed 932 (Enraf-Nonius, Rotterdam, Netherlands)	2: VM and VL, in the areas of greatest muscle bulk	Along the direction of the fibers of each muscle	Visual and auditory	80% of average of 3 aximal contractions	Contract VM above threshold while attempting to keep VL below threshold
Yip and Ng[49]	Custom-designed device	2: Midpoint of VMO, about 4 cm superior and 3 cm medial to the superomedial border of the patella; VL: 10 cm superior and 7 cm lateral to the superior border of the patella	Electrode over the VMO oriented 55° to the diagonal Electrode over the VL oriented 15° to the diagonal	Visual	NA	Increase activity of VMO while maintaining stable activity in VL during exercise
Draper[50]	Cyborg model J33 portable unit (Autogenic Systems, Chicago, IL)	1: Placed just proximal to the patella and 2 cm medial	NA	Visual and auditory	Initial threshold value selection different for each patient; threshold settings reevaluated at each session and reset if necessary	NA
Draper and Ballard[51]	Myotrac electromyographic biofeedback unit (Thought Technology Ltd, West Chazy, NY)	1: Placed 3–5 cm above the superior border of the patella and 2–3 cm medial	NA	Visual and auditory	Threshold that the patient could achieve only by contracting with maximal effort	NA
Kirnap et al[54]	Myomed 932	2: VMO: placed 4 cm above the upper edge of the patella on the VMO muscle and at 3 cm medial; VL: placed 10 cm above the upper edge of the patella and 6–8 cm lateral	Angle of 55° by the vertical plane Angle 15° from the vertical plane	Auditory	Increase threshold every day	NA
Levitt et al[55]	BioPrompt portable electromyography unit (EMPI, Inc, St Paul, MN)	2: VMO and VL described but reference regarding placement described only VM and VL over the muscle bellies, not VMO (Basmajiana)	Reference demonstrates vertical placement of the electrodes over each muscle[a]	Visual and auditory	NA	Maximally contract quadriceps
Durmus et al[52]	Myomed 432[b]	2: "Two superficial electrodes were placed over the patient's rectus femoris, vastus medialis, and vastus lateralis muscles"	NA	Visual and auditory	NA	Increase visual and auditory signals at every contraction
Yilmaz et al[56]	Myomed 932	2: VM and VL	Parallel to the muscle fibers	Visual and auditory	NA	NA

Abbreviations: NA, not available; VL, vastus lateralis; VM, vastus medialis; VMO, vastus medialis oblique.

[a] Basmajian JV, ed. *Biofeedback: Principles and Practices for Clinicians*. 3rd ed. Baltimore, MD: Williams & Wilkins; 1989.

[b] This model was not listed on the manufacturer's Web site.

