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Original Article

The Effect of Neuromuscular Exercise on Postural Control and Functional Performance in Female Taekwondo Players with Functional Ankle Instability

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Abstract

Background: Functional ankle instability (FAI), a common complication after ankle sprain in Taekwondo players, is associated with some postural control problems. The present study aimed to investigate the effects of neuromuscular exercise program on dynamic postural control and functional performance in female Taekwondo players with functional ankle instability.
Methods: This quasi-experimental study recruited a convenience sample of thirty female Taekwondo athletes in Babol, Mazandaran Province, Iran from April to May 2024. The study participants were randomly allocated to one of the two groups: a neuromuscular exercise program (NEP) group (n=15) or a control group (n=15). NEP included upper and lower balance, strength, proprioception and hop exercises. The exercise program was performed three times weekly, for eight weeks. Medio-lateral (ML) and anterior-posterior (AP) center of pressure (COP) sway area, time to stabilization (TTS), and functional performance were assessed before and after the intervention using the single-leg hop (SLH) and triple hop (TRH) tests. Center of pressure (COP) data were recorded using a Kistler force plate. A two-way repeated-measures ANOVA was employed to analyze within-group and between-group differences.
Results: Mean displacement of medio-lateral (108.40±22.79 vs 142.80±34.13, P=0.001) and anterior-posterior (288.06±72.17 Vs 349.60±114.95, P=0.001) of center of pressure significantly decreased in the exercise group after neuromuscular exercise program compared with the control group. Also, time to stabilization significantly decreased in medio-lateral (1.21±0.1 Vs 1.64±0.21, P=0.001) and anterior-posterior (0.87±0.09 Vs 1.05±0.25, P=0.006) directions in the exercise group compared with the control group.
Conclusions: Eight weeks of neuromuscular exercise program decreased center of pressure sway area and time to stabilization in female Taekwondo players with functional ankle instability. Taekwondo is a postural stability and balance-demanding sport; therefore, it is crucial for coaches to incorporate neuromuscular exercise program in the training sessions.

Keywords: Ankle Sprain, Postural Balance, Physical Performance, Exercise Therapy

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1. Introduction

Ankle sprain is one of the most common injuries in many sports. It has been shown that the prevalence of ankle sprains in Taekwondo is high due to unilateral activities and movements (1). An ankle sprain typically occurs during weight-bearing when the foot is in contact with the ground, especially unilaterally and usually due to excessive supination of the rear part of the foot (2).

The incidence of chronic complications after an ankle sprain is ranging from 32% to 74% (3, 4) including swelling, pain, instability and weakness (1). These residual symptoms characterize a condition known as Chronic Ankle Instability (CAI) (3). Clinically, CAI is categorized into two distinct types; mechanical instability involves objective physical laxity of the ligaments and altered joint mechanic (1). In contrast, functional instability is defined by subjective feelings of instability and neuromuscular deficits, such as impaired proprioception and muscle control, without necessarily having increased ligamentous laxity (5). Neuromuscular impairments are considered a major risk factor in the development of functional ankle instability (FAI) (5).

Postural control and functional performance are critical components of athletic success, especially in sports like Taekwondo that need rapid changes in direction, correct kicking techniques, and dynamic balance (6). Female Taekwondo athletes are particularly susceptible to functional ankle instability, which commonly manifests as a history of repeated sprains, impaired joint position sense, and reduced control of the stabilizing muscle (7, 8). FAI not only increases the risk of re-injury but

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also compromises postural stability, agility, and sport-specific performance, which are essential for competitive success (6, 8).

Neuromuscular exercise (NE) has emerged as a promising intervention to address these deficits by enhancing proprioception, muscle activation patterns, and dynamic stability (9, 10). NE typically includes balance training, plyometrics, and sport-specific drills designed to improve feedforward and feedback mechanisms of postural control (6, 8). Recent studies have demonstrated the efficacy of NE in improving balance and functional performance in athletes with FAI, though its specific application in female Taekwondo players remains unknown (7, 8).

