Universität Bielefeld

Fakultät für Psychologie und Sportwissenschaft

Abteilung Sportwissenschaft

Arbeitsbereich Sportmedizin

Inaugural-Dissertation
zur Erlangung des Doktorgrades
der Naturwissenschaften
(Dr. rer. nat.)

Comparison of electrical activity of lateral and medial stabilizers of the patella and further diagnostically relevant risk factors in athletes with and without patellofemoral pain and in a Tai Chi group

Vorgelegt von:

Nahid Khoshraftar Yazdi

Gutachter:

Prof. Dr. med. Elke Zimmermann

Prof. Dr. Stephan Starischka

Bielefeld, im Juli 2010

To my parents, who taught me to pick a goal in life and to take it seriously

To my family, Majid and Andisheh,

my reason for being

Contents

1. Introduction

Runners, jumpers and other athletes such as skiers, cyclists and soccer players put heavy stress on their knees. Studies have shown that forty-two percent of all overuse injuries affect the knee joint, and patellofemoral pain syndrome (PFPS), or simply "runner's knee," is the most common overuse injury among runners.

PFPS can be defined as a Retro-patellar (behind the patella) or Peripatellar (around the patella) pain, resulting from physical and biomechanical changes on the patellofemoral joint. This pain is often made worse by sitting for prolonged periods, stair climbing or any activity which involves bending the knee. PFPS can persist and affect athletic activity indefinitely. In fact, athletes must modify their athletic activity as they continue to be plagued by pain for several years.

Despite high incidence of PFPS, the exact cause of these disorders remains enigmatic and abides one of the most vexatious clinical challenges in rehabilitation medicine. The mechanism for PFPS is not well understood; however it has been suggested that the condition may rise from abnormal muscular and biomechanical factors that alter tracking of the patella within the femoral trochlear notch.

Due to high incidence PFPS among athletes, as well as disagreement about the relevant effectors, more research needs to be conducted to determine the factors which cause PFPS. The purpose of this study was to consider the factors that may affect knees and cause PFPS. Insufficiency of lateral and medial stabilizer muscles of the patella (vastus lateralis and tensor fascia lata muscles as lateral stabilizers and vastus medialis obliquus muscle as a medial stabilizer) may have an effect on the patella and develop patellar malaligment and, consequently, PFPS. On the other hand, the ankles, knees and hips act as link system making possible the transmission of forces into the pelvis and spine during running, jumping, kicking and throwing. If one of these joints has anatomical and biomechanical abnormalities, it can affect the other joints. Therefore, changes in lumbar curve, pelvic tilt and leg alignment may have an effect on knee joints. Since the shortness of muscles often correlates with sport injuries, decreased flexibility of the muscles around the knee and hip may be present during knee pain. In the present study, flexibility of hip flexor muscles and iliotibial band, which is a tendon of tensor fascia lata and gluteus maximus, were considered.

For consideration of the effect of these risk factors in creation of PFPS, two athletic groups, with and without PFPS, was chosen. The electrical activity of tensor fascia lata (TFL), vastus lateralis (VL) and vastus medialis obliquus (VMO) muscles was compared in these two groups. In addition, lumbar lordosis, pelvic tilt, leg deformities such as leg length discrepancy, knee varus and valgus, foot pronation and foot arch, and flexibility of iliotibial band and hip flexor muscles were compared in the above mentioned groups.

Also, range of motion of hip in flexion, extension, abduction, adduction, external rotation and internal rotation, and range of motion of knee in flexion and extension were studied for considering of effect of patellofemoral pain on range of motion.

Since Tai chi helps or reduces the load on the lower limb joints, particularly in the knee, the subjects doing Tai chi, were chosen as a third group. Tai chi consists of slow, continuous movements that incorporate elements of strengthening, balance, postural alignment, relaxation and concentration. All of the above mentioned risk factors and hip and knee range of motion were compared in the Tai chi group with patients and a control group. It is assumed that Tai chi exercise can be suggested to patients in order to improve the patella malaligment and the alleviation of PFPS.

2. Theoretical aspects

The knee joint, which appears like a simple hinge-joint, is one of the most complex joint. Moreover, knee is more likely to be injured than is any other joint in the body. It is made of the two main joints: tibiofemoral (the articulation between the tibia and femur) and patellofemoral (the articulation between the patella and femur).

The patella is a unique structure that plays a central role in the normal biomechanics of the knee.[1] The major functions of the patella are to increase the extensor moment of the quadriceps muscle and to minimize the concentration of stress by transmitting forces evenly to the underlying bone.[2] In other words, the main biomechanical function of the patella (knee cap) is to improve the quadriceps efficiency by increasing the lever arm of the extensor mechanism. As the knee flexes (the tibia moving on the femur), it articulates with the trochlear region of the femur along the upper two third of its posterior surface. During knee flexion the patella moves downward. [3]

McConnel stated that the patellofemoral joint is largely a soft-tissue joint. In the first 20°, the patella is under the influence of the surrounding soft-tissue structures so that it is particularly vulnerable and susceptible to problems. After 20° of knee flexion, the bony architecture is increasingly responsible for controlling the position of the patella.[2]

Stability of the patellofemoral joint involves dynamic and static stabilizers, which control movement of the patella within the trochlea, referred to as patellar tracking.[4] Fibers from the ilitibial band (ITB) and vastus lateralis (VL) stabilize the patella laterally and fibers of the vastus medials oblique (VMO) stabilize the patella medially.[3]

The vastus medialis (VM) is divided into two distinct parts the longus (VML) originating from the shaft of the femur[5] and the VMO originates from the adductor tubercle of the distal medial femur and inserts into the medial retinaculum and superomedial portion of the patella.[6] The longus, where the fibers are oriented 15-18 degrees medially to the frontal plane and the obliquus, where the fibers are oriented 50-55 degrees medially in the frontal plane.[7] The VML acts with the rest of the quadriceps to extend the knee. Although the VMO does not extend the knee, it is active throughout knee extension to keep the patella centered in the trochlea of the femur.[7]

The VL, which is a lateral stabilizer, originates in outer surface of the greater trochanter of the femor and insert to lateral border of the patella. [8] The fibers of the VL are oriented 12-15 degrees laterally in the frontal plane.[7]

The ITB, which is a tendinous portion of the Tensor fascia lata (TFL) and gluteus maximus, [9] provides dynamic lateral stabilization of the patella.[10] Since the TFL muscle is a lateral stabilizer of patella and an internal rotator of hip, [11] and TFL/ITB complex tightness may contribute to the development of PFPS, [12] in the current study we considered this muscle.

The TFL muscle takes origin from the anterior iliac crest in an arc and through iliotibial band is attached to lateral condyle of the tibia. Passive (such as the medial and lateral retinaculum and the joint capsule) and dynamic stabilizers affect function and allow for proper patellar tracking.[4] Patellar tracking can be altered by imbalances in these stabilizing forces affecting the distribution of forces along the patellofemoral articular surface, the patellar and quadriceps tendons, and the adjacent soft tissues.[4] Forces on the patella range from between one third and one half of a person’s body weight during walking to three times body weight during stair climbing and up to seven times body weight during squatting.[13]

2.1. Definition of patellofemoral pain syndrome

Patellofemoral pain syndrome (PFPS) is a term for a variety of pathologies or anatomical abnormalities leading to a type of anterior knee pain.[14] PFPS is the most common knee complaint found with adolescents and young adults[15'16] and the most common single diagnosis among runners and in sports medicine centers.[17] This term (PFPS) is often used interchangeably with anterior knee pain or runner's knee.[4] Forty-two percent of all overuse injuries affect the knee joint, and patellofemoral pain syndrome (PFPS), or simply "runner's knee," is the most common overuse injury among runners.[18]

PFPS is a chronic injury that can persist and affect athletic activity indefinitely.[15] It encompasses disorders in which pain and point tenderness is present in or around the patellofemoral joint.[19] Pain may be precipitated by an increase in the frequency or intensity of repetitive loaded activities.[20] Repetitive, high-frequency overload delivered to a malalignment extensor mechanism yields persistent, debilitating, unremitting pain in some athletes.[21] once the patellofemoral joint becomes overload and irritated, secondary subchondral bone degeneration, chronic retinacular strain, small-nerve injury, or persistent aggravation of the peripatellar synovium may occur.[15]

Some authors describe patients with PFPS under the rubric of condromalascia patella.[22] However, Chondromalacia patella, a condition in which there is softening of the patellar articular cartilage, occurs in only a subset of patients who present with anterior knee pain.[4]

2.2. Prevalence

Researchers have shown an incidence as high as one in four, and even higher, among athletes. Despite this high incidence, the exact cause of these disorders remains enigmatic.[23'24'25'26] Wilk et al. have stated that PFPS remains one of the most vexatious clinical challenges in rehabilitation medicine.[27]

2.3. Symptoms

The major complain of patients with PFPS is retropatellar pain during activities such as running, squatting, going up and down stairs, prolonged sitting, cycling, and jumping.[16] Patients with PFPS typically describe pain around, behind or underneath the patella.[15] Pain is often described as dull and aching or throbbing but occasionally there may be episodes of acute sharp pain.[17] Clinical criteria include pain on direct compression of the patella against the femoral condyles with the knee in full extension, tenderness of the posterior surface of the patella on palpation, pain on resisted knee extension and pain with isometric quadriceps muscle contraction against suprapatellar resistance with the knee in 15° of flexion.[16] Some patients report uncomfortable grating while flexing or extending the knee and this complaint may be constantly present with knee movement.[17]

2.4. Risk factors

Various authors have attributed PFPS to intrinsic and extrinsic risk factors.[15] Extrinsic risk factors are related to factors outside the human body, such as the type of sports activity, the manner in which sport is practiced, the environmental conditions, and the equipment used. Intrinsic risk factors relate more to individual physical characteristics and physiological traits.[15]

A combination of factors, such as abnormal lower limb biomechanics, abnormal lateral tracking of the patella, soft tissue tightness, muscle weakness and excessive exercise, may result in increased cartilage and subchondral bone stress, subsequent PFPS and subtle patellar malalignment or more overt patellar maltracking.[28,29,30,31]

One of factors that affect on abnormal patella tracking is muscle imbalance.

2.4.1. Lateral and medial stabilizer muscles of patella

Soft tissue structures provide both dynamic and static stabilization of the patellofemoral joint. As the VMO is an important dynamic medial stabilizer of the patella, [31,32] the ITB and VL provide dynamic lateral stabilization of the patella. [33,34,35] Despite of important role of ITB on the patella, most of studies considered only imbalance between the VMO and VL muscles.

Insall (1982) suggested that mechanism of abnormal lateral tracking of the patella is an imbalance in the activity of the VMO muscle relative to the VL. Habitual lateral tracking may produce adaptive changes, and in time the quadriceps tendon comes to lie more to the lateral side of the knee. The VMO becomes stretched and the VL becomes contracted.[36]

Grabiner et al. (1991) stated that the biomechanical balance between the VMO and VL is considered to be a factor influencing patellar tracking within the intercondylar notch. It is assumed that the medial tracking role of the VMO counteracts the laterally directed force of the VL on the patella.[37]

Lateral tracking of the patella may be due to inadequate medial control from the VMO in persons with PFPS. This inadequate control could be due to a reduction in the tension-producing capacity of the VMO or a problem with the timing of VMO activity. [31]

Souza and Gross (1991) compared VMO/ VL integrated electromyographic (IEMG) ratios of healthy subjects and patients with unilateral PFPS under isotonic and isometric quadriceps femoris muscle contractions. The results indicated VMO/ VL ratios for isotonic stair-climbing activities were significantly greater than VMO/ VL ratios for isometric contractions and normalized VMO/ VL ratios in healthy subjects were significantly greater than that of the patients. They stated that patients with PFPS may have abnormal VMO/ VL activation patterns.[30]

Boucher (1992) studied isometric maximum knee extension at 90°, 30° and 15° of knee flexion for recording the electrical activity of the VMO and VL in the subjects with and without PFPS. His results demonstrated that VMO/ VL and VML/ VL ratios showed no significant differences between groups and between the three angles. They concluded that in advanced cases of patellofemoral pain syndrome the VM may even be less active relative to the VL in the last degrees of extension compared to 90°.[38]

Karst and Willett (1995) also considered the onset timing of EMG activity of the VMO and VL in asymptomatic subjects and subjects with PFPS during reflex knee extension, active knee extension in non-weight-bearing and weight-bearing situations. They showed no differences between the two groups with respect to the relative timing of initial VMO and VL activity under any of three conditions tested.[39]

Cowan et al. (2001) considered the electromyographic (EMG) onset of the VMO and VL in the patients and control group during the functional task of stair stepping. The results showed that in the PFPS population, the EMG onset of the

VL occurred before that of VMO in both the step up and step down phases of the stair-stepping task.[40]

Owings and Grabiner (2002) studied the activation timing and amplitude of the VMO and VL in the health subjects and patients with PFPS during maximum voluntary knee extension contractions initiated from a flexed and an extended position. Their results showed that there were no between group differences in activation timing. The activation amplitude of the VMO and VL muscles of the PFPS subjects was altered to the greatest extent during eccentric contractions and differed significantly from that of the control group.[25]

Mellor and Hodges (2005) demonstrated that coordination of motor units between the medial and lateral vasti muscles in people with anterior knee pain is reduced compared to people without knee pain. They believed that it confirms that motor control dysfunction is a factor in this condition and has implicated for selection of rehabilitation.[41]

McClinton et al. (2007) in a case control study compared the onset timing and activation of the VMO and VL between subjects with and without PFPS at various step heights. The result of their study demonstrated that quadriceps onset timing and activation magnitude during stair ascent was similar between two groups, regardless of step height.[42]

Moraes Santo et al. (2007) determined difference between the VMO/VLL muscles activation during treadmill gait level and ascending to 5% degree between patients and healthy subjects. They showed no significant difference in the VMO/ VL ratio between the two groups, regardless the condition. They stated that although there was not significant difference, the subjects of the control group showed higher values in the VMO/ VL ratio in two tested conditions than the subjects of the PFPS group.[43]

Santos at al (2008) suggests that there is an imbalance in the electric activity and abnormal recruitment patterns among the VMO, VLL and VLO muscles in individuals with PFPS, with greater delay and lower amplitude of activation of the VMO in this group.[44]

Van Tiggelen et al. (2009) showed that delayed onset of electromyographic activity of the VMO-VL is one of the contributing risk factors to the development of PFPS.[45]

The other soft tissue which influences the patella is TFL. To my knowledge a few studies considered the electrical activity of the TFL

Banovetz et al. (1996) suggested that the VL, TFL and rectus femoris (RF) all produce a lateral force moment on the patella and the VMO counteracts this lateral force moment.[5]

McConnel (1996) expressed that the decrease in activity of the TFL will result in a decreased lateral pull on the patella which, because the patella is not being displaced laterally, will enhance VMO activity.[7]

Smith (1997) believed that ITB tightness results in over-activity in the TFL and diminished activity in the VMO.[46]

Wheatly and Jahnke (1951) did an electromyographic study of the thigh and hip muscles. They used essentially isokinetic movements and found the the vasti fire later than the RF and TFL in active extension in the patients.[47]

Gregersen and et al. (2006) determined whether activation patterns of the VMO, VL and TFL were affected by changes in the varus/valgus in the cyclists without history of overuse knee injury. Their results revealed that the VMO/ VL activation ratio increased significantly and the TFL activation decreased significantly as the varus moment decreased. They suggested that everting the foot may be beneficial towards or ameliorating PFPS in cycling.[48]

2.4.2. Lumbar lordosis and pelvic tilt

2.4.2.1. Lumbar lordosis

The trunk can be described as a complex of three functional components: the thorax, lumbar spine and pelvis. The thorax and pelvis can be modeled as rigid bodies, because sagittal plane rotation and displacement within these structures are limited by anatomic constrains. The lumbar spine acts as a flexible bridge between these two relatively rigid segments.[49]

Physical therapists routinely assess relaxed standing posture to help identify possible problems with the spine or peripheral joints.[50]

To my knowledge, there are few studies which indicate a relation between lumbar lordosis and PFPS. However, some studies indicated the relationship between lumbar spine disorders and knee injuries.[51,52]

Watson (1995) showed that knee injuries were found to be associated with lumbar lordosis.[52]

Dvorak et al. (2000) stated that knee injuries were showed to be associated with a higher degree of lumbar lordosis and the presence of sway back.[53]

Erkula (2002) indicated that tight hamstring can lead to increased thoracic kyphosis, decreased lumbar lordosis, posterior pelvic tilt and a flexion posture in the knee. These postural changes generally lead to anterior knee pain.[54]

Murata (2003) indicated that a loss of lumbar lordosis is related to degenerative changes in the knee. This may be called the “knee-spine syndrome”.[55]

Goncalves da Rocha et al. (2006) in a case report described the rehabilitation of a patient with severe knee pain and chronic low back dysfunction. They stated that clinical examination by analysis of passive and active movements elicited pain in the knee, and pain referred to the knee from the hip and lumbar spine.[51]

Only Press and Young (1998) indicated the relationship between lumbar lordosis and PFPS. They proposed that an increased lumbar lordosis may contribute to PFPS.[56]

Tsuji et al. (2002) suggested that in elderly Japanese, decreased lumbar lordosis and sacral inclination lead to increasing thigh muscle tension and knee flexion while standing. This increases low back pain and PFPS.[57]

2.4.2.2. Pelvic tilt

Other factor may be associated with PFPS is pelvic tilt. Pelvis position is the most important contributing factor on patellofemoral joint biomechanics.[58]

McConnel (1996) stated that a stable pelvis will minimize unnecessary stress on the knee. He expressed that for example; a patient with internally rotated femurs, posterior tilted pelvis and hyperextended knee will usually have poor inner range quadriceps control and will not use knee flexion for shock absorption on heel strike, but will increase the amount of lateral pelvic tilt.[7]

Hruska (1998) indicated that weakness of the muscles which help to maintain pelvic stability may result in increased medial femoral rotation and valgus knee moments, augmenting compressive forces on the patellofemoral joint.[58]

Sathe et al. (2002) suggested that muscle imbalances lead to an increase in anterior tilt of the pelvis leading to excessive medial femoral rotation. Medial femoral rotation, in turn, increases compression of the lateral patellar facet thereby producing pain.[59]

Plastaras et al. (2005) expressed that anterior pelvic tilting causes an increased knee flexion angle, and thus, produces more eccentric force loads on the quadriceps.[60]

Tyler et al. (2006) stated that patients with PFPS demonstrated significant weakness in their hip flexor. This weakness may not adequately provide a stable pelvis during gait, which essentially inhibits the pelvis from going into an anterior pelvic tilt and concomitant femoral internal rotation.[61]

Sweeting and Mock (2007) indicated that the increased anterior pelvic tilt predisposes indirectly the patient to patellofemoral joint syndrome.[62]

2.4.3. Malalignment of lower-extremity

Malalignment of the lower extremity has been considered a contributory factor in the development of PFPS.[63] These biomechanic abnormalities may arise from anatomic as well as functional factors.[64]

However, Wen et al. (1997) studied 304 runners enrolling in a marathon training program. The alignment measurements consisted of arch index, heel valgus, knee tuberclesulcus angle, and knee varus and leg length discrepancies (LLD). They concluded that lower-extremity alignment is not a major risk factor for running injuries.[65]

Lower extremity alignment factors associated with patients with PFPS include: LLD, excessive rearfoot pronation, poor flexibility, inadequate pelvic control, genu varum, genu valgum, excessive quadriceps angle (Q angle) and genu recurvatum. [66,67]

Among above mentioned lower extremity abnormalities, we studied LLD, genu varum and valgum, excessive foot pronation and arch index.

