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Research paper

Comparing the Muscles Activity during Walking, Pedaling, Frog Kicking and Elliptical Training in Healthy and PFPS Men

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Abstract

Objective: This study aimed to compare the peak of muscles activity during training with treadmill, stationary bicycle, breaststroke stimulation machine, and elliptical in the forward and backward direction in healthy and patellofemoral pain syndrome (PFPS) men.

Methods: Twenty-four participants were randomly assigned into the two groups (12 healthy 24.8 ± 2.6 years old and 12 PFPS 23.5 ± 2.4 years old). An electromyography (EMG) device was used to record lower body muscles activities during training with treadmill, ergometer, frog kick machine, and elliptical in the forward and backward direction. The Mixed ANOVA and Bonferroni Test were used to evaluate the effect of each training on the selected muscles. To determine the correlation between tibial tubercle deviation (TTD) and visual analog scaling (VAS), the Pearson correlation coefficient was used.

Results: The MVIC% peak values of Vastus Medialis Oblique (VMO), Gluteus Maximus (GL-Max) were low and Rectus Femoris (RF) and Vastus Lateralis (VL) were significantly high in the PFPS group ($P < 0.05$). The MVIC% peak values of VMO muscle in backward elliptical (BW-Ell) were higher than other exercises ($P < 0.05$). The Pearson test shows a positive correlation between VAS and TTD ($r = 0.76$).

Conclusion: According to the results of the PFPS group, in most of the tasks, the activity of the Gl-Max and VMO muscles was low and the activity of the RF and VL muscles was more than the healthy group. Since in the reverse elliptical exercise, the VMO/VL was more than other tasks, it was perhaps because of the strengthening of the Gl-Max muscle and BW-Ell training, which is suitable for PFPS. In addition, it may be possible to quantify the severity of PFPS with the help of TTD measurement.

Keywords: Patellofemoral syndrome, Aerobic exercises, Surface electromyography, Sports equipment

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Introduction

Anterior knee pain syndrome or Patellofemoral Pain Syndrome (PFPS) is a usual musculoskeletal case defined by ambiguous and indistinctive pain in the anterior and upper surface of the knee, behind the patella, or by circumferential pain [1,2]. Usually during the weight-bearing activities when knee flexion increases, the patellofemoral joint (PFJ) reaction force will increase, too [3]. Conforming to the 4th World Conference of the International Patellofemoral Pain Research Retreat (i.PPRR) in 2016, some of the criteria-symptoms for the diagnosis of the syndrome presented by patients, are the crepitus of the PFJ during activities with the knee flexion, the sensitivity to the touch of edge of the patella, as well as the collection of fluid in the patellofemoral joint [4]. PFPS within the five years of the investigation were diagnosed between 1.5% and 7.3% of all the injuries [5]. This syndrome is more usual in young and active people with a rate of 21-45% [6].

The i.PPRR in 2017 introduced the interaction among the different risk factors for the PFPS and their direct connection to clinical training [7]. They created an pathomechanical model of the occurrence of PFPS, because the main risk factors that lead to the look of the syndrome are those that fetch increased loads on the PFJ. In the following model, the unusual tension on the PFJ affects all the structures that siege it, and whose damage leads to the onset of the PFPS [7].

It has been reported that an imbalance of the vastus medialis oblique (VMO) and vastus lateralis (VL) muscle activities leads to the extreme lateral moving of the patella and rubbing of the lateral femoral condyle, which causes decreased articular contact surface and induces pain [8]. The ideal VMO/VL activities ratio for healthy participants at knee extension is 1/1.[9] This ratio may shift in patients with PFPS to 0.54/1; this is possible as the imbalance of the VMO and VL muscle activities produces patellar maltracking in PFPS [10].

Backward running decreases the joint stress and developes the quadriceps strength more than forward running [11]. It has been also shown that backward walking (BW-W) training improves quadriceps strength, [12] and hamstring flexibility in healthy participants [13]. It improves the body equilibrium [14] and gait spatiotemporal parameters in neurologically disorder patients [15]. The onset of peak PFJ reaction force occurs later in stance phase during BW-W compared to FW-W,[16] and the peak PFJ reaction force is lower during backward running (three times the weight) compared to forward running (five times the weight) at the same speed [17,18]. There is also evidence reporting the use of BW-W in the rehabilitation of patients with PFPS improved pain, function, and knee extensor strength [19].

A study reported a significant increase in the VMO and VL muscles activity during BW-W compared to FW-W in both PFPS and healthy groups, and during BW-W, the VMO muscle activity of the PFPS group was significantly higher than the control group. The VMO activity of the PFPS group while BW-W was 2 times and the VL activity of this group was 1/2. The VMO/VL ratio of the PFPS group during BW was significantly higher than the FW [20].

Motomo Nakashima et al. studied breaststroke swimming in 2013 with the help of simulations and experimental participants. They found that the RF muscle participates in hip flexion during the recovery phase and knee extension during the kick phase due to the biarticular. Just as the BF is a biarticular muscle, it plays a role in the knee flexion during the recovery phase and the hip extension during the kick phase. In this study, BF muscle activity was low in both simulation and experimental groups, which is related to the low role of this muscle in breaststroke. The TB activity peak during dorsiflexion is present throughout the recovery phase and the first kick. Motomo also stated that BF muscle activity more than 100% of MVIC is possible while swimming; This is because of the time it takes to use the muscle, which is an average of 5 seconds [21].

FW-Ped reduces ACL stress compared to other rehabilitation exercises such as stair climbing, leg extensions, and squats [22]. The hamstring muscles play a key role in stabilizing and assisting the ACL ligament by preventing anterior leg-to-thigh movement due to quadriceps extensor force. In the propulsive phase of FW-Ped, the RF muscle, and during the recovery phase, the BF muscle is activated in greater amounts [23]. Moreover, BW-Ped reduces the compressive stress of the tibiofemoral joint but increases the PFJ reaction force. Thus, BW-Ped is not recommended for PFPS patients. BW-Ped should also not be recommended after injury or ACL surgery [24].

The previous studies compard overground walking, treadmill walking, stationary cycling, and elliptical training. Elliptical training showed greater rectus femoris activity and greater rectus femoris/semitendinosus coactivation than all other conditions. Also, during stationary cycling, the hamstring co-contraction with quadriceps was less than in the other training [25]. This is the first study to compare muscle activation during stationary cycling and elliptical training to overground and treadmill walking. But so far, little study has compared muscular activity during training with treadmill, stationary bicycle, frog kick machine, and elliptical during both forward and backward directions in the healthy and PFPS groups. The aim of this study was to compare the muscle activity during walking, pedaling, frog kicking, and elliptical training in two directions in the healthy and PFPS groups.

