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Original Article

Comparison of Electrical Activity of Core Stability Muscles of Trunk and Knee Muscles in People With and Without Patellofemoral Pain Syndrome during Stair-Stepping

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Abstract

Introduction: Patellofemoral Pain Syndrome (PFPS) is known as one of the most frequent knee diseases in athletic and non-athletic people and the most frequent cause of anterior knee pain. Despite the high prevalence of PFPS, its predisposing factors are not known. Among the potential factors, neuromuscular control disorders of lumbopelvic hip complex or core have been recently focused because the stability of this complex is vital for movements of limbs and the instability of core redounds to the instability of whole movement chain. The knee is the most prevalent joint influenced by core disorders; it seems that knee is a victim of core stability disorders. **Materials and Methods:** This is a descriptive-analytic case-control study. Thirty-two subjects including 17 patients with PFPS (10 female, 7 male) and 15 healthy subjects (8 female, 7 male) participated in this study. Electrical activity of vastus medialis obliqus, adductor longus, gluteus maximus, external oblique abdominus (EOA), internal oblique abdominus (IOA) and transverse abdominus (TA) and multifidus was recorded during the stair-stepping activity. All statistical analyses were performed with the SPSS version 20.0 software. **Results:** The results showed there was a significant difference (P=0.026 for EOA, P=0.03 for IOA and TA) between the offset time of electrical activity of core abdominal muscles in patients with PFPS and healthy subjects during stair-stepping. However, there were no significant differences in other parameters. **Conclusion:** The end of electrical activity of abdominal muscles in patients with PFPS during stair-stepping was longer than healthy subjects. However, managing patients with PFPS is challenging because there is no consensus regarding its predisposing factors and treatment. Therefore, more accurate recognition of this syndrome is needed to develop an appropriate treatment.

Keywords: Core Stability Muscles; Electromyography; Knee Muscles; Patellofemoral Pain Syndrome

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Introduction

Patellofemoral Pain Syndrome (PFPS) is one of the most frequent knee diseases in athletic and non-athletic people (1-3), when there is no recognized knee disorder (2-7). It is the most prevalent cause of pain at the anterior knee and around the patella (8). This is mainly caused by activities that apply repetitive forces to the limbs (2) and impose abnormal pressure to the patellofemoral joints (7); such activities include sitting for long periods, squatting, kneeling, running, jumping, and going up and down the stairs (7, 9, 10). Therefore, PFPS is mostly experienced by young people and athletes (1, 3, 11-15). Although the prevalence rate of this syndrome has been reported to be 15% in women and 12% in men (16), its predisposing factors are not clearly known (13).

Generally, these factors are divided into internal and external factors (7). External factors include modified limb kinematics (11, 17) and physical activities having a high frequency and duration (11). The internal factors include excessive stretching of the patella to the outside (6-8, 11, 12, 17, 18), excessive movement of the patella (7), being upper than its natural position (17), stiffness of the retinaculum patella (7, 11), reduction of homeostasis of the tissues around the patellofemoral joint (11), instability of vastus medialis obliquus (VMO) and vastus lateralis (5, 10, 18), and increased angle of quadriceps femoris muscle (19).

Among all the above factors, excessive stretching of the patella to the outside is more acceptable (2, 5, 6, 8, 9, 13, 18) because of the interconnection of factors located far from and close to the knee, including muscular and non-muscular structures as well as neural control systems (14, 20). Among the factors far from the knee joint, the neuromuscular control disorders of the hip, pelvis, and trunk contribute to the development of PFPS (14).

The lumbopelvic hip complex or core includes all the active and passive structures of this region and is the basis of all movements (14). In fact, the stability of hip, pelvis, and trunk is essential for the movement of limbs (20). Any defect in the core stability may redound to the instability of the whole movement chain (14). Studies have shown that knee is the most prevalent joint influenced by core or lumbopelvic hip complex disorders (14). Recent evidence has also indicated the effects of weak neuromuscular control of trunk on other joints, including damage to the limbs (20). Therefore, the examination of the joints above and below the knee is of importance since daily activities are often carried out in closed loops (20).

