Journal of Musculoskeletal Research, Vol. 17, No. 1 (2014) 1450001 (10 pages)

DOI: 10.1142/S0218957714500018

EFFECTS OF ADDING BIOFEEDBACK TRAINING TO ACTIVE EXERCISES AFTER TOTAL KNEE ARTHROPLASTY

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Received 4 October 2013
Accepted 4 March 2014
Published 11 April 2014

ABSTRACT

The purpose of this study was to evaluate the effects of adding biofeedback training to active exercise training on quadriceps torque, voluntary activation and functional activity after total knee arthroplasty (TKA). A total of 45 patients with unilateral TKA participated in this study; their ages ranged from 58 to 67 years. They were assigned randomly to two groups. Group I comprised 21 patients who practiced an active exercise training program for 30 to 45 min/session, two sessions/week, for 4 months. Group II contained 24 patients who practiced biofeedback training in addition to the active exercise training program for 30 to 45 min/session, two sessions/week, for 4 months. Isometric peak torque of the quadriceps, voluntary activation and knee functional activity were measured. The results revealed significant improvements in quadriceps torque, voluntary activation and knee functional activity for both groups, with more improvement in knee functional activities in group II. There were nonsignificant differences between the two groups in both quadriceps peak torque and voluntary activation after training ($p > 0.05$). **Conclusion:** An active exercise program can enhance quadriceps peak torque, voluntary activation and knee functional activity after unilateral TKA. The addition of biofeedback training increases the benefits for the knee functional activity of a patient.

Keywords: Total knee arthroplasty; Active exercise; Biofeedback; Voluntary activation.

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INTRODUCTION

Total knee arthroplasty (TKA) is a common surgical procedure designed to alleviate knee pain and improve the functional activity of patients with chronic knee osteoarthritis (OA).[9,17] Quadriceps weakness after TKA has been shown to be a result of chronic arthritic changes. The quadriceps of the affected side produces 75% of the peak torque of the unaffected side, and it demonstrates only 72.9% of the quadriceps activation recorded before knee arthroplasty.[21] It is very important to design a rehabilitation program that allows daily living activities and increases functional performance of the knee.[9,17,25]

Despite quite dramatic improvements in knee pain and functional activity after TKA, patients have lower scores, as a result of advanced knee OA, in comparison with those without knee problems. However, immediately after TKA patients show impairments in muscle strength in parallel with their deficiencies of physical function[16]; for example, they have an increased risk of falling and decreased ability to climb stairs.[33] In addition, they show gait impairments such as short step length, reduced velocity and loss of balance, as well as walking with a stiff knee.[11] These changes are attributed partially to residual weakness of the quadriceps muscle after knee arthroplasty.[29] It has been reported that, one month after knee arthroplasty, the quadriceps peak torque is only 40% and its voluntary activation is only 82% in comparison with preoperative values of the same limb.[21]

Failure of voluntary activation (FVA) is the inability of the central nervous system voluntarily to activate muscle fully and to produce all available force, despite the patient exerting maximal conscious effort. This results commonly from pain or effusion after TKA.[12,23] Voluntary activation and quadriceps strength are usually reduced in patients with OA. This deficit is accompanied by further reduction after TKA,[31] and function never returns to a normal level when compared with the unaffected side or healthy subjects.[4,22,23] In the current study, the burst superimposition technique was used to evaluate Quadriceps force (17). In this technique, a supra-maximal burst of electrical stimulation was applied over a maximal voluntary isometric contraction (MVIC). FVA was determined by the amount of electrical increase of force beyond a person's MVIC at the immediate application of an electrical burst.[23]

Strengthening exercise programs were used after TKA have had limited success with regard to long-term benefits or improvement in quadriceps voluntary activation.[19,20] A specific therapeutic intervention such as electrical stimulation or biofeedback may be added to a strengthening exercise program in order to improve voluntary activation and gain full activation of the quadriceps muscle.[12,21,31] It was postulated recently that neuromuscular electrical stimulation could be added to isometric exercises to improve force production and voluntary activation of the quadriceps muscle after unilateral[21] and bilateral[30] TKA. Such electromyographic (EMG) biofeedback training is used to increase the patient's awareness and control of muscle contraction. It is effective in increasing muscle strength and decreasing the duration of rehabilitation for patients with various conditions such as patello-femoral pain syndrome and chronic knee OA.[10,26,33]