Methods

Twelve healthy and 12 PFPS men were selected with 24.8 ± 2.6 and 23.5 ± 2.4 years old in this study. The inclusion criteria for the study included anterior knee pain that feels more around the back of the patella and is aggravated by descending stairs, sitting for a long time, and squat. The signs of pain are not associated with traumatic injury and have had signs of pain for at least two months. Then, participants with this condition were selected by Clarke clinical test and Visual Analog Scaling (VAS). The minimum VAS score was three [24]. Furthermore, the Modify Function Identity Questionnaire (MFIQ) was used to evaluate pain in the participants. The reliability and validity of the Persian version of this questionnaire using the Cronbach's Alpha turned out to be0.82 [26]. The questionnaire comprised 10 items related to pain and function; the first 2 items had 3 selective answers: Option one had 10 points, Option two had 5 points, option three had 0 points, other items had four selective Options: Option one (I cannot) 10 points, option two (I'm doing hard) 5 points, option three (No problem) 0 points, option four (I'm not fitting) 0 points that ranged from 0 to 100, showing the severity of the problem.

A medical test designed to diagnose the PFPS is called the Clarke test. The patient was asked to actively contract his quadriceps muscle, while the examiner exertd pressure on his upper patella and strove to prevent its proximal motion [27]. The VAS questionnaire is a self-assessment questionnaire that has 10 states that express the severity of pain and the person has the closest score, depending on the degree of pain. To measure Tibial Tubercle Deviation (TTD) with aid of a caliper, the proximal and distal centers of the patella were marked, then by placing the ruler along with the RF muscle and on the two centers, a line was plotted. The distance between the line and tibial tuberosity was measured and expressed in Centimeter (figure 1) [28]. The means of VAS, MFIQ, Height, Weight, Age, and TTD were showed in table 1.

Table 1. Specifications of the two groups and values of VAS, MFIQ, and TTD

Groups	VAS	MFIQ	Cm (Height)	Kg (Weight)	Year(Age)	TTD(cm)
Healthy	٠	٠	180.6 ± 8	76.5 ± 12	24.8 ± 2.6	1.15 ± 0.2
PFPS	4.8 ± 1.5	33 ± 18	178.5 ± 7.4	77.5 ± 12	23.5 ± 2.4	1.65 ± 0.3

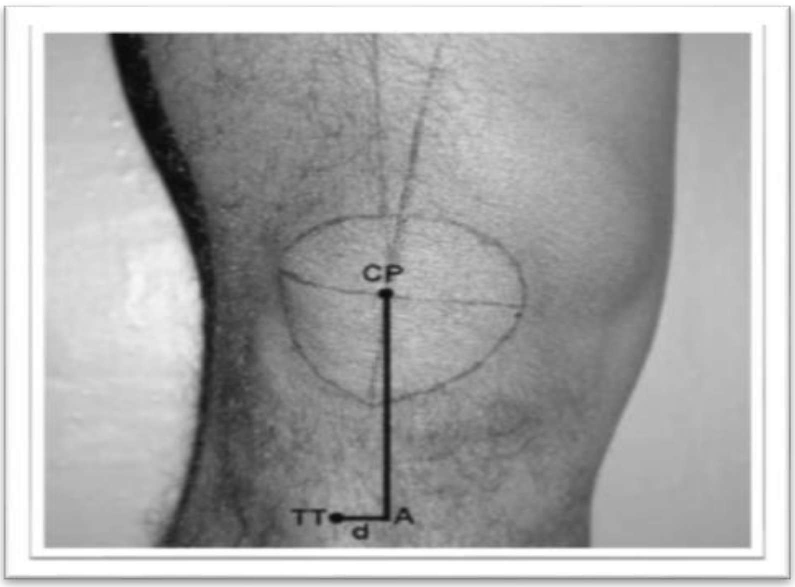

Figure 1. Tibial Tubercle Deviation (TTD) measuring

The EMG device MA300-22 Sixteen Channels was used to measure muscle electrical activity. First, unwanted hairs were shaved and skin with cotton and alcohol was cleaned, then pre-amplifying surface electrodes according to SENIAM European protocol were placed on VMO, VL, Lateral Gastrocnemius (Gas-L), Tibialis anterior (TB), Gluteus medius (GL-Med), GL-Max, Biceps Femoris (BF) and RF muscles. The distance between the positive and negative poles of the electrodes (center to center) was 17mm. Earth electrode was placed on Anterior Superior Iliac Spine (ASIS). The electrodes and cables were fixed so as not to interfere with the subject's movement, and signals were recorded at a sampling frequency of 2000 Hz. First, participants shaked once their right foot, and after 3 seconds, walked forward 5 steps with 2 km/h on the treadmill while theraband created 20 pounds' resistance around his lumbar. In Bw-W, participants walked backward 5 steps with 2km/h speed on the treadmill with the same theraband (figure 2 part A). Within frog kick and inverse frog kick (FK, In-FK), the subject was asked to do a synchronization cycle, and after three second, to do 5 cycles for each direction (forward and reverse) with a frog kick machine (figure 2-part C). The same protocol was used for forward and backward pedaling with stationary bike (Fw-Ped, Bw-Ped showed in figure 2-part B), Fw-Ell and Bw-Ell training by elliptical machine (figure 2-part D). Finally, for the normalization of Root Mean Square (RMS) values, participants performed 2 replicates of the 3-second MVIC for each muscle, this test was performed with a dynamometer for quadriceps and hamstring muscles.

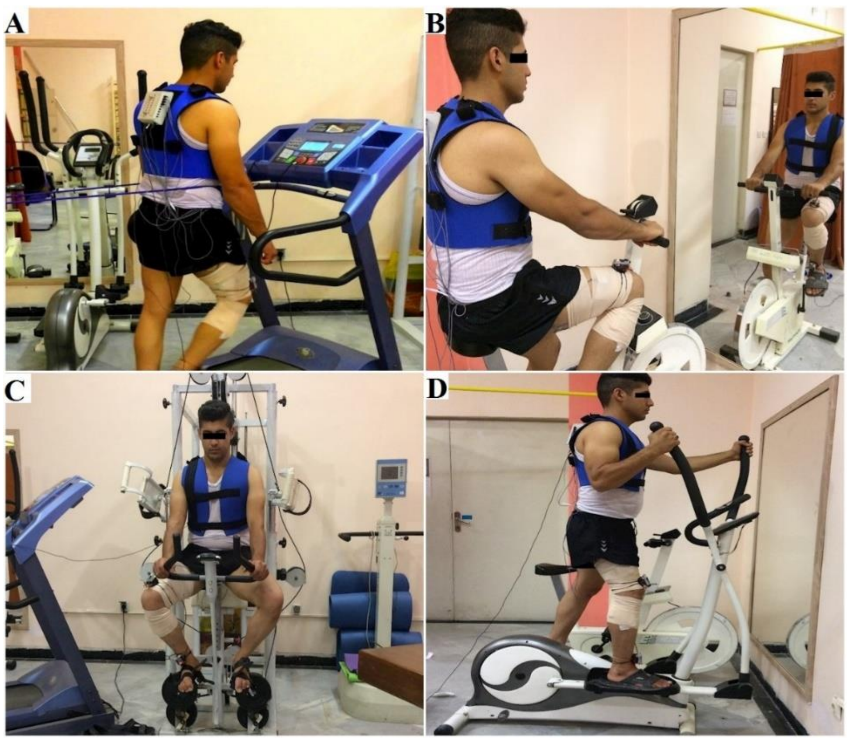

Figure 2. A) Treadmill training. B) Stationary cycling training. C) Frog kick training. D) Elliptical training in forward and reverse direction.