These findings indicate that knee is a victim of neuromuscular control disorders of the lumbopelvic hip complex (20).

In addition to the etiology of PFPS, the treatment of these patients is often challenging due to the lack of theoretical consensus on its predisposing factors (21).

Considering that recognizing appropriate treatment program for patients with PFPS is important for physiotherapists and that more effective and correct treatment requires a wider and more comprehensive understanding of this syndrome and its effects on other parts of the body, we decided to compare the electrical activity of core stability muscles of trunk and some of the knee muscles in patients with and without PFPS. We have considered PFPS in this study as it is one of the most commonly used syndrome by researchers to record the electrical activity of the muscles.

The present study aimed to compare the onset time, offset time, duration and intensity of electrical activity of VMO, adductor longus (AL), gluteus maximus (G. max), eternal oblique abdominus (EOA), internal oblique abdominus (IOA), transverse abdominus (TA), and multifidus in patients with and without PFPS during climbing of stairs.

Materials and Methods

The present research is a descriptive-analytic case-control study carried out at the Biomechanics Laboratory of the School of Rehabilitation Sciences of Shahid Beheshti University of Medical Sciences. The simple non-randomized available sampling method was used to select the sample. Invitations for collaboration were distributed among the staff and students of the school and the affiliated dormitories. All the subjects were asked to sign the consent form after the objectives and procedures of the research were described to them. The subjects were then categorized into the case and control groups. Non-athlete subjects (people with less than 3 workout sessions of 2 hours per week) aged 18-40 years old (14), with history of pain in anterior knee and around the patella (no cause of injury) that lasted for three days (14, 20, 22, 23) during the past three months, and whose pain increased at least in two positions of long sitting with knee bending, squatting, kneeling, running, jumping, and climbing up and down stairs (14, 20, 22, 23) were included in the case group. The case group subjects also completed the Functional Index Questionnaire. These people did not receive any physical and medical treatment in the last 3 months (24), their minimum and maximum scores on the visual analogue scale of pain in the last two weeks were 3 and 7 (14, 22), and their minimum score in the functional index questionnaire was 11 (14, 20, 22, 23). The control group subjects were non-athletes (people with less than 3 workout sessions of 2 hours per week) aged 18-40 years old (14) who did not report any history of pain in anterior knee and around the patella. The participants of both the groups were matched by age, sex, and body mass index (BMI).

In order to increase the accuracy of the research, we have considered the lack of pain, musculoskeletal injuries, history of surgery and significant deformity or instability in the limbs (14, 20, 22, 23) for both groups. The women in the study were not pregnant (14), and the BMI of all participants was between 20 and 25.

If any subject felt an increased pain in the knee by more than two scores on the visual analog scale or was reluctant to continue for any reason, then they were omitted from the study.

For easy preparation of skin and placing electrodes, the subjects were asked to wear a special gun at the beginning. The location of electrodes on the skin was cleaned with soap and warm water, and a thin-walled tamper if necessary, and then dried. The electrodes of the 8-channel Surface Electromyography (Data Log Biometrics Ltd, type NOS.SX2301, Cwmfelinfach, Gwent, UK), which are silver-silver chloride and with an electrode interval of 2 centimeters, were placed parallel to the muscle fibers in the limbs of the case and control group subjects according to the SENIAM method and a previous research (20). For those with PFPS in both limbs, the one that was more painful was evaluated (25). Electromyographic signals with a bandwidth of 20 to 500 Hz were recorded at a frequency of 1000 Hz.

For maximum reduction of electromyographic noise, the following solutions were proposed: 1) precise fitting of surface electrodes to the skin of subjects by electrode adhesives and anti-allergic adhesives on the electrodes, 2) tying the subject limb after connecting all the electrodes with elastic band so as to prevent the movement and collision of the wires to each other and the body, and 3) turning off the lights, cell phones and any radio and electronic devices in the laboratory. The above solutions were applied to all the participants.