Patients retain limited functional abilities and gait deficits after TKA in spite of the application of standard rehabilitation and strengthening programs. This may be attributed to persistent movement abnormalities, quadriceps weakness and FVA.[22,23] EMG biofeedback is a recent technique that is designed to activate muscle contraction and increase force production by the muscles.[22,23] Therefore, the program designed for this study, which includes active exercises and EMG biofeedback training, may be more effective after TKA than programs based on exercise alone. The purpose of the study was to evaluate the benefits of adding EMG biofeedback training to active exercises on quadriceps torque, voluntary activation and knee function activity after TKA.

METHODOLOGY

Subjects

A total of 45 patients (25 female and 20 male) participated in this study. Their ages ranged from 58 to 67 years. Their main indication for knee arthroplasty was chronic OA. They were selected from the Nasser Institute and Al Helal hospitals Cairo-Egypt. All patients underwent unilateral TKA. The measurements and training programs were conducted in the physical therapy outpatient clinic of the Faculty of Physical Therapy, Cairo University. The patients were assigned randomly to two groups by a blinded and independent research assistant who opened sealed envelopes that contained a computer-generated randomization card.

Group I: A total of 21 patients (8 male and 13 female) participated in an active exercise training program. **Group II:** A total of 24 patients (15 male and 9 female) applied EMG biofeedback training in addition to the active exercise training program.

Inclusion Criteria

Patients who met the following criteria participated in this study: (1) they underwent program participation more than three weeks after surgery; (2) their age ranged from 58 to 67 years; (3) the prostheses used for TKA were cemented fixed and bore non-constrained prostheses, (4) the patients had body mass index (BMI) $<$ 30.0; (5) they did not participate in sporting activity but independently undertook at least moderate activity.

Exclusion Criteria

Patients were excluded from the study if they did not complete the training program, had BMI $>$ 30, had undergone previous knee surgery with post-operative complications such as wound infection, instability or suffered from any disease that affects muscular activity such as diabetes mellitus, hemiplegia, rheumatoid arthritis or visual or hearing impairments.

Ethical Approval

The study was approved by the institutional review board before assessment and treatment of patients was commenced. All patients signed a consent form before participation and they were informed that the data collected would be submitted for publication.

Instrumentation

- A Biodex system 3 Isokinetic dynamometer, (20 Ramsay Road, Shirley, New York, 11967-4704) was used to evaluate quadriceps muscle torque and voluntary activation (using a burst superimposition technique).
- A Uniphy Phyaction Neuromuscular stimulator (Uniphy, PO box 558, 5600AN Eindhoven, Netherlands) was used to stimulate the quadriceps muscle during voluntary activation.
- The Western Ontario McMaster osteoarthritic index (WOMAC) was used to evaluate knee functional activity. It is a 24-item questionnaire that focuses on lower limb activities and covers pain, stiffness and functional difficulty. It therefore gives feedback on functional mobility of the knee.[8,17]

- Pathway TR-20C surface EMG trainer biofeedback was used for quadriceps training.

Assessment Procedure

Every patient in both groups underwent the following assessment procedures before and after each training program:

1. Assessment of the isometric quadriceps peak torque using the Biodex Isokinetic dynamometer. This is a reliable and valid method for assessment of muscle torque.[5] The quadriceps peak torque was measured in isometric mode[13,29] because this mode is safe for the patient and produces maximal muscle tension. The angle of measurement selected was 75° of knee flexion because this angle is expected to be within the available pain-free range of motion of the knee joint.[13] Each patient was able to achieve 75° of knee flexion without additional pain and performed 3 s of maximal knee extension. The trial was repeated three times with a 30-s rest period between tests. The quadriceps isometric peak torque was normalized to the patient's BMI. This assessment was done without electrical stimulation.[13,29]
2. Assessment of the quadriceps voluntary activation was performed using the Biodex Isokinetic dynamometer, using a burst superimposition technique. This is considered a reliable and valid method to evaluate voluntary activation.[3,22,23] Two self-adhesive electrodes were placed over the quadriceps femoris muscle at the motor point of the vastus medialis and proximal rectus femoris muscles. All patients performed two submaximal contractions and one MVIC lasting for 2 to 3 s to warm up the muscle and to familiarize the patient with the testing procedure.[30,31] After 3 min of rest, each patient was instructed to achieve maximal contraction of the quadriceps muscle for approximately 3 s. Approximately 2 s into the contraction, a stimulator delivered a supra-maximal burst of electrical stimulation through two electrodes.[22] The current had a frequency of 100 Hz, the stimulation time was 3 s and the rest time was 10 s for three repetitions of the contraction. If maximal voluntary force has been reached, it is not associated with more muscular force with stimulation; this indicated optimal muscle recruitment. If the muscular force increases during the application of the electrical stimulus, the test was repeated. About 3 min of rest was provided between contractions in an attempt to decrease fatigue.[22,23] The trial that achieved the highest volitional force during the three attempts was used for analysis. The extent of voluntary activation is presented as the central activation ratio (CAR).[18] It is calculated by dividing the maximal voluntary force by the maximal force produced by the combination of voluntary force and the superimposed burst stimulation. A CAR of 1.0 indicates complete activation of the muscle, with no increase of the maximal voluntary force being detected during the electrical stimulation. A CAR of less than 1.0 suggests incomplete activation of the evaluated muscle by the central nervous system.[22,23,31]
3. The WOMAC was used to evaluate knee functional activity. It was completed by every patient.[8] This index consists of 24 questions: 5 questions for pain, 2 questions for joint stiffness and 17 questions for physical function. It is considered in the literature to provide complete information on the outcome with regard to functional abilities.[17]

Treatment Programs

An active exercise training program was applied for both groups, and applied EMG biofeedback training was added for group II. The treatment program was started on the 3rd week after surgery.

Group I: Each patient participated in an active exercise training program for 30 to 45 min, two sessions per week, for 4 months.[2,30] The program included two stages. ***First stage:*** Each patient applied all the following exercises for one to three sets of 10 repetitions. The exercises were: patellar mobilization; active assistive exercise for knee flexion and extension; quadriceps static contraction exercises; strengthening exercises including straight leg raising, terminal knee extension, hip abduction (in lateral recumbence), knee extension curl, ankle dorsiflexion, planter flexion, eversion and inversion. Patients were transferred to the second stage if they were able to perform three sets of 10 repetitions for all the previous exercises correctly. ***Second stage:*** Strengthening exercises were performed against external resistance. The maximal resistance for knee training was determined using the law of one maximal repetition. Exercises were applied against pre-determined individualized resistance for three sets of 10 repetitions.

Group II: Each patient applied EMG biofeedback training in addition to the previously described exercise training program for 30 to 45 min, two sessions per week, for 4 months. The patient's skin was cleaned until the skin was reddened using alcohol wipes to remove oils, dirt and dead skin, before application of the electrodes. The electrodes were placed on the quadriceps; one electrode was placed 4 cm above the upper edge of patella on the vastus medalis muscle and 3 cm medial, at an angle of 55° to the vertical plane (parallel to the muscle fibers). Other electrodes were placed 5 cm above the upper edge of the patella on the vastus lateralis muscle and 6 cm lateral at an angle of 15° to the vertical plane.[10] All electrodes and lead wires were fixed in place using an adhesive plaster. Subsequently, multiple-angle isometric exercises of the quadriceps were performed with EMG biofeedback. In the 1st session, maximal EMG activity of the quadriceps was measured using the EMG biofeedback apparatus. The goal of biofeedback training was set at 80% of the maximal activity and the apparatus was set to give a tone when the muscle's EMG activity was "above" this level. Every patient was able to exceed the set level and a tone was heard each time, in addition he or she was encouraged verbally. When the patient exceeded the level on three successive occasions, the goal was reset at new higher value, and so on. At the end of each session, the maximal EMG activity was recorded as the starting goal of next session. Each patient was asked to hold each contraction for 5 s and relax for 10 s, with a total of 3–4 contractions for each position.[6]

Statistical Analysis

The data collected were analyzed using SPSS (version 16.0). The study sample was divided into only two groups and each group had two readings only (pre and post). Therefore, the paired *t*-test was used to compare mean values of the quadriceps peak torque, CAR and WOMAC index before and after intervention within each group. An independent *t*-test was used to compare mean values of all measured variables before and after intervention between the groups. Statistical significance was determined at a p-value < 0.05 and 95% confidence intervals were calculated.