In this study, EMG raw signals were filtered at 10_500 Hz by band-pass filter and conversion to Root Mean Square (RMS) [29]. Normalization was done by the Maximum Voluntary Isometric Contraction (MVIC) [30]. For BF MVIC, the participants were lying on a table, with a knee angle of 45 degrees, while the dynamometer was fitted to the ankle and isometric force was estimated. For VMO, VL, and RF MVIC records, the subject sat on a chair with 90 degrees of hip and 60 degrees of knee flexion angle, then the knee was extended isometrical with the dynamometer. In these situations, the subject was asked to display maximum knee extension strength against the resistance in the leg's front. The reason for choosing 60 knee angle degrees during MVIC was that, at this angle, the amount of patella pressure on the femur decreases. To measure the MVIC values of the Gas-L muscle, the participants performed an isometric plantar flexion test while the ankle joint was 90 degrees and the knee was extended. For Gl-Med muscle MVIC record, hip isometric abduction against the resistance was created by the examiner at the lower end of the leg. Furthermore, for Gl-Max MVIC, participants do hip isometric hyperextension at 10-15 degrees with external rotation. Within this test, the knee was completely extended, and two examiners made resistance to the thigh motion in the posterior. TB muscle MVIC was recorded during dorsiflexion with examiner's the resistance of two hands. Participants performed three isometric contractions for 5 seconds, and recovery was 30 seconds between two trials. The maximum RMS data were extracted from raw EMG using EMG Graphing software, then all peaks of the signals were compared with each other. The SPSS software version 25 was used for data analysis. The Mixed ANOVA and Bonferroni test at the significance level of 0.05 were used to evaluate the effect of each training on the selected muscles. To determine the correlation between TTD and VAS, the Pearson correlation coefficient was used, too.

Results

The MVIC% peak values of VMO and Gl-Max in PFPS group was lower than healthy group during all tasks unlike RF and VL ($P < 0.05$). During FW-W, the MVIC% peak values of VMO and GL-Max were low and the MVIC% peak values of TB and RF were high in the PFPS group and during BW-W, the MVIC% peak values of GL-Max were low in the PFPS group ($P < 0.05$).

During FK, In-FK, FW-Ped and BW-Ped, VMO MVIC% was low and RF MVIC% during this task was high in the PFPS group ($P < 0.05$).

During FW-Ell, MVIC% peak values of VMO and GL-Max were low and Rf was high in PFPS group but MVIC% peak values of VL was identical and MVIC% peak values of VMO, VL and Gl-Max during BW-Ell in PFPS group were low ($P < 0.05$).

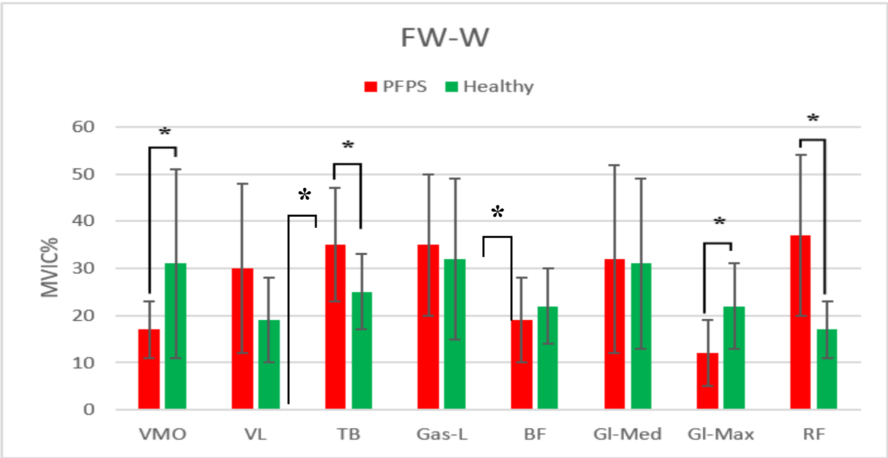

Figure 3- The percentage maximum voluntary isometric contraction (MVIC) of vastus medialis oblique (VMO), vastus lateralis (VL), tibialis anterior (TB), lateral gastrocnemius (Gas-L), biceps femoris (BF), gluteus medius (Gl-med), gluteus maximus (Gl-Max), rectus femoris (RF), during forward walking (FW).

*significant difference between the groups (P≤0.05).

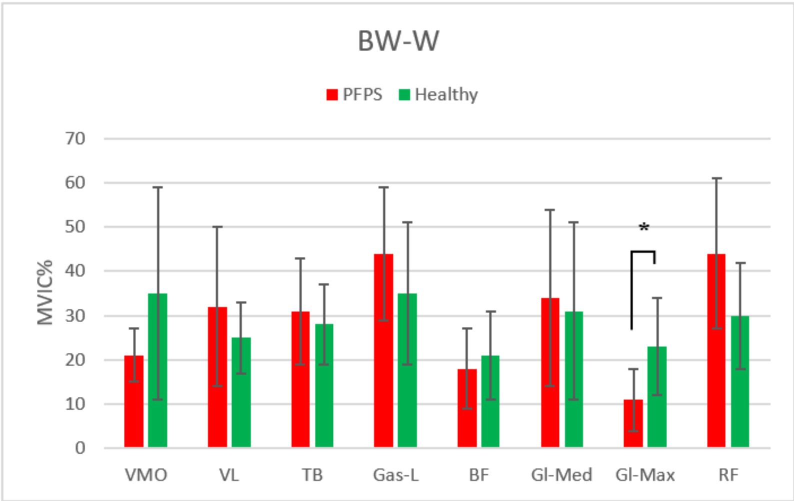

Figure 4- The percentage maximum voluntary isometric contraction (MVIC) of vastus medialis oblique (VMO), vastus lateralis (VL), tibialis anterior (TB), lateral gastrocnemius (Gas-L), biceps femoris (BF), gluteus medius (Gl-med), gluteus maximus (Gl-Max), rectus femoris (RF), during backward walking (BW).