In order to compare the intensity of electrical activity of the muscles in terms of RMS 3ms between subjects, electromyographic waves should be normalized. Thus, it was necessary to record the submaximal voluntary isometric contraction of all muscles in the study (Figure 1).

The SENIAM method was used to record electromyographic activity in three muscles as follows:

For recording the submaximal voluntary isometric contraction of the VMO muscles, the subject was asked to sit on the edge of a flat bed. The recording electrods were placed 4 cm superior to and 3 cm medial to the superomedial patellar margin with an orientation of 55 degrees to the vertical (5).

For recording the submaximal voluntary isometric contraction of the G. max muscles, the subject was asked to lie on the abdomen with the hip at 0° and the knee bending at 90°. The recording electrods were placed at the midpoint of a line running from the inferior lateral angle of the sacrum to the greater trochanter (25, 26).

For recording the submaximal voluntary isometric contraction of the multifidus muscles, the person was asked to lie on the abdomen. Then the recording electrods were placed at the level of the fifth lumbar vertebra (2-3 cm from the center) on the line stretched from the lowest superior posterior pelvis to the space between the first and second lumbar vertebrae.

The electromyographic activities of the remaining muscles-because there was no instruction regarding this in the SENIAM method-were recorded using the previous studies as follows:

For recording the submaximal voluntary isometric contraction of the AL muscles, the subject was asked to lie on the one side. The recording electrods were placed at the anterior-inner level of the hip and in the superior third of the line connecting the symphysis pubis to the adductor tubercle (24).

For recording the electrical activity of the muscles of IOA and TA, a common electrode was used. For recording their submaximal voluntary isometric contraction, the patient was asked to lie on the back and the recording electrods were placed 2 cm inside and below the superior posterior pelvis.

To record the submaximal voluntary isometric contraction of the EOA muscles, the patient was asked to lie on the back. The recording electrods were placed in the middle of a line connecting the superior posterior pelvis to the lowest chest point in the frontal axis (23).

Then, the subject was asked to pedal on a fixed bike for 5 minutes with painless speed and range (24). After connecting the stability and reference electrodes, 3 submaximal voluntary isometric contractions (at intervals of 30 seconds) were recorded from all muscles under study. The subject was asked to hold each contraction for 5 seconds (23). When recording a contraction, the researcher gave the appropriate verbal command to the subject (25). Finally, the maximum value was selected as a submaximal voluntary isometric contraction of that muscle, and an RMS of 3 seconds was considered for the purpose of calculation and normalization. The reference electrodes were tied on the wrists of the subjects.

To determine the time of foot contact and foot detach, the foot switch was used (biometrics, FS4 contact switch, UK) and connected to the electromyography (EMG) device (20). Foot switch signals were recorded at 1000 Hz sampling frequency.

Next, the subject was required to step up 3 times (20) on the three stairs (11) designed for the test, at his normal speed. The characteristics of the stairs were as follows: the first and second steps were 20 cm in height (20), 50 cm in width, and 30 cm in depth, whereas the last step was 50 cm in depth and similar height and width with no handrails (20). In order to match the subject with the test environment and conditions, this task was initially performed without the EMG being switched on (20).

The device was then switched on to record the electrical activity of the muscles while stepping up the stairs. For this purpose, the subject was required to step up all three steps and stand on the third step until the device was turned off as instructed by the researcher (20). Then the subject was asked to

Figure 1. Recording of the muscles activities during stair climbing

start the test with the foot that was not under study in order to place the foot on the second step. All the subjects performed 3 test trials with 30 seconds of rest between each trial in order to prevent fatigue (20).

In order to perform statistical calculations, the data for the second step was selected, and the mean of onset time, offset time, duration and intensity of electrical activity in terms of RMS for the muscles were calculated in 3 trials.

