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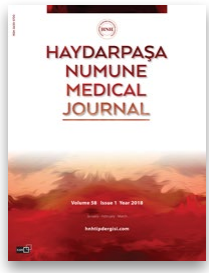

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ORIGINAL ARTICLE

Evaluation of the Effectiveness of Electromyographic Biofeedback Training in Patients with Patellofemoral Pain Syndrome

Merve Çalkın Korkmaz[1], Mehmet Ağırman[2], Sena Tolu[2], Arzu Dinç[2], Ahmet Salim Göktepe[2]

[1]Department of Physical Medicine and Rehabilitation, Division of Rheumatology, Marmara University Faculty of Medicine, İstanbul, Türkiye
[2]Department of Physical Medicine and Rehabilitation, İstanbul Medipol University Faculty of Medicine, İstanbul, Türkiye

Abstract

Introduction: This study aimed to evaluate the effects of adding electromyographic (EMG) biofeedback to an exercise program on pain, function, and electrical activity in the isometric contraction of the vastus medialis obliquus (VMO) and vastus lateralis (VL) muscles in patients with patellofemoral pain syndrome (PFPS).

Methods: The study included 30 patients with PFPS. The biofeedback group received physiotherapy and an EMG biofeedback-guided exercise program, and the control group received only physiotherapy with a home exercise program. The Visual Analog Scale (VAS) and PFPS Severity Scale (PSS) were used to evaluate pain severity. The Kujala Patellofemoral Scale (KPS) and the Functional Index Questionnaire (FIQ) were used to evaluate the effect of knee pain on daily living activities and lower extremity function.

Results: Compared to baseline, the VAS-current and severe pain, PSS, KPS, and FIQ scores and the mean and maximum isometric contraction values of the VMO and VL muscles were significantly improved in both groups. However, the maximum VMO and VL isometric contraction differential values were significantly increased only in the biofeedback group.

Discussion and Conclusion: Our findings suggest that the EMG biofeedback adjunct to a physiotherapy program for PFPS produces additional benefits for pain relief, improvement of daily life activities, and increasing muscle strength.

Keywords: Electromyographic biofeedback; exercise; patellofemoral pain syndrome.

Patellofemoral pain syndrome (PFPS) is an umbrella term used for the clinical presentation of retropatellar pain originating from the patellofemoral joint[1]. It is mostly seen in adolescents and adults with knee complaints[2]. PFPS is a clinical diagnosis and has no pathognomonic sign or symptom. Pain that is often localized behind, underneath, or around the patella is exacerbated by daily activities, such as climbing stairs, squatting, hiking, running, prolonged sitting, and standing up from sitting, since these activities led to increased patellofemoral compression[1,2].

The etiology of PFPS is multifactorial, resulting from a complex interaction between intrinsic anatomic and extrinsic factors. Overuse, malalignment, and trauma are commonly identified causative factors[1-3]. However, lower extremity muscle imbalance, delayed vastus medialis obliquus (VMO) activation, cartilage damage, decreased muscular flexibility, and reduction in strength have been also discussed as causative factors for PFPS[1-6]. The main biomechanical mechanism is overloading the knee's extensor mechanism and abnormal force generation and distribution during

Correspondence (İletişim): Sena Tolu, M.D. Department of Physical Medicine and Rehabilitation, İstanbul Medipol University Faculty of Medicine, İstanbul, Türkiye
Phone (Telefon): +90 505 442 47 22 **E-mail (E-posta):** dr.sena2005@gmail.com
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the movement of the patella within the femoral trochlea. Therefore, subchondral bone, synovium, retinaculum, skin, muscle, and nerve have been implicated as the most likely sources of pain in PFPS[3,4].

VMO performs as a medial stabilizer for the patella and keeps an appropriate patellofemoral alignment during knee movement. The previous studies have revealed that the delayed onset of VMO activity and reduction in muscle strength decreases medial patellar stability deteriorates the force vector balance between VMO and the vastus lateralis (VL), and increases lateral pull on the patella and patellofemoral joint compression on the lateral facet[5,7-9]. It has also been shown that patients with PFPS had a lower VMO/VL electromyographic (EMG) ratio than healthy controls[10]. Eventually, there are changes in patellofemoral contact and pressure area, which increases the risk of PFPS[5,7-9].