RESULTS

- The data of this study met the assumption of the null hypothesis. There were no significant differences after adding EMG biofeedback training to an exercise training program in all the measured parameters of knee function except for the WOMAC score.
- Patient characteristics: Demographic data on the 45 patients showed nonsignificant differences

Table 1 Patient's Demographic Data of the Two Groups.

Variables	Biofeedback Group		Exercise Group		*p*-Value
Age[a]	60.6 ± 5.08		60.00 ± 0.89		0.75[b]
BMI[a]	26.18 ± 0.45		25.28 ± 0.44		0.477[b]
Sex	*Male*	*Female*	*Male*	*Female*	
	62.5%	37.5%	30%	61.9%	
Extensor lag after TKR	3 cases (15%)		4 cases (21%)		
Affected side	*RT*	*LT*	*RT*	*LT*	
	14	10	12	9	

[a]Mean ± SD.
[b]Independent *t*-test.
Note: Extensor lag after *TKR* is the lack of full knee extension with full contraction of the quadriceps.

in age, BMI and extensor lag between the patients in the two groups (Table 1).

- Quadriceps isometric peak torque, normalized to patient BMI: There were significant improvements in quadriceps isometric peak torque, normalized to the patient's BMI, in both groups after the treatment program ($p < 0.05$), with non-significant differences between the groups ($p > 0.05$) (Table 2).
- The CAR of the quadriceps was significantly improved in both treated groups ($p < 0.05$). However, there were no significant differences between the EMG biofeedback and exercise groups ($p > 0.05$; Table 3).
- The WOMAC score for knee function was significantly improved after both treatment programs ($p < 0.05$). There were significant functional improvements in the EMG biofeedback group in comparison with the exercise group after treatment ($p < 0.05$; Table 4).

Table 2 Comparison of Quadriceps Isometric Peak Torque/BMI Before and After Treatment Programs.[a]

Variables	Pre-Test	Post-Test	*p*-Value
Biofeedback Group	2.01 ± 0.23	2.3 ± 0.32	0.00[c]
Exercise Group	1.92 ± 0.6	2.31 ± 0.66	0.01[c]
p-value	0.75[b]	0.97[b]	

[a]Mean ± SD.
[b]Non sig. by independent *t*-test.
[c]Sig by paired *t*-test.

Table 3 Comparison of CAR Before and After Treatment Programs by Group.[a]

Variables	Pre-Test	Post-Test	*p*-Value
Biofeedback Group	0.89 ± 0.04	0.93 ± 0.026	0.03[c]
Exercise Group	0.87 ± 0.031	0.91 ± 0.034	0.00[c]
p-value	0.41[b]	0.97[b]	

[a]Mean ± SD.
[b]Non sig. independent *t*-test.
[c]Sig paired *t*-test.

Table 4 Comparison of WOMAC Score Before and After Treatment Programs by Group.[a]

Variables	Pre-Test	Post-Test	*p*-Value
Biofeedback Group	39.66 ± 11.18	16.00 ± 4.73	0.00[c]
Exercise Group	45.66 ± 6.59	32.00 ± 4.73	0.026[c]
p-value	0.28[b]	0.00[c]	

[a]Mean ± SD.
[b]Non sig. independent *t*-test.
[c]Sig paired *t*-tests.
[c]Sig independent *t*-tests.

DISCUSSION

Quadriceps peak torque and voluntary activation were selected as outcome measures because they are significantly impaired in patients who have chronic arthritis, with further deterioration and reduction of the patient's functional activities after surgery.[7,13] EMG biofeedback was chosen as a recently developed physical therapy intervention for use after TKA. Some studies have applied biofeedback as a training regime for different knee disorders,[6,10] in addition to the recommendation for early application of neuromuscular electrical stimulation to the quadriceps after a unilateral TKA.[21]

The results of this study showed significant improvements in quadriceps peak torque and voluntary activation in both groups, without significant differences between them. Although the differences were not significant, they were in favor of the EMG biofeedback group. This may be because EMG biofeedback training enhances and encourages patients to develop greater awareness and control over their involuntary physiological processes. It may contribute also to increased muscular output by increasing motor unit recruitment and/or increasing the firing rate of motor units.[4,6,12] The additional time in EMG biofeedback training may be the reason for the observed differences between the two groups.