To determine the time variables of the research (onset time, offset time, and duration of electrical activity), the signals recorded by the foot switch were needed. Here, the onset and offset time of the electrical activity of the muscles during stepping up were the intervals between the onset or end of the foot switch signal and the onset or end of the EMG signal. The duration of electrical activity of the muscles was also considered as the interval between the onset and offset time of the electrical activity. These calculations took place in Excel (Microsoft Excel 2007) and were visualized from the graphs. The intensity of electrical activity of the muscles was calculated in terms of RMS in the Data Log device. In fact, the intensity of electrical activity of each muscle during stepping up was calculated, and then this value was normalized to the intensity of the electrical activity of the same muscle during the recording of the submaximal voluntary isometric contraction as follows:

$$\frac{\text{The intensity of electrical activity during stepping up}}{\text{The intensity of the electrical activity for the submaximal voluntary isometric contraction}} \times 100$$

Results

The present study was performed on 17 patients (10 females, 58.8%; 7 males, 41.2%) with PFPS and 15 healthy subjects (8 females, 53.3%; 7 males, 46.7%). In fact, 56.3% of all participants were female, and 43.7% were male. Among the case group, 8 patients (47.1%) had a dominant limb with PFPS and 9 patients (52.9%) had non-dominant limb involvement. In the control group, the dominant limbs of 8 subjects (53.3%) and the non-dominant limbs of 7 subjects (46.7%) were evaluated. In total, the ratio of dominant to non-dominant limbs was equal in the participants of both the groups. According to the Chi-square test, the two groups were not significantly different regarding gender (P=0.75) and limb (P=0.72).

The demographic characteristics of the participants including age and BMI are presented in Table 1.

According to the Chi-square test, the two groups were not significantly different regarding gender (P=0.05) and BMI (P=0.29). Thus, the homogeneity of the two groups was confirmed.

Shapirovic test was used to check the normal distribution of statistical data. The statistical distribution of variables such as onset time, offset time, duration and intensity of electric activity of multifidus muscles, G. max and VMO was normal. Similarly, the statistical distributions of onset time, offset time and duration of electrical activity of AL muscles, and the intensity of electrical activity of the EOA, IOA and TA muscles were normal. The other variables including the onset time, offset time and duration of the electrical activity of EOA, IOA and TA muscles, as well as the intensity of electrical activity of the AL muscle had abnormal statistical distribution.

In Tables 2 and 3, the statistical indicators of the variables of electric activity of core stability muscles of the trunk are given with respect to the groups.

Regarding the statistical data distribution, independent t-test and Mann-Whitney tests determined that the two groups did not show any significant difference in terms of electrical activity of the muscles tested (multifidus, G. max, EOA, IOA, TA, AL and VMO) during stepping up (P>0.05). However, the exceptions were for the offset time of electrical activity of EOA (P=0.02) as well as IOA and TA (P=0.03). In fact, in the group of patients with PFPS, the offset time of the electrical activity of the EOA, IOA and TA was significantly higher than that of the control group.

Table 1. Demographic characteristics (n=32)

Underlying variable	Group	N	Mean (SD)
Age	Case	17	26.29 (5.6)
	Control	15	27.6 (5.46)
	Total	32	26.91 (5.48
BMI	Case	17	22.23 (2.99)
	Control	15	25.61 (2.78)
	Total	32	23.82 (3.32)

Table 2. Statistical indices of electrical activity of trunk core muscle in group (n=32)