As the stabilization of the patella is mainly provided by strengthening the quadriceps femoris muscle, the effectiveness of different forms of exercises has been analyzed[6]. In the previous studies, both open and closed kinetic chain exercises were found effective in the improvement of pain, muscle strength, and long-term functional status in patients with PFPS[6,10-14].

Studies have revealed that EMG biofeedback has been used as an additional therapy to a conventional exercise program that facilitates the activation of VMO in the rehabilitation of PFPS. However, there is not yet any consensus regarding the additional benefits of including EMG biofeedback in exercise program[10,13-15]. The aim of this study was to investigate the effectiveness of EMG biofeedback as an adjunct therapy to a physiotherapy program on the improvement of functional status, pain, and isometric contraction of the VMO and VL muscles in patients with PFPS.

Materials and Methods

Patients

A total of 40 patients with PFPS were consecutively recruited from January to October 2017. The criteria for inclusion were as follows: (1) Age between 18 and 55 years, (2) having anterior knee pain for 1–24 months, (3) having at least one positive test that could trigger patellofemoral pain (sitting with knees at 90°, squatting, kneeling, going downstairs or upstairs, running, and jumping), and (4) having at least one positive result in patellar compression, patella medial, or lateral facial palpation sensitivity or Clark tests.

The exclusion criteria were as follows: (1) A previous history of patellofemoral dislocation and subluxation, (2) Kellgren-Lawrence Grade III-IV osteoarthritis, (3) positive Lachman, anterior drawer or pivot-shift tests, which knee instability, meniscal tear or positive meniscal tests, or limitation of joint mobility, (4) quadriceps muscle atrophy, (5) history of traumatic injury and infection or surgery of the lower extremity with knee joint involvement, (6) any type of inflammatory arthritis or other rheumatic diseases, (7) a history of malignancy, and (8) any contraindication for the use of hot pack (HP), ultrasound diathermy (US), transcutaneous electrical nerve stimulation (TENS) (e.g., infection, metal implants, pregnancy, thrombophlebitis, or impaired sensation, or skin lesion at the site of application), and[9] taking pain relief medications.

Study Design

The present study used a prospective, single-center, randomized, and controlled design. The patients were randomly assigned by a computer-generated table of random numbers to each study group. The study protocol was approved by the Medipol University Ethics Committee (Date: October 27, 2016, number: 10840098-604.01.01-E.24327), and written informed consent was obtained from all patients. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Treatment Procedures

Forty patients (21 males and 19 females) with PFPS between the ages of 20 and 55 years (mean age±standard deviation (SD), 37.77±10.49), who met the eligibility criteria, were randomized into two treatment groups. The more symptomatic or painful knee of each patient was chosen as the index knee for treatment. Both groups received five sessions per week for 3 weeks (a total of 15 sessions). All patients were treated by the same physiotherapist using a standard physiotherapy program consisting of HP and TENS for 20 min and US for 5 min (a frequency of 1 MHz and intensity of 1.5 W/cm^2 were applied on a circular basis). The biofeedback group also received an EMG biofeedback-guided standard exercise program in each session.

EMG Biofeedback Training

EMG biofeedback training was performed with a Chattanooga Group Intelect Advanced Color Combo + EMG machine (Fig. 1). The EMG device was placed where the patient could easily see. The EMG signals with a vertical graph for both VMO and VL were displayed on the screen of the device.

Electrode Placement

Before starting treatment, the electrode attachment areas

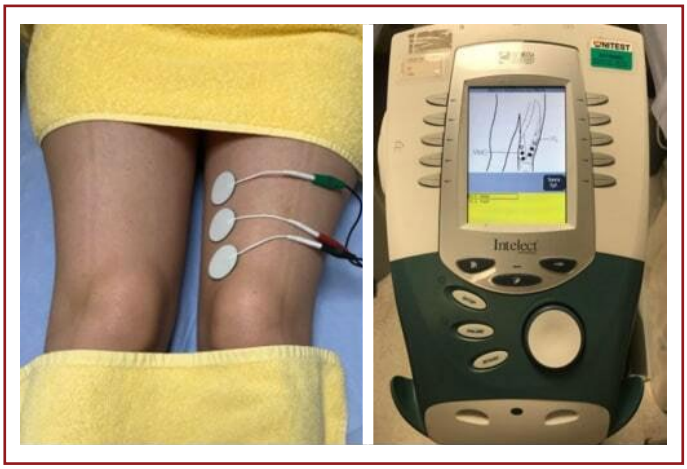

Figure 1. Chattanooga group intellect advanced color combo + EMG machine.