Table 4. Characteristics of the Therapeutic Interventions in the Included Trials

Authors	Control Group Treatment	Exercises Performed	Exercise Variables	Nonexercise Care	Treatment Period and Frequency
Dursun et al[53]	Exercise only	Quadriceps setting, straight-leg raises, hip adductor strengthening, terminal knee extensions, and closed kinetic chain exercises; hamstrings, triceps surae, iliotibial band, and quadriceps stretching; proprioception training; bicycling	Duty cycle 10:20 s	NA	4 wk, 5 d/wk (EMGB group wore the device only 3/5 weekly sessions)
Yip and Ng[49]	Exercise only	Quadriceps, hamstrings, gastrocnemius, hip adductors, and iliotibial band flexibility; quadriceps setting, terminal knee extension, semisquat, wall slide, lunge, step-up, step-down, eccentric hamstrings exercise, and hip adduction exercises; balance and proprioception training; plyometric and agility training	NA	NA	8-wk daily home exercise program
Draper[50]	Exercise only	Quadriceps setting, straight-leg raises, active and passive range of motion, isokinetic exercises	1 wk postoperatively: 10 repetitions 2 wk: increased repetitions 4 wk: straight-leg raises, 5 sets of 10 each in prone, supine, and side-lying position	Electric stimulation progress to weight bearing tolerated at 12 wk	12 wk (18 or 26 sessions, depending on the patient's schedule)
Draper and Ballard[51]	Exercise and electrotherapy	Quadriceps setting, straight-leg raises, active and active-assistive range of motion, hamstrings stretching, isotonic knee extension and flexion exercises	Duty cycle 10:20 s (in conjunction with EMGB or electrotherapy), 3 sets of 10 (wk 1–2), 5 sets of 10 (wk 3–6), progressively increasing intensity	Progress to weight bearing as tolerated at 4 wk	6 wk total wk 1–4: daily home exercise program, 3×/d wk 5–6: 3 sessions/wk at rehabilitation clinic
Kirnap et al[54]	Exercise only	Phase 1: quadriceps setting, straight-leg raises Phase 2: hip adductor strengthening and terminal knee extension added Phase 3: closed kinetic chain exercises and lateral step-up exercises added	Duty cycle 5:10 s over 20 cycles	Cryotherapy and patellar mobilization	2 wk, 5 d/wk
Levitt et al[55]	Exercise only	Quadriceps setting	Duty cycle 5:10 s	NA	10-d home exercise program, 3×/d
Durmus et al[52]	Exercise and electrotherapy	Isometric knee extension (EMGB at 25°–30° knee flexion, electrotherapy at 60° knee flexion)	EMGB duty cycle 10:50 s, electrotherapy duty cycle 10:10 s	NA	4 wk, 5 d/wk
Yilmaz et al[56]	Exercise only	Quadriceps isometrics, minisquats, hip adductor isometrics, 4-way straight-leg raises, terminal knee extension	10 repetitions	NA	3 wk, 3×/d, both supervised group and home exercise programs

Abbreviations: EMGB, electromyographic biofeedback; NA, not available.

evidence of the effectiveness of EMGB. For further information on the findings of individual studies, see Table 5.

For the pooled analyses, pain-related outcome measures and quadriceps strength values were extracted. Six of the 8 trials contained data that could be used in the pooled analysis of pain-related outcomes.[49,52–56] The outcomes measures used in the pooled analysis were the Western Ontario and McMaster Universities Arthritis Index (WOMAC) pain scale,[52,56] Functional Index Questionnaire,[53] Patellofemoral Pain Severity Scale,[49] Lysholm Knee Score,[54] and Pain Rating Scale.[55] The data for the pooled analysis of the quadriceps strength measures were derived from 5 studies; factors analyzed were peak knee extensor torque at 60°/s[56] and 120°/s,[49,55] isometric knee extensor torque at 60°,[51] and a 1-repetition maximum effort of the right knee during an isotonic knee extension test.[52]

The overall pooled analysis for pain-related outcome measures after EMGB demonstrated heterogeneity of the included studies ($\chi^2_5 = 43.14$, $P < .01$, $I^2 = 88\%$), and therefore interpretation of the pooled data was inappropriate. Pooled analyses within the subgroups were also heterogeneous, the exception being the patellofemoral pain syndrome data ($\chi^2_1 = 0.15$, $P = .70$, $I^2 = 0\%$). The overall effect within the patellofemoral pain group was equivocal ($z = 1.70$, $P = .09$), despite nearly reaching statis-