Variable electrical activity of the muscle	Group	N	Mean (SD)	*P*-value
Start time of multifidus activity	Case	17	1.31 (52.16)	0.411*
	Control	15	172.15 (457.82)	
Offset time of multifidus electrical activity	Case	17	-37.55 (89.12)	0.794*
	Control	15	-181.55 (466.9)	
The duration of the multi-phydios electrical activity	Case	17	1399.16 (264.92)	0.526*
	Control	15	1648.5 (821.52)	
The intensity of the multi-phydeus electrical activity	Case	17	2.8 (2.51)	0.105*
	Control	15	4.98 (4.83)	
The onset of electrical activity of the gluteus maximus	Case	17	527.04 (1004.1)	0.602*
	Control	15	557.78 (840.81)	
Offset time of the electrical activity of the gluteus maximus	Case	17	-447.89 (658.83)	0.628*
	Control	15	-989.26 (1184.97)	
The duration of the electrical activity of the gluteus maximus	Case	17	2203.82 (1654.7)	0.97*
	Control	15	2681.1 (1765.69)	
The intensity of the electrical activity of the gluteus maximus	Case	17	2.58 (2021)	0.058*
	Control	15	2.51 (3.76)	
Time to start the electrical activity of Ablicus Abduminos	Case	17	1575.69 (985.29)	0.062**
	Control	15	2229.28 (914.81)	
Offset time of the electrical activity of Ablicus Abduminos	Case	17	-1152.03 (734.5)	0.026**
	Control	15	-1944.84 (1090.74)	
The duration the electrical activity of Ablicus Abduminos	Case	17	4286.95 (1473.26)	0.078**
	Control	15	5300.2 (1664.62)	
The intensity of the electrical activity of Ablicus Abduminos	Case	17	1.97 (2.68)	0.941*
	Control	15	2.78 (4.78)	
The onset of the internal electrical activity of the Ablycos and Transversal Abdomin	Case	17	1836.95 (1051.06)	0.369**
	Control	15	2176.42 (1051.73)	
Offset time of the internal electrical activity of the Ablycos and Transversal Abdomin	Case	17	-1195.63 (673.94)	0.03**
	Control	15	-1851.41 (946.34)	
The duration the internal electrical activity of the Ablycos and Transversal Abdomin	Case	17	4324.15 (1555.05)	0.056**
	Control	15	5387.2 (1456.91)	
The intensity of the internal electrical activity of the Ablycos and Transversal Abdomin	Case	17	1.48 (1.54)	0.35*
	Control	15	2.85 (3.13)	

** Mann-Whitney test; ** independent T-test*

Table 3. Statistical indices of electrical activity of the muscles around the knee in the group (n = 32)

Variable electrical activity of the muscle	Group	N	Mean (SD)	*P*-value
Start time of Vastos Medialis Ablucus	Case	17	0.59 (51.5)	0.551*
	Control	15	80.12 (235.48)	
Offset time of Vastos Medialis Ablucus	Case	17	-32.65 (63.5)	0.602*
	Control	15	-79 (234.9)	
The duration of Vastos Medialis Ablucus	Case	17	1334.65 (270.99)	0.576*
	Control	15	1462.13 (446.33)	
The intensity of Vastos Medialis Ablucus	Case	17	1.79 (1.41)	0.71*
	Control	15	1.82 (1.57)	
The onset of Eddartor's lung ossicular electrical activity	Case	17	7.06 (53.71)	0.216*
	Control	15	142.12 (267.55)	
Offset time of Eddartor's lung ossicular electrical activity	Case	17	-51.64 (56.34)	0.576*
	Control	15	-157.68 (257.33)	
The duration of Eddartor's lung ossicular electrical activity	Case	17	1362.67 (225.91)	0.313*
	Control	15	1596.4 (471.45)	
The intensity Eddartor's lung ossicular electrical activity	Case	17	1.53 (0.88)	0.063**
	Controll	15	1.78 (2.53)	

** Mann-Whitney test; ** independent T-test*

Discussion

The present study compared the electrical activity of core stability muscles of trunk and knee muscles in patients with and without PFPS during stair-stepping activity. The results showed that there was no significant difference between the two groups except for the offset time of electrical activity of abdominal muscles, which was significantly higher in the case group. The electrical activities of the EOA, IOA and TA muscles in patients with PFPS were compared to that of the healthy ones. It seems necessary for the patient with this syndrome to continue the electrical activity of their core stability muscles for a longer time after removing the limb from the stairs, so that the stability of the limb is maintained. Therefore, the limbs with PFPS seem to require an electrical activity of the muscles far away from the knee joint to maintain its stability.