were shaved and the physiotherapist cleaned the patients' skin with an alcohol swab to reduce skin resistance. Skin-adhesive 1.25-inch (3 cm) surface electrodes were attached to VMO and VL to record muscle activity (Fig. 1). To ensure that the electrodes were accurately placed, we marked the placements for the electrodes on the skin in each patient.

Exercise Procedure

The patients in the biofeedback group were informed about the procedure in detail. They were also got motivated to behold muscle activity and increase the VMO and VL activation while performing the exercises. Isometric quadriceps, straight leg raising, and terminal knee extension exercises (knee extension exercise in the terminal 30° of motion) were performed with EMG biofeedback for 15 sessions. The exercises were undertaken in 20 repetitions in the form of 10 s at contraction and 10 s at rest. The program was completed after a total of 100 repetitions throughout the session.

The patients in the control group were given the same exercise set as a home exercise program. The first set of exercises was performed under the supervision of clinical physiotherapists. The patients' adherence to the exercise program was checked verbally every day before physiotherapy began. In both groups, the maximum and mean isometric contraction values of VMO and VL were measured by EMG biofeedback before and at the end of the 15^{th} session.

Study Assessment

Demographic variables (age, gender, and body height and weight, body mass index [BMI] [kg/m^2]), symptom duration (months), comorbidities, and present medications were recorded. Detailed physical examinations were performed in all the patients. The outcome measures were assessed immediately after the last treatment by a blinded physiatrist using the Visual Analog Scale (VAS), Functional Index Questionnaire (FIQ), Kujala Patellofemoral Scale (KPS), and PFPS Severity Scale (PSS). The maximum and mean contraction values of the VMO and VL muscles were determined with the biofeedback device.

VAS was used to evaluate pain severity. The patients were asked mark their pain intensity level on a 100-mm ruler (0=no pain and 100=highest level of pain). The worst pain the patients reported to have ever experienced before and at the end of treatment was noted as VAS-severe pain, and their current pain level as VAS-current pain.

KPS was used to analyze the impact of knee pain on the activities of daily living. KPS is a 13-item tool that questions difficulties and pain throughout an activity. The total score is 100 (ranging 0–100). 0 refers a most painful and dysfunctional knee and 100 refers a normal, painless, and completely functional knee[16,17].

PSS was used to measure patellofemoral pain associated with functional activities (climbing/descending stairs, squatting, walking, jogging, running, participating in a sport, sitting for 20 min with knees at 90° flexion, kneeling on knees, resting, and following an activity). This is a ten-statement VAS survey for patients to score their pain level in 10 functional activities. The final score is calculated by averaging the score of each of the 10 statements and standardizing them to a percentage out of 100[18].

FIQ contains of eight questions used for evaluating functional limitations in patients with PFPS. Each question is answered as either "unable to do" (0 point), "could do with a problem" (1 point), or "could do without problem" (2 points). The maximum score is 16 points[19].

Statistical Analysis

The data analysis of the study was performed using IBM SPSS version 17.0 (SPSS Inc., Chicago, IL, USA). The Shapiro–Wilk test was used to evaluate the normality of data. Descriptive analyses were presented as mean±SD, median, minimum, and maximum for continuous variables. Categorical variables were meant as numbers. The inter-group comparisons were undertaken using the independent samples t-test and the Mann–Whitney U test for continuous variables, and the Pearson Chi-square test for categorical variables. Intra-group differences compared to the baseline values were evaluated using the paired-samples t-test and the Wilcoxon signed-rank test. A p value of 0.05 or less was accepted as statistically significant.

Results

A total of 40 patients with PFPS were assessed for eligibility and 30 of these patients were included in the study. The remaining 10 patients refused to participate in the study. The 30 patients were randomly allocated to two study arms: A biofeedback group treated with physiotherapy and EMG biofeedback in addition to an exercise program in each session and control group treated with only physiotherapy and given a home exercise program (Fig. 2).