Table 5. Dependent Variables and Outcomes of Interest From Included Studies

Authors	Knee Strength Assessment	Pain and Functional Outcomes Assessed	Measurement Intervals	Between-Groups Results at End of Intervention Period
Dursun et al[53]	NA	10-point VAS, greatest level of knee discomfort over the past wk Functional Index Questionnaire	Baseline and 1, 2, 3 mo	No differences between groups for VAS or Functional Index Questionnaire
Yip and Ng[49]	Isokinetic peak torque and total work on a Cybex dynamometer (Cybex International, Medway, MA) at 120°/s normalized to body weight	Patellofemoral Pain Syndrome Severity Scale	Baseline and 4, 8 wk	No differences between groups for isokinetic peak torque or the Patellofemoral Pain Syndrome Severity Scale
Draper[50]	Isometric peak torque on Cybex II dynamometer at 90°, 60°, and 45° of knee flexion, normalized to uninjured limb	NA	Posttest only at 12 wk postoperatively	EMGB group had less side-to-side peak torque difference than the non-EMGB group at all 3 angles
Draper and Ballard[51]	Isometric peak torque on a Cybex II dynamometer at 60° of knee flexion, normalized to uninjured limb	NA	Posttest only at 6 wk postoperatively	EMGB group had less of a side-to-side peak torque difference than the exercise and electrotherapy group
Kirnap et al[54]	NA	Lysholm Knee Score	Preoperatively and 3 d and 2 wk, 6 wk postoperatively	Improvement in Lysholm Knee Score of the EMGB group relative to exercise-only control group
Levitt et al[55]	Isokinetic peak torque on a Biodex II device (Biodex Medical Systems, Shirley, NY) at 120°/s, raw score	Pain Rating Scale (similar to VAS, but lower number represents more severe pain)	Baseline (no baseline knee torque), 14 d	No differences in pain rating scale or isokinetic peak torque between groups
Durmus et al[52]	1-, 10-repetition maximum isotonic quadriceps strength	VAS, WOMAC, 50-m walk, ascent and descent of 10-stair flight	Baseline, 4 wk	No differences in the outcomes between EMGB and exercise and electrotherapy control group
Yilmaz et al[56]	Isokinetic peak torque on a Cybex dynamometer at 60°/s and 180°/s and isometric knee extension torque at 65° knee flexion, raw scores	VAS, WOMAC, Nottingham Health Profile	Baseline, 3 wk	Improvements were noted in the Nottingham Health Profile dimensions of sleep and energy in the EMGB group relative to exercise only-control group

Abbreviations: EMGB, electromyographic biofeedback; NA, not available; VAS, visual analogue scale; WOMAC, Western Ontario and McMaster Universities Arthritis Index.

tical significance. Standardized effects for the included studies are presented in Figure 2.

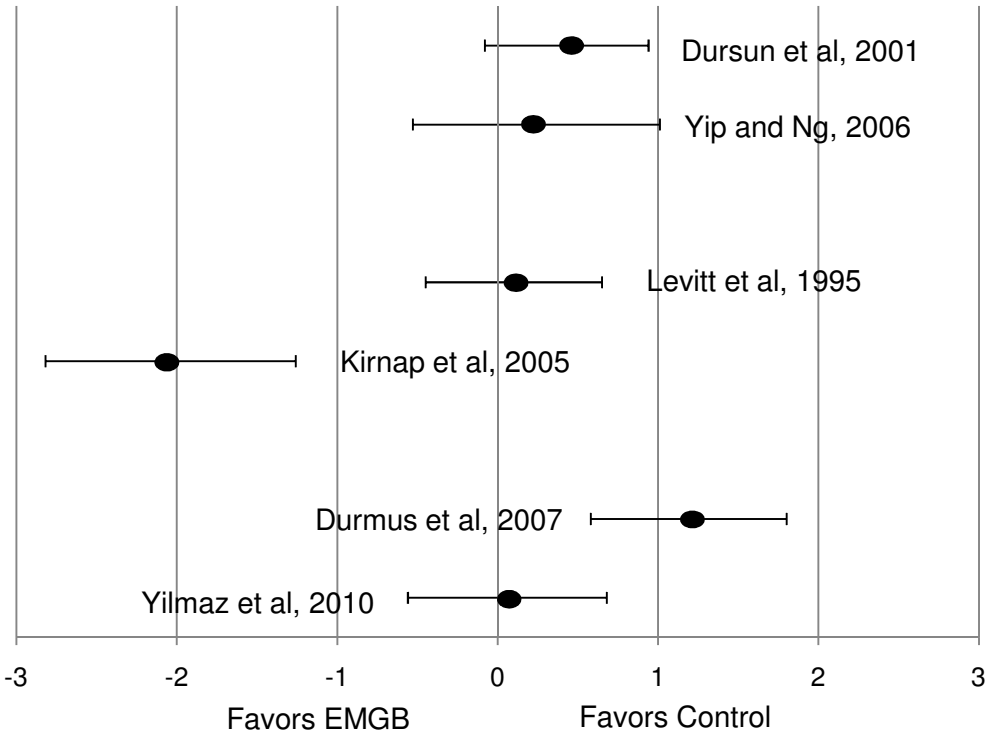
Similarly, the overall pooled effect for quadriceps strength after EMGB yielded heterogeneous data ($\chi^2_4 = 18.33$, $P < .01$, $I^2 = 78\%$), which precluded an analysis of the effect. The pooled analysis within the osteoarthritis subgroup demonstrated both insignificant heterogeneity ($\chi^2_1 = 1.10$, $P = .29$, $I^2 = 9\%$) and an improvement in the strength of the control group relative to the EMGB group ($z = 2.99$, $P = .003$). Standardized effects for the included studies are presented in Figure 3.