While the body of research on neuromuscular exercises (NE) continues to expand, their specific impact on postural control and functional performance in female Taekwondo athletes with functional ankle instability (FAI) remains underexplored. Existing evidence has primarily focused on male athletes or non-sport-specific populations, leaving a gap in understanding how tailored NE protocols can benefit this high-risk group (8). It has been demonstrated that Taekwondo players with repetitive ankle sprain have lower postural control in injured and uninjured limb than controls based on center of pressure (COP) parameters (11). Although research exists on the immediate impacts of plyometric training on balance (12), the influence of structured neuromuscular training on postural control in Taekwondo athletes with FAI is not well-documented based on the literature search.

Functional performance deficit is another complication in athletes with FAI (13). Functional performance tests are useful and valuable tools for determining specific movement patterns in sports and exercise. Hop tests are reliable and valid instrument for assessing functional performance in athletes with CAI (14). Previous studies demonstrated that neuromuscular training could improve hop test performance in patients who have undergone anterior cruciate ligament (ACL) reconstruction (15, 16). However, less is known about the effect of neuromuscular training on hop performance in athletes with FAI. Therefore, this study aimed to evaluate the effects of an 8-week neuromuscular exercise program on dynamic postural control and functional performance in female Taekwondo players with functional ankle instability.

2. Methods

2.1. Design

This was a quasi-experimental study, with pretest posttest design and a control group conducted in Babol, Mazandaran Province, Iran from April to May 2024.

2.2. Selection and Description of Participants

A convenience sample of thirty physically active female Taekwondo athletes with Functional Ankle Instability (FAI) was recruited for this study. The participants were randomly allocated to one of the two groups: a neuromuscular exercise group (N=15; age: 19.13±3.70 years, height: 1.69±0.12 m, weight: 58.33±8.77 kg) or a control group (N=15; age: 20.20±3.96 years, height: 1.71±0.13 m, weight: 60.46±8.83 kg), as illustrated in Figure 1.

The allocation sequence was generated by an independent researcher using a computer-based, permuted block randomization method with varying block sizes of 4 and 6 to ensure balanced group sizes. Assignments for the two groups (intervention and control) were placed in sequentially numbered, opaque sealed envelopes to ensure concealment. An envelope was opened only after a participant had completed all baseline assessments. The inclusion criteria for FAI, adopted from previous research (17, 18) included: 1) a history of a minimum of three ankle sprains within the preceding three years; 2) a self-reported sensation of the ankle "giving way" during sports activities; 3) self-reported reduced ankle function; 4) no acute ankle sprain in the previous six months; and 5) engagement in sports activities at least three times per week.

The exclusion criteria were: 1) bilateral ankle instability or sprain; 2) a history of lower extremity surgery; or 3) any other significant lower extremity injury beyond the ankle.

2.3. Sample Size Determination

The required sample size was calculated using G*Power (v.3.1) with an alpha level of 0.05 and using COP (10±8 mm) and TTS (50±40 ms) data from prior research (19).