***significant difference between the groups (P≤0.05).**

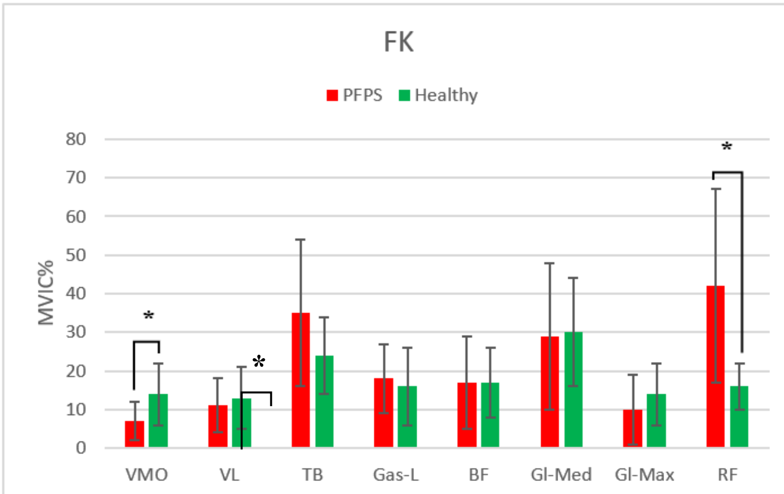

Figure 5- The percentage maximum voluntary isometric contraction (MVIC) of vastus medialis oblique (VMO), vastus lateralis (VL), tibialis anterior (TB), lateral gastrocnemius (Gas-L), biceps femoris (BF), gluteus medius (Gl-med), gluteus maximus (Gl-Max), rectus femoris (RF), during frog kicking (FK).

*significant difference between the groups (P≤0.05).

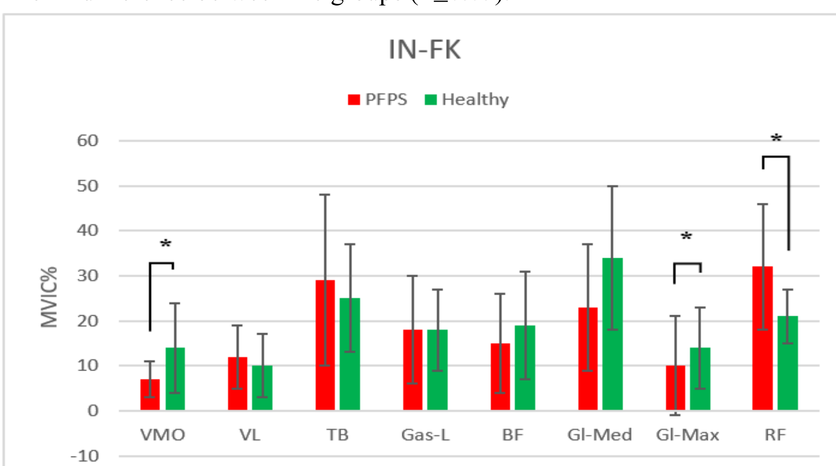

Figure 6- The percentage maximum voluntary isometric contraction (MVIC) of vastus medialis oblique (VMO), vastus lateralis (VL), tibialis anterior (TB), lateral gastrocnemius (Gas-L), biceps femoris (BF), gluteus medius (Gl-med), gluteus maximus (Gl-Max), rectus femoris (RF), during inverse frog kicking (In-FK).

*significant difference between the groups (P≤0.05).

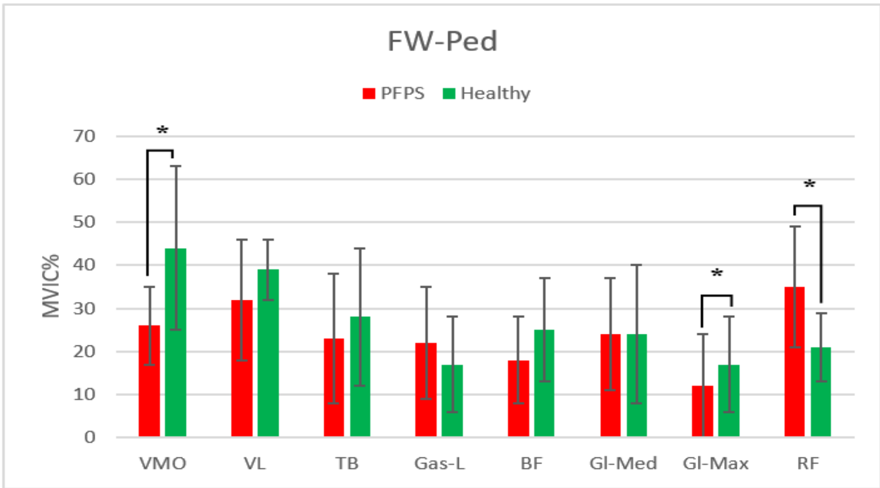

Figure 7- The percentage maximum voluntary isometric contraction (MVIC) of vastus medialis oblique (VMO), vastus lateralis (VL), tibialis anterior (TB), lateral gastrocnemius (Gas-L), biceps femoris (BF), gluteus medius (Gl-med), gluteus maximus (Gl-Max), rectus femoris (RF), during forward pedaling (FW-Ped).

*significant difference between the groups (P≤0.05).

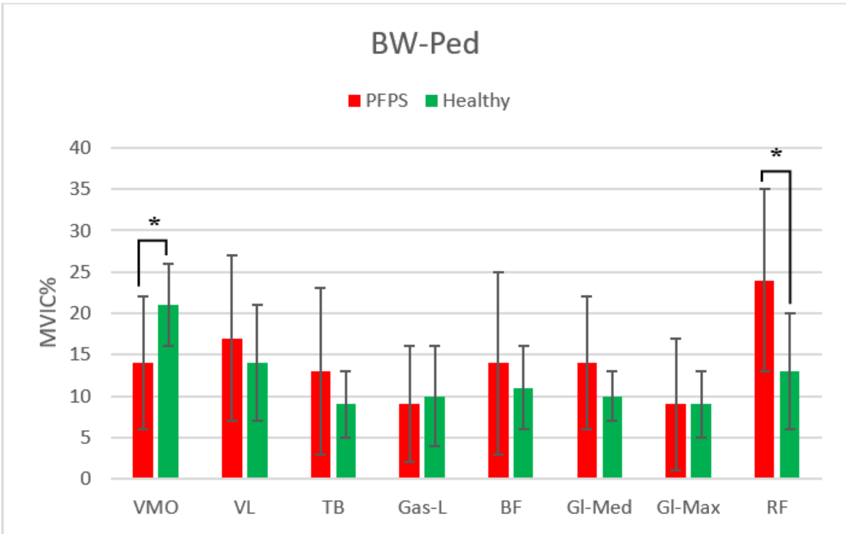

Figure 8- The percentage maximum voluntary isometric contraction (MVIC) of vastus medialis oblique (VMO), vastus lateralis (VL), tibialis anterior (TB), lateral gastrocnemius (Gas-L), biceps femoris (BF), gluteus medius (Gl-med), gluteus maximus (Gl-Max), rectus femoris (RF), during backward pedaling (BW-Ped).

*significant difference between the groups (P≤0.05).