DISCUSSION

Does EMGB of the quadriceps improve patient-oriented outcomes and quadriceps strength after knee dysfunction? Our findings are largely equivocal because of the limited number of trials in this area. However, with great caution we note that EMGB appeared to benefit short-term postsurgical pain and quadriceps strength in 3 of 4 studies.[50,51,54,55] Furthermore, EMGB was not effective for chronic knee conditions, such as patellofemoral pain and osteoarthritis, and may border on being less effective than exercise alone for patients in these subgroups.

Surgical Knee Conditions

The evidence in favor of EMGB as an adjunct to exercise postoperatively has substantial limitations. First, the external validity of one of the positive studies[50] is severely compromised by its focus on open ACL reconstructions, which are no longer performed. Nonetheless, positive results were noted during arthroscopic meniscectomy[54] and arthroscopic ACL reconstruction,[51] which are common surgical procedures. Internal validity of the trials that focused on ACL reconstruction[35,51] was confounded by the use of posttest-only designs. Therefore, it is unclear whether the differences found between the groups were present immediately after randomization or whether they resulted from the EMGB intervention. The difficulty encountered by the researchers in these studies was that a baseline postoperative isokinetic knee extensor torque measurement after ACL reconstruction was contraindicated because of fragile graft fixation and compromised patellar tendons. Unfortunately, these same authors[35,51] failed to include functional outcome or pain scale measurements, which could have been used as evidence for postoperative similarities between the experimental and control groups. Lastly, both postoperative ACL reconstruction



Study or Subgroup	EMGB Group Mean ± SD	EMGB Group Total	Control Group Mean ± SD	Control Group Total	Standard Mean Difference IV, Fixed	95% CI
Patellofemoral pain						
Dursun et al, 2001[53]	–12 ± 1.7	30	–12.8 ± 2	30	0.43	–0.09, 0.94
Yip and Ng, 2006[49]	35.4 ± 22.7	13	29.9 ± 21.2	13	0.24	–0.53, 1.01
Arthroscopic surgery						
Levitt et al, 1995[55]	6.6 ± 3	28	6.3 ± 3	23	0.10	–0.45, 0.65
Kirnap et al, 2005[54]	–85 ± 8.4	20	–68.1 ± 7.8	20	–2.04	–2.82, –1.26
Osteoarthritis						
Durmus et al, 2007[52]	3.04 ± 0.48	25	2.44 ± 0.51	25	1.19	0.59, 1.80
Yilmaz et al, 2010[56]	9.52 ± 4.42	19	9.3 ± 3.07	20	0.06	–0.57, 0.68

Abbreviations: CI, confidence interval; EMGB, electromyographic biofeedback; IV, inverse variance.

Figure 2. Standardized mean differences for patient-oriented outcomes (ie, functional outcome or pain).

studies[35,51] had lower than average PEDro methodology scores, potentially skewing the results.