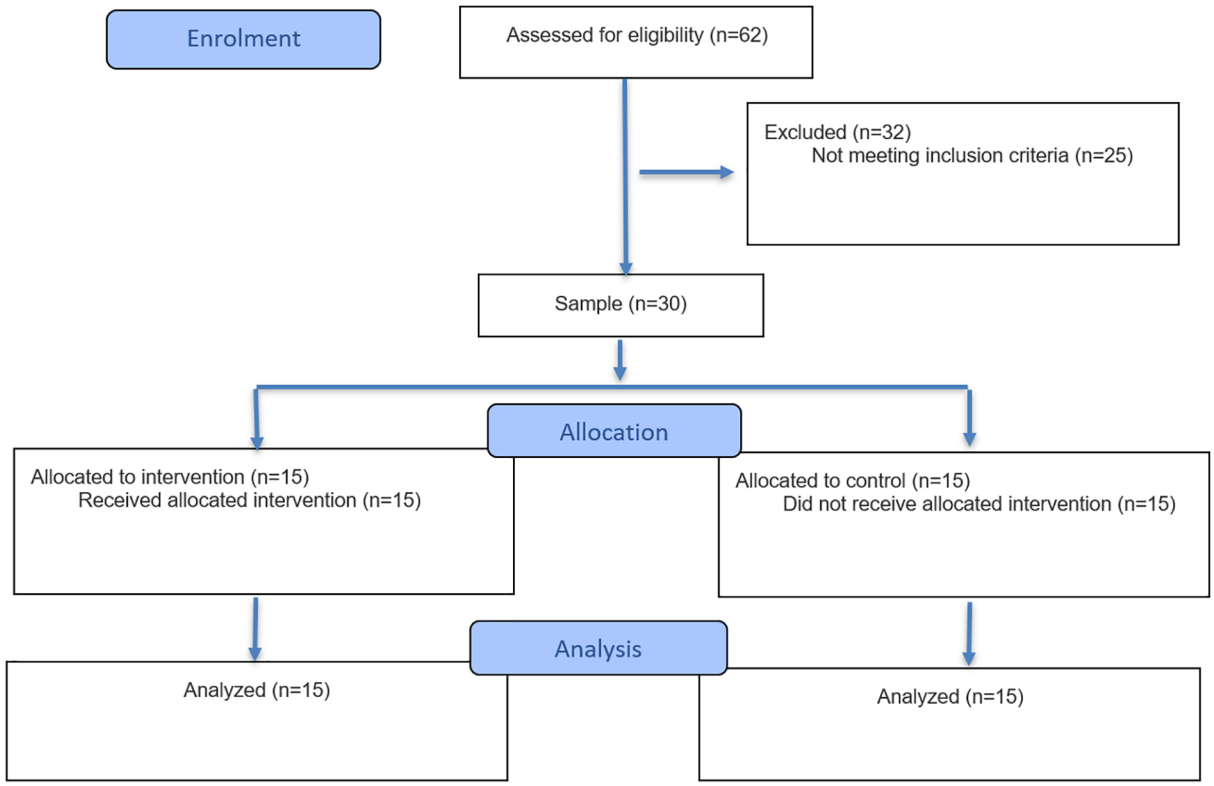

Figure 1: The figure shows the CONSORT flow diagram of the study.

According to the effect size assumptions, a priori power analysis determined that a total sample size of 30 participants (15 per group) was sufficient to achieve the desired statistical power (20).

2.4. Data Collection and Measurements

Postural control was quantified by analyzing center-of-pressure (COP) displacements in the anteroposterior (AP) and mediolateral (ML) planes. A Kistler force plate (60 × 90 cm; Winterthur, Switzerland) recorded ground reaction forces at 1000 Hz. The raw COP signal was processed using a 4th-order, zero-lag, low-pass Butterworth filter with a 5 Hz cutoff frequency. Subsequently, the data were time-normalized to 500 points using a custom MATLAB (R2020a, MathWorks) script. The primary outcome measures were the total COP path excursions in the ML (x-axis) and AP (y-axis) directions during the entire stance phase following foot contact.

For calculating TTS, we used a ground reaction forces (GRF) range-of-variation window for the last 5 seconds of each trial (seconds 15–20). We calculated a normalized reference variable by taking the smallest absolute GRF ranges during the last 5 seconds of each trial for AP, ML and vertical components and dividing these components by participant body weight to normalize. Vertical TTS is defined as the time for vertical ground reaction force to reach and stay within 5% of body weight after landing. We used sequential estimation to calculate medio-lateral and anterior-posterior TTS. An algorithm is used in this method to calculate the cumulative mean of a data sequence. The overall series mean was used as the baseline reference, and the cumulative average of the ground reaction force data was compared with this mean. Mediolateral and anteroposterior time to stabilization were defined as the time elapsed from landing until the sequential cumulative average first remained within±0.25 standard deviations (SD) of the overall series mean (21).

All participants received standardized instruction for the single-leg landing task. Starting from a 30 cm platform on their involved (FAI) limb with the contralateral knee flexed to 90°, the participants landed on the force plate with the test limb. To standardize posture, participants placed their hands on their hips to minimize upper-limb contributions and trunk compensations during the task. Following three practice trials for familiarization, five successful test trials were recorded. Each trial required maintaining a stable single-leg stance for 20 seconds after landing.

We used single-leg hop (SLH) and triple hop (TRH) for distance to assess functional performance. For SLH, the participants were required to perform maximal distance hop in forward, and for TRH they performed three consecutive jumps forward on the same leg. For both tasks, the distance between the starting toe position and the final heel position was measured. The participants performed SLH and TRH on both FAI and healthy limb, and the limb symmetry index (LSI) has been compared between the two groups.