The baseline characteristics of the patients are given in Table 1. There was no statistically apparent difference between the two groups in terms of demographic characteristics (age, gender, and BMI), symptom duration, and baseline clinical parameters (p>0.05).The intra-and inter-group changes in the VAS-current and VAS-severe pain and KPS, PSS, and FIQ scores are shown in Table 2. In both groups, the VAS-current and severe pain significantly decreased compared to the baseline (p=0.001). Similarly, the KPS, PSS, and FIQ scores were significantly improved in both groups following treatment (p<0.001 for all).

When the changes in the VAS-severe pain, KPS, PSS, and FIQ scores over time were compared, there were statistically significant differences between the two groups (p=0.004,

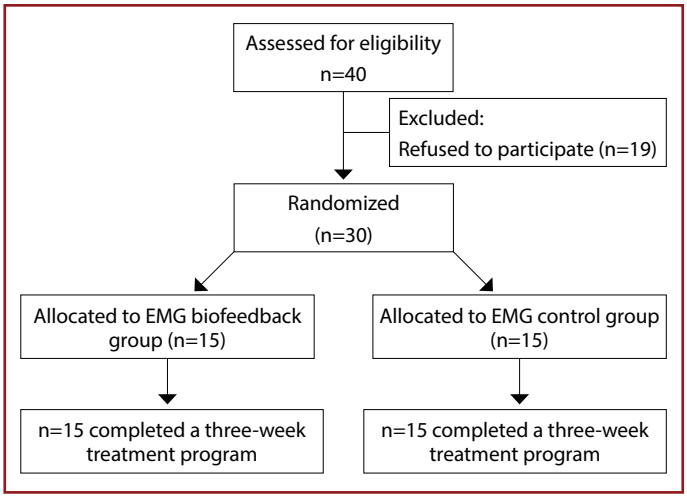

Figure 2. Flowchart of the study.

Table 1. Patient characteristics

	Biofeedback Group (n=15)	Control Group (n=15)	p
Age, years*	37.53±12.08	38.66±10.43	0.785[1]
Gender (female/male), n	8/7	9/6	0.713[2]
BMI* (kg/m^2)	26.15±4.95	27.27±3.74	0.491[1]
Symptom duration, months**	12 (2-24)	9 (2-24)	0.336[3]
VAS-current pain score**	5 (3-10)	5 (3-9)	0.699[3]
VAS-severe pain score**	10 (5-10)	9 (5-10)	0.182[3]
AKPS score*	71.06±7	74.93±6.46	0.127[1]
PSS score*	60.06±13.66	57.60±16.87	0.663[1]
FIQ score*	8.26±2.15	9.73±1.90	0.058[1]

BMI: body mass index; AKPS: Kujala Anterior Knee Pain Patellofemoral Scale; PSS: Patellofemoral Pain Syndrome Severity Scale; FIQ: Functional Index Questionnaire. *Data are expressed as mean±SD, ** Data are expressed as median (minimum- maximum); n: number of subjects; [1]Independent samples t- test; [2] Chi-square test; [3] Mann-Whitney U test; statistically significant at p<0.05.

Table 2. Comparison of the changes within and between the study groups

	Biofeedback Group	Control Group	p[2]
VAS-current pain score**			
Baseline	5 (3-10)	5 (3-9)	0.097
Post-intervention	2 (0-5)	3 (1-5)	
Delta (baseline to post-intervention)	-3 [(-5) to -2]	-2 [(-5) to -1]	
p[1]	0.001	0.001	
VAS-severe pain score**			
Baseline	10 (5-10)	9 (5-10)	0.004
Post-intervention	5 (0-8)	6 (3-8)	
Delta (baseline to post-intervention)	-5 [(-10) to 3]	-3 [(-5) to1]	
p[1]	0.001	0.001	
KPS score*			
Baseline	71.06±7	74.93±6.46	0.005
Post-intervention	85.06±8.26	82.46±11.50	
Delta (baseline to post-intervention)	14.0±5.01	7.53±6.43	
p[1]	<0.001	<0.001	
PSS score*			
Baseline	60.06±13.66	57.60±16.87	0.003
Post-intervention	30.46±13.72	39.06±13.58	
Delta (baseline to post-intervention)	-29.60±9.69	-18.53±8.97	
p[1]	<0.001	<0.001	
FIQ score*			
Baseline	8.26±2.15	9.73±1.90	<0.001
Post-intervention	13.06±1.79	12.86±1.06	
Delta (baseline to post-intervention)	4.80±1.69	2.40±1.05	
p[1]	<0.001	<0.001	