2.4.3.1. Leg length discrepancy (LLD)

Leg length discrepancy (LLD) or anisomelia is one of the abnormal biomechanics of leg. LLD is defined as a condition in which paired legs are noticeably unequal.LLD is a relatively common problem found in as many as 40 to 70% of the population.[68] LLD can be subdivided into two etiological groups: a structural LLD (SLLD) defined as those associated with a shortening of bony structures, and a functional LLD (FLLD) defined as those that are a result of altered mechanics of the lower extremities.[67] Gurney expressed that the degree of LLD that is clinically significant remains controversial. Some investigators have tried to quantify a significant LLD, accepting as much as 20-30 mm, while others define a significant discrepancy in terms of functional outcomes. [68]

Beattie et al. (1990) stated that LLD are thought to contribute to the occurrence or severity of many clinical syndromes. Among these conditions are low back pain, sacroiliac pain and a variety of running injuries. [69]

Several authors have found that LLD created significant changes in gait such as increased ground reaction forces, increased energy consumption and increased lower extremity kinetic energy (Behave et al., 1999; Gurney et al., 2001). [70,71]

LLD may be a source of injury in runners and should be suspected if there is asymmetrical weight bearing, hip external rotation, knee flexion, and pronation in standing (Plastaras et al., 2005).[60]

Messier et al. (1991) indicated that no anthropometric variables discriminate between the runners with PFPS and non-injured control group of runners. Both groups had mean LLD that ranged from 0.02 to 0.18 cm and similar ankle and knee flexibility.[72]

Reid (1993) stated that among all alignment measurements found in the literatures, only LLD is consistently found to be a significant factor in the etiology of PFPS.[73]

Witvrouw et al. (1999) studied anthropometric variables, lower leg alignment characteristics, muscle length and strength in 282 students in a two-year prospective study. During this 2-year follow-up study, 24 of the 282 students developed PFPS. Statistical analysis revealed that no significant differences in LLD between the students with and without PFPS.[15]

Duffey et al. (2000) examined the differences between a non-injured cohort of runners and runners afflicted with anterior knee pain. Their results showed no difference in LLD between the groups. They suggested that a moderate LLD (≤0.5 cm) is normal and under most conditions is not a contributing factor in overuse injuries in runners.[74]

2.4.3.2. Varus and valgus knee deformity

Genu varum and genu valgum are the other anatomic factors which have been hypothesized to be associated with increased risk of injury among athletes. [75]

Valgus at the knee may increase the Q angle, as the patella would be displaced medially with respect to the anterior superior iliac spine (ASIS). In comparison, varus position of the knee could decrease the Q angle, as the patella would be brought more in the line with the ASIS. Knee valgus may be result of femoral adduction (relative to the pelvis), tibial abduction (relative to the femur), or the combination of both (Christopher and Powers, 2003).[67]

Milgorm and et al. (19991) in a prospective study of 390 infantry recruits revealed that increased medial tibial intercondylar distance had a statistically significant correlation with the incidence of PFPS caused by overactivity.[76]

Doucette and Goble (1992) stated that malalignment of lower extremity including increased Q-angle, genu valgum and excessive foot pronation increase the tendency of the patella to displace laterally.[77]

Cowan et al. (1996) showed that genu valgum, excessive Q-angle and genu recurvatum are anatomic risk factors for overuse injuries associated with vigorous physical training. [78]

Lun et al. (2003) determined if measurements of static lower limb alignment are related to lower limb injury in recreational runners. Their results showed significant difference when runners with PFPS were compared with non-injured runners in right ankle dorsiflexion, right knee genu varum and left forefoot varus.[79]

In a case report in a patient with PFPS was not observed genu varus or valgum (Cibulka and Threlkeld-Watkins, 2005).[80]

Waryasz and McDermott (2008) in a review article stated that the characteristics of genu varum and genu valgum have not been found to contribute to PFPS.[14]

2.4.3.3. Excessive foot pronation

Altered foot biomechanics, such as excessive, prolonged or pronation alter the tibial rotation at varying times through range, thus having an effect on patellofemoral joint mechanics.[2]

Excessive foot pronation is a risk factor contributing to alterations in lower-extremity kinematics and musculoskeletal injury (Bonci, 1999) [81] and a cause for overuse running injuries (Messier and Pittala, 1988).[82]

Eng and Pierrynowski (1989) suggested that excessive foot pronation during the stance phase can alter the normal rotation of the tibia in the frontal and transverse planes as a result of anatomical congruency of the talus within the ankle mortise. In turn, aberrant tibial rotation can disrupt the normal patellofemoral relationship.[83]

Messier et al. (1991) found no significant differences in maximum pronation, maximum pronation velocity and total rearfoot movement in 36 runners evaluated with and without PFPS. They stated that rearfoot movement variables were not significant etiologic factor in the development of PFPS.[72]

Powers and colleagues (2002) performed 3-dimensional motion analysis during self-selected free and fast-walking velocities on 24 females with PFPS and 17 controls, and found no group differences with respect to the magnitude and timing of peak foot pronation and tibial rotation.[84]

Cheung et al. (2006) stated that it has been suggested that the rearfoot movement at touch down was much larger in forefoot runners, it is therefore speculated that forefoot runners are at higher risk of overuse injuries because of their larger foot pronation movements.[85]

Hetsroni et al. (2006) found no consistent association between the incidence of anterior knee pain and any of parameters of foot pronation. However; a statistically significant association was found between anterior knee pain and pronation velocity. They concluded that their study does not support the hypothesis that anterior knee pain is related to excessive foot pronation.[86]

The relationship between the standing foot posture and PFPS was investigated in a population of novice recreational runners. The results indicated no significant evidence between an excessively pronated or supinated foot posture and PFPS (Thijs et al., 2008).[87]

2.4.3.4. Arch index

Messier and et al. (1991) presented that runners with and without PFPS had normal arched foot.[72]

Kaufman et al. (1999) in considering of relationship between foot structure and the development of musculoskeletal overuse injuries established no statistically significant relationship between foot structure and PFPS.[88]

Witvrouw et al. (1999) indicated that there was no significant difference in the division of foot type between students with and without PFPS.[15]

Duffey et al. (2000) showed that the anterior knee pain group had a significantly higher arch index, suggesting a more cavus and rigid foot that is less able to absorb shock.[74]

Esterman and Pilotto(2005) considered correlation of foot shape with injuries such as stress fracture, periostitis, iliotibial band syndrome and PFPS in 230 Air

Force recruits. Their results showed no correlation between foot shape and injuries. However, the flat feet group had significantly poorer subjective physical health than did the normal feet group.[89]

Pes cavus (high arch) and pes planus (flat feet) have not been found to contribute to PFPS (Waryasz et al., 2008).[14]

2.4.4. Limited flexibility and range of motion

2.4.4.1. Range of motion (ROM)

Van Mechelen et al. (1992) investigated a group of runners with lower extremity injuries and compared them with controls with respect to range of motion (ROM) of the hip and ankle joints. They found that injured group had more restricted ROM at the hip joint, but ROM at the ankle joint showed no statistically significant differences.[90]

Messier et al. (1991) suggested that anthropometric variables including limb length, arch indices and ankle and knee ROM were not significant discriminator between the group with PFPS and the control group.[72]

Thomee et al. (1995) showed that subjects with PFPS did not differ in lower extremity alignment, patellar alignment and lower extremity ROM measurements when compared with control group. In addition, patients had no differences in lower extremity alignment and ROM between their right and left side.[91]

According to female runners sustained certain lower extremity injuries more than male, Ferber et al. (2003) considered differences in hip and knee kinematics and kinetics in women and men recreational runners during running. They found that female demonstrated a significantly greater peak hip adduction and hip internal rotation.[92]

Cibulka and Threlkeld-Watkins (2005) in a case report of the patient with pain in the right knee showed that active ROM of the right knee was full, with 0-140 degrees of knee motion.[80]

In a study about differences in lower extremity mechanics during single-legged jumps, pain, exertion, hip and trunk strength, and 3-dimensional lower extremity joint mechanics were recorded at the beginning and end of the protocol. The results showed that women with PFPS demonstrated increased hip adduction angle, hip flexion angle, hip abduction angular impulse, and decreased hip internal rotation angles throughout the exertion protocol. Both groups demonstrated decreased jump height, hip flexion and internal rotation, knee flexion, and hip extension impulse at the end of the protocol (Willson and Davis, 2008).[93]

2.4.4.2. Muscle flexibility

Muscular inflexibility is a leading contributor to injury. Inflexibility of the quadriceps, hamstrings, or ITB may restrict range of motion around the knee and are likely to increase the forces on the knee.[64]

McConnel (2002) suggested that a decrease in the flexibility of the soft-tissue structures that surround the patella, such as lateral retinaculum, TFL, hamstring, gastrocnemius and rectus femoris, is a significant contributing factor in the etiology of PFPS, as it adversely affects the tracking of the patella.[2]

Smith et al. (1991) investigated the relationship between thigh muscle flexibility and anterior knee pain in skaters. They showed that skaters with knee pain had tighter quadriceps muscles than those without pain. Poor hamstring flexibility was correlated with PFPS.[94]

Puniello (1993) presented that TFL/ITB complex tightness may contribute to the development of PFPS.[12]

Fredericson et al. (2006) in a review article stated that literatures supports the concept that tight quadriceps muscles create high patellofemoral stress during sports or the activities of daily living, thus potentiating PFPS.[28]

Piva et al. (2005) investigated soft tissue length between patients with PFPS and control group. The results showed that patients demonstrated significantly less flexibility of the gastrocnemius, soleus, quadriceps, and hamstrings compared to healthy control group. No differences existed in flexibility of the ITL/TFL complex and strength of the hip external rotators and abductors. [95]

White et al. (2009) studies hamstring length in the patients with PFPS and control group. They found that patients had shorter hamstring muscles than asymptomatic controls. They stated that it is not clear whether this is a cause or effect of the condition.[96]

In a case report of the patient with 8 month history of anterior right knee pain were used Thomas and Ober tests for measuring flexibility of hip flexors and ITB. The results showed no difference between the left and right rectus femoris muscles, iliotibial band, or hip flexor muscles (Cibulka and Threlkeld-Watkins, 2005).[80]

2.5. Treatment

Although PFPS represent a common problem, there is no consensus regarding the optimal management of this condition, perhaps in part because of the various sources of pain that may contribute to the disorder. This could explain why there are so many treatment protocols described in the literature. The rehabilitation program must match the specific deficits of each patient while emphasizing the reduction of pain and inflammation.[66]

Normal patellofemoral function requires balanced postural and phasic muscle activity, as well as full joint mobility of the related bony articulations of the lower extremity and pelvis (Green, 2003).[3] The aims of treatment for PFPS are to optimize the patellar position and to improve the lower limb mechanics. [7] An optimal patellar position is achieved by stretching the tight lateral structures and by changing the activation pattern of the VMO (McConnel, 1996).[7]

Many PFPS patients respond well if conservative treatment focuses on controlling inflammation, releasing tight lateral structures, quadriceps strengthening, and avoidance of harmful activities (Maurer et al., 1995).[97]

Souza and Gross (1991) suggested that isotonic quadriceps femoris muscle exercise may elicit more favorable muscle activation patterns than isometric exercise for patients with PFPS.[30]

Eng and Pierrynowski (1993) showed that in addition to an exercise program, the use of soft foot orthotics is an effective means of treatment for the patient with PFPS.[98]

Cerny (1995) stated that neither exercises purported to selectively activate VMO activity nor patellar taping improves the VMO/VL ratio over similar exercises. Although subjects reported that patellar taping decreased pain 94% during the step-down exercise.[99]

Tang et al. (2001) evaluated the EMG of VMO and VL muscles in open and closed kinetic chain exercises in subjects with PFPS and healthy volunteers. They found the VMO/ VL ratios of PFPS subjects were significantly lower than those of unimpaired subjects during knee isokinetic closed chain exercises. However, there was no statistical difference in VMO/ VL ratio between subjects with and without PFPS during closed kinetic chain exercises. Maximum VMO/ VL ratio was obtained at 60° knee flexion in closed kinetic chain exercise. They included in closed kinetic chain exercises, more selective VMO activation can be obtained at 60° knee flexion.[100]

In considering the effect of physical therapy on alleviation of PFPS, Crossly et al. (2002) studied a standardized treatment program consisting of six treatment sessions, once weekly. Physical therapy included quadriceps muscle retraining, patellofemoral joint mobilization, patellar taping, and daily home exercise. This group was compared with a group who used placebo treatment. The placebo treatment consisted of sham ultrasound, light application of a non-therapeutic gel, and placebo taping. The results indicated that physical therapy group demonstrated significantly greater reduction in the scored for average pain, worst pain, and disability than did the placebo group.[101]

Cowan et al. (2002) showed that after physical therapy, the onset of VMO preceded VL in the eccentric phase and occurred at the same time in the concentric phase of the stair-stepping task. There was no change in time of EMG onset in the control and placebo groups.[102]

Mascal et al. (2003) considered a 14-week period treatment with focusing on endurance training of the hip, pelvis, and trunk musculature in two patients with PFPS. They found that both patients experienced a significant reduction in PFPS, improved lower-extremity kinematics during dynamic test, and were able to return to their original levels of function.[103]

Post (2005) in a review article concluded that evaluation and treatment should include lower extremity flexibility, muscular control, and careful evaluation of tender structures.[104]

C.N.Sacco et al. (2006) showed higher efficiency of the VM muscle in carrying out eccentric exercises and increased muscle activity in both the VM and VL muscles while climbing stairs after physical therapy treatment. [105]

In a study about the role of hip muscle function in the treatment of PFPS, was indicated that improvements in hip flexion strength combined with increased iliotibial band and iliopsoas flexibility were associated with excellent results in patients with PFPS (Tyler et al., 2006).[61]

Cowan et al. (2006) investigated the effect of patellar taping on the amplitude of EMG activity of vasti muscles in subjects with and without PFPS. They showed that application of medially directed therapeutic tape significantly decreased pain in the patients. However, patellar taping did not alter the amplitude of vasti EMG when either the PFPS or control participants completed the concentric stair stepping task.[106]

Fagan and Delahunt (2008) in a review article concluded that no randomized controlled trails exist to support the use of hip joint strengthening in subjects with PFPS. Physiotherapy treatment programs appear to be an efficacious method of improving quadriceps muscle imbalance.[107]

Ng et al. (2008) compared the effects of an 8-week exercise program with and without EMG biofeedback on the relative activations of VMO and VL. Twenty-six subjects with PFPS were randomly allocated into an “exercise” group (group 1) and a “biofeedback + exercise” group (group 2). Both groups performed the same exercise program but subjects in group 2 received real time EMG biofeedback information on the relative activations of VMO and VL during exercise. The results revealed that the incorporation of an EMG biofeedback into a physiotherapy exercise program could facilitate the activation of VMO muscle such that the muscle could be preferentially recruited during daily activities. [108]

Due to the effect of Tai chi training in reducing the load in lower limb joints, particularly knee joint and special attention to postural alignment, in the present study, Tai chi training and its effects on knee disorders was studied.

2.6. Tai chi

2.6.1. Definition

Tai chi (TC) is the popular abbreviation for T'ai Chi Chuan (TCC) and is translated as "The Supreme Ultimate Boxing System". TC began as a martial art form.[109] It is an ancient form of a traditional Chinese physical exercise that has been practiced for self-defense and health promotion.[110] Tai chi is a mind-body exercise and combines deep diaphragmatic breathing and relaxation with many fundamental postures that flow imperceptibly and smoothly from one to the other through slow, gentle, graceful movements.[111,112] TC is a popular form of exercise in China among older adults.[113]

TC consists of slow and continuous movements that incorporate elements of strengthening, balance, postural alignment, relaxation and concentration. [114]

2.6.2. Benefits of Tai chi (TC)

TC is considered to be a suitable form of exercise for rehabilitation sporting injuries. It promotes integrated improvement in skeletal alignment, tendon function and joint flexibility. Because of its low impact loading and low velocity nature and emphasis on proprioceptive and internal sense of body position and motion, TC helps or reduces the load on the lower limbs joints, particularly in knee and ankle, which are often sites of degeneration in the athletes (savio et al., 2007).[115]

TC exercise strengthens the pelvic and leg muscles, loosens the hip joint and promotes good balance (Bryant, 2003). [116]

Van Deusen and Harlowe (1987) conducted randomized controlled trails in which participants with rheumatoid arthritis were included in a therapeutic dance program that combined elements of TC with occupational therapy. They compared this intervention with wait-listed participants. They found that lower extremity ROM was significantly greater in the active intervention group at week 8.[117]

The health-related fitness of geriatric TC practitioners was evaluated by Lan et al. (1996). They found that the TC group showed higher oxygen uptake at the ventilatory threshold. In addition, the TC practitioners were characterized by greater trunk flexibility and lower percentage of body fat in comparison with their sedentary counterparts.[118]

Lan et al. (1998) indicated that a 12-month TC program is effective on increasing in thoracic/ lumbar flexibility, increasing in muscle strength of knee extensor, increasing of knee flexors in older individuals.[119]

Therapeutic effects of a short-term TC exercise program for the elderly were evaluated in a pretest-posttest quasi-experimental design. Findings included significant improvement in trait anxiety and pain perception. Improvements in mood, flexibility, and balance may have a profound effect on the incidence of falls, injuries, resulting disability, and overall quality of life (Ross et al., 1999). [120]

Hong et al. (2000) suggested that long term regular TC exercise has favorable effects on the promotion of balance control, flexibility, and cardiovascular fitness in older adults.[121]

TC puts a great emphasis on the exact joint position and direction. Therefore, the repeated practice of TC might be expected to develop a heightened sense of the position of the joints. Therefore, Tsang et al. (2003) studied whether elderly TC practitioners have developed better joint propriception and standing balance control than control subjects. They found that long-term TC practitioners had improved knee joint propriception and expanded their limits of stability during weight shifting in stance.[112]

XU et al. (2004) compared improvement ankle and knee proprioception and kinaesthesis in three groups; elderly long term TC practitioners, elderly long term swimmers/runners and elderly sedentary controls. They found that elderly people who regularly practiced TC not only showed better proprioception at the ankle and knee joints than sedentary controls, but also better ankle kinaesthesis than swimmers/runners. They concluded that the large benefits of TC exercise on propriception may result in the maintenance of balance control in older people.[122]

In a cross-sectional study, knee muscle strength, body sway in perturbed single-leg stance, and balance confidence was compared between older TC practitioners and healthy older adults. The results demonstrated that long-term TC practitioners had better muscle strength, less body sway and greater balance confidence (Tsang et al., 2005).[123]

Taylor-Piliae et al. (2006) showed statistically significant improvements in all balance, muscular strength and endurance, and flexibility measures after 6 weeks, and they increased further after 12 weeks.[113]

2.6.3. Tai chi and knee disorders

To my knowledge, there is no study to indicate the effect of TC on the alleviation of PFPS. However, some researchers studied the effect of TC in the patients with knee osteoarthritis.

Macfarlane et al. (2005) suggested that TC training in older women improved knee extension strength and hamstring flexibility.[124]

Fransen et al. (2007) determined whether TC or hydrotherapy classes for individuals with chronic symptomatic hip or knee osteosrthritis (OA) result in measurable clinical benefits. They demonstrated that after 12 weeks of hydrotherapy classes or TC classes for fairly sedentary older individuals, both classes can provide large and sustained improvement in physical function in these patients.[114]

Brismee et al. (2007) evaluated the effects of TC consisting of group and home-based sessions in elderly subjects with knee osteoarthritis. The TC program included 6 weeks of group TC sessions, 40 min/ session, three times a week, followed by another six weeks (weeks 7-12) of home-based TC training. Subjects were requested to discontinue TC training during a six-week follow-up detraining period (weeks 13-18). Subjects in the attention control group attended six weeks of health lectures following the same schedule as the group-based TC intervention (weeks 0-6), followed by 12 weeks of no activity (weeks 7-18).They found that the group and home based TC program provided significant knee pain reduction and physical function improvement in elderly subjects with knee osteoarthritis. These effects were not sustained after detraining.[125]

Soo Lee et al. (2008) evaluated data from controlled clinical trails testing the effectiveness of TC for treating osteoarthritis. They stated that TC may be effective for pain control in these patients; however the evidence is not convincing for pain reduction or improvement of physical function.[126]

A clinical study was conducted to examine the effects of TC on gait kinematics, physical function, and pain in 40 elderly people with knee osteoarthritis. After 6 weeks of instructed TC training (1 hour per sessions, 2 sessions per week), results showed that stride length, stride frequency and consequently gait speed were increased in the participants. Besides, participant's physical function was significantly improved and knee pain was also significantly decreased.[127]

2.7. Overall view of Theoretical aspects

Patellofemoral pain syndrome (PFPS) is a term for a variety of pathologies or anatomical abnormalities leading to a type of anterior knee pain and is the most common knee complaint found with adolescents and young adult runners.

Despite the high prevalence of PFPS, its etiology is not well understood. The most commonly accepted hypothesis is abnormal lateral tracking of the patella. According to previous studies some risk factors have been suggested:

1. The mechanism of abnormal lateral tracking of the patella is an imbalance in the activity of the VMO muscle relative to the VL. Some studies indicated significant differences in delayed onset and lower amplitude of activation of the VMO related to VL in PFPS subjects. However, some else authors found no differences in onset and amplitude activation of VMO related to VL. Despite the fact that ITB/ TFL complex is also a lateral stabilizers of patella, no study has yet considered the EMG of TFL. Only some authors showed that tightness of ITB or TFL may cause PFPS.

2. A few studies investigated the relationship between the degree of lumbar lordosis and PFPS. They showed that increased or decreased lumbar lordosis may contribute with PFPS.

3. Most of the studies showed that anterior pelvic tilt causes PFPS.

4. Some studies suggested that lower-extremity malalignment associated with PFPS. However, others believed that lower-extremity alignment is not a risk factor of PFPS.

5. Authors showed that inflexibility of the quadriceps, hamstrings, or ITB increase the forces on the knee and cause PFPS.

6. Subjects with PFPS did not differ in lower extremity ROM compared with control group.

According to the various sources of pain that may contribute to the disorder, there is no consensus regarding the optimal management of this condition.

The aims of treatment for PFPS are to optimize the patellar position and to improve the lower limb mechanics. Some suggestions for treatment involved: Quadriceps muscle strengthen, flexibility of hamstring and TFL, patellar taping, physical therapy, endurance training of the hip, pelvis, and trunk musculature, hip flexion strength combined with increased iliotibial band and iliopsoas flexibility, exercise program with EMG biofeedback on the relative activations of the VMO and VL.

Based on the effect of Tai chi (TC) training on reducing the load in lower limb joints, TC training and its effects on knee disorders was studied.

Tai chi is a mind-body exercise and combines deep diaphragmatic breathing and relaxation with many fundamental postures. Benefits of TC include:

1. Improvement in skeletal alignment, tendon function and joint flexibility

2. Strengthen the pelvic and leg muscles, loosen the hip joint and promote good balance

3. increasing thoracic/ lumbar flexibility

4. Improvement in health and cardiovascular fitness

5. Improvement in mood and reduction of anxiety

6. Improvement of knee proprioception and kinaesthesis

To my knowledge, no study considered the effect of TC training on PFPS. However, some studies showed that TC reduces pain, improves physical function, increases stride length, stride frequency and consequently gait speed in elderly subjects with knee osteoarthritis.

3. Methodology

3.1. Study design

The present study was done with three groups: a group of patients, a control group and a TC group. Each person was tested for electrical activity of the muscles (see 3.2) and diagnostically relevant risk factors (see 3.3-5). Due to the fact that some subjects didn't agree to take part in the EMG measurement, the group sizes differ between the EMG measurement and the other tests.