2.5. Neuromuscular Exercise Program (NEP)

The exercise group performed NEP for 8 weeks, three times weekly and for 24 sessions in total. Each exercise session was 45 minutes, including 15 minutes for warm up and 30 minutes for performing specific NEP. NEP included upper and lower, balance, strength, proprioception and hop exercises (Table 1). The difficulty of the exercise progressed gradually from the first week to the eighth week. The control group received no intervention and performed their routine exercises of Taekwondo.

2.6. Procedure

Following baseline assessments, participants were randomly allocated into either an experimental group, which underwent a specialized 8-week neuromuscular exercise program (NEP), or a control group, which continued with their regular Taekwondo practice. The NEP was conducted three times per week for approximately 30 minutes per session, either before or after regular team practice, and was carefully supervised by the research team. The intervention was progressive, systematically increasing in difficulty each session. The initial phase focused on foundational static and dynamic balance exercises (e.g., single-leg stands on stable and then unstable surfaces, star excursion balance reaches). This progressed to incorporate plyometric and sport-specific drills (e.g., controlled hop-to-hold landings, directional jumps, and simulated kicking maneuvers with an emphasis on stable single-leg postures) designed to challenge postural control under dynamic and Taekwondo-relevant conditions. All participants, in both groups, completed identical pre- and post-intervention testing sessions conducted by blinded assessors. Postural control was the primary outcome, measured quantitatively using a force plate to record center of pressure (COP) displacement and sway area during single-leg drop landing. Functional performance was assessed using two hop tests: the single-leg hop test and the triple-hop test.

2.7. Data analysis

The normality of all data sets was verified using the Shapiro-Wilk test. A repeated-measures ANOVA was employed to examine the effects of time and group, as well as their interaction (time × group), on the dependent variables. In cases of significant interactions, we used post hoc analyses with Bonferroni corrections to identify specific differences both within groups (from pretest to posttest) and between groups (comparing NEP and CG). The strength of the identified effects was quantified

Table 1: Description of the neuromuscular exercise program

Week 1 and 2	Week 3 and 4	Week 5 and 6	Week 7 and 8
1. Single Leg Balance (SLB) (60 sec)	1. Single Leg Balance (SLB) on a mat (30 sec)	1. Single Leg Balance (SLB) on a mat (60 sec)	1. Single Leg Stance (SLS) on a cushion ball (60 sec)
2. SLB with medicine ball throwing	2. Single Leg Stance (SLS) on a mat with ball throwing	2. Single leg stance on a cushion ball with ball throwing	2. Single Leg Stance (SLS) on a BUSO ball with ball throwing
3. Single leg dead lift	3. Single leg dead lift on mat	3. Single leg dead lift with dumbbell	3. Single leg dead lift with trunk rotation
4. Lateral single leg hop (SLH)	4. Lateral hops between two cones with 30 cm distance	4. Lateral hops between two cones with 45 cm distance	4. Lateral hops between two cones with 1 meter distance
5. Lateral single leg hop (SLH) -forward-backward	5. Lateral single leg hop (SLH) -forward-backward between two cones with 30 cm distance	5. Lateral single leg hop (SLH) -forward-backward between two cones with 45 cm distance	5. Lateral single leg hop (SLH) -forward-backward between two cones with 1 meter distance
6. Lateral single leg hop (SLH) -random directions (right, left, forward, backward) with verbal cue	6. Lateral single leg hop (SLH) -random directions (right, left, forward, backward) on mat with verbal cue	6. Lateral single leg hop (SLH) -random directions (right, left, forward, backward) on mat with verbal cue	6. Lateral single leg hop (SLH) -random directions (right, left, forward, backward) on mat with verbal cue

SLH: Single Leg Hop; SLB: Single Leg Balance; SLS: Single Leg Stance; BUSO: Both Sides Utilized

using Cohen's d, interpreted as small (d≥0.2), moderate (d≥0.5), or large (d≥0.8). Data analysis was performed using intention-to-treat principles, with appropriate statistical tests to compare within-group and between-group changes from baseline to the 8-week follow-up. All analyses were performed in SPSS version 26.0, IBM Corp., Chicago, IL, with the alpha level for significance set at P<0.05.