VAS: Visual Analog Scale; KPS: Kujala Patellofemoral Scale; PSS: Patellofemoral Pain Syndrome Severity Scale; FIQ: Functional Index Questionnaire. *Data are expressed as mean±SD, ** Data are expressed as median (minimum- maximum); p[1]: p value for the comparison of intra-group differences from baseline to post-intervention; p[2]: p value for inter-group comparisons of delta values; statistically significant at p<0.05.

Table 3. Comparison of the isometric strength of the changes in VMO and VL within and between the study groups

	Biofeedback Group	Control Group	p^2
Mean VMO isometric contraction			0.505
Baseline	80 (35-250)	75 (20-165)	
Post-intervention	180 (55-370)	130 (80-210)	
Delta (baseline to post-intervention)	70 (15-230)	45 (10-170)	
p^1	0.001	0.001	
Maximum VMO isometric contraction			0.205
Baseline	100 (40-280)	95 (25-190)	
Post-intervention	205 (75-470)	170 (100-250)	
Delta (baseline to post-intervention)	85 (20-275)	60 (10-175)	
p^1	0.001	0.001	
Mean VL isometric contraction			0.934
Baseline	105 (30-375)	75 (15-165)	
Post-intervention	170 (60-400)	145 (50-305)	
Delta (baseline to post-intervention)	55 (0-260)	40 (10-180)	
p^1	0.001	0.001	
Maximum VL isometric contraction			0.739
Baseline	135 (40-405)	90 (20-210)	
Post-intervention	180 (85-495)	160 (70-345)	
Delta (baseline to post-intervention)	40 (5-190)	40 (10-190)	
p^1	0.001	0.001	
Maximum VMO and VL isometric contraction differential			0.054
Baseline	0.83 (0.37- 1.57)	1.0 (0.42-2.44)	
Post-intervention	1.07 (0.47- 2.32)	1.06 (0.65- 1.42)	
Delta (baseline to post-intervention)	0.13 [(-0.54) to 1.95]	-0.03 [(-1.44) to 0.62]	
p^1	0.025	0.802	

VMO: Vastus medialis obliquus; VL: Vastus lateralis; p^1: p value for the comparison of intra-group differences from baseline to post-intervention; p^2: p value for inter-group comparisons of delta values; statistically significant at $p<0.05$.

p=0.005, p=0.003, and p<0.001, respectively). Only the change in the VAS-current pain score did not statistically significantly differ between the two groups (p=0.097).

The intra-and inter-group changes in the isometric quadriceps contraction values of the VMO and VL muscles are presented in Table 3. In both groups, the mean and maximum isometric contraction values of the VMO and VL muscles were significantly increased compared to the baseline (p=0.001). The maximum VMO and VL isometric contraction differentials were calculated as the differences between the baseline, post-intervention, and delta values of the maximum isometric contracture value of these muscles. These differential values were significantly increased compared to the baseline only in the biofeedback group (p=0.025). In addition, in the biofeedback group, the delta of the differential value was higher than in the control group, but it did not reach a significant level (p=0.054).

Discussion

Two main findings emerged from the analysis of our study evaluating the effectiveness of EMG biofeedback-guided strength training exercises of quadriceps muscle to improve pain and functional status in patients with PFPS. First, EMG biofeedback is effective and well-tolerated treatment modality on improving physical function and reducing pain in PFPS and secondly EMG biofeedback produce additional benefits to functional improvement and severe pain reduction compared with only exercise program in PFPS.

A muscular imbalance between the VMO and VL muscles or decreased muscle strength of VMO can cause to extreme lateral tracking of the patella and pathological changes in patellofemoral joint pressure and knee joint stability[12,20]. Exercise is considered a mainstay in the conservative treatment of PFPS and particularly improve the medial force on the patella by strengthening VMO which is the primary dynamic medial stabilizer of the patella[21]. Both open and closed kinetic chain exercises have been shown to significantly improve function and muscle strength[6,10-14].