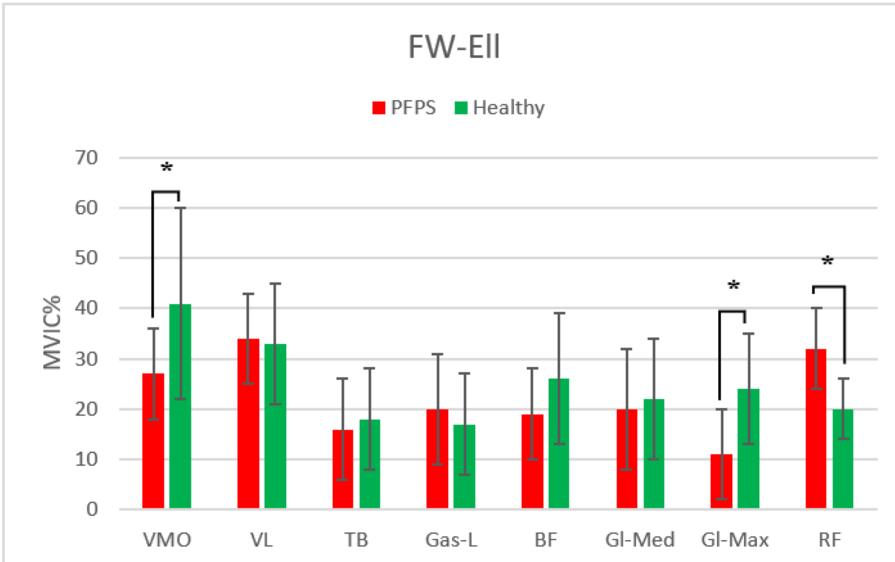

Figure 9- The percentage maximum voluntary isometric contraction (MVIC) of vastus medialis oblique (VMO), vastus lateralis (VL), tibialis anterior (TB), lateral gastrocnemius (Gas-L), biceps femoris (BF), gluteus medius (Gl-med), gluteus maximus (Gl-Max), rectus femoris (RF), during forward Elliptical (FW-Ell).

*significant difference between the groups (P≤0.05).

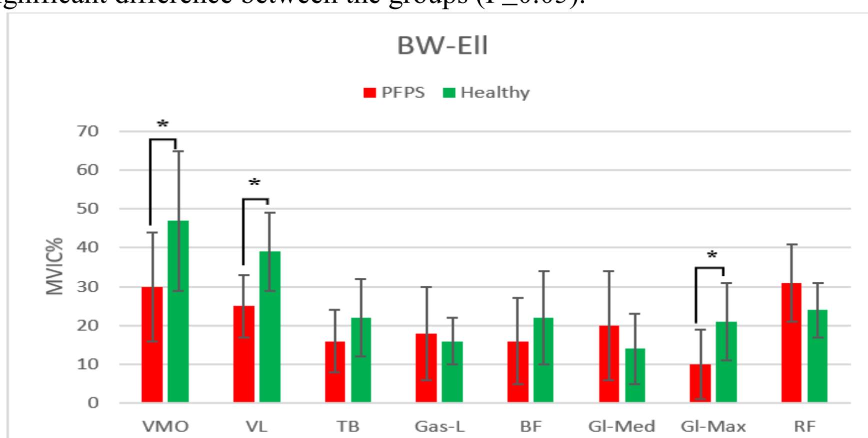

Figure 10- The percentage maximum voluntary isometric contraction (MVIC) of vastus medialis oblique (VMO), vastus lateralis (VL), tibialis anterior (TB), lateral gastrocnemius (Gas-L), biceps femoris (BF), gluteus medius (Gl-med), gluteus maximus (Gl-Max), rectus femoris (RF), during backward Elliptical (BW-Ell).

*significant difference between the groups (P≤0.05).

The MVIC% peak values of RF muscle in PFPS group was higher than healthy group (P = 0.001). However, these values were higher during Bw-W in both healthy and PFPS groups than other exercises (P <0.05). The MVIC% peak values of VMO muscle in the healthy group were higher than the PFPS group (P = 0.004) and the activity of this muscle in the two groups during Bw-Ell training was higher than other exercises and with four activities Fw-W, FK, In-FK, Bw-Ped were significantly different (P <0.05). The MVIC% peak values of VL muscle during Fw-Ped in the two groups was higher than other training, but the difference between its values and three activities: FK, In- FK and Bw-Ped was significant (P <0.05). The MVIC% peak values of TB muscle during Fw-Ell, Bw-Ell and Bw-Ped were statistically lower in two groups than Fw-W and Bw-W (P <0.05). The MVIC% peak values of Gas-L muscle in Bw-W were higher than the Fw-Ell, Bw-Ell, Bw-Ped, Fw-Ped, FK and In- FK (P <0.05). The MVIC% peak values of Gl-Max muscle in the healthy group were higher than the PFPS group in all exercises (P = 0.022) except Bw-Ped. The statistical results did not show a significant difference in the of MVIC% peak values of BF and GL-Med muscles during all training. (P> 0.05).

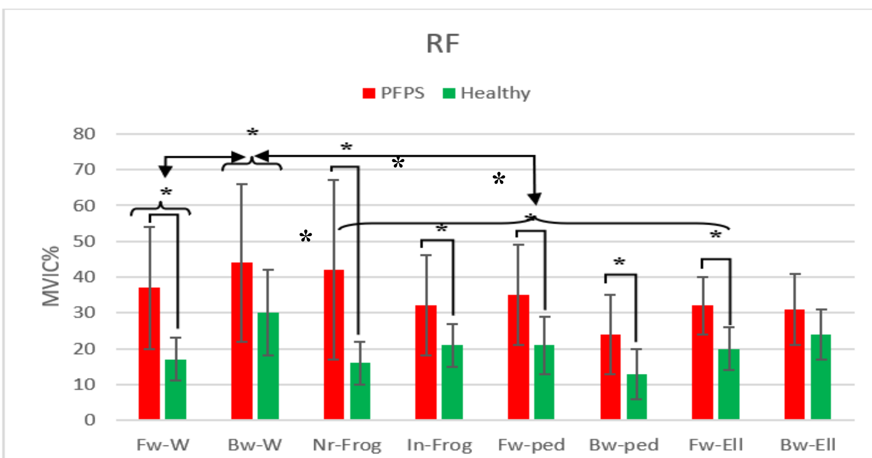

Figure 11- The percentage maximum voluntary isometric contraction (MVIC) of rectus femoris (RF) during forward walking (FW-W), backward walking (BW-W), frog kicking (FK), inverse frog kicking (In-FK), forward pedaling (FW-Ped), backward pedaling (BW-Ped), forward elliptical (FW-Ell), backward elliptical (BW-Ell).

*significant difference between the groups (P≤0.05).