These findings are in agreement with previous studies.[6,10,33] It was found that the addition of biofeedback to exercise training could accelerate the improvement of patello-femoral pain in the first few weeks of treatment.[6,33] A significant difference in quadriceps contraction in favor of the biofeedback group after arthroscopic meniscectomy was reported.[10]

Application of electrical burst-superimposition strength-testing is highly recommended in many studies.[22,23,30,31] The CAR has been considered one of best predictors of quadriceps force production.[22,23] It is calculated as the maximal volitional force divided by the maximal force produced by the combination of volitional effort and the superimposed burst.

The results of this study revealed improvement in CAR after treatment in both groups, without significant differences between the two groups. All patients in the current study had a history of chronic OA before surgery. FVA in patients with OA is attributed to pain, swelling and effusion, as well as impairment in central nervous system activation which is associated with FVA or muscle inhibition.[12,21,31] In addition, Stevens *et al.*[30] found that an exercise program and electrical stimulation improved CAR in patients after TKA. However, in their study a nonstatistical analysis was performed: The results for each patient were displayed separately, owing to the small sample size. In our study, CAR was presented in form of mean $\pm$ SD (standard deviation) and subjected to statistical analysis.

The limited success of EMG biofeedback in improving voluntary activation may be attributed to its use during training sessions. Patients were trained to improve activation by maintaining or increasing the EMG (electrical activity) of the muscle, while during assessment the patients were asked to maintain and increase muscle torque (mechanical activity).[27] It was found that, during a constant EMG task, the torque of the muscle decreased, while during the constant torque task, the EMG activity of the muscle increased steadily. This suggests that using torque feedback to improve voluntary activation may be more efficient than using EMG biofeedback.[27] In addition, maximal isometric contraction was held for 3 s, then the supra-maximal twitch was applied and it may not be an ideal method for twitch interpolation. High-frequency fatigue could have happened in the first 3 s of contraction and it would have been better if the twitch stimulation was applied in that period.

The WOMAC index of knee functional activities increased significantly after training in both groups. The functional scores of the biofeedback group were increased significantly more than those of the exercise group. Improvement of knee function may allow more vigorous activity. Better knee function usually allows greater quadriceps strength as a result of higher activity.[29,33] The function, improvement in quality of life and patient satisfaction after surgery may be correlated to decreased pain after TKA.[14,15,17] These findings are supported by previous studies that found that scores on self-report questionnaires and functional tests improved steadily after surgery with post-operative training including neuromuscular electrical stimulation, in comparison with home exercises and advice.[21,24]

In contrast, in recent study, the authors found that a multidisciplinary rehabilitation after TKA did not give functional recovery or improvement in quality of life than conventional care.[8] In their study, the treatment program included strengthening, stretching and mobility exercises for the lower limbs, in addition to functional exercise in the form of walking. The time of program was 10 days only.[8] In the current study, the program was applied for 4 months, in addition to the EMG feedback training.

LIMITATIONS OF THE STUDY

Unfortunately, the current study has some limitations; for example, a potential limitation of the current study is that the number of patients was relatively small. A larger sample size would provide further insight into the efficacy of this training regime. Also, the intervention in this study was limited to four months, and measurements were performed before and after four months of the training program without further follow-up assessment. In addition, our assessment of muscle performance included only isometric mode and not include the dynamic (isokinetic) mode. Finally, the maximal isometric contraction in current study was held for 3 s then the supramaximal twitch was applied. Consequently, high frequency fatigue could have happened in the first 3 s of contraction and it would have been better if the twitch stimulation was applied in that period. So, in future study this twitches interpolation technique has been recommended.

CONCLUSION

Active exercises can accelerate recovery of quadriceps peak torque, voluntary activation and knee functional activities after unilateral TKA. The use of EMG biofeedback may enhance functional activities of patients with unilateral TKA. The use of EMG biofeedback may add benefit with extra time of training. Application of guided exercises with EMG biofeedback may add advantage in rehabilitation after unilateral TKA.

ACKNOWLEDGMENTS

The authors acknowledge Dr. Mona H. El Laithy and Dr. Hisham A. Mohamed for their assistance in data collection of this work.

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