Previously, studies have been done on the electrical activity of the knee muscles and the core stability muscles of the trunk, and a number of different results have been presented. The results of the present study are inconsistent with the results of Motealleh *et al.* who used similar muscle and common tasks (20, 27, 28). According to this group, the core stability muscles of the trunk and the knee extensor mechanism, except for the vastus lateralis and erector spinae, in the control group start working earlier than in the patients with PFPS (20, 27, 28). This group did not record the electromyographic activity of the EOA while the present study showed a significant difference between the two groups at the offset time of electrical activity for this muscle. In the present study, the participants were asked to step up the stairs with normal speed while the participants in Motealleh *et al.*'s study stepped up at their fastest pace. It can be said that movement at higher speeds affects the movement chain and the electrical activity of muscles, regardless of being a part of the lumbopelvic hip complex or knee joint, especially when the limb has pain and disorder. During the stairs-stepping activity at normal speed, only the electrical activity of the core stability muscles of the trunk to maintain the stability of the limb differs for the groups with and without PFPS. Also, the participants in the study of Motealleh *et al.* were all male while there were female participants in the present study (roughly half of the participants). In the study of Aminaka *et al.* (24), the electrical activity of the muscles was examined during stepping up and down the stairs, but the core muscles of the trunk were not considered. Their results suggest that the duration of electrical activity of gluteus medius and VMO muscles in patients with PFPS was shorter and the duration of electrical activity of AL muscle in the group was longer than that of healthy subjects. Also, the AL muscles in the group with PFPS began to function later than the control group (24). The AL muscle has been studied only by a few studies, but the VMO muscles are popular in the area of PFPS. The present study results, in consistency with the study by Aminaka *et al.*, did not show any significant difference in the onset time of electrical activity of this muscle among the case and control subjects.

Some studies have also examined the electrical activity of core muscles of the trunk in patients with PFPS, but the intended tasks and the results were different (14, 23, 25, 26, 29). Therefore, it is necessary to further study the electric activity of core stability muscles of the trunk in these patients, especially with respect to functional and daily activities. Nakagawa *et al.* examined the biomechanics of trunk muscles and its association with the kinematics of the hip and knee. The electrical activity of the iliocostalis and EOA muscles during squatting on one leg was not significantly different in the PFPS and control groups (23). The tasks in this study are less practical than that of our present study. In another study, Rojhani Shirazi *et al.* compared the calling patterns of core muscles of the trunk in response to an external disorder among people with and without PFPS. Their results showed that the gluteus medius muscle in patients with PFPS activates later than the muscles of the trunk but at the same time with the erector spinae muscle. However, in healthy people, this muscle begins to function with the muscles of the trunk and before the erector spinae muscle (14). In this study, the order of muscles in response to an external disorder has been considered, and the exact pattern of muscle activity is not specified. Willson *et al.* also investigated the electrical activity of gluteal muscles and found no significant difference in G. max muscles between the two groups (26). This finding is consistent with our findings on G. max muscles, with the difference being that their study had running task. This muscle has rarely been studied as one of the core muscles of the trunk. In a review of 10 case-control studies on the electrical activity of gluteal muscles, Barton *et al.* reported that there is limited evidence on the electrical activity of G. max muscle because it was considered only in two papers. This systematic review also showed that the intensity of the electrical activity of this muscle was greater in people with PFPS when stepping down the stairs (29). In this regard, Souza *et al.* examined the possible differences in kinematics, muscular strength, and electrical activity of the hip muscles.

According to this study, the recruitment in G. max muscle of patients with PFPS was found to be increased during running and stepping down the stairs compared to the control group (25). Here, it should be noted that it is difficult to compare the results of various studies due to the variety of methods and implementation process in the studies.