3. Results

The participants were 30 female Taekwondo athletes, equally divided into a control group (n=15) and a neuromuscular exercise group (n=15). The demographic characteristics of the participants and the mean (SD) values of the dependent variables by time and group are presented in Table 2 and Table 3, respectively. The two groups were comparable at baseline for age, height, body mass, and other demographic variables (Table 2).

3.1. Postural Stability Outcomes

Analysis indicated that the mean displacement of the center of pressure significantly decreased in the exercise group after the neuromuscular exercise program compared with the control group. Specifically, mediolateral (ML) COP displacement was reduced from 141.86±42.62 to 108.40±22.79 mm in the exercise group, whereas there was no significant difference in control form pretest to posttest. Similarly, anteroposterior (AP) COP displacement significantly decreased from 362.26±111.79 to 288.06±72.17 to mm in the exercise group. It should be noted that there was a significant difference between the control and exercise groups in mediolateral and anteroposterior center of pressure displacement at posttest (Table 3).

Time to stabilization (TTS) also improved significantly in the exercise group compared with the control group. In the ML direction, TTS decreased from 1.67±0.19 to 1.21±0.10 in the exercise group, indicating faster stabilization after landing. In the AP direction, TTS decreased from 1.08±0.10 to 0.87±0.09 in the exercise group, again favoring the exercise group (Table 3). However, no significant between and within-group difference was observed for vertical TTS, suggesting that the NEP primarily improved dynamic stability in the horizontal (ML and AP) planes rather than in the vertical direction (Table 3).

3.2. Functional Performance

Functional performance was assessed using the

Table 2: Demographic characteristics of participants (mean±SD)

Demographics Variables	NEP Group (N=15)	Control Group (N=15)	P
Age (years)	19.13±3.70	20.20±3.96	0.45
Height (meters)	1.69±0.12	1.71±0.13	0.40
Weight (kg)	58.33±8.77	60.46±8.83	0.61
BMI (kg/m2)	23.43±5.13	24.40±2.98	0.98
Time since last injury (months)	8.93±1.27	8.73±1.66	0.33

SD: Standard Deviation; NEP: Neuromuscular Exercise Program; BMI; Body Mass Index

Table 3: Center of pressure and time to stabilization measures by group and time (Mean±SD)

Measure	Group	Pretest	Posttest	Within-group *P value	Between-group (Pre) *P value	Between-group (Post) *P value
Center of Pressure, Mediolateral Displacement (mm)	NEP	141.86±42.62	108.40±22.79	0.001		
	Control	144.73±40.30	142.80±34.13	0.41	0.65	0.001
Center of Pressure, Anterior-Posterior Displacement (mm)	NEP	362.26±111.79	288.06±72.17	0.005		
	Control	352.26±120.67	349.60±114.95	0.25	0.54	0.001
Anterior-posterior Time to Stabilization (sec)	NEP	1.08±0.10	0.87±0.09	0.009		
	Control	1.07±0.17	1.05±0.25	0.48	0.49	0.006
Medio-lateral Time to Stabilization (sec)	NEP	1.67±0.19	1.21±0.10	0.001		
	Control	1.65±0.23	1.64±0.21	0.54	0.84	0.003
Vertical Time to Stabilization (sec)	NEP	1.10±0.07	1.12±0.09	0.18		
	Control	1.13±0.12	1.15±0.95	0.16	0.52	0.73

NEP: Neuromuscular Exercise Program

single-leg hop (SLH) and triple-hop (TRH) tests, and the limb symmetry index (LSI) was calculated for both tasks. Analysis showed no significant between-group differences in LSI for SLH distance or TRH distance. This indicated that, although the NEP significantly improved postural stability (COP displacement and TTS in ML and AP directions), it did not result in additional between-group improvements in hop performance as measured by LSI over the study period.

4. Discussion

The present study investigated the effects of an eight-week neuromuscular exercise program (NEP) on postural control and functional performance in female Taekwondo athletes with functional ankle instability (FAI). The main findings indicated that NEP significantly improved postural control, as evidenced by reductions in mediolateral (ML) and anteroposterior (AP) center of pressure (COP) sway and time to stabilization (TTS). However, no significant improvements were observed in functional performance measures, including single-leg hop (SLH) and triple hop (TRH) distances.