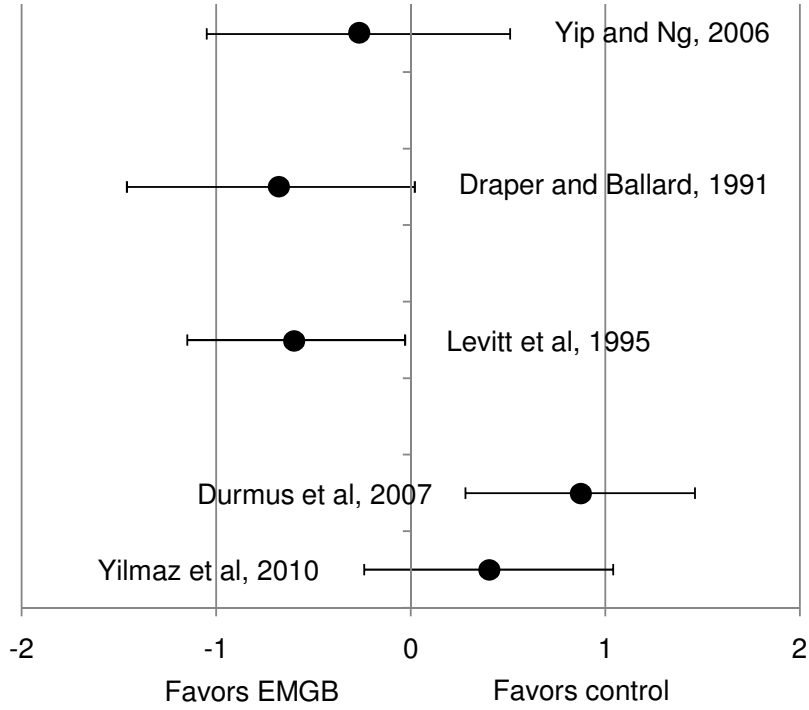
Perhaps improvements in pain and quadriceps strength in postsurgical patients result from extrinsic EMGB competing with intrinsic feedback from nociceptors during painful movements or muscle contractions. Evidence[57] suggests that pain is directly related to fear of movement and inversely related to function of the ACL-reconstructed knee. Most pain and fear of movement exist immediately after surgery and progressively decline over time.[57] During the early postoperative period, EMGB combined with encouragement from the clinician may sufficiently motivate the patient to overcome the fear of movement and intense pain, subsequently minimizing disuse atrophy of the quadriceps.

Physiologically, it is counterintuitive that EMGB may be effective in increasing quadriceps strength early after surgery. A large effusion tends to occur immediately after knee surgery secondary to the trauma. Several groups[22,58,59] have established that even a minimal knee joint effusion may cause arthrogenic muscle inhibition of the quadriceps. Arthrogenic muscle inhibition reduces the ability of the patient to produce a true maximal contraction, either with or without EMGB, because the reflex response is beyond the patient's conscious control.[60] Researchers have demonstrated EMGB-related improvements in the electric activity of the quadriceps after arthroscopic knee procedures.[54,55] Perhaps quadriceps exercise concurrent with EMGB encourages patients to increase muscle activation, resulting in an improvement in muscular function.

Chronic Knee Conditions

Patients with chronic knee conditions, such as patellofemoral pain syndrome and osteoarthritis, did not appear to derive any benefit from the use of EMGB with exercises. In fact, most data from these subgroups indicated that EMGB might even be a detriment relative to exercise-only or an exercise plus electrotherapy treatment. Whether this trend is an artifact or a result of the EMGB intervention is unclear. Perhaps the novel use of EMGB could be confusing and distracting to some; however, if this were the case, the effect should have been seen across all studies, independent of patients' knee conditions.