Conclusion

The electrical activity of abdominal muscles in patients with PFPS is different and longer than that of healthy subjects when stepping up the stairs. Therefore, it is important to include stability exercises and timing activities for abdominal muscles in the treatment of these patients.

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All authors made substantial contributions to conception, design, acquisition, analysis and interpretation of data.

References

1. Besier TF, Fredericson M, Gold GE, Beaupré GS, Delp SL. Knee muscle forces during walking and running in patellofemoral pain patients and pain-free controls. Journal of biomechanics. 2009;42(7):.905-898
2. Cowan SM, Hodges PW, Bennell KL, Crossley KM .Altered vastii recruitment when people with patellofemoral pain syndrome complete a postural task. Arch Phys Med Rehabil. 2002 Jul;83(7):95-989. PubMed PMID: 12098160. Epub 2002.07.05. eng.
3. Ott B, Cosby NL, Grindstaff TL, Hart JM. Hip and knee muscle function following aerobic exercise in individuals with patellofemoral pain syndrome. Journal of Electromyography and Kinesiology. 2011;21(4):.7-631
4. Cowan SM, Bennell KL, Crossley KM, Hodges PW, McConnell J. Physical therapy alters recruitment of the vasti in patellofemoral pain syndrome. Medicine and science in sports and exercise. 2002;34(12):.85-1879
5. Cowan SM, Bennell KL, Hodges PW, Crossley KM, McConnell J. Delayed onset of electromyographic activity of vastus medialis obliquus relative to vastus lateralis in subjects with patellofemoral pain syndrome. Archives of physical medicine and rehabilitation. 2001;82(2):.9-183
6. Dieter BP, McGowan CP, Stoll SK, Vella CA. Muscle activation patterns and patellofemoral pain in cyclists. Medicine and science in sports and exercise. 2014;46(4):.61-753
7. Wong Y-m. Recording the vastii muscle onset timing as a diagnostic parameter for patellofemoral pain syndrome: Fact or fad? Physical Therapy in Sport. 2009;10(2):.4-71
8. Boling MC, Bolgla LA, Mattacola CG ,Uhl TL, Hosey RG. Outcomes of a weight-bearing rehabilitation program for patients diagnosed with patellofemoral pain syndrome. Archives of physical medicine and rehabilitation. 2006;87(11):.35-1428
9. Bolgla LA, Malone TR, Umberger BR, Uhl TL. Comparison of hip and knee strength and neuromuscular activity in subjects with and without patellofemoral pain syndrome. International journal of sports physical therapy. 2011;6(4):.285
10. Stensdotter A-K, Hodges P, Öhberg F, Häger-Ross C. Quadriceps EMG in open and closed kinetic chain tasks in women with patellofemoral pain. Journal of motor behavior. 2007;39(3):-194 .202
11. Cavazzuti L, Merlo A, Orlandi F, Campanini I. Delayed onset of electromyographic activity of vastus medialis obliquus relative to vastus lateralis in subjects with patellofemoral pain syndrome. Gait & posture. 2010Jul;32(3):5-290. PubMed PMID: 20727760. Epub 2010.08.24. eng.
12. Herrington L, Pearson S. Does level of load affect relative activation levels of vastus medialis oblique and vastus laterialis? Journal of Electromyography and Kinesiology. 2006;16(4):.83-379
13. Patil S, Dixon J, White LC, Jones AP, Hui AC. An electromyographic exploratory study comparing the difference in the onset of hamstring and quadriceps contraction in patients with anterior knee pain. The Knee. 2011;18(5):.32-329
14. Shirazi Z, Moghaddam M, Motealleh A. Comparative evaluation of core muscles recruitment pattern in response to sudden external perturbations in patients with patellofemoral pain syndrome and healthy subjects. Archives of physical medicine and rehabilitation. .2014
15. Spairani L, Barbero M, Cescon C, Combi F, Gemelli T, Giovanetti G, *et al.* An electromyographic study of the vastii muscles during open and closed kinetic chain submaximal isometric exercises. International journal of sports physical therapy. 2012;7(6):.617
16. Boling M, Padua D, Marshall S, Guskiewicz K, Pyne S, Beutler A. Gender differences in the incidence and prevalence of

patellofemoral pain syndrome. Scandinavian journal of medicine & science in sports. 2010;20(5):.30-725