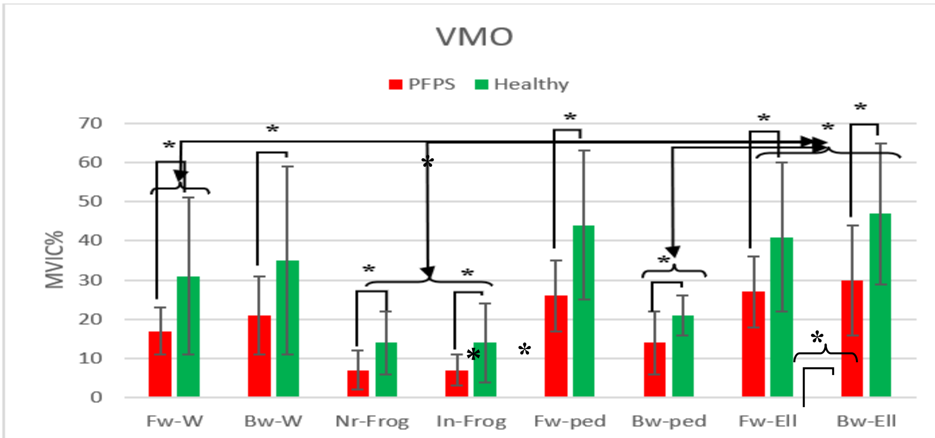

Figure 12- The percentage maximum voluntary isometric contraction (MVIC) of vastus medialis oblique (VMO) during forward walking (FW-W), backward walking (BW-W), frog kicking (FK), inverse frog kicking (In-FK), forward pedaling (FW-Ped), backward pedaling (BW-Ped), forward elliptical (FW-Ell), backward elliptical (BW-Ell).

*significant difference between the groups (P≤0.05).

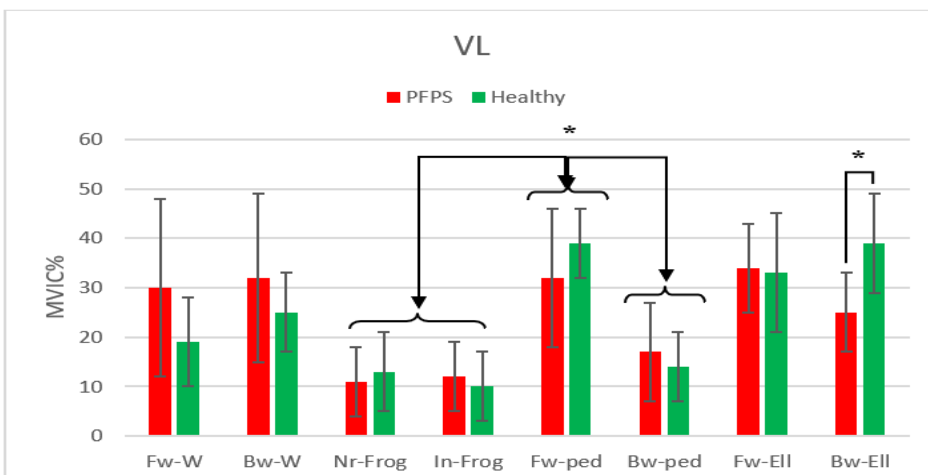

Figure 13- The percentage maximum voluntary isometric contraction (MVIC) of vastus lateralis (VL) during forward walking (FW-W), backward walking (BW-W), frog kicking (FK), inverse frog kicking (In-FK), forward pedaling (FW-Ped), backward pedaling (BW-Ped), forward elliptical (FW-Ell), backward elliptical (BW-Ell).

*significant difference between the groups (P≤0.05).

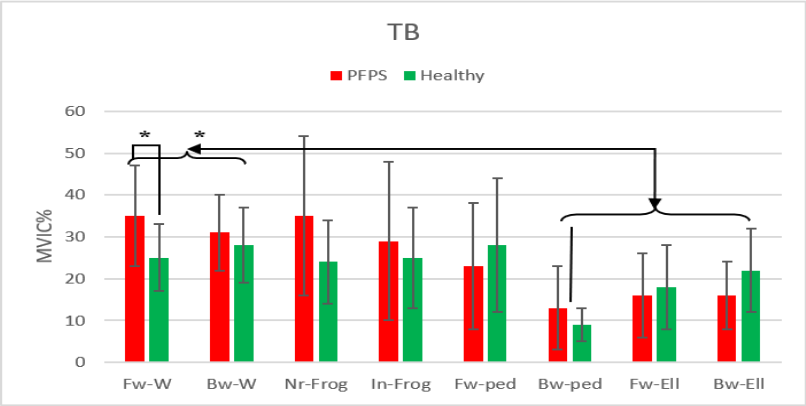

Figure 14- The percentage maximum voluntary isometric contraction (MVIC) of tibialis anterior (TB) during forward walking (FW-W), backward walking (BW-W), frog kicking (FK), inverse frog kicking (In-FK), forward pedaling (FW-Ped), backward pedaling (BW-Ped), forward elliptical (FW-Ell), backward elliptical (BW-Ell).

*significant difference between the groups (P≤0.05).

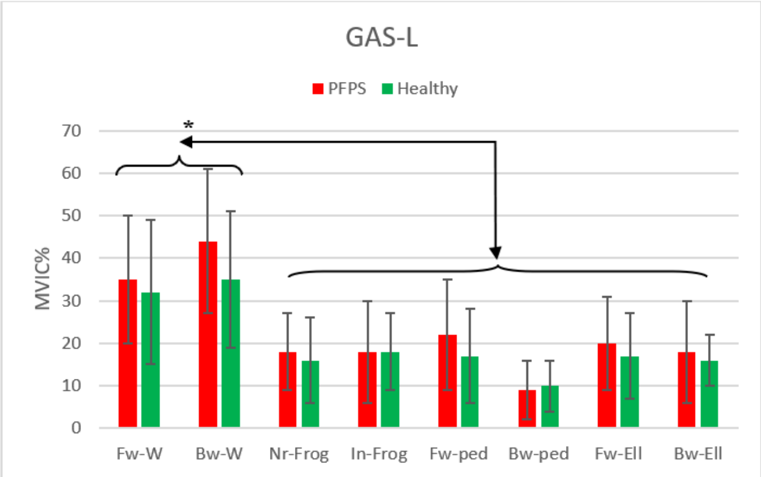

Figure 15- The percentage maximum voluntary isometric contraction (MVIC) of lateral gastrocnemius (Gas-L) during forward walking (FW-W), backward walking (BW-W), frog kicking (FK), inverse frog kicking (In-FK), forward pedaling (FW-Ped), backward pedaling (BW-Ped), forward elliptical (FW-Ell), backward elliptical (BW-Ell).

*significant difference between the groups (P≤0.05).