3.2. Recording of electrical activity of lateral and medial stabilizer muscles of patella

3.2.1. Subjects

Subjects volunteered to participate in this study and were placed in an experimental group (N=9) or a control group (N=11) based on the presence of symptoms of PFPS with no evidence of any other specific pathologic condition and a Tai chi (TC) group (N=11). The patients with PFPS and control group were athletes who were active in sports such as running, football, basketball, and handball, at least more than 10 years. The TC group was individuals who were active in TC training more than 5 years.

The control group was composed of 4 women and 7 men with a mean age of 25.1 ± 3.2 years and BMI 22.2 ± 2.7. They were healthy and athletic, and reported no history of knee injury.

The experimental group consisted of 3 women and 6 men with a mean age of 26.3 ± 2.6 years and BMI 23.6 ± 2.5, who had history of PFPS with duration of symptoms more than 6 months and intensity sufficient to limit function or cause the individual to seek intervention. These symptoms consisted of retropatellar pain during physical activities such as jumping, running, squatting, and going up or down stairs. Clinical criteria include pain on direct compression of the patella against the femoral condyles with the knee in full extension, tenderness of the posterior surface of the patella on palpation, pain on resisted knee extension and pain with isometric quadriceps muscle contraction against suprapatellar resistance with the knee in 15° of flexion. Participants were excluded if they had signs or symptoms of meniscal injury, pre-patellar bursitis, ligament laxity or tenderness, tenderness over the patellar tendon, illiotibial band syndrome, or pes anserinus tendonitis, patellar apprehension sign, patellar dislocation and previous knee surgery. The subjects did not have pain at rest, and did not have pain during a submaximal isometric contraction of knee flexion.

The TC group included of 7 women and 4 men with a mean age of 43.6 ± 9.7 years and BMI 24.34 ± 3.77. They were healthy and reported no history of knee injuries.

3.2.2. Instrumentation and procedures

Before beginning the study, every subject signed an informed consent document. Active biopolar Ag/AgCl surface electrodes (pre- amplification gain= 10, recording diameter, 1 mm; center-to-center distance, 20 mm) were used.

The electrodes location was estimated by the following method: [128,129] (Figure 1)

Vastus Lateralis: Two anatomical landmarks (the anterior superior iliac spine (ASIS) and the superior lateral side of the patella (SLSP)) were determined. Electrodes were placed at 2/3 on the line from the ASIS to the SLSP in the direction of the muscle fibers.

Vastus medialis obliquus: Two anatomical landmarks (ASIS and the superior medial side of the patella (SMSP)) were determined. A quadriceps line was drawn from the ASIS to the SMSP. Electrodes were placed at 80% of the quadriceps line (starting from ASIS) with a medial inclination of 50°.

Tensor fascia lata: Two anatomical landmarks (ASIS and greater trochanter (GT)) were determined. A line was drawn from the ASIS to the GT. Electrodes were placed at 50% of this line with an inclination of 30°.

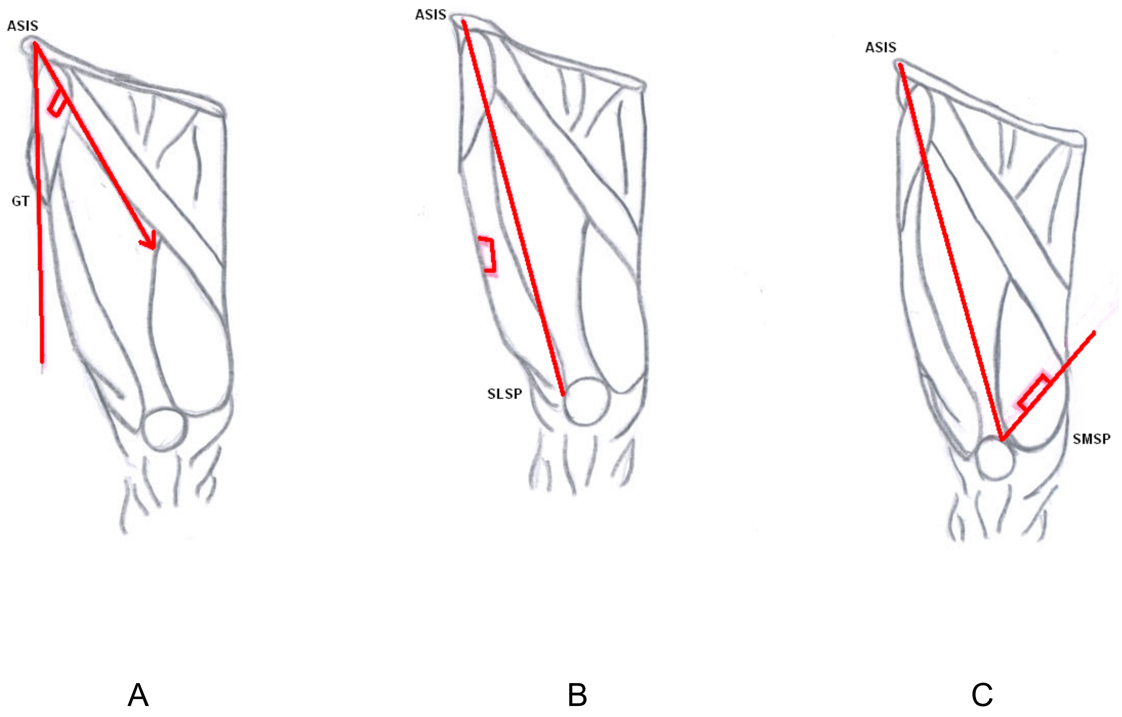

Figure 1. Schematic drawing of proper electrode positioning over the Tensor fascia lata (A), Vastus lateralis (B), and Vastus medialis obliquus(C) muscles.

The subject's skin was prepared by shaving, then used abrasive paste for gentle local abrasion and cleaned with isopropyle alcohol. The long axis of the electrodes was positioned over each muscle in the assumed direction of the underlying muscle fibers. The resistance between the electrode pair was also measured by an EMG electrode impedance tester.

The protocol prescribed submaximal isometric contractions with 60% of maximal voluntary contraction (MVC) for the knee extension. A device was designed for displaying the exact degree of knee extension. We named it angle meter (Figure 2). Subjects warmed up on a treadmill for 5 minutes. Each subject was seated on the chair. The hip-trunk angle was approximately 100°.The angle meter was positioned so that knee flexion angle was 90° and the estimated center of knee joint rotation was on a level with the angle meter's axis of rotation. The subjects put their foot on the pedal of the angle meter. By moving the pedal upwards, the knee was extended and when the angle meter displayed 45°, the subjects had to maintain the position for 6 seconds (Figure 3). Afterward, they contracted isometrically again at 30° and 15° maintaining the contraction for 6 seconds at each stage. The test was repeated 3 times. A rest of 1 min was given between tests. The mean of the three measurements were used for analysis.

EMG raw signals were recorded by using a Noraxon Inc., Scottsdale, AZ, USA EMG system. Signals were amplified differentially (total gain= 1000; CMRR> 130db). A band-pass Butterworth filter with cut-off frequencies ranging from 15 to 500 HZ was applied. The transmitted signals were sampled at 1 kHz, input to an analog-to digital circuit (Data translation Inc., Marlboro. MA. USA. 16-bit resolution), and were stored. All signals processing was supported by the Noraxon MyoResearch XP software.

The activation signals of the VMO, VL and TFL were full-wave rectified through root mean square (RMS). Amplitude was analyzed by calculating IEMG in a window of 6 seconds and normalized by the mean value calculated within this time-window. Signals were also time normalized from 0-100% over these six seconds.

Figure 2. Engle meter

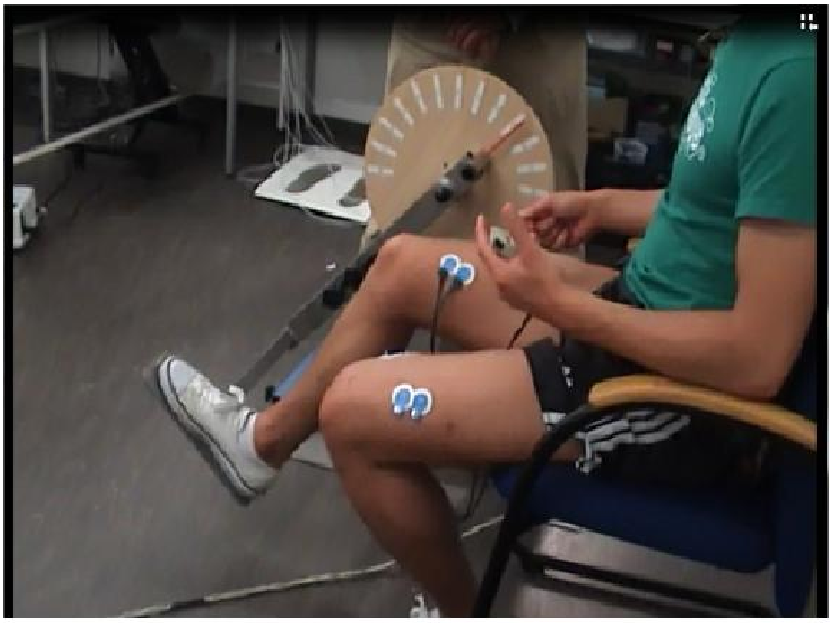

Figure 3. Recording of EMG of muscles in different angles

3.3. Measuring angles of lumbar lordosis and pelvic tilt

3.3.1. Subjects

23 healthy subjects (7 women, 16 men) with a mean age of 25.2 ± 3.2 years and BMI 22.80 ± 2.8, and 15 patients with PFPS (3 women, 12 men) with a mean age of 25.0 ± 4.3 years and BMI 24.19 ± 2.37, and 12 TC subjects (7 women and 5 men) with a mean age of 42.6 ± 10 and BMI 24.26 ± 3.61 took part in this study.

3.3.2. Instrumentation and procedures

The inclinometer technique described by Mayer[130] was adopted for measuring angles of lumbar lordosis and pelvic tilt. Gravity inclinometer with 2 bases was used in this study (Figure 4). Ng et al. (2001) stated that use of the inclinometer technique to record lumbar lordosis is a reliable measure. [131]

Surface bony landmarks were found with the participant in the forward bending position and L5 was located by palpating intervening vertebrae from S2, which is at the level of posterior superior iliac spine (PSIS), and by checking to make sure that the iliac crest was aligned at approximately L4-L5. In the same manner, T12 was found by palpating intervening vertebrae up from S2. The T12-L1 and L5-S1 interspinous spaces were marked on the skin .[81,132]

3.3.3. Lumbar lordosis

The participant was asked to stand in a relaxed posture with the heels about shoulder width apart, hands hanging freely by the side and eyes looking forward. The lumbar lordosis was measured with inclinometer recordings at T12-L1 and L5-S1 (Figure 5). The output of the inclinometer indicated the angles θ_1 (the angle between L5 and S1) and θ_2 (the angle between T12 and L1) and the lumbar curvature C was calculated by $C= (\theta_1+ \theta_2)$ as described by Adams [133] (Figure 6).

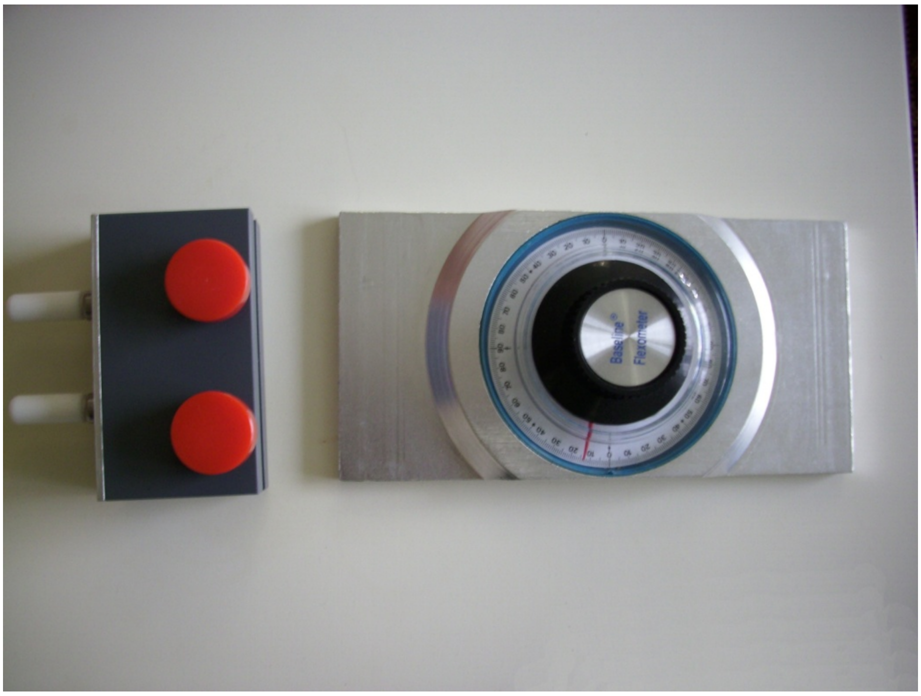

Figure 4. Gravity inclinometer

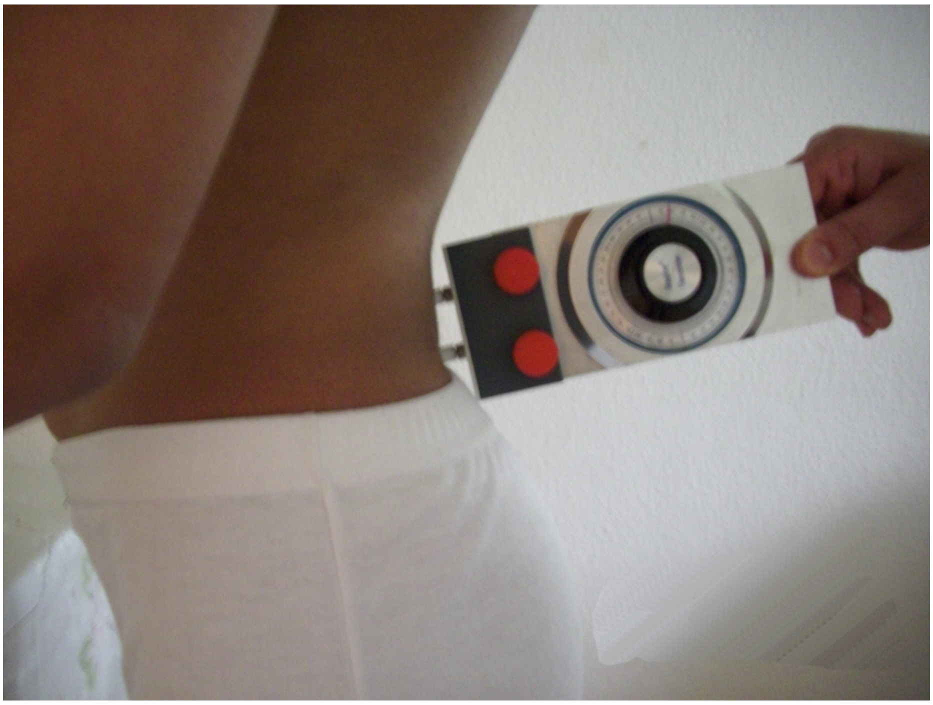

Figure 5. Measurement of lumbar lordosis

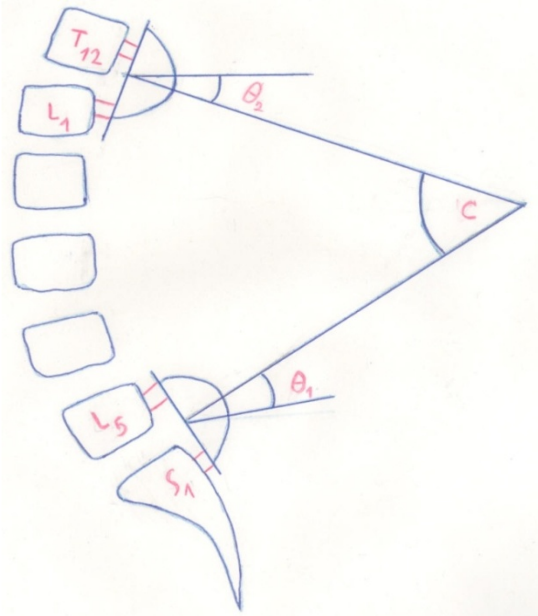

Figure 6. The lumbar curvature C is calculated from the angles θ_1 and θ_2 measured by using the gravity inclinometer.

3.3.4. Pelvic tilt

Pelvic inclination was measured with an inclinometer. Walker et al. showed a high degree of reliability of this method.[134] Each subject stood with their bare feet and was asked to assume a comfortable, erect posture with their body weight evenly distributed between both feet. The examiner palpated the right anterior superior iliac spine (ASIS) and PSIS and placed the tips of the inclinometer on those landmarks. Pelvic tilt was measured in degrees. A positive value represented an anterior tilt and a negative value represented a posterior tilt. Measures were then taken on the left side.[135]

3.4. Measuring of lower-extremity alignment

3.4.1. Leg length discrepancy (LLD)

Supine-long sitting test was used for measuring LLD. The patient lies supine while the therapist places her/his thumbs on the inferior borders of the medial malleoli to outline the position of the malleoli. The two malleoli are approximated to facilitate comparisons of their positions. The patient then sits up; he can use his hands if necessary but must push evenly with each hand to avoid shifting the pelvis. The therapist notes any change in relationship of the malleoli. One leg appearing to lengthen in relationship to the other when the patient moves from supine to sitting, indicates posterior innominate rotation on that side. Conversely, one leg appearing to shorten in relationship to the other indicates an anterior innominate rotation on that side. One leg remaining consistently shorter or longer in relationship to the other indicates an anatomical leg-length difference.[136]

The standing flexion test, prone knee flexion test and sitting PSIS test were also done. According to Cibulka et al.[137] performing all these tests together has a high reliability.

3.4.2. Genu varum and genu valgum

The medial tibial intercondylar distance was measured as follows. The subject was instructed to stand naturally, with their legs together. Depending on the alignment of the knees, either the medial malleoli or the knees touched. For the subjects in whom the malleoli touched (genu varum), the distance between the medial condyles of the tibias was measured to the nearest centimeter. If the knees touched (genu valgum), the distance between the medial malleoli was measured to the nearest centimeter. If the distance between medial condyles of the tibias and the medial malleoli were both less than 1 cm, the knees were evaluated as normal.[15,76]

3.4.3. Excessive foot pronation

Rearfoot-to-leg orientation was used for evaluation of foot pronation. The subject was instructed to stand naturally, with the feet shoulder width apart. The angle between a longitude line bisecting the rearfoot (calcaneus) with the bisecting line of distal one-third of the lower leg was measured. The neutral posture was assumed 0°. A negative value of this angle represented pronation, whereas a positive value represented supination, [138] (Figure 7).

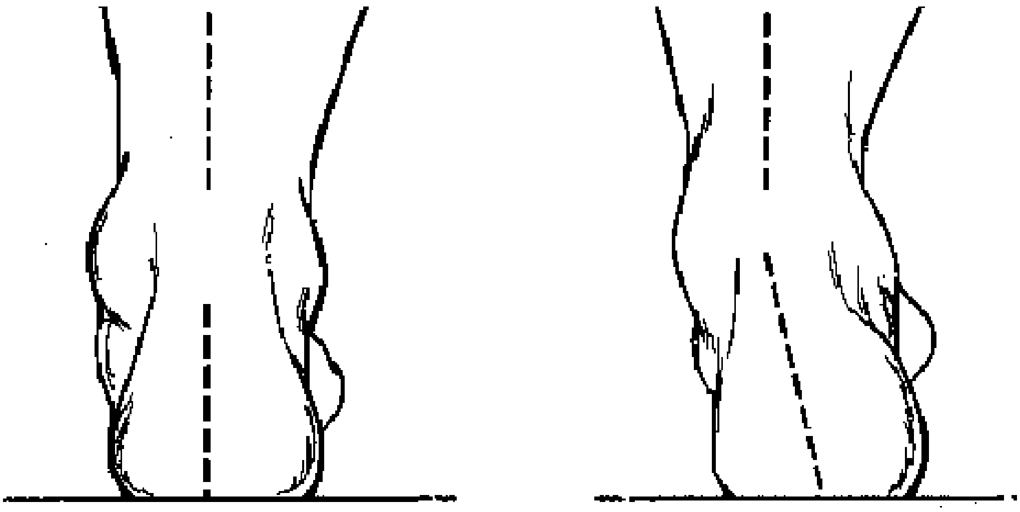

Figure 7. Rearfoot-to-leg orientation

3.4.4. Arch index

The study of the plantar stance usually consists of the morphologic evaluation of the footprint. The footprint index is defined as the ratio of the non-contact to the contact areas of the toeless footprint. The non-contact area is the part between the medial borderline of the footprint and the medial footprint outline. The contact area is the area of the footprint without the toes.[139]

A footprint can be defined as normal, when the print of the foot's isthmus, which is the middle part of the foot touching the ground along its lateral edge, is 1/3 of the forefoot's print. In a footprint of a flatfoot the isthmus is more than 1/3 of the forefoot's print, and in a footprint of a claw foot the isthmus is smaller than 1/3 of the forefoot's print, (Figure 8).[140]

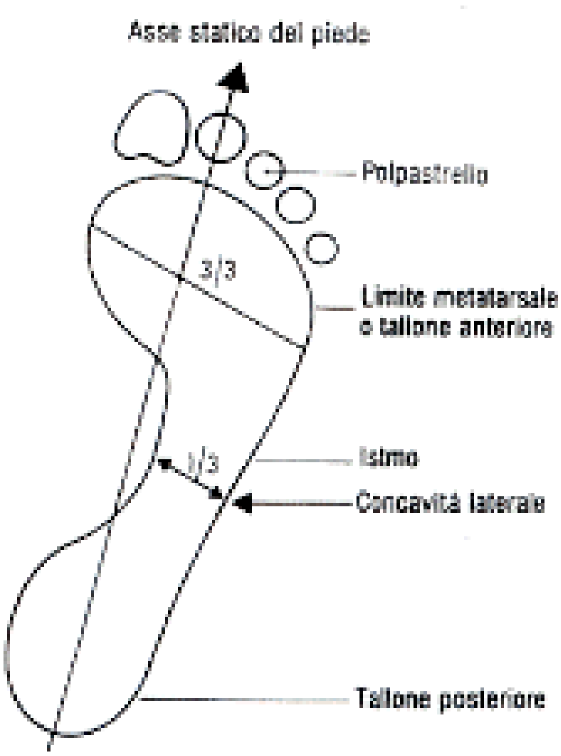

Figure 8. Footprint

3.5. Measuring of range of motion of knee and hip

A bi-armed goniometer was used to measure Knee and hip ROM. According to Miller measuring ROM of joints by using a goiniometer is a valid method compared to X- ray measurements.[141] Active ROM of knee and hip was measured with the subject in three different positions and compared with normal range.[142]

3.5.1. Knee

Knee flexion was performed in the supine position. The fulcrum was aligned with the lateral epicondyle of the femur. The stationary arm was in line with the greater trochanter and midline of the femur, the moving arm with the lateral malleolus and midline of the fibula. Subject flexed the hip and knee, with the foot on the table. The opposite leg was kept extended on the table (Figure 9). Knee flexion ROM was measured and compared with normal range (120°-150°).