17. Coqueiro KRR, Bevilaqua-Grossi D, Bérzin F, Soares AB, Candolo C, Monteiro-Pedro V. Analysis on the activation of the VMO and VLL muscles during semisquat exercises with and without hip adduction in individuals with patellofemoral pain syndrome. Journal of Electromyography and Kinesiology. 2005;15(6):-596 .603
18. Pal S, Besier TF, Draper CE, Fredericson M, Gold GE, Beaupre GS, *et al.* Patellar tilt correlates with vastus lateralis: vastus medialis activation ratio in maltracking patellofemoral pain patients. Journal of Orthopaedic Research. 2012;30(6):.33-927
19. Wong Y, Ng G. Resistance training alters the sensorimotor control of vasti muscles. Journal of Electromyography and Kinesiology. 2010;20(1):.4-180
20. Motealleh A, Maroufi N, Sarrafzadeh J, Sanjari MA, Salehi N. Comparative Evaluation of Core and Knee Extensor Mechanism Muscle Activation Patterns in a Stair Stepping Task in Healthy Controls and Patellofemoral Pain Patients. Journal of Rehabilitation Sciences and Research. 2015;1(4):.91-84
21. Toumi H, Best T, Pinti A, Lavet C, Benhamou C, Lespessailles E. The role of muscle strength & activation patterns in patellofemoral pain. Clinical Biomechanics. 2013;28(5):.8-544
22. Bolgla LA, Malone TR, Umberger BR, Uhl TL. Reliability of electromyographic methods used for assessing hip and knee neuromuscular activity in females diagnosed with patellofemoral pain syndrome. Journal of Electromyography and Kinesiology. 2010;20(1):.7-142
23. Nakagawa TH, Maciel CD, Serrão FV. Trunk biomechanics and its association with hip and knee kinematics in patients with and without patellofemoral pain. Manual therapy. .2014
24. Aminaka N, Pietrosimone BG, Armstrong CW, Meszaros A, Gribble PA. Patellofemoral pain syndrome alters neuromuscular control and kinetics during stair ambulation. Journal of Electromyography and Kinesiology. 2011;21(4):.51-645
25. Souza RB, Powers CM. Differences in hip kinematics, muscle strength, and muscle activation between subjects with and without patellofemoral pain. journal of orthopaedic & sports physical therapy. 2009;39(1):.9-12
26. Willson JD, Kernozek TW, Arndt RL, Reznichek DA, Scott Straker J. Gluteal muscle activation during running in females with and without patellofemoral pain syndrome. Clinical Biomechanics. 2011;26(7):.40-735
27. Motealleh A, Maroufi N, Sarrafzadeh J, Sanjari M-A. The test-retest reliability of the onset of core and vasti electromyographic activity while ascending and descending stairs in healthy controls and patellofemoral pain patients. Medical Journal of The Islamic Republic of Iran (MJIRI). 2011;24(4):.31-221
28. Motealleh A, Maroufi N, Sarrafzadeh J, Sanjari M-A. comparitive evaluation of core and knee extensor mechanism muscle activation pattern in a stair stepping task in healthy controls and patellofemoral pain pateints Tehran, Iran: Iran university of medical sciences; .2011
29. Barton CJ, Lack S, Malliaras P, Morrissey D. Gluteal muscle activity and patellofemoral pain syndrome: a systematic review . British journal of sports medicine. 2012:bjsports-.090953.1-2012