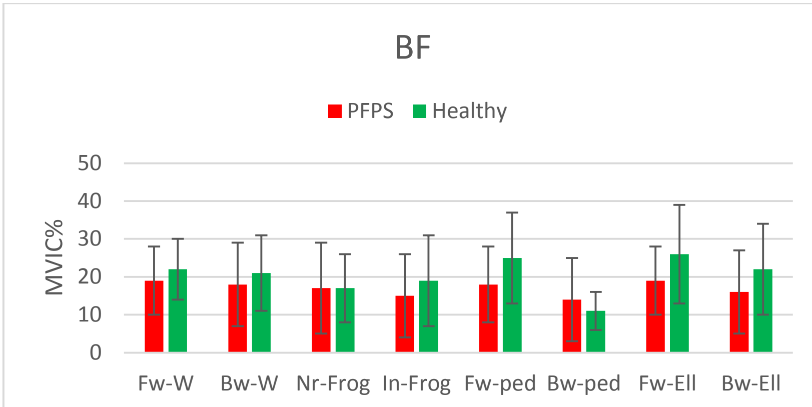

Figure 16- The percentage maximum voluntary isometric contraction (MVIC) of biceps femoris (BF) during forward walking (FW-W), backward walking (BW-W), frog kicking (FK), inverse frog kicking (In-FK), forward pedaling (FW-Ped), backward pedaling (BW-Ped), forward elliptical (FW-Ell), backward elliptical (BW-Ell).

*significant difference between the groups (P≤0.05).

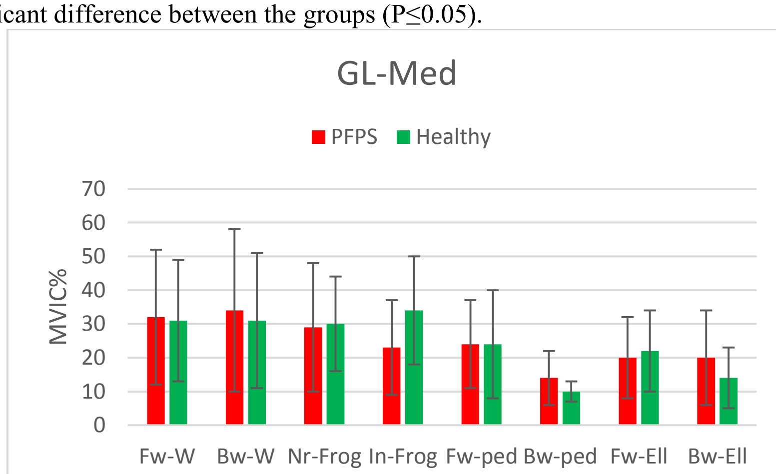

Figure 17- The percentage maximum voluntary isometric contraction (MVIC) of gluteus medius (Gl-med) during forward walking (FW-W), backward walking (BW-W), frog kicking (FK), inverse frog kicking (In-FK), forward pedaling (FW-Ped), backward pedaling (BW-Ped), forward elliptical (FW-Ell), backward elliptical (BW-Ell).

*significant difference between the groups (P≤0.05).

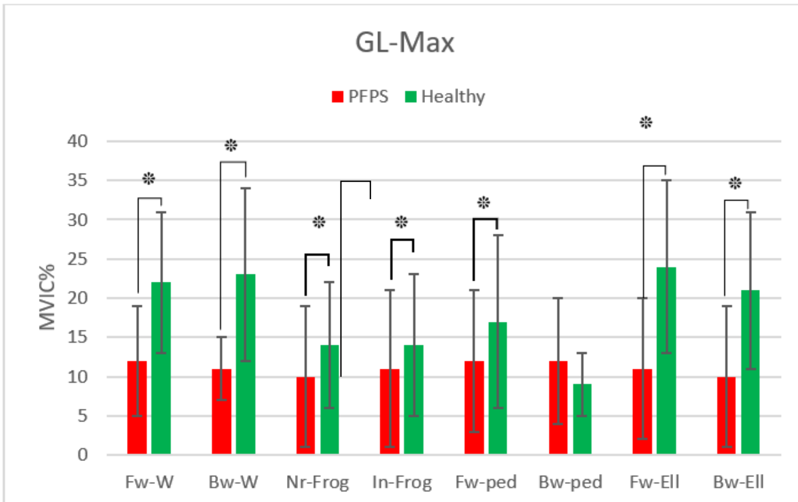

Figure 18- The percentage maximum voluntary isometric contraction (MVIC) of gluteus maximus (Gl-Max) during forward walking (FW-W), backward walking (BW-W), frog kicking (FK), inverse frog kicking (In-FK), forward pedaling (FW-Ped), backward pedaling (BW-Ped), forward elliptical (FW-Ell), backward elliptical (BW-Ell).

*significant difference between the groups ($P \leq 0.05$).

TTD values for PFPS group were higher than healthy group ($P = 0.0247$) (Figure 19). The Pearson test showed a strong positive correlation between VAS and TTD ($r = 0.76$, $P = 0.00$).

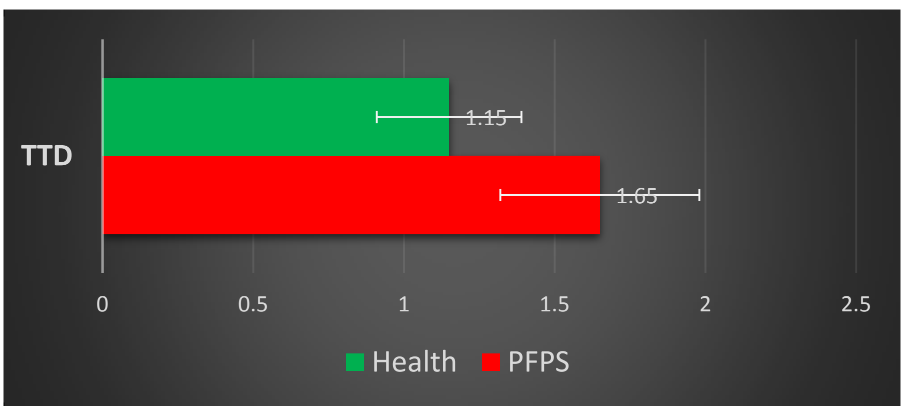

Figure 19- The tibial tubercle deviation (TTD) values for PFPS and healthy group.

Table 2- correlation between visual analog scaling (VAS) and tibial tubercle deviation (TTD)

Vriables	TTD	
	p	r
Visual Analog Scaling (VAS)	0.00	0.759

The ratio of Hamstring to Quadriceps force in the healthy group was higher than the PFPS group, but there was no statistically significant difference (P > 0.05) (Figure 20).