Knee extension was completed in the same position when knee and hip joints were straightened. The goniometer positioning for knee extension was the same as it is for knee flexion. Extension ROM was measured and compared with normal range (5°-10°).

Figure 9. Measurement of knee flexion

3.5.2. Hip

Hip flexion was performed in the supine position. The fulcrum was aligned with the greater trochanter of the femur. The stationary arm was positioned along the lateral midline of the abdomen, using the pelvis for reference, the moving arm along the lateral midline of the femur.

Subject flexed knee on the measured side and extended the opposite leg and rested on the examining table. The hip joint being examined was bended while pelvis was stabilized to prevent rotation or posterior tilting (Figure 10). Flexion ROM was measured and compared with normal range (130°-140°).

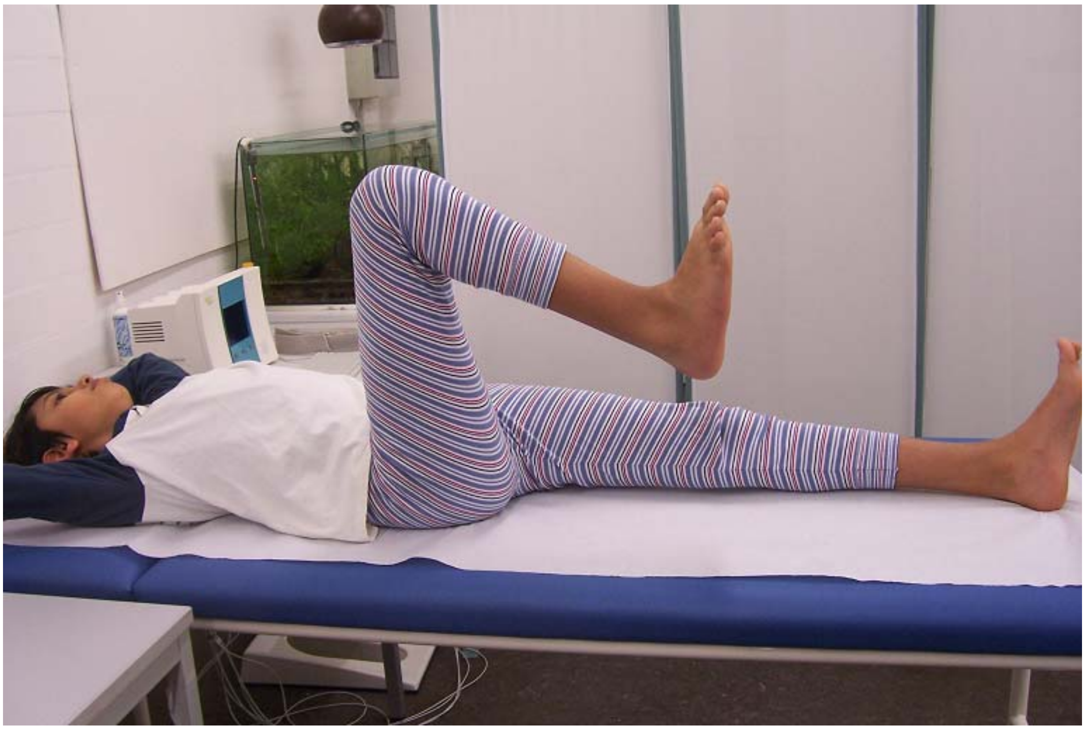

Figure 10.Measurement of hip flexion

Hip extension was done with the subjects in lateral position and the knee on the measured side extended. Subjects fixed the opposite hip joint in maximal flexion. The leg being examined was then extended under the examiner's guidance while the pelvis was stabilized to prevent rotation or anterior tilting (Figure 11). Goniometer positioning was the same as for hip flexion. Hip extension ROM of each subject was compared with normal range (10°-30°).

Figure 11. Measurement of hip extension

Hip abduction was performed in the supine position. Fulcrum was placed in line with the ASIS. The moving arm of the goniometer was aligned with the midline of the patella, the stationary arm with the ASIS of the opposite side.

The knee on the measured side was kept straight, and the examiner supported the weight of the leg as the subject moved it out to the side (Figure 12). Hip abduction was measured and compared with normal range (30°-50°).

Figure 12. Measurement of hip abduction

Hip adduction was done in the same position with abduction. The goniometer positioning was the same as for abduction, fulcrum at the ASIS, moving arm aligned with the midline of the patella, and the stationary arm with the ASIS of the opposite side.

When measuring adduction, the opposite hip joint must be slightly flexed. Subject moved his leg being examined to inside (Figure 13). Adduction ROM was measured and compared with normal range (20°-30°).

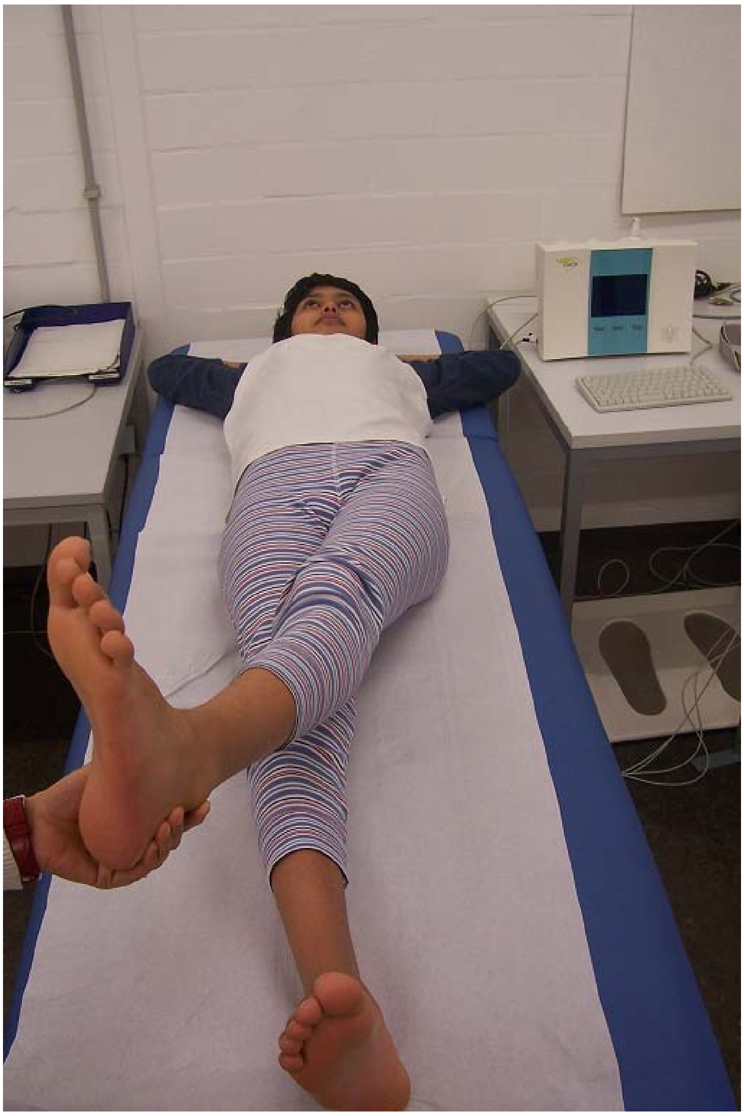

Figure 13. Measurement of hip adduction

Hip internal was measured in a prone position, with the knee flexed to 90 degree. The fulcrum was aligned with the patella and both arms of the goniometer with the midline of the tibia. The lower leg was used as a pointer. During internal rotation, the axis of the lower leg pointed outward (Figure 14). Hip internal rotation was measured and compared with normal range (30°-40°).

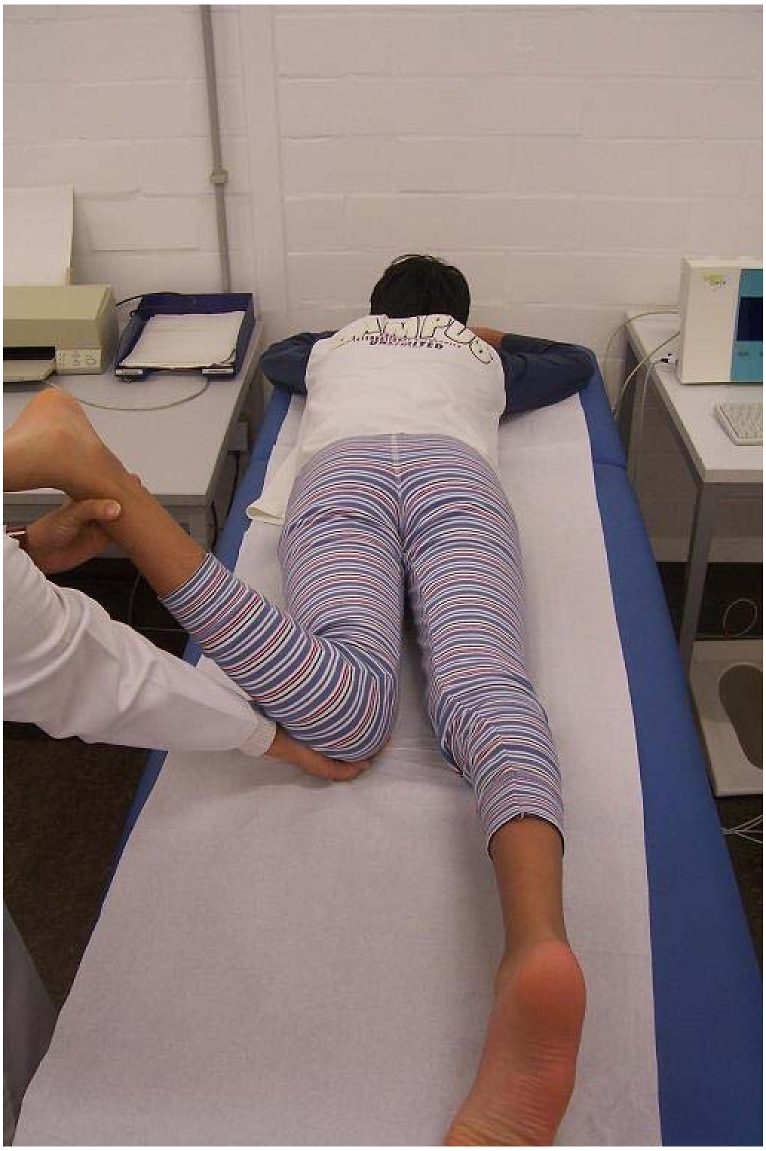

Figure 14. Measurement of hip internal rotation

Hip external rotation was measured in the same position and goniometer positioning of internal rotation. During external rotation, the axis of the lower leg pointed inward (Figure 15). Hip external rotation was measured and compared with normal range (40°-50°).

Figure 15. Measurement of hip external rotation

3.6. Examination of flexibility of hip flexors and iliotibial band

3.6.1. Ober test

Length of iliotibial band was examined using the Ober test according to the procedure described by Reese and Bandy, [143] (Figure 16). The intrarater reliability of the Ober test has been shown to have an intraclass correlation coefficient of 0.90.[61]

The subject was positioned in side lying, with the tested leg superior and the pelvis perpendicular to the table. The lower leg was slightly flexed at the hip and knee to maintain stability and to restrain body rotation. The subject's pelvis was stabilized with the examiner's free hand. Examiner passively first, abducted and second extended the subject's hip in line with the trunk. Examiner then asked the subject to relax all muscles of the lower extremity while allowing the uppermost limb to drop into adduction toward the table through the available hip adduction ROM. As the limb dropped toward the table, examiner supported the limb at the medial joint in order to lower the limb with greater control. In addition, this support hand prevented flexion and internal rotation of the hip. The end position of hip adduction was defined as the point at which tilting of the pelvis was palpated, when the hip adduction movement stopped, or both.

Hoppendfeld suggested that when performing the Ober test, if the iliotibial band is normal, the thigh should drop to the adducted position, and if contracture is present in the iliotibial band, the thigh should remain abducted.[144]

Figure 16. Ober test

3.6.2. Thomas test

The Thomas test was used to measure hip flexor flexibility.[145] The subject was asked to lie supine on the table with the gluteal folds at the edge of the table. The contralateral limb was held by the subject in a knee-to-chest position. Subjects were instructed to push their low back into the table. The tester then lowered the subject's leg to the point where motion ceased or there was external rotation of the femur. At this point, hip flexibility was determined. The ROM was quantified as tight if the measurement was above horizontal and loose if below horizontal. Horizontal was considered normal hip flexor flexibility, [146] (Figure 17).

Figure 17. Thomas test

3.7. Statistical analyses

ANOVA with Post Hoc Tukey test was used to compare the activation amplitude of the VL, VMO, TFL muscles and their ratios between the patients, control and TC groups.

ANOVA with LSD Post Hoc test was used to compare the angle of lumbar lordosis and pelvic tilt between the groups.

A descriptive analysis was done. Leg deformities in the patients and control group were compared by Pearson chi-square and Fisher's exact tests.

The one-way ANOVA was used to compare knee and hip ROM and Fisher's exact test was done to compare flexibility of muscles between the groups.

Statistical analysis was performed with SPSS Version 17.0, and a value of 0.05 was accepted as reflecting significance.

4. Results

4.1. The electrical activity of the VMO, VL and TFL muscles

4.1.1. Comparison of the activation amplitude of the VMO

Significant differences were identified in the activation amplitude of the VMO at 30° and 45°angles between the subjects with and without PFPS (P=0.05 and P= 0.03, respectively. According to the ANOVA analysis, VMO electrical activity in the subjects with PFPS was significantly greater than that of the subjects without PFPS. The mean values of VMO electrical activity in the patients at the angles of 30° and 45° were 38.9% and 34.6% respectively. However, the mean values of VMO electrical activity in the control group were 26.4% at an angle of 30°and 22.3 % at an angle of 45°. No significant differences were demonstrated in the activation amplitude of the VMO at 15° angle between two groups.

In addition, no significant differences were identified in the activation amplitude of the VMO at 15°, 30° and 45°angles between the subjects with and without PFPS and Tai chi group (P> 0.05)), (Figure 18). The mean values of VMO electrical activity in the TC group at above mentioned angles were 69.1%, 38.3% and 35.9 %, respectively. The mean values and standard deviations of VMO IEMG value have been reported in Table 1.

Table 1. The means and standard deviations (%) of normalized VMO IEMG value for knee flexion angles in the subjects with and without PFPS and Tai chi group.

Group (n)	Knee Flexion Angle		
	45°	30°	15°
Control (11)	22.3± 11.3	26.4± 11.5	72.3± 7.3
Patients (9)	34.6± 12.6	38.9± 15.3	73.6± 10.5
Tai chi (11)	35.9± 26.1	38.3± 26.1	69.1± 16.0

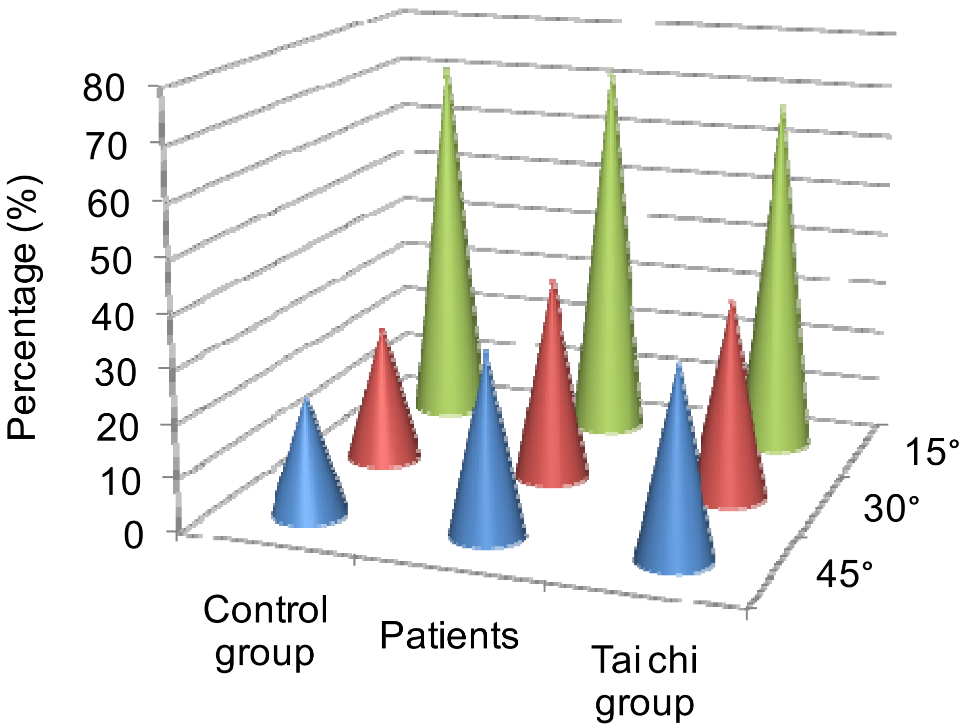

Figure 18. Comparison of VMO electrical activity in the subjects with and without PFPS and Tai chi group at 45°, 30° and 15° angles of knee flexion

4.1.2. Comparison of the activation amplitude of the VL

No significant differences were demonstrated in the activation amplitude of the VL at 15°, 30° and 45° angles between the patients, control and TC groups (P> 0.05), (Figure 19). The VL electrical activity in the subjects with PFPS was higher than that of the subjects without PFPS and was lower than that of the TC group at 30° and 45° angles of knee flexion. However; these differences were not significant. The mean values of VL electrical activity in the patients at the angles of 15°, 30° and 45° were 78.0%, 46.1% and 41.3%, respectively. However, the mean values of VL electrical activity in the control group at above mentioned angles were 80.3%, 40.7% and 37.3 %, respectively.

Furthermore, the mean values of VL electrical activity in the TC group at the angles of 15°, 30° and 45° were 71.1%, 46.6% and 44.7%, respectively. The mean values and standard deviations of VL IEMG value have been presented in Table 2.

Table 2. The means and standard deviations (%) of normalized VL IEMG value for knee flexion angles in the subjects with and without PFPS and Tai chi group.

Group (n)	Knee Flexion Angle		
	45°	30°	15°
Control (11)	37.3±18.1	40.7± 17.1	80.3± 8.9
Patients (9)	41.3±21.4	46.1± 23.2	78.0± 11.0
Tai chi (11)	44.7± 23.9	46.6± 23.8	71.1± 13.6

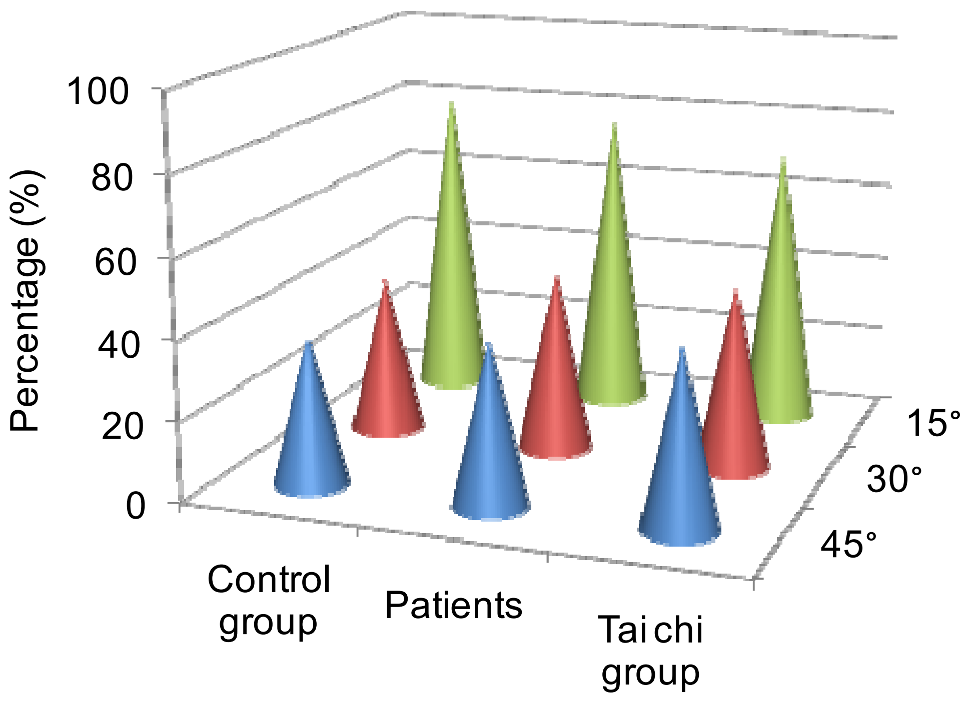

Figure 19. Comparison of VL electrical activity in the subjects with and without PFPS and Tai chi group at 15°, 30° and 45° angles of knee flexion

4.1.3. Comparison of the activation amplitude of the TFL

No significant differences were demonstrated in the activation amplitude of the TFL at 15°, 30° and 45° angles between the patients, control and TC groups ($P > 0.05$), (Figure 20). The TFL electrical activity in the subjects with PFPS was higher than that of the subjects without PFPS at 15° and 45° angles of knee flexion and was higher than that of the TC group at 30° and 45° angles. However; these differences were not significant. The mean values of TFL electrical activity in the patients at the angles of 15°, 30° and 45° were 71.4%, 41.7% and 33.4%, respectively. However, the mean values of TFL electrical activity in the control group at above mentioned angles were 66.1%, 45.2% and 32.4 %, respectively

In addition, the mean values of TFL electrical activity in the TC group at above mentioned angles were 72.2%, 41.4% and 30.3 %, respectively. The mean values and standard deviations of TFL IEMG value have been showed in Table 3.