Despite many studies conducted previously (22-26), there is no consensus about the best training/rehabilitation technique for preventing lateral ankle sprain and recurrent instability (27). However, it has been demonstrated that neuromuscular/balance training is widely established rehabilitation mode for people with ankle instability (28). Previous studies indicated the positive effect of neuromuscular training (e.g., single leg balance, balance on unstable surface under varied visual conditions (eyes open/closed) (29, 30).

The observed improvements in COP and TTS are consistent with previous studies reporting that neuromuscular and balance training enhances both static and dynamic postural control in individuals with ankle instability (19, 30). These findings support the role of NEP as an effective rehabilitation strategy for improving sensorimotor function in this population. Neuromuscular training is thought to enhance central nervous system efficiency, leading to improved neuromuscular coordination and postural regulation (31, 32).

Balance improvement is critically important for Taekwondo players who perform repeated movements on one leg (33). Improved muscle reaction time could be one explanation for the reduction of COP sway and TTS in ML and AP directions. It has been shown that neuromuscular training can significantly increase peroneal and tibialis anterior muscle's reaction time, which account for ML (34) and AP stability (35). Indeed, neuromuscular exercises can promote the anticipatory activity of these muscles before foot contact, which is critical for stabilizing the body in dynamic movements. Another explanation could be activating mechanoreceptors and improving proprioceptive feedback after NEP. This leads to better muscle coordination and faster reflex responses, which are vital in Taekwondo when landing after jumps or kicks (36). Our NEP included stretch-shortening cycle such as hop which can improve muscle strength around the ankle and decrease TTS in CAI patients (19). When the muscles become stronger, they can provide more stable of support and promote the athletes' ability to alterations in direction of movement (37).

In contrast to postural control outcomes, SLH and TRH distances did not significantly change after the intervention. This finding is in line with some previous studies suggesting that short-term neuromuscular interventions may not be sufficient to elicit measurable improvements in hop performance, which may depend more on maximal strength and power development (16, 38, 39). It is possible that the NEP primarily targeted sensorimotor control rather than force production capacity, which could explain the lack of significant changes in functional performance measures (40).

4.1. Limitations

This study had several limitations. First, the sample consisted exclusively of female Taekwondo athletes, which may limit the generalizability of our findings to male athletes, other martial arts populations, or individuals with different activity levels. Second, we did not include a control group that performed an alternative intervention, which limits our ability to attribute improvements solely to the NEP rather than to other factors such as concurrent training or natural skill development over time. Third, the eight-week duration of the intervention may not be sufficient to determine the long-term retention of postural control improvements or the sustained effects on injury prevention. Fourth, we did not assess psychological

factors such as fear of falling or ankle sprain-related confidence, which could influence postural control and functional performance in athletes with FAI. Finally, while we measured COP sway and TTS during landing tasks, we did not evaluate movement patterns during sport-specific Taekwondo actions, which may better reflect the transfer of training effects to actual athletic performance.

5. Conclusions

The study results indicated that the structured neuromuscular exercise (NE) intervention led to a significant enhancement in postural control for female Taekwondo players with FAI. This improvement was quantified by a notable reduction in center of pressure (COP) displacement after the training period. The study findings highlight that neuromuscular exercise is an effective tool for improving postural stability in female Taekwondo athletes with FAI. By integrating NE into training, rehabilitation, and injury prevention programs, athletes can achieve better balance, reduced injury risk, and enhanced sport-specific performance.

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Authors' Contributions

Kosar Ghorbani: Substantial contributions to the conception and design of the work; the acquisition, analysis, and interpretation of data for the work; drafting the work and reviewing it critically for important intellectual content. Raheleh Ghaffari: Substantial contributions to the conception and design of the work; the acquisition, analysis, and interpretation of data for the work; drafting the work and reviewing it critically for important intellectual content. Komeil Dashti Rostami: Substantial contributions to the conception and design of the work; the acquisition, analysis, and interpretation of data for the work; drafting the work and reviewing it critically for important intellectual content. All authors have read and approved the final manuscript and agree to be accountable for all aspects of the work, such as the questions related to the accuracy or integrity of any part of the work.

Conflict of interest: None declared.

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Ethical Approval

The ethics committee of the Shahrood University of Technology, Shahrood, Iran approved the present study with the code of IR.SHAHROODUT.REC.1403.034. Also, written informed consent was obtained from the participants.

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