There are few studies evaluating the effect of neuromuscular re-education such as EMG biofeedback on knee osteoarthritis and PFPS. While the application of exercise programs with EMG biofeedback showed positive effects in some studies,[10,14,15] others failed to show any additional benefits in terms of improving pain, function, and muscle strength[13,22,23]. In this study, we analyzed the effectiveness of EMG biofeedback therapy in reducing pain, physical function, and isometric muscle strength of VMO and VL when used as an adjunct to conventional therapy in patients with PFPS. Our study results revealed that a 3-week treatment program provided significant improvements in the pain and functional status scores of the two groups. Furthermore, the biofeedback group had significantly more improvement in severe pain and functional status than the control group. On the contrary, the previous studies did not find an apparent difference between the biofeedback and control groups in terms of the pain and functional status of patients with PFPS[13,14]. Considering the contradictory results obtained from the previous studies, our result may be explained by the use of physical therapy agents (HP, TENS, and US), which also affect the treatment efficacy of PFPS.

In our study, the pair-wise comparisons between the two groups (EMG biofeedback-combined exercise program and an exercise only group) showed that the mean and maximum contraction of VL and VMO after 3 weeks were significantly increased compared to the baseline values in both groups. The inter-group analysis revealed that the improvement in the contraction values in the EMG biofeedback group did not significantly differ compared to the control group. Dursun et al.[13] did not find any superiority of a strengthening exercise program assisted with EMG biofeedback in their study. However, they showed that both groups of patients had significant clinical improvement in the pain level, functional status, and mean and maximum contraction values of the VMO and VL muscles. Yip and Ng reported that the biofeedback group achieved faster improvements in lateral patellar rotation and peak torque per body weight than the exercise only group; however, there is no statistically detected difference between the groups in terms of peak torque[14].

In patients with knee osteoarthritis, Anwer et al.[23] demonstrated that a 5-week isometric exercise program combined with EMG biofeedback increased quadriceps muscle strength compared to an exercise program alone. Similarly, Raeissadat et al.[24] found that the VAS score was significantly decreased in the biofeedback group compared to a control group. Therefore, we consider that EMG biofeedback may help patients to learn muscular control, improve the synchronization of work-rest times during exercise, and achieve better patellofemoral stability.

In our study, a significant increase was determined in the maximum VMO and VL isometric contraction differential values in the biofeedback group. The same group also had a higher differential value than the control group, but this did not reach a significant level. Similarly, Ng et al.[10] analyzed the effects of an EMG biofeedback-combined exercise program on the relative activation of VM and VL in patients with PFPS. According to the results, the EMG biofeedback group had a significantly higher VMO/VL EMG ratio. The authors suggested that EMG biofeedback provided visual and auditory information on muscular contractions or movements on a real-time basis; thus, patients could achieve effective and appropriate muscle contraction[10]. Therefore, we consider that EMG biofeedback improves muscle compliance to exercise and increases the motivation of patients to engage in rehabilitation programs.

The important limitation of our study is the non-significant differences between the two groups in terms of the isometric contraction of the VL and VMO muscles. These results may have been due to the limited number of patients included in the study and the short-term follow-up.

Addition of EMG biofeedback to the physiotherapy exercise program might accelerate the improvement in PFPS symptoms within the first few weeks of treatment. Biofeedback can enhance patient motivation and compliance, and thus improve clinical outcomes, and may shorten the treatment process and reduce the treatment cost. EMG biofeedback can provide benefits in patients with PFPS, who are able to understand and respond to visual or auditory instructions.

Ethics Committee Approval: The study protocol was approved by the Medipol University Ethics Committee (Date: October 27, 2016, number: 10840098-604.01.01-E.24327), and written informed consent was obtained from all patients.

Peer-review: Externally peer-reviewed.

Authorship Contributions: Concept: A.S.G., M.Ç.K.; Design: A.S.G., M.Ç.K.; Data Collection or Processing: A.S.G., M.A., M.Ç.K.; Analysis or Interpretation: S.T., A.D., A.S.G.; Literature Search: S.T., A.S.G., M.A.; Writing: S.T., M.Ç.K.

Conflict of Interest: None declared.

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