Table 3. The means and standard deviations (%) of normalized TFL IEMG value for knee flexion angles in the subjects with and without PFPS and Tai chi group.

Group (n)	Knee Flexion Angle		
	45°	30°	15°
Control (11)	32.5±16.2	45.2± 19.8	66.1± 11.3
Patients (9)	33.5±16.2	41.7± 15.4	71.4± 8.0
Tai chi (11)	30.3± 16.3	41.4± 17.2	72.2± 13.0

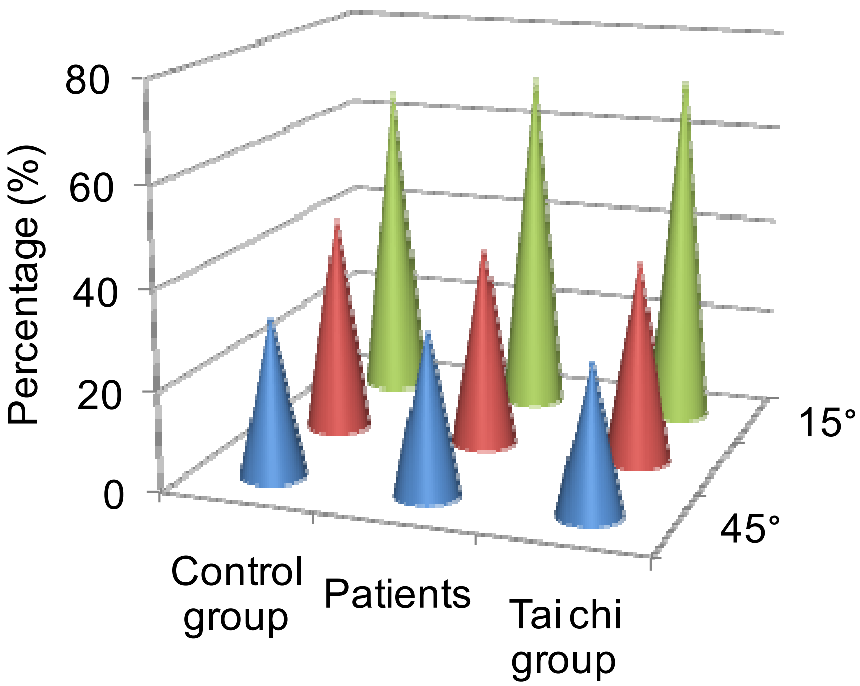

Figure 20. Comparison of TFL electrical activity in the subjects with and without PFPS and Tai chi group at 15°, 30° and 45° angles of knee flexion

4.1.4. Comparison of VMO/ VL ratio

In the present study, VMO/ VL, VMO/ TFL and VMO/ (TFL+ VL) ratios were considered and compared in the subjects with and without PFPS and TC group. There were no significant differences in the VMO/ VL ratio at 30° and 15° angles of knee flexion between the patients and control group ($P > 0.05$). However, a non-significant positive trend was observed at 45° angle of knee flexion ($P=0.07$).

Furthermore, there were no significant differences in the VMO/ VL ratio across all knee flexion angles between the subjects with and without PFPS and TC group ($P > 0.05$), (Figure 21). The VMO/ VL ratio in the subjects with PFPS was greater than that of the control and TC groups at 30° and 45° angles of knee flexion. However, this ratio in the patients at 15° angle of knee flexion was greater than that of the control group and less than that of the TC group. The mean values of VMO/ VL ratio in the patients, control and Tai chi groups have been reported in Table 4.

Table 4. The VMO/ VL ratio for knee flexion angles in the subjects with and without PFPS and Tai chi group.

Group (n)	Knee Flexion Angle		
	45°	30°	15°
Control (11)	0.67± 0.29	0.68± 0.22	0.90± 0.08
Patients (9)	1.01 ± 0.51	0.98± 0.46	0.95± 0.12
Tai chi (11)	0.75± 0.28	0.76± 0.24	0.97± 0.12

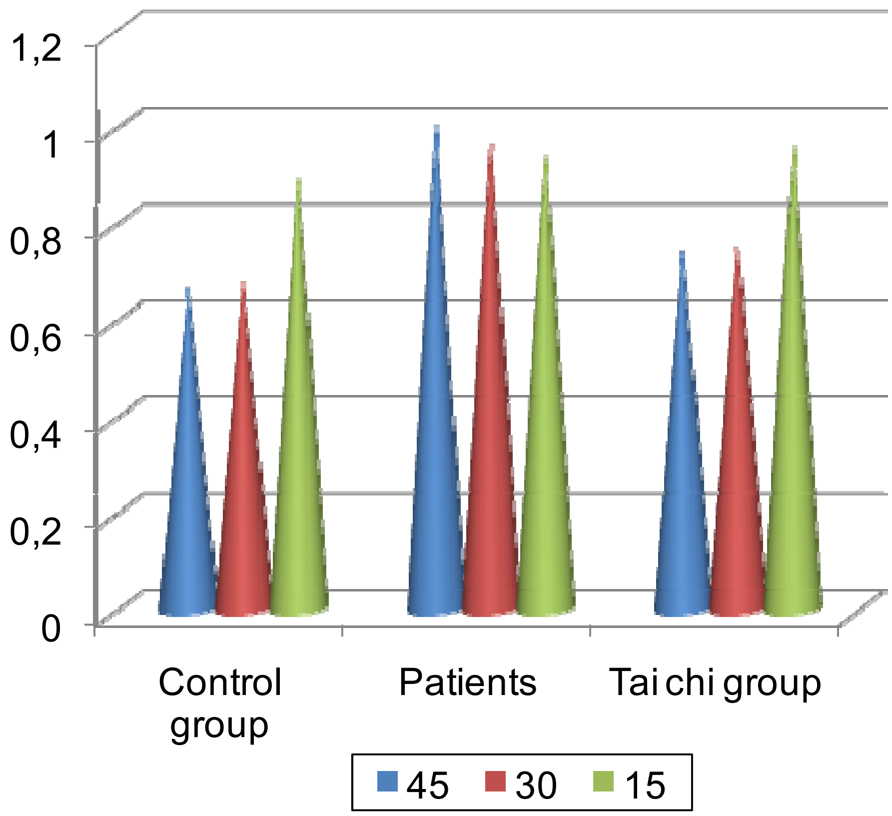

Figure 21. Comparison of VMO/ VL ratio in the subjects with and without PFPS and Tai chi group at 15°, 30° and 45° angles of knee flexion

4.1.5. Comparison of VMO/ TFL ratio

No significant differences were identified in the VMO/ TFL ratio at 45° and 15° angles of knee flexion between the subjects with and without PFPS (P> 0.05). However, a non-significant positive trend was observed at 30° angle of knee flexion (P=0.06).

No significant differences were demonstrated in the VMO/ TFL ratio across all knee flexion angles between the subjects with and without PFPS and Tai chi group (P> 0.05), (Figure 22). The VMO/ TFL ratio in the subjects with PFPS was greater than that of the control groups at 30° and 45° angles of knee flexion and was greater than that of TC group at 15° and 45° angles. The mean values of VMO/ TFL ratio in the patients, control and Tai chi groups have been presented in Table 5.

Table 5. The VMO/TFL ratio for knee flexion angles in the subjects with and without PFPS and Tai chi group.

Group (n)	Knee Flexion Angle		
	45°	30°	15°
Control (11)	0.79± 0.41	0.66± 0.33	1.14± 0.31
Patients (9)	1.48 ± 1.31	0.99± 0.43	1.04± 0.17
Tai chi (11)	1.44± 1.42	1.05± 0.94	0.98± 0.25

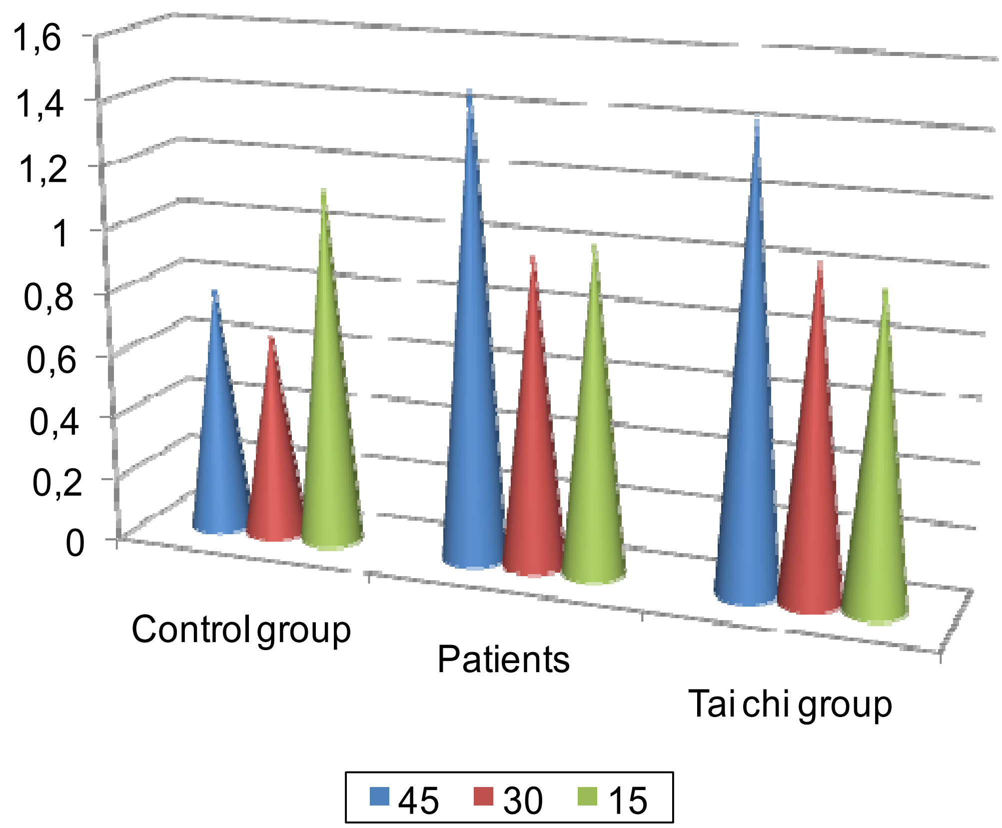

Figure 22. Comparison of VMO/ TFL ratio in the subjects with and without PFPS and Tai chi group at 15°, 30° and 45° angles of knee flexion

4.1.6. Comparison of VMO/ (TFL+ VL) ratio

There was a significant difference in the VMO/ (TFL+ VL) ratio at 30° of knee flexion between the patients and control group (P=0.02). This ratio at 30° of knee flexion for the subjects with PFPS (0.46) was significantly greater than for the subjects without PFPS (0.31).There was no difference in this ratio at 15° and 45°angles of knee flexion between the two groups. However, a non-significant positive trend was observed at 45° angle (P=0.06).

No significant differences were found in the VMO/ (TFL+ VL) ratio across all knee flexion angles between the subjects with and without PFPS and Tai chi group (P> 0.05), (Figure 23). This ratio at all angles for the patients was greater than that of the TC group. The mean values and standard deviations of VMO/ (TFL+ VL) ratio in the patients, control and Tai chi groups have been shown in Table 6.

Table 6. The VMO/ (TFL+ VL) ratio for knee flexion angles in the subjects with and without PFPS and Tai chi group.

Group (n)	Knee Flexion Angle		
	45°	30°	15°
Control (11)	0.34± 0.13	0.31± 0.11	0.50± 0.07
Patients (9)	0.48 ± 0.19	0.46± 0.14	0.49± 0.07
Tai chi (11)	0.46± 0.22	0.41± 0.19	0.48± 0.08

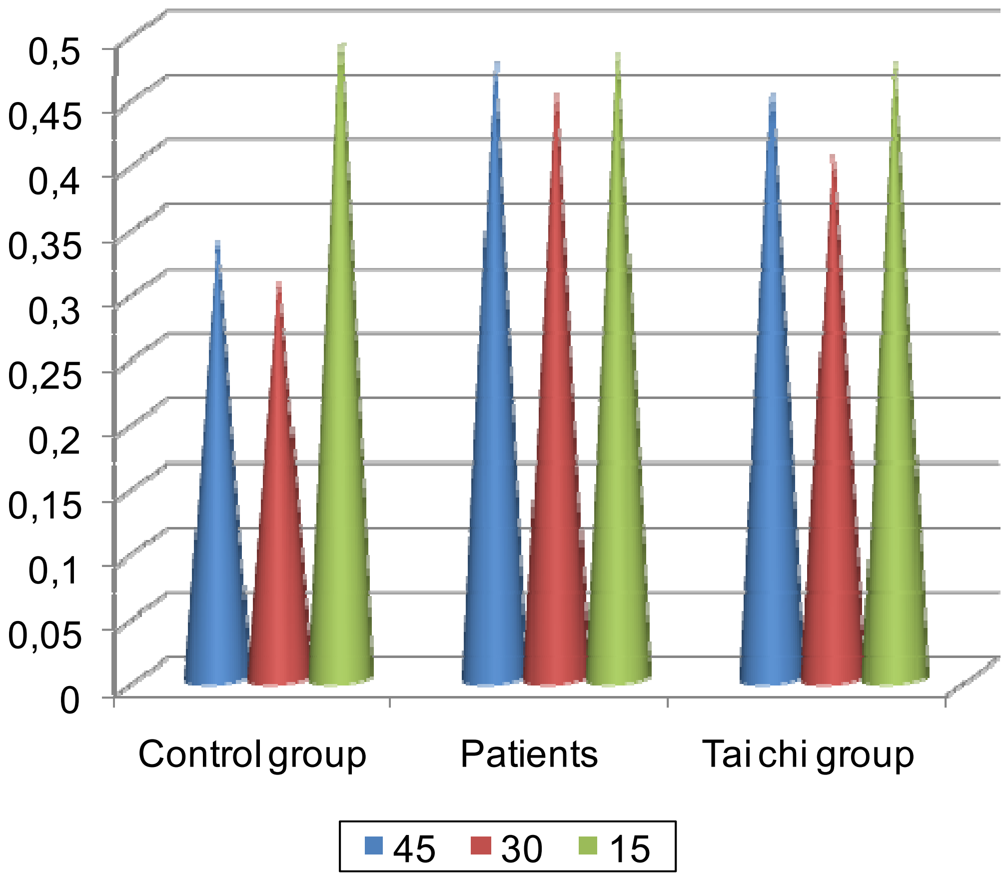

Figure 23. Comparison of VMO/ (TFL+VL) ratio in the subjects with and without PFPS and Tai chi group at 15°, 30° and 45° angles of knee flexion

4.2. Lumbar lordosis and pelvic tilt

4.2.1. Lumbar lordosis

No significant differences were demonstrated in the angle of lumbar lordosis between the patients, control and TC group. However, a strong trend was observed (P=0.06). According to Post Hoc test, there were significant difference in angle of lumbar lordosis between the patients and control group (P=0.03). The results showed that the degree of lumbar lordosis in the subjects with PFPS was significantly less than that of the subjects without PFPS.

However, no significant differences were showed in angle of lumbar lordosis in the patients and Tai chi group as well as control and Tai chi groups (Figure 24). The mean values and standard deviations of angle of lumbar lordosis in the patient, control and Tai chi groups have been reported in Table 7.

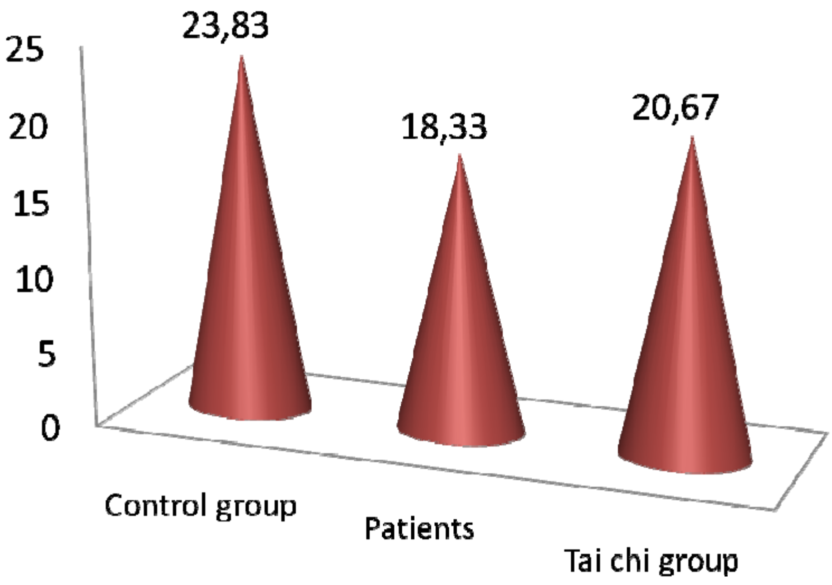

Figure 24. Comparison of the angle of Lumbar lordosis in the subjects with and without PFPS and Tai chi group

4.2.2. Pelvic tilt

There were significant differences in pelvic tilt between patient, control and Tai chi groups (P=0.04), (Figure 25). According to Post Hoc test, significant differences were showed between the patients and Tai hi group (P=0.04) as well as the control and Tai chi groups (P=0.02). The angle of anterior pelvic tilt in Tai chi group (3.33°) was significantly less than that of the patients (6.40) and control group (6.74). However, there were no significant differences between patients and control group (P> 0.05). These results have been summarized in Table 7.

Table 7. Comparison of angles of lumbar lordosis and pelvic tilt in the subjects with and without PFPS and Tai chi group

Group(n) / Deformities	Patients (15)	Control group (23)	Tai chi group (12)
Lumbar lordosis	18.33°±8.29°	23.83°± 6.36°	20.67°± 5.85°
Pelvic tilt	6.40° ± 3.78°	6.74° ± 3.99°	3.33°± 3.34°

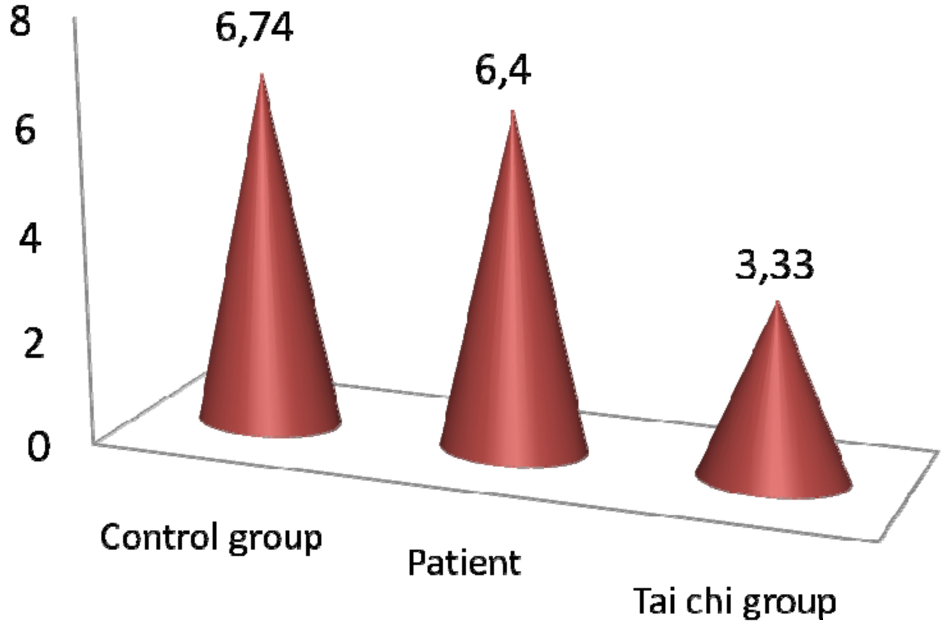

Figure 25. Comparison of the angle of pelvic tilt in the subjects with and without PFPS and Tai chi group

4.3. Malalignment of lower-extremity

4.3.1. Leg length discrepancy

Significant differences were identified in LLD between the patients and Tai chi group (P=0.04) as well as Tai chi and control groups (P=0.01). However, no significant differences were identified in LLD between the subjects with and without PFPS (P> 0.05).

67% of the patients and 70% of the control group had LLD; however in the Tai chi group only 25% had LLD (Figure 26). 53% of the patients with PFPS who had LLD, the left leg was longer than the right leg. However, in the control group who had LLD, only in 30% of them the left leg was longer than the right leg. This result has been reported in Table 8.