Electromyographic feedback is commonly used to increase VMO activation and reduce patellofemoral pain. The VMO is a dynamic stabilizer of the patellofemoral joint and may influence patellar tilt and lateral shift in those with patellofemoral pain.[61]



Study or Subgroup	EMGB Group Mean ± SD	EMGB Group Total	Control Group Mean ± SD	Control Group Total	Standard Mean Difference IV, Fixed	Standard Mean Difference 95% CI
Patellofemoral pain						
Yip and Ng, 2006[49]	–138.1 ± 85.8	13	–116.1 ± 69.7	13	–0.27	–1.05, 0.50
Anterior cruciate ligament reconstruction						
Draper and Ballard, 1991[51]	–46.4 ± 10.5	15	–37.9 ± 12.4	15	–0.72	–1.46, 0.02
Arthroscopic surgery						
Levitt et al, 1995[55]	–43 ± 27	28	–29 ± 18	23	–0.59	–1.15, –0.03
Osteoarthritis						
Durmus et al, 2007[52]	–11.92 ± 0.65	25	–12.6 ± 0.88	25	–0.87	0.28, 1.45
Yilmaz et al, 2010[56]	–54.47 ± 17.97	19	–62.95 ± 22.8	20	–0.40	–0.23, 1.04

Figure 3. Standardized mean differences for quadriceps muscle strength.

Despite this mechanical influence, patellofemoral degeneration in human cadavers does not correspond with structural attributes of the VM[62] or VMO.[63] A delay of VMO activation onset may or may not exist in patients with patellofemoral pain,[64] but if it does, whether the neuromuscular impairment is a cause or effect of patellofemoral pain is unknown.

Although evidence against the effectiveness of EMGB for patellofemoral pain is modest, quadriceps exercise alone does reduce patellofemoral pain.[15,65] The mechanism of pain reduction is unknown, but it is unlikely that the quadriceps exercises preferentially activate the VMO.[66] In a randomized controlled trial, Syme et al[44] found that VMO-specific exercises were no better than general quadriceps exercises for reducing patellofemoral pain. Furthermore, arthroscopic debridement of the patellofemoral joint and subsequent quadriceps exercises were no better than quadriceps exercise alone,[67] and the surgical intervention may lead to prolonged quadriceps inhibition.[68]

Limitations to the Systematic Review

Several limitations to this systematic review exist. First, a small number of trials was included in the review. Also, patient populations, interventions, and outcomes in the included studies varied significantly, making comparisons very difficult. In particular, the exercise variables were conspicuously absent from most of the investigations. Allocation was inadequately concealed, and adequate blinding of the participants, therapists, and assessors was lacking, which often positively biases outcomes.[69] In addition, intention-to-treat analyses were not performed; these assessments may yield biased data, but the magnitude and direction of the bias are variable.[70,71] As more research becomes available and journals become more stringent about the reporting of trial methods, the effect of bias will be reduced and the true clinical effectiveness of EMGB will become clearer.

Suggestions for Future Research

We can make several recommendations for researchers who want to study the clinical effectiveness of EMGB. First, the possible trends noted in surgical and nonsurgical knee conditions in this review should be challenged. Although the postoperative use of EMGB may indicate effectiveness in reducing pain and increasing quadriceps strength, the recommendation is

cautious and tentative. With greater conviction, we can suggest that EMGB is ineffective for chronic knee conditions, such as patellofemoral pain syndrome and osteoarthritis. However, the basis for these recommendations is 8 trials, which is clearly insufficient for a confident conclusion.

Contemporary approaches to rehabilitation should be attempted in future research. The included studies used primarily straight-leg raises and quadriceps setting. These exercises are noninvasive and can be performed by most patients, but a criterion-based progression of functional exercises may better reflect current clinical practice.

Methodologic bias is a concern that must be addressed by future authors. Nearly all investigators failed to conceal patient allocation; analyze intention to treat; and blind patients, therapists, or assessors. Using the Consolidated Standards of Reporting Trials (CONSORT) guidelines to plan future trials may reduce many of these shortcomings.

CONCLUSIONS

This review yielded preliminary trends in the effectiveness of EMGB and quadriceps exercise. Potential improvements in knee extensor torque and functional outcome with EMGB were demonstrated in participants with surgical knee conditions, such as ACL reconstructions and meniscectomies, albeit from a limited data pool. However, participants with chronic knee conditions, such as patellofemoral pain and osteoarthritis, did not appear to benefit from EMGB. These recommendations are tentative and warrant further examination of the topic.

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