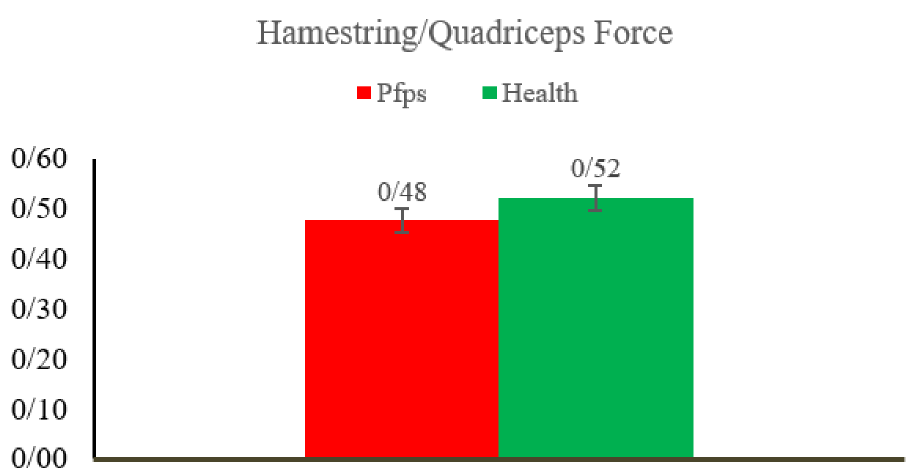

Figure 20- The ratio of Hamstring to Quadriceps force estimated by dynamometer.

The ratio of VMO to VL in the healthy group was higher than the PFPS group exept BW-Ell, however, there was no statistically significant difference between tow groups (P> 0.05).

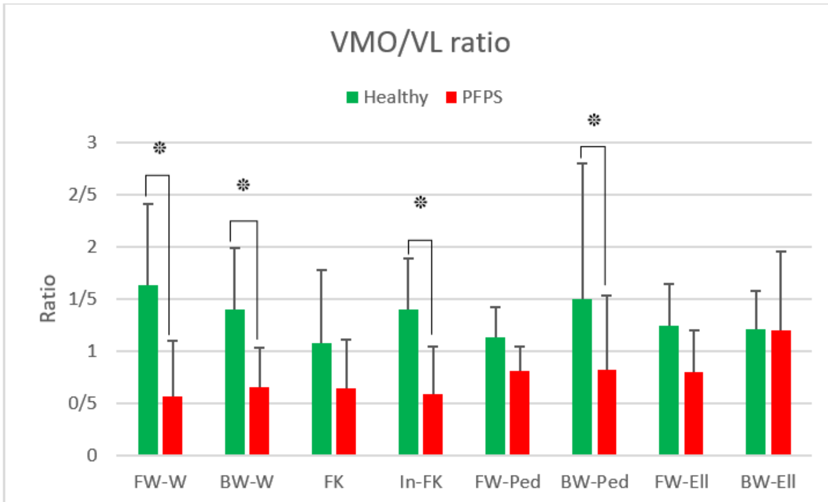

Figure 21- the ratio of vastus medialis oblique to vastus lateralis.

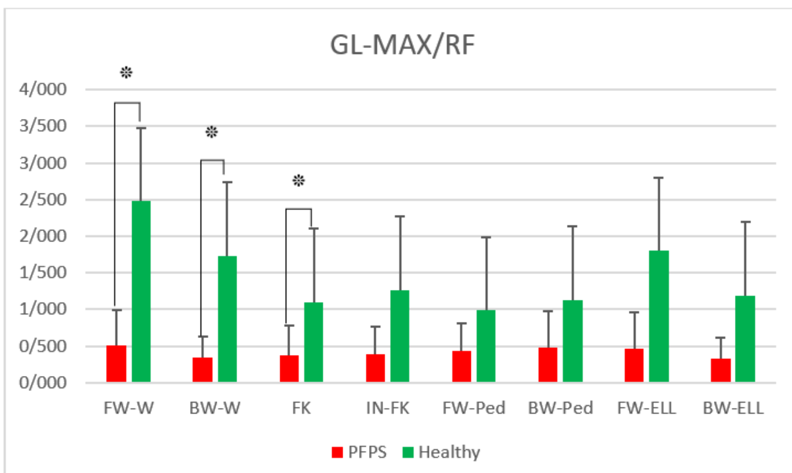

Figure 22- the ratio of vastus medialis oblique to vastus lateralis.

Discussion

The results indicated that in most of the tasks, the VMO and GL-Max muscles of the patient group showed less activity compared to the healthy group [31], while the RF muscle of this group had more activity. The previous studies have shown that in people with PFPS, the VMO and Gluteal muscle show less activity during daily activities [31-33], which can make the patellar maltracking move

outward and cause pain [34]. On the other hand, in a closed kinetic chain task, if the activity of the hip extensors decreases, the RF muscle will show more activity to compensate for it [35]; Tasks that are accompanied by weight-bearing increase knee flexion and RF activity, and the compressive force of PFJ also increases [36]. Therefore, it is possible that the increased activity of the RF muscle relative to the GL-Max increase the risk of PFPS.
Due to the fact that the weakness of GL-Max [37] and VMO [38] muscles and excessive activity of the RF muscle at high knee flexion angles can be a risk factor for the occurrence of PFPS. The studies have shown that strengthening the GL-Max and VMO muscles and the use of elliptical training can improve PFPS. Elliptical training dynamically activates the gluteal muscle while preventing hyper activation of the RF during functional weight-bearing activity compared to conventional gluteal strengthening exercises [39].

The comparison of tasks revealed that during BW-W, the RF muscle shows more activity than other tasks in the two groups, which can be due to the simultaneous role of hip flexion and knee extension [40]. During BW-W, the compressive force of PFJ is estimated to be less than FW-W [41] and the VMO muscle shows more activity [42,43], so it can be used in the rehabilitation protocol of PFPS patients. In a research comparing elliptical exercise, stationary bike, walking on a treadmill and the ground, it was showed that the FW-Ell exercise revealed the highest amount of RF activity and RF co-contraction and semi-tendon [25]; Meanwhile, in this study, during BW-ELL, the VMO muscle of two groups showed more activity than other tasks, and the VL muscle showed less activity in the PFPS group than in the healthy group.

During FW-W and BW-W, TB and GAS-L muscles showed more activity than other tasks in the two groups. According to the study, there is a direct relationship between the activity of these muscles and the ground reaction force [44,45], and also between the ground reaction force and PFJ compressive force [46,47], while the amount of activity of these two muscles during FW-Ell and BW-Ell was lower than other tasks.

Due to the fact that a strong correlation between TTD and VAS was observed. The previous researches have mentioned TTD as a quantitative method of measuring the risk factor of PFPS [48] and reported its normal value in healthy people to be 14.4 ± 4.1 mm for men and 13.6 ± 4.0 for women [49,50]. Therefore, this method may be used to quantitatively determine the pain level of PFPS patients. Finally, according to the previous studies, the ratio of hamstring strength to quadriceps was not significant between the two groups, but the ratio of VMO/VL [51] and GL-Max/RF [52] in the PFPS group was lower than the healthy group.

Conclusion

According to the results of the PFPS group, in most of the tasks, the activity of the Gl-Max and VMO muscles was low and the activity of the RF and VL muscles was more than the healthy group. Since in the reverse elliptical exercise, the VMO/VL was more than other tasks, it was perhaps because of the strengthening of the Gl-Max muscle and BW-Ell training, which is suitable for PFPS. In addition, it may be possible to quantify the severity of PFPS with the help of TTD measurement.

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