Table 8. Incidence of LLD (%) in the subjects with and without PFPS and Tai chi group

Group (n)	Right side	Left side	No LLD
Control (23)	40%	30%	30%
Patients (15)	14%	53%	33%
Tai chi (12)	0%	25%	75%

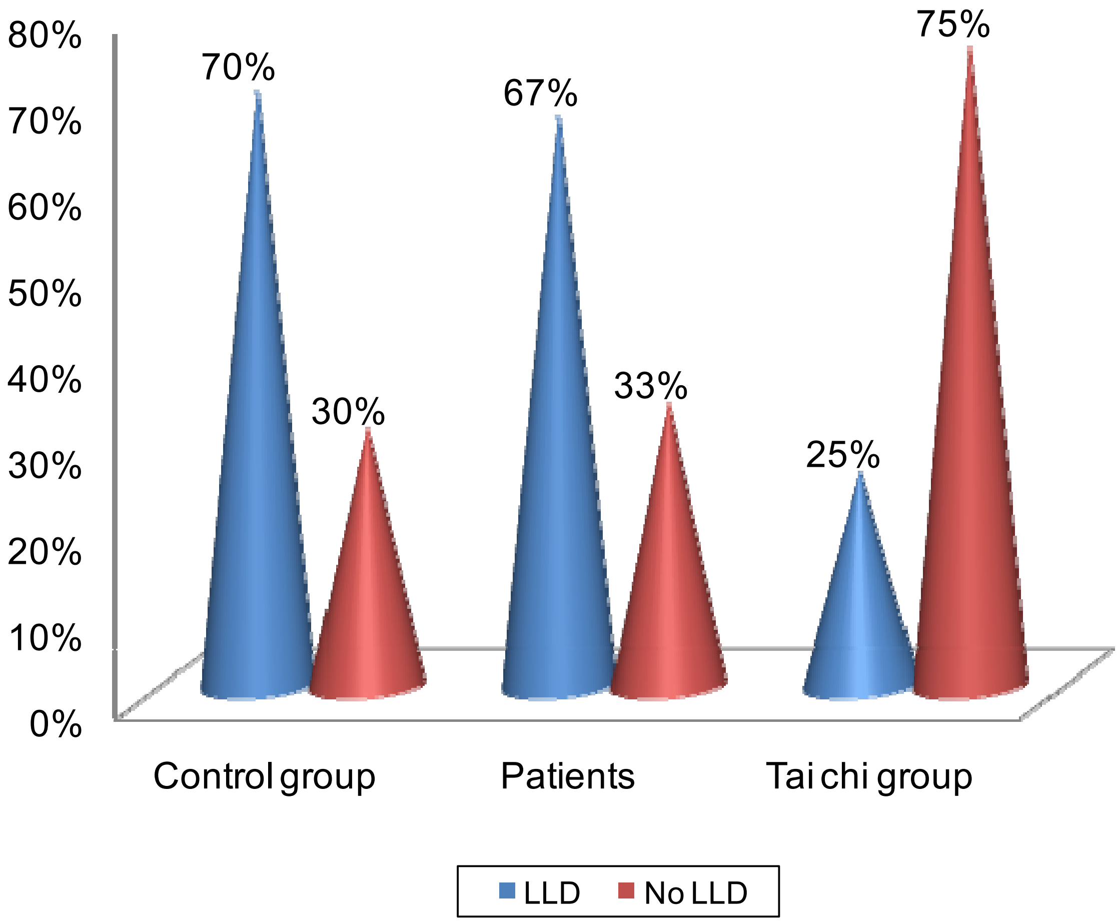

Figure 26. Incidence of LLD in the subjects with and without PFPS and Tai chi group

4.3.2. Varus and valgus knee deformity

No significant differences were found in genu varum and genu valgum deformities between the patients, control and Tai chi groups (P>0.05). Thirteen of the 15 patients (87%) demonstrated no knee deformities; only 2 of the patients (13%) had genu valgum and none of them showed genu varum. In the control group, 17 of the 23 subjects (74%) had no knee deformities, 3 of them (13%) had genu valgum and 3 of them (13%) had genu varum. In TC group, 9 of the 12 subjects (75%) had no knee deformities, 2 of them had genu valgum (17%) and only one person had genu varum (8%), (Figure 27). These results showed that in the patients and Tai chi group incidence of Genu valgum was more than Genu varum. However, in the control incidence of Genu valgum group was as same as Genu varum. These results have been presented in Table 9.

Table 9. Incidence of varus and valgus knee deformity (%) in the subjects with and without PFPS and Tai chi group

Group (n)	Genu varum	Genu Valgum	No deformity
Control (23)	13%	13%	74%
Patients (15)	0%	13%	87%
Tai chi (12)	8%	17%	75%

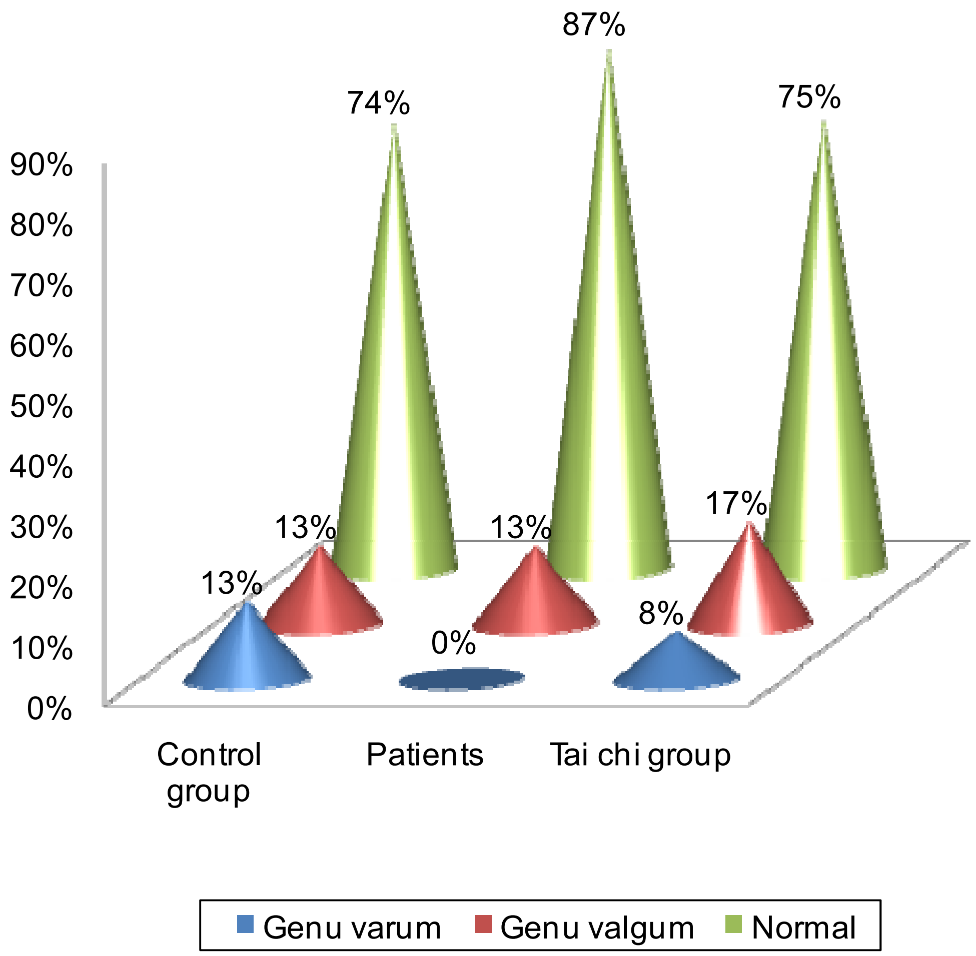

Figure 27. Incidence of knee deformities in the subjects with and without PFPS

4.3.3. Excessive foot pronation

No significant differences were demonstrated in excessive foot pronation between the patients, control and Tai chi groups (P>0.05). Eight of the 15 patients (53%), 15 of the 23 control subjects (65%) and 5 of 12 TC group (42%) had excessive foot pronation and the rest of the subjects had normal foot. None of them had foot supination (Figure 28). This finding indicated that incidence of excessive foot pronation was less in the TC group than that of the patients and control group. This result has been showed in Table 10.

Table 10. Incidence of foot pronation (%) in the subjects with and without PFPS and Tai chi group

Group (n)	Pronation	Normal	Supination
Control (23)	65%	35%	0%
Patients (15)	53%	47%	0%
Tai chi group (12)	42%	58%	0%

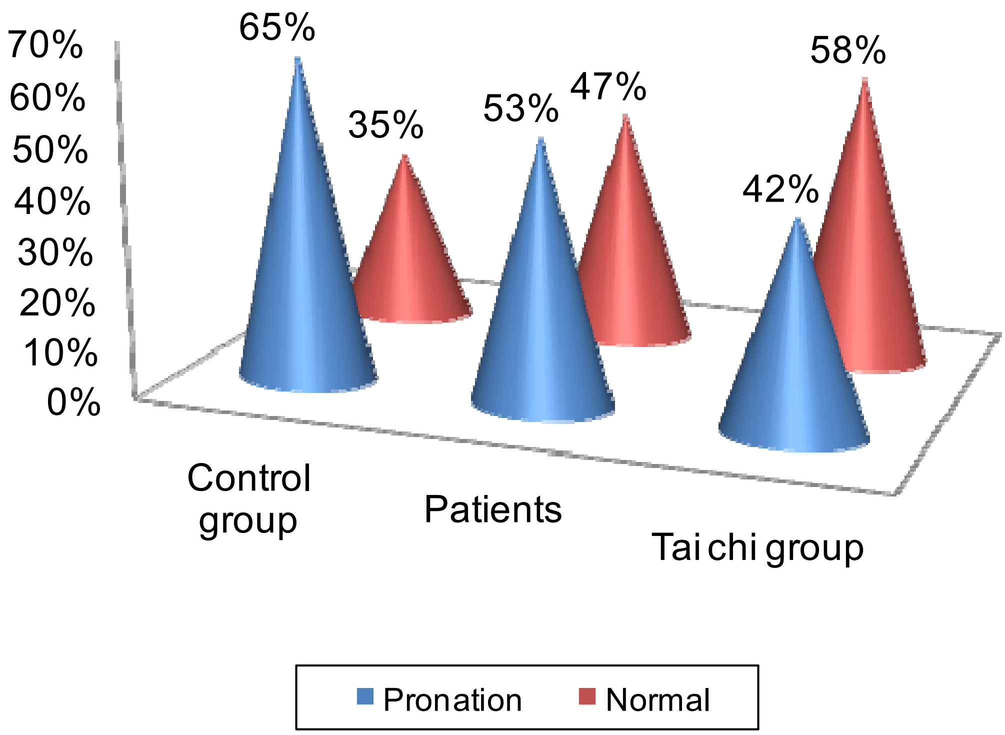

Figure 28. Incidence of excessive foot pronation in the subjects with and without PFPS and Tai chi group

4.3.4. Arch index

There were not significant differences in foot arch between the patients, control and TC groups (P>0.05).Eight of the 15 patients with PFPS (53%), 9 of the 23 healthy individuals (35%) and 5 of 12 Tai chi group (42%) had flat foot and the rest of patients, control and TC groups had a normal foot arch (Figure 29). Incidence of flat foot in the patients was more than that of the control and TC groups .This result has been presented in Table 11.

Table 11. Incidence of flat and high arch foot (%) in the subjects with and without PFPS and Tai chi group

Group (n)	Flat foot	Normal	High arch foot
Control (23)	35%	65%	0%
Patients (15)	53%	47%	0%
Tai chi group (12)	42%	58%	0%

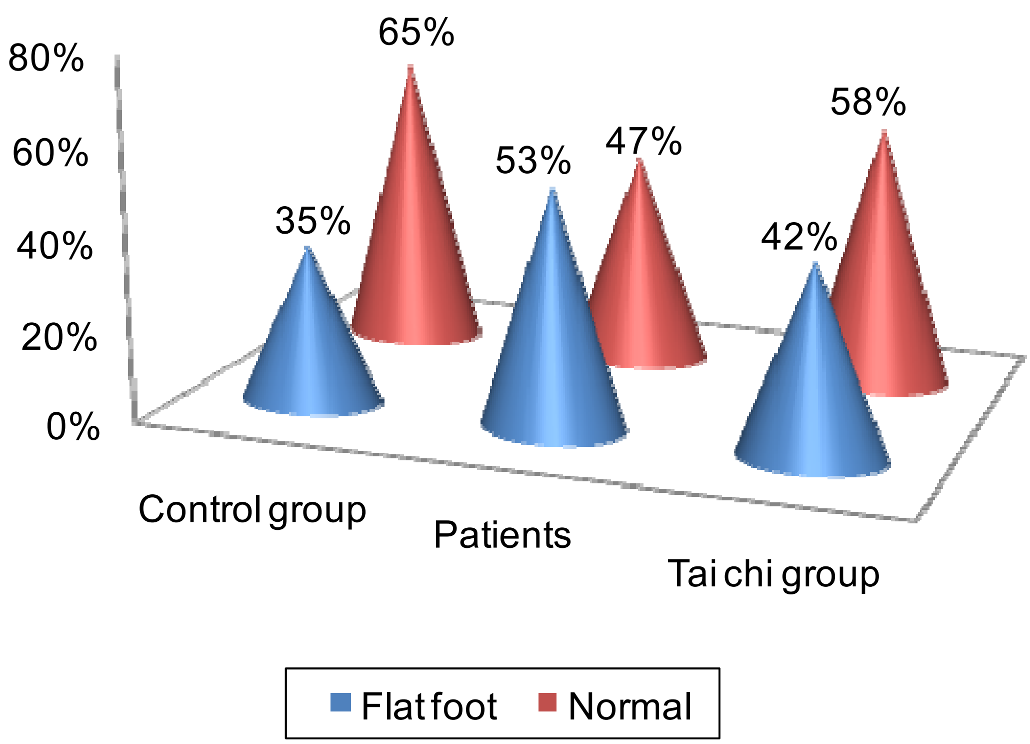

Figure 29. Incidence of flat foot in the subjects with and without PFPS and Tai chi group

The percentage of incidence of leg deformities in the patients, control and Tai chi groups has been summarized in Table 12 and compared in Figure 30.

Table 12. The percentage of incidence of LLD, varus and valgus knee deformity, excessive foot pronation, flat foot in the subjects with and without PFPS and Tai chi group

Leg deformities	Patients	Control group	Tai chi group
Leg length difference	67%	70%	25%
Genu valgum	13%	13%	17%
Genu varum	0%	13%	8%
Foot pronation	53%	65%	42%
Flat foot	53%	35%	42%

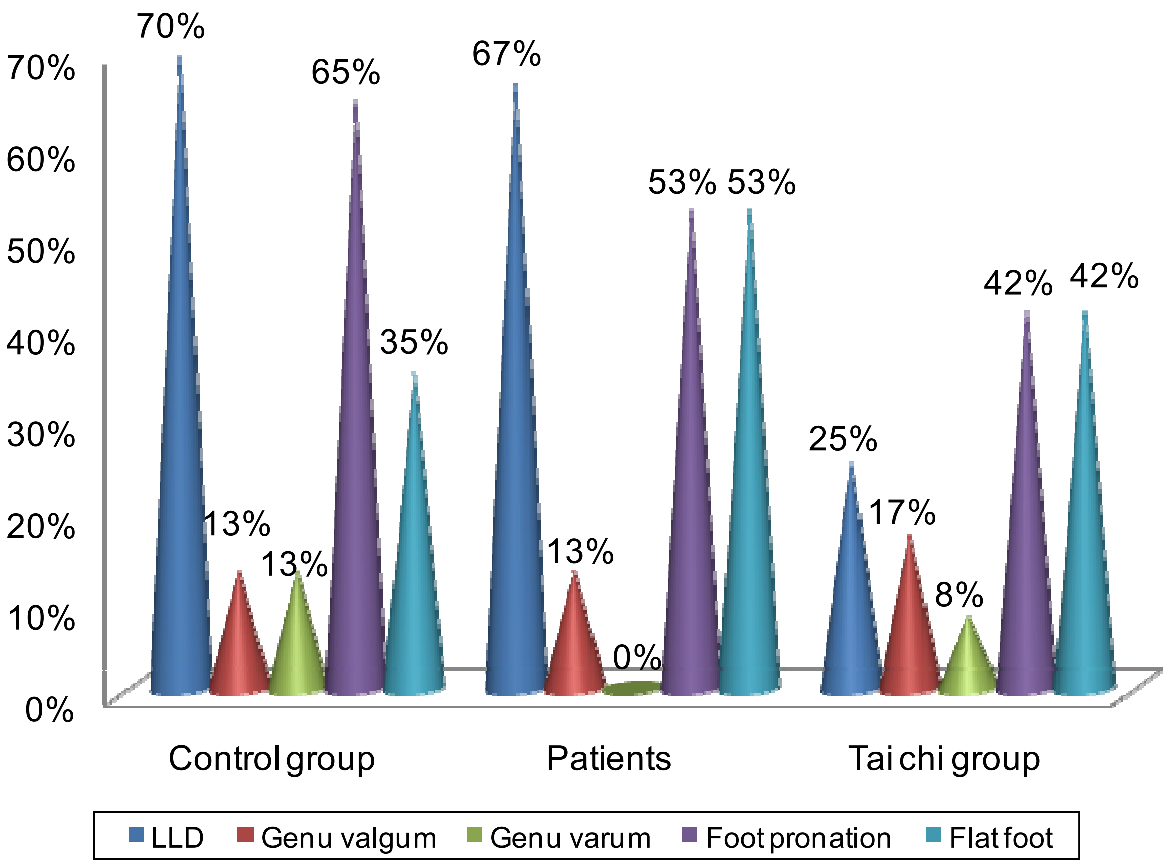

Figure 30. Comparison of incidence of leg length discrepancy (LLD), knee deformities (KD), foot pronation (FP) and flat foot (FF) in the subjects with and without PFPS and Tai chi group

No significant differences were found between the patients and control group with multi-leg deformities. These results were reported in the Table 13.

Table 13. Incidence of multi-leg deformities (%) in the subjects with and without PFPS

Group / Multideformities	Control	Patients
Flat F*. and knee D**.	9%	7%
Flat F. and F. pronation***	35%	33%
Flat F. and LLD	30%	27%
Knee D. and F. pronation	13%	13%
Knee D. and LLD	17%	13%
F. pronation and LLD	48%	33%
Flat F. and knee D. and F. pronation	9%	13%
Flat F. and LLD and F. pronation	26%	13%
Flat F. and LLD and knee D.	9%	13%
F. pronation and LLD and knee D.	13%	13%
All deformities	9%	13%

* Flat foot

** Knee deformities

***Foot pronation

4.4. Range of motion and flexibility

4.4.1. Range of motion

4.4.1.1. Knee

No significance differences were found in ROM of knee flexion and extension between the subjects with and without PFPS and Tai chi group (P>0.05), (Figure 31). The mean values and standard deviations of ROM of knee flexion and extension in the groups have been reported in Table 14.

Table 14. The mean values and standard deviations of ROM of knee flexion and extension in the subjects with and without PFPS and Tai chi group.

Group (n)	Knee flexion	knee extension
Control (23)	134°± 9°	7°± 4°
Patients (15)	134°± 7°	6°± 4.5°
Tai chi group (12)	134°± 6°	5.5° ± 3.5°

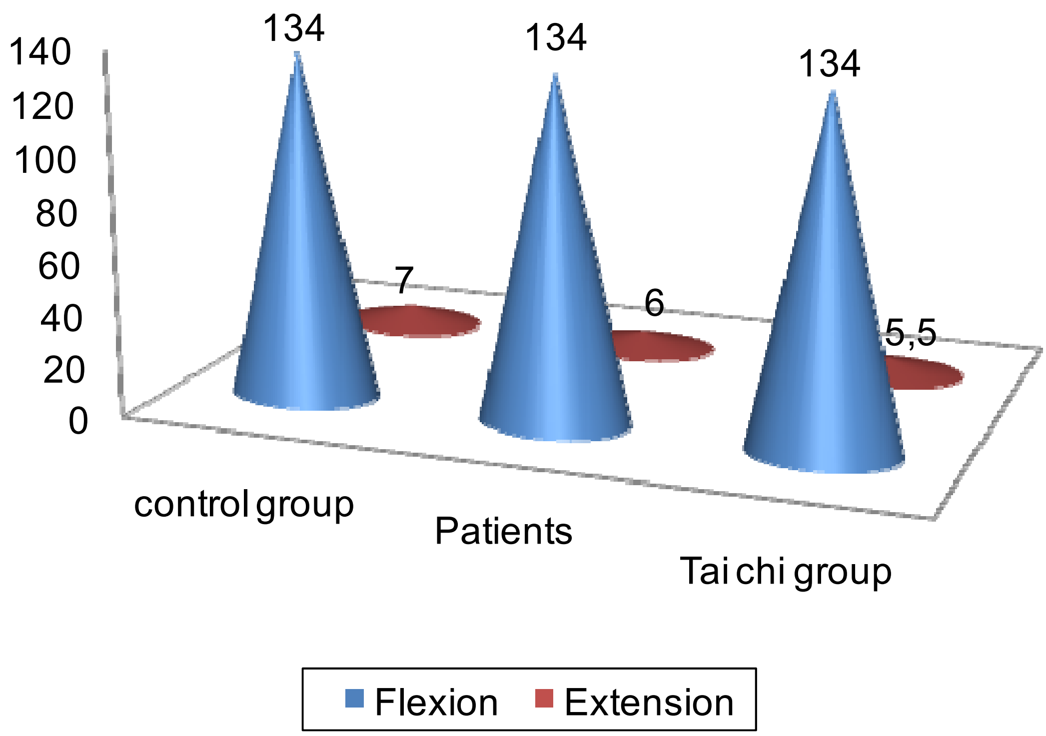

Figure 31. Comparison of range of motion (ROM) of knee flexion and extension in the subjects with and without PFPS and TC group

4.4.1.2. Hip

No significant differences were demonstrated in hip flexion, extension, abduction, adduction, internal rotation and external rotation between the patients, control and TC groups (P> 0.05), (Figure 32). The mean values and standard deviations of ROM of hip in the subjects with and without PFPS and TC group have been reported in Table 15.

Table 15. The mean values and standard deviations of ROM of hip in the subjects with and without PFPS and Tai chi group.

Hip movement	Control group	Patients	Tai chi group
Flexion	125°± 8°	121°± 9°	122°± 12°
Extension	16°± 5°	17°± 8°	18°± 4°
Adduction	20°± 4°	19°± 5°	20°± 4°
Abduction	61°±10°	62°± 12°	60°± 9°
Internal rotation	38°± 9°	36°± 10°	40°± 9°
External rotation	56°± 8°	50°± 13°	50°± 10°

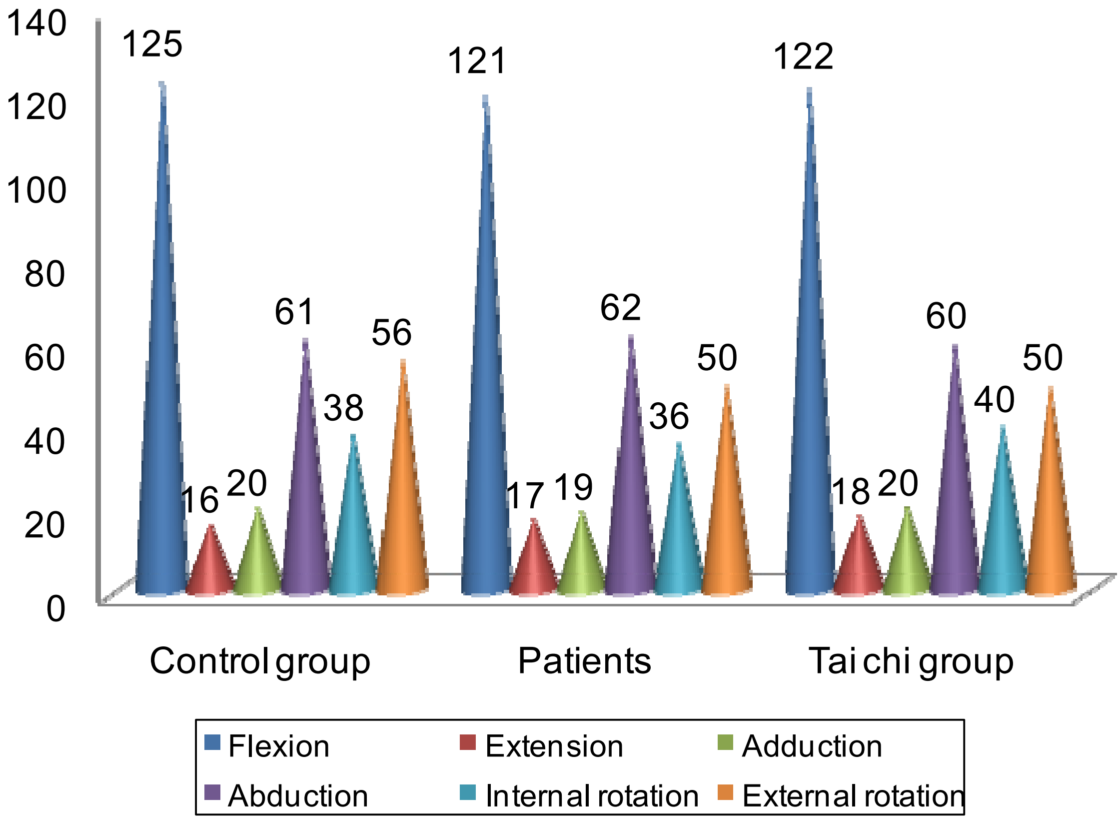

Figure 32. Comparison of ROM of hip in the subjects with and without PFPS and TC group

4.4.2. Hip flexor and iliotibial band flexibility

4.4.2.1. Flexibility of hip flexors

According to Exact fisher test no significant differences were demonstrated in flexibility of hip flexor between subjects with and without PFPS and TC group (P>0.05). Fourteen of the 15 patients with PFPS (93%), twenty of the 23 healthy individuals (87%) and 8 of the 12 subjects in TC group (67%) had shortness of hip flexors (Figure 33). This finding indicated that incidence of shortness of hip flexors in TC group was less than those of the two other groups. This result has been presented in Table 16.

Table 16. Percentage of the subjects presenting normal or shortness of hip flexors

Group (n)	Shortness	Normal
Control (23)	87%	13%
Patients (15)	93%	7%
Tai chi group (12)	67%	33%

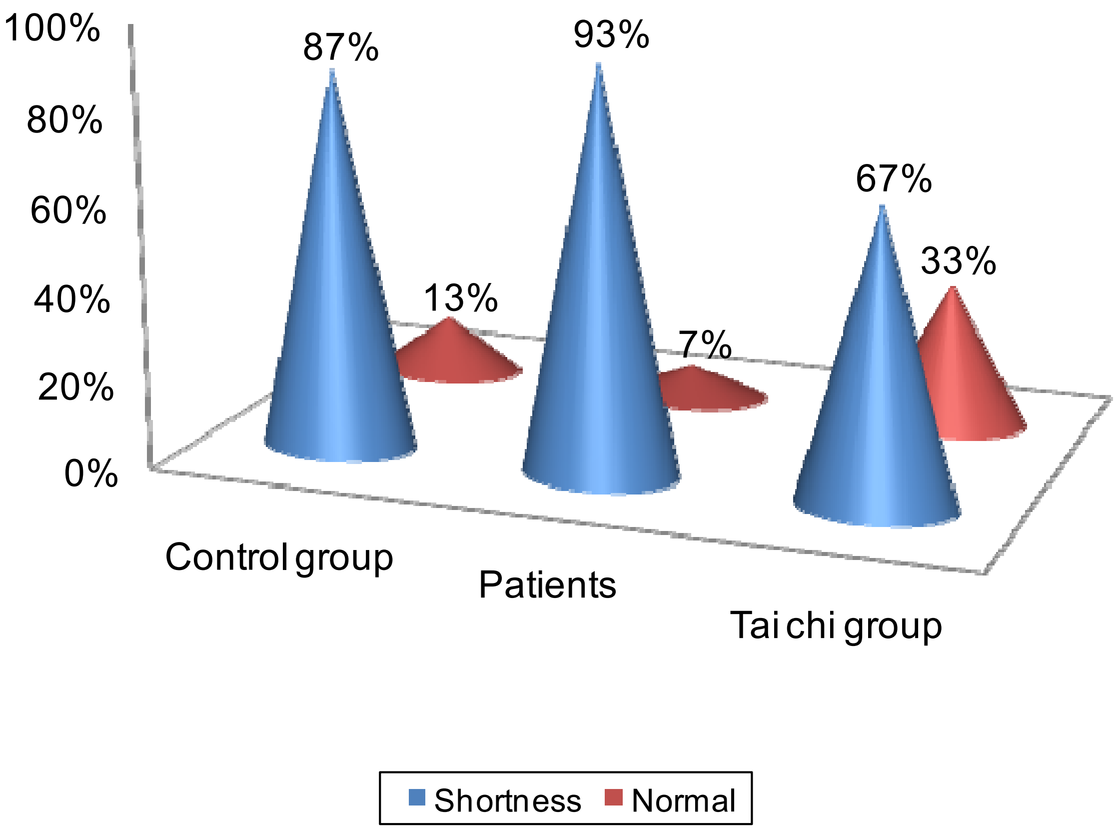

Figure 33. Comparison of flexibility of hip flexors between the subjects with and without PFPS and Tai chi group

4.4.2.2. Flexibility of Iliotibial band

Significant differences were showed in flexibility of Iliotibial band between the control and TC group (P=0.05). However, there were no significant differences between the patients and Tai chi group as well as patients and control group (P>0.05). Seven of the 15 patients with PFPS (47%), fourteen of the 23 healthy individuals (61%) and 3 of the 12 TC group (25%) had shortness of Iliotibial band (Figure 34). This finding showed that TC group had more flexibility in ITB than those of the patients and control group. This result has been reported in Table 17.

Table 17. Percentage of the subjects presenting normal or shortness of Iliotibial band

Group (n)	Shortness	Normal
Control (23)	61%	39%
Patients (15)	47%	53%
Tai chi group (12)	25%	75%

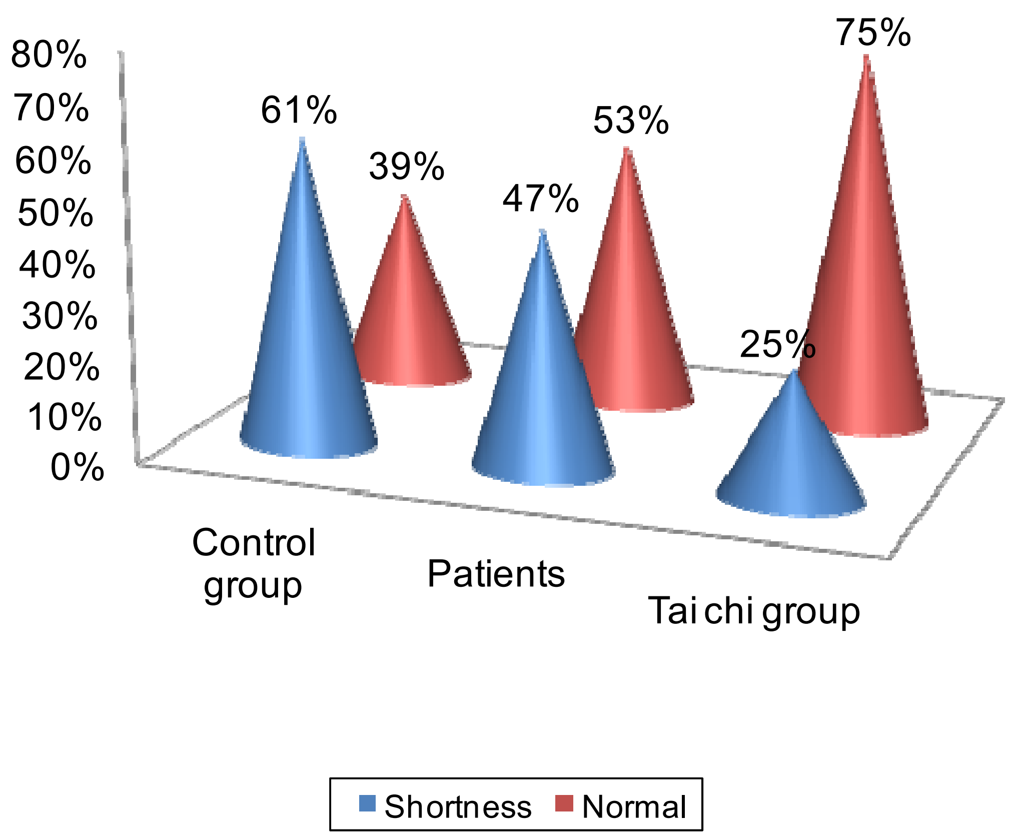

Figure 34. Comparison of flexibility of Iliotibial band between the subjects with and without PFPS

4.5. Overall view of results

Taken together, the results of this study showed that there are significant differences in the activation amplitude of the VMO at 30° and 45°angles between the subjects with and without PFPS. VMO electrical activity in the subjects with PFPS was significantly greater than that of the subjects without PFPS. In addition, significant differences were demonstrated in VMO/ (TFL+ VL) ratio at an angle of 30° of knee flexion between the two groups. This ratio was greater for the patients than that of the control group.

There were no significant differences in electrical activity of VMO, VL, TFL and their ratios across all angle knee flexions between the Tai chi group and patients as well as the Tai chi and control groups.

Significant differences were identified in the angle of lumbar lordosis between the subjects with and without PFPS. This angle in the subjects with PFPS was significantly less than that of the subjects without PFPS. However, no significant differences were demonstrated in the angle of lumbar lordosis between the patients and Tai chi group as well control and Tai chi groups

There were significant differences in pelvic tilt between the TC group and patients as well as TC and control groups. The angle of anterior pelvic tilt in TC group was significantly less than that of the patients and control group. However, no significant differences were demonstrated in pelvic tilt between the patients and control group.

Among leg deformities, significant differences were showed only in LLD between patients and the Tai chi group as well as control and the Tai chi group. However, no significance differences were shown in LLD, between the subjects with and without PFPS. There were no significant differences in other leg deformities between groups.

In addition, no significant differences were found in knee and hip ROM and hip flexor and iliotibial band flexibility between groups.

5. Discussion

5.1. The electrical activity of the muscles and treatment

5.1.1. The electrical activity of the VMO, VL and TFL muscles

In the current study, the electrical activity of muscles (VMO, VL and TFL) was investigated at 3 different angles of knee flexion (45°, 30°, 15°) during submaximal isometric contraction in subjects with and without PFPS. The normalized EMG data of VMO and VL indicated that in subjects with PFPS, the activation amplitude of the VMO muscle during the contraction at 30° of knee flexion was significantly greater compared with that of the subjects without PFPS (P= 0.05). There was no significant difference in the activation amplitude of the VL muscle between the two groups at the same angle. However, Owings (2002) reported the activation amplitude of both muscles (VMO and VL) of the subjects with PFPS were significantly higher than those of the control subjects during eccentric contraction.[25]

Following the data analysis, we found no significant differences in VMO/ VL ratio across all knee flexion angles between two groups. This finding has been reported by previous studies:

Souza and Gross (1991) suggested that patients with PFPS may not differ from healthy individuals with regard to VMO/ VL activation patterns.[30] McClinton et al. (2007) showed no differences in activation magnitude of VMO related to VL during stair ascent between the subjects with and without PFPS or across step heights.[42] Moraes Santos et al. (2007) suggested that the ratio of electrical activity of the VMO and VLL muscles in individuals with and without PFPS is equal in the gait on flat surface as well as ascending to 5 degrees.[43] Although Santos et al. (2008) found no significant differences in the VMO/ VLL ratio between groups, they showed significant difference in the VMO/ VLO ratio between the patients and control group.[44]

Since it was suggested that imbalance in stabilizing forces affect on patellar tracking and subsequent PFPS [4], and the TFL as same as VL is a lateral stabilizer of patella that produces lateral force on the patella, [5,10] therefore these results may indicate that in addition the VL, the TFL muscle is also important in considering the ratio of lateral and medial dynamic stabilizer of patella.

With regard to the role of the TFL/ ITB complex, which is an important lateral dynamic stabilizer of the patellofemoral joint, in particular from 0° to 30° of knee flexion,[10,147] several studies suggested that TFL/ITB complex tightness may contribute to the development of PFPS.[12,148] On the other hand, some researchers indicated there is a correlation between hip internal rotation and PFPS.[149,150] Berger et al. (1998) stated that the direct correlation of combined (femoral and tibial) internal component rotation to the severity of the patellofemoral complication suggests that internal component rotation may be the predominant cause of patellofemoral complications in patients with normal axial alignment.[149] Ireland et al. (2003) indicated that female runners, who have demonstrated significant knee valgus and hip internal rotation movements during running, are especially prone to PFPS.[150] According to Press and Young (1998), internal rotation may be caused by a tight TFL and a weak gluteus medius.[56] McConnel (2002) showed that decreased flexibility of TFL muscle is a contributing factor in the etiology of PFPS.[2] Since TFL is an internal rotator of the hip and a lateral stabilizer of patella,[11] we considered the electrical activity of this muscle. To the author's knowledge, only two studies considered the electrical activity of the TFL muscle.

Wheatly and Jahnke (1951) found the the vasti fire later than the RF and TFL in active extension in the patients with PFPS.[47] Gregersen and et al. (2006)

revealed that the VMO/ VL activation ratio increased significantly and the TFL activation decreased significantly as the varus moment decreased in the cyclist.[48] However, none of studies considered the activation amplitude of the TFL in the patients with PFPS.

As the TFL and the VL play the role of the dynamic lateral stabilizers of the patella, the VMO represent a dynamic medial stabilizer of the patella. This function of VMO counteracts the force of lateral stabilizers on the patella. Due to balances in lateral and medial stabilizing forces, patellar tracking is prevented. Therefore, an insufficiency of these muscles can have an affect on the patella and develop patellar malaligment and consequently PFPS.

In the present study, we found no significant differences in VMO/ TFL ratio between two groups across all knee flexion angles, however, significant differences were demonstrated in VMO/ (TFL+VL) ratio at 30° of knee flexion for the two groups. This ratio was greater for the subjects with PFPS (0.46) than for the subjects without PFPS (0.31). This result showed that there was no significant differences in (TFL+ VL) at angle of 30° of knee flexion between two groups, but the electrical activity of the VMO was significantly higher in patients than that of the healthy subjects. Powers (2000) believed that increase motor unit activity of the VM appeared to be in response to meeting the increased demand of providing patellar stability.[151] With regard to the significant differences in VMO/ (TFL+ VL) ratio between patients and control group, it may be assumed that VMO as a medial stabilizer of the patella recruits more volume of active motor units, thus preventing more patella tracking. Roberts and Gabaldon (2008) stated that it is generally assumed the EMG intensity provides a reliable estimate of the volume of recruited muscle, but not necessarily of the developed force.[152] According to Roberts and Gabaldon[152], high activation level of the VMO of the subjects with PFPS is not necessarily associated with developed force in this muscle. Powers (2000) suggested that increased motor unity activity of the VM muscle appears to be associated with abnormal patellar kinematics in women, but it is not necessarily a cause of abnormal patellar kinematics.[151] It may be presumed that VMO with more activation and more recruited motor unit tries to counteract the lateral forces of VL and TFL on the patella and prevent more patella tracking.

This finding may provide evidence that PFPS is associated with a disruption in the control of the VMO during the isometric contraction at 30° of knee flexion. Further, this study indicated not only VL, but also TFL is important to compare the stabilizers of patella in patients with PFPS; heretofore no study has considered the activation amplitude of TFL in the patients with PFPS.

In addition, the results of the present study showed that VMO/ (TFL+ VL) ratio differed at 30° of knee flexion between the subjects with and without PFPS. In another study, which was done by Orchard about the Iliotibial friction syndrome in runners, was showed that friction occurs at 30° of knee flexion.[153] Besier et al. (2001) stated that the greatest potential for tension development in the ACL is during sidestepping, where the knee experience combined loads of anterior tibial force, internal rotation, and valgus moments and the knee angle is between 30° and 40° of flexion.[154] It may be assumed that this angle plays an important role for injuries occurring in runners.

5.1.2. Treatment

In general, the goals of patellofemoral treatment are to maximaize quadriceps strength while minimizing the patellofemoral joint reaction forces and stress and restore the equilibrium of the patellar tracking system.[155,156] In the current study, the TC group was chosen to compare with patients and control group. Based on the effect of TC training on reducing load on the knee joint and emphasis on posture alignment,[4] it was hypothesized that TC training may be effective in preventing of patella tracking and alleviation of PFPS.

We found no study that showed Tai chi exercise is beneficial for PFPS. Only some studies suggested that Tai chi may be effective for pain control in patients with knee osteoarthritis.[114,157] It is claimed that Tai chi is beneficial for arthritis by alleviating joint pain and increasing strength, flexibility and balance in older patients .[123,158,159] Savio et al. (2007) stated that Tai chi is considered to be a suitable form of exercise for rehabilitation of sport injuries.[115] They affirmed that because of its low impact loading and low velocity nature, and emphasis on proprioceptive and internal sense of body position and motion, Tai chi helps or reduces the load on the lower limbs joints, particularly in knee and ankle, which are often sites of degeneration in athletes.[115]

The results of comparison of electrical activity of the TFL, VL and VMO muscles at 15°, 30° and 45° angles of knee flexion demonstrated no significant differences in the activation amplitude of these three muscles at the above mentioned angles between patients and TC group as well as control and TC groups. In addition, there were no significant differences in the VMO/ VL, VMO/ TFL and VMO/ (TFL+ VL) ratios between the groups.

To my knowledge, no studies have compared electrical activity of the TFL, VL and VMO muscles between athletes with and without PFPS and TC group. Only Tseng et al. (2007) investigated knee muscle activity patterns in experienced TC practitioners during normal walking and TC stepping.[160] They found that knee muscle (VL and VM) activation patterns had higher levels with greater co-contraction during TC exercise compared to normal walking.

In comparison with other treatment methods, the results of the present study (comparison of electrical activity of VMO related to VL) are similar to the results of Cerny (1995)[99] and Cowan (2006)[106] who considered the effect of patellar taping on PFPS. Cerny stated that although patella taping didn't change the VMO/ VL ratio, subjects reported decreased pain 94% during the step-down exercise.[99] Cowan showed that application of tape over the patella did not alter the amplitude of vasti EMG, nevertheless it decreased pain in subjects with PFPS.[106] However, MacGregor et al. (2004) demonstrated that stretch applied to the skin over the patella increased VMO surface EMG and suggested that cutaneous stimulation may be one mechanism by which patella taping produces a clinical effect.[161] Christou (2004) suggested that taping the patella medially can contribute positively to PFPS rehabilitation. He proposed that the benefits of patellar taping are not due to change in patellar position, but rather due to enhance support of the patellofemoral ligaments and/or pain modulation via cutaneous stimulation.[162]

In contrast to the present result, some studies showed their treatment regime changed the electrical activity of the VMO related to VL. Cowan et al. (2002) demonstrated that a "McConnel"-based physical therapy treatment regime for PFPS alters the motor control of VMO relative to VL in a functional task and this is associated with a positive clinical outcome.[102] Crossley et al. (2002) suggested that a six-treatment, 6 weeks physical therapy regimen is efficacious for alleviation of PFPS.[24]

Ng et al. (2008) showed that the incorporation of an EMG biofeedback into a physiotherapy exercise program could facilitate the activation of VMO muscle such that the muscle could be preferentially recruited during daily activities.

Tang et al. (2001) stated that in closed kinetic chain exercises, more selective VMO activation can be obtained at 60° knee flexion.[100] Hanten and Schulthies showed that during hip adduction, the electrical activity of the VMO is significantly greater than that of the VL.[163] They suggested that hip adductor contraction, in conjunction with quadriceps sets and straight leg raises, is recommended to facilitate VMO strengthening. However; Mirzabeigi et al. (1999) revealed that VMO muscle cannot be significantly isolated during strengthening exercise.[164]

All of the above mentioned studies considered the treatment methods on the patients. However, we compared the subjects who do TC training with the patients and a control group. Other results may be found, if the subjects with PFPS performed TC training for a certain period of the time. This maybe explains the difference of our results with others.

One limitation in our study was the age of the TC group. The range of age in the patients and control group was 20-30 years old; however in the TC group the average age was more than 33 years old. All of TC practitioners in Bielefeld were over 33 years old and people who were younger than 30 years old didn't take part in TC exercise.

Hinman et al. (2006) in considering of the effect of age on the onset of VMO relative to VL showed that both younger and older participants demonstrated a relatively synchronous onset of VMO and VL with no differences between age groups evident. [165] However, Dixon and Howe (2007) stated that due to muscle atrophy, the EMG signals of older people often have lower amplitude and poorer signal to noise ratio than that of younger people.[166] Since Tseng et al. (2007) indicated that TC exercise causes higher levels of knee muscle (VL and VM) activation patterns with greater co-contraction,[160] and our results showed no-significant differences in electrical activation of VMO and VL between the young athletes and TC group, who were older than the two other groups, it may be assumed that TC training effects the quality of the EMG signals. More research for revealing role of TC on treatment of PFPS needs to be conducted.

5.2. Lumbar lordosis and pelvic tilt:

5.2.1. Lumbar lordosis

In the current study, the angles of lumbar lordosis and pelvic tilt were investigated in subjects with and without PFPS by gravity inclinometer. We found that the angle of lumbar lordosis was different for the two groups and it was significantly less for the patients than for the healthy subjects. The mean value of lumbar lordosis was 23.83± 6.35 for the subjects without PFPS compared with 18.33± 8.29 for the subjects with PFPS. This result indicated that the patients with PFPS showed more instances of decreased lumbar lordosis than the control group.

This finding is in disagreement with the finding by Press and Young (1998). They proposed that an increased lumbar lordosis may contribute to PFPS.[56]

Although Tsuji et al. (2002) studied correlation between sacral inclination and lumbar lordosis with PFPS in elderly people, [57] their results were in agreement with our findings. They suggested that in elderly Japanese, decreased lumbar lordosis and sacral inclination lead to increasing thigh muscle tension and knee flexion while standing. This increases low back pain and PFPS.

To my knowledge, there are not many studies about the relation between lumbar lordosis and PFPS. Some researchers investigated relationship between lumbar lordosis and lumbar spine problems with knee disorders.

Murata et al. (2003) showed a correlation between the knee angle and lumbar lordosis, indicating that the loss of lordosis is related to degenerative changes in the knee.[55] He pointed that it is difficult to determine whether the deformity of the lumbar spine is the primary factor or whether the knee is the initial factor.

Nicolas et al. (1977) described the link theory in which the ankle, knees and hips act as link system making possible the transmission of forces into the pelvis and spine during running, jumping, kicking and throwing[167]. Nadler et al. (1997)

stated that biomechanical studies have confirmed not only how the joints of the lower limb work together to transfer forces between limb segments during motion, but that a compromised joint leads to proximal and distal joint dysfunction. [168] He also showed that PFPS and chronic ankle instability are conditions most commonly associated with low back pain treatment.

Rocha et al. (2006) concluded that knee pain is referred from the lumbar spine problems.[169] Decreased lumbar lordosis is also one of the lumbar spine problems and causes by muscle inflexibility. It was showed that flexibility of lumbar lordosis enhances its shock-absorbing ability.[170] Therefore it is suggested that inflexibility of lumbar spine or decreased lumbar lordosis reduces its shock-absorbing ability. It seems that this shock may be transferred to lower-extremity and particularly knee and causes pain. It has also been resulted by the current study.

On the other hand, many researchers have indicated that the shortened hamstrings can lead to PFPS syndrome and decreased lumbar lordosis.[54,94,171] Although, with regard to the correlation of the lower extremity disorders and lumbar spine, knee problems like PFPS may be caused by altered lumbar lordosis, however the shortened hamstrings have not been considered in the present study. This study denoted that decreased lumbar lordosis is one of the risk factors that make PFPS; however, it is too difficult to determine whether the deformity of the lumbar spine is the primary factor or whether the knee is the initial factor.

5.2.2. Pelvic tilt

In the current study no significant differences were found in anterior or posterior pelvic tilt between the patients and control group. The mean value of pelvic tilt was 6.74± 3.99 for the subjects without PFPS compared with 6.40 ± 3.78 for the subjects with PFPS. To my knowledge, there is no research about the relation between posterior pelvic tilt and PFPS. However, some researchers indicated a relation between anterior pelvic tilt and PFPS.[62,131]

Tyler et al. (2006) stated that patients with PFPS demonstrated significant weakness in their hip flexor during hip flexion strength testing in a sitting position.[61] Such findings suggest a possible inability of the hip musculature to control femoral rotation during activities resulting in PFPS. Hip flexor weakness may not adequately provide a stable pelvis during gait, which essentially inhibits the pelvis from going into an anterior pelvic tilt and concomitant femoral internal rotation.[61] However; anterior pelvic tilt is also associated with shortening of the hip flexors, including the rectus femoris.[134]

Sweeting and Moch (2007) indicated that the increased anterior pelvic tilt causes greater knee flexion at heel strike and mid stance. Increased knee flexion causes the patella to compress against the femur with greater force, predisposing the patient to patellofemoral joint syndrome.[62] However; Sol suggested that for decreasing the impact of vertical forces at the knee joint, the knee joint's role as a shock absorber should be enhanced through an increased knee flexion angle.[172]

Although the above mentioned studies stated that anterior pelvic tilt effects on knee and causes PFPS, they didn't compare the angle of pelvic tilt in the patients with PFPS and healthy group. They explained the effect of pelvic tilt on knee, base on biomechanical aspects. However, in the present study, we compared the angle of pelvic tilt in the subjects with and without PFPS and found no significant differences in this angle between the two groups.

5.2.3. Treatment

We also considered the angle of lumbar lodosis and pelvic tilt in the TC group and compared it with the patients and control group. We found that the TC group had no significant differences in the angle of lumbar lordosis in comparison with the patients and control group. The angle of lumbar lordosis in the TC group (20.67± 5.85) was more than that of the patients (18.33± 8.29) and less than that of the control group (23.83± 6.36), however, there was no significant difference between the TC group with the two other groups. Although no studies identified the effect of TC on lumbar lordosis in patients with PFPS, some researchers showed that TC practice is beneficial for greater flexibility of thoracic/lumbar lordosis.[119,173]

Sweeting and Mock (2007) suggested that regular stretch and exercise routine like Pilates, TC, Yoga with specific emphasis on strengthening of core muscles, provide lumbopelvic stability.[62] Gallagher (2003) stated that by minimizing segmental spinal rotation, the lumbar spine is maintained in a neutral position in the transverse plane.[174] He affirmed that one advantage of this neutral spine (in all planes) is to balance the forces seen by the spinal elements.

However, we found no differences in the angle of lumbar lordosis between the TC group and young athletes, in regard to the age of TC group and according to Gelb et al. (1995) who reported a decrease in lumbar lordosis above the age of 40 years, [175] the findings of the current study may highlight an important point. These results show that TC training is beneficial in providing of flexibility of lumbar lordosis.

As we indicated, there are a few studies which considered the relationship between lumbar lordosis and PFPS. As a result, we found no treatment regimes that focus on the treatment of lumbar lordosis in patients with PFPS. Only Mascal et al. (2003) considered endurance training of the hip, pelvis and trunk musculature in the two patients and showed that both patients experienced a significant reduction in PFPS.[103] In order to clear up how TC training has an effect on the patients with PFPS who have decreased lumbar lordosis, is needed more research with a focus on performance TC training in these patients.

In addition, our results showed that there are significant differences in pelvic tilt between the TC group and two other groups. The degree of anterior pelvic tilt in Tai chi group (3.33°) was significantly less than those of the patients (6.40°) and control group (6.74°).

Since TC exercise emphasizes stability of the pelvic, it would be expected that subjects doing TC, have less pelvic drop. It was notable in our findings that despite the older age of TC group, they had less anterior pelvic tilt than those of the two groups.

Some studies indicated the importance of pelvis in TC and effect of TC exercise on pelvic control. Alfred Huang (1993) believed that pelvis is the center of structure balance and also the center for control of movement, and pelvis design is appropriate for support and transfer of weight as well as for balance and movement.[176] In the other study has been stated that in Tai chi exercises, weight-bearing hip abductors (gluteus medius) dynamically stabilize pelvis in the coronal plane preventing pelvic drop.[177] These findings are in agreement with our results that TC group had less pelvic drop than those of athletes with and without PFPS.

Bryant and James (2003) showed that TC exercise strengthens pelvic and leg muscles, loosens hip joint and promotes good balance. [116] According to McConnel (1996), a stable pelvis will minimize unnecessary stress on the knee.[7] In regard to the effect of TC on pelvic, it may be proposed that TC exercise with stabling pelvis, reduces stress on knee and alleviates pain.

In comparison with TC exercise, a physical therapy program may also alleviate pain in patients. Whereas weakness of hip flexor muscles (which help to maintain pelvic stability) is one of the risk factors of PFPS, Crossly et al. (2002) showed that physical therapy included quadriceps muscle retraining, patellofemoral joint mobilization, patellar taping and daily home exercise reduces pain. [101]

Since TC strengths pelvic muscles, stabiles lumbopelvic and prevents pelvic drop, [116,177] it may be suggested that patients with PFPS who have anterior pelvic tilt, and this deformity causes pain in their knees, use TC exercises to improve their pelvic drop and subsequent alleviate pain.

5.3. Malalignment of lower extremity:

In the present study, LLD, genu varum, genu valgum, flat foot and foot pronation were investigated in subjects with and without PFPS .We found that incidence of LLD in the patients and control group was almost the same and 67% of the patients and 70% of the control group had LLD. LLD is a risk factor for overuse injuries[76] and causes stress fracture, hip pain and low back pain [68,178].

The civilian sports medicine literature suggests that the extremes of anatomic variation and malalignment of the lower extremities predispose runners and athletes to injury.[78]

5.3.1. Leg length discrepancy

LLD may have several adverse effects on the lower extremity during running.[179] It may alter the pattern of mechanical stress within the joint and also affect muscle tension patterns around the joint.[74] Although there is a link between overuse injury and LLD, to my knowledge no researcher has proved a positive correlation between LLD and PFPS. Only Kujala et al. (1987) indicated that LLD causes patellofemoral joint incongruence [180], although they did not illustrate directly the role of LLD on PFPS. Our finding is in agreement with the findings of several authors. [15,74,72] Witvrouw et al. (1999) showed that during 2-year follow-up study, 24 of the 282 students developed PFPS. Statistical analysis revealed that no significant differences in LLD between the students with and without PFPS.[15] Duffey et al. (2002) demonstrated no difference in LLD between the runners with and without anterior knee pain. [74] They suggested that a moderate LLD (≤0.5 cm) is normal and under most conditions is not a contributing factor in overuse injuries in runners. Messier et al. (1991) indicated that runners with and without PFPS had mean LLD that ranged from 0.02-0.18 cm. [72] In the present study LLD was under 0.5 cm in the most of subjects. According to Duffy [74] and Messier[72] and the finding of the present study, maybe higher LLD contributes in PFPS.

In contrast to the our results, Reid (1993) in a review study stated that among all alignment measurements found in the literatures, only LLD is consistently found to be a significant factor in the etiology of PFPS.[73] However; he didn't explain that which range of LLD is a risk factor for PFPS.

We also observed that incidence of LLD in the left leg of the patients was more than that in the control group; however no significant difference was demonstrated between the two groups.

5.3.2. Varus and valgus knee deformity

Genu varum and genu valgum are the other anatomic factors which have been hypothesized to be associated with increased risk of injury among athletes. In the current study, none of groups showed signs of genu varum or genu valgum and the most of the subjects with and without PFPS had no knee deformities.

There are various opinions about the correlation between genu varum and genu valgum with PFPS. In agreement with our findings, Waryasze and McDermott (2008) in a review article concluded that characteristics of genu varum and genu valgum have not been found to contribute to PFPS.[14] In addition, Cibulka and Threlkeld-Watkins (2005) in a case report in a patient with PFPS observed no genu varum or valgum.[80]

Although Lun et al. (2003) in considering 6 patients found significantly difference in right knee genu varum in injured and non-injured groups; they stated that a small number of cases and a lack of agreement between the injured side and significant side of alignment measurement make it difficult to determine which of these alignment measurements are clinically significant.[79]

The findings of Milgorm[76] and Doucette[77] were in disagreement with our findings. Milgorm et al. (1991) revealed that the presence of genu varum had a significant correlation with the incidence of PFPS.[76] However, Doucette and Goble (1992) indicated that genu valgum is a factor which increases the tendency of the patella to displace laterally.[77] Furthermore, Christopher and Powers (2003) stated that Valgus at the knee may increase the Q angle, as the patella would be displaced medially with respect to the ASIS.[67] In comparison, varus position of the knee could decrease the Q angle, as the patella would be brought more in the line with the ASIS.[67] A larger Q angle would tend to create lateral vector and potentially a greater predisposition to lateral patellar tracking when compared to a smaller Q angle.[181]

Taunton et al. (2002) in considering of biomechanical variables for the most common injuries demonstrated that among the patients with PFPS, the incidence of genu varum (32%) was more than the other biomechanical variable and genu valgum with incidence 29% was the second one.[17]

In our study, incidence of genu valgum (13%) was more than genu varum (0%) in the patients; however this difference was not significant.

5.3.3. Excessive foot pronation

Foot pronation has been recognized as a risk factor contributing to alterations in lower –extremity kinematics [81] and a cause for overuse running injuries.[82] There are a few studies that considered the relation between foot pronation and PFPS. In the current study no significant differences were found in foot pronation and supination between the subjects with and without PFPS.

This finding is in accordance with the findings of other studies. Messier et al. (1991) found no significant differences in maximum pronation, maximum pronation velocity and total rearfoot movement in 36 evaluated runners (16 with PFP and 20 controls). [72]

Powers and colleagues (2002) performed 3 dimensional motion analyses during self-selected free- and fast-walking velocities on 24 females with PFP and 17 controls and found no group differences with respect to the magnitude and timing of peak foot pronation and tibia rotation.[84] Christopher suggested that according to the results of Powers and Messier, one cannot assume a cause-and-effect relationship between abnormal pronation and PFPS; however, it is entirely possible that certain individuals with PFPS may demonstrate abnormal foot pronation.[67]

Hetsroni et al. (2006) and Thijs et al. (2008) indicated that no significant evidence between excessive foot pronation or supination and PFPS.[86’87]

Although all the above mentioned studies and the current study found no differences in foot pronation and PFPS, Eng and Pierrynowski (1989) suggested that excessive foot pronation during the stance phase can alter the normal rotation of the tibia in the frontal and transverse planes as a result of anatomical congruency of the talus within the ankle mortise. In turn, aberrant tibial rotation can disrupt the normal patellofmoral relationship.[83]

From the results of this study and previous studies it can be concluded that excessive foot pronation and supination may not contribute to PFPS.

5.3.4. Arch index

In the present study no significant differences were found in flat or high arch foot between the patients and control group. 53% of the patients and 35% of control group had flat foot; however this difference was not significant. These results are in agreement with the finding of other studies.

Witvrow et al. (1999) revealed no significant difference in the division of foot type between the students with and without PFPS.[15] In the other research by Messier et al. (1991) with the two groups (with and without history of overuse injuries), it was presented that both groups had normal arched foot.[72] Esterman and Pilotto (2005) showed no correlation between foot shape and injuries (such as stress fracture, periostitis, iliotibial band syndrome and PFPS).[89] However, They stated that the flat feet group had significantly poorer subjective physical health than did the normal feet group. In addition, Waryasz et al. (2008) suggested that pes cavus (high arch) and pes planus (flat feet) have not been found to contribute to PFPS.[14]

In contrast to the our study, Duffey et al. (2000) demonstrated that the anterior knee pain group had a higher arched foot relative to control group and that this position causes a more cavus and rigid foot that is less able to absorb shock.[74]

In addition, our results showed no significant differences in multi-leg deformities. We considered two deformities together, three deformities together and all deformities together and compare them between the patients and control group. As we pointed, we found no significant differences in these multi-leg deformities between two groups.

Taken together, the results of this study suggest that abnormal biomechanics of the lower limb cannot cause PFPS; however the individuals with PFPS may demonstrate one or more of the abnormal biomechanics.

5.3.5. Treatment

Incidence of leg deformities were compared between the patients with PFPS and a control group with TC group. The results indicated that there were significant differences in LLD between TC group and athletes with and without PFPS. 75% of TC group had no LLD. In compared with the TC group, only 33% of the patients and 30.4% of the control group had no leg length difference.

One of the aims of treatment of PFPS is improvement of the lower limb mechanics. Therefore, stretching the tight lateral structures and strengthening quadriceps was recommended by other authors.[7,97]

Eng et al. (1993) also showed that in addition to an exercise program, the use soft foot orthotics is an effective means of treatment for the patients with PFPS and excessive forefoot varus or pronation.[98]

Furthermore, Post (2005) concluded that evaluation and treatment should include lower extremity flexibility and muscular control.[104]

No study considered the effect of TC in treatment of LLD, only some researchers indicated that TC exercise focuses on postural alignment.[120,182]

Li et al. (2005) stated that the particular characteristic of TC exercise, which emphasizes control over one's displacement of body mass, postural alignment, and ROM of joints and muscles of the lower body, may be part of a larger mechanism responsible for specific gains in leg strength and postural stability.[182]

Of particular interest is that despite the fact that the TC group was older than the other two groups, they had less LLD. This finding emphasizes that TC exercises prevents leg length difference. Although in our findings there were no significant differences in LLD between the patients and control group, it has been showed that LLD is a risk factor for running injuries.[55] TC exercise can help to decrease of presence of this problem in runners.

In the present study no significant differences were demonstrated in genu valgum and genu varus between the patients with PFPS and the TC group as well as the control and TC groups. However, Gallagher (2003) believed that TC may reduce genu valgum angulation through engagement of the external hip rotators.[174] He stated that rotator muscular activity opposes the forces that tend to cause valgus at the knee and to some extent, foot pronation.

In addition, the results showed that neither in foot pronation/supination nor in arch index (flat and high arch foot) significant differences between the TC group and two other groups. To my knowledge no previous study was done about TC effects on these deformities. However, some researchers indicated that TC improves lower-extremity biomechanical efficiency during activities of daily living.[182,183]

One explanation for no significant differences in the above mentioned deformities between the groups may lies in the age of groups. From the results of this study it can be concluded that despite the older age of TC group, they had no deformities and it may be conducted that TC exercise maintains postural alignment.

5.4. Range of motion and flexibility

5.4.1. Range of motion (ROM)

In the current study, knee ROM (includes: flexion and extension) and hip ROM (includes: flexion, extension, abduction, adduction, internal and external rotation) were investigated in subjects with and without PFPS. The results showed that no significant differences in knee and hip ROM between the two groups.

This finding is in accordance with the findings of other researchers. Messier et al. (1991) found runners with PFPS had no differences in knee ROM with control group.[72] Also, Thomee et al. (1995) stated that subjects with PFPS did not differ in lower-extremity alignment and lower-extremity ROM measurements in comparison to control group.[93] Dixit et al. (2007) stated that patients with PFPS usually demonstrate a full ROM of the knee.[4]

The finding of Van Mechelen et al. (1992) was in disagreement with our finding. They investigated a group of runners with lower extremity injuries and compared them with controls with respect to ROM of the hip and ankle joints.[90] They found that the injured group had more restricted ROM at the hip joint, but ROM at the ankle joint showed no statistically significant differences.[90] Although PFPS is one of the lower extremity injuries, according to variety of lower-extremity injuries, Van Mechelen et al. hadn't indicate which injuries were considered and whether PFPS also was one of the considered injuries. This reason may explain the difference found between their and our study.

In the other study, Willson and Davis (2008) showed that women with PFPS demonstrated increased hip adduction angle, hip flexion angle, hip abduction angular impulse, and decreased hip internal rotation angles throughout the exertion protocol.[93] Although these findings are in disagreement with our findings, there were differences between our and their studies. Their subjects were women with and without PFPS who did functional lower-extremity exertion protocol of repetitive single-legged jumps and they measured the knee and hip angles during and after protocol by VICON 3-D motion analysis system. However, our subjects were men and women with and without PFPS that we evaluated the knee and hip angles by goniometer.

From the results of this study it can be concluded that athletes with PFPS had no restricted ROM of knee and hip joints in comparison to the control group. It may be suggested that PFPS has no affect on knee and hip ROM.

5.4.2. Flexibility

We also investigated flexibility of hip flexor muscles by Thomas test and ITB flexibility by Ober test between athletes with and without PFPS. Our results indicated that no significant differences in flexibility of hip flexors and iliotibial band between the two groups.

This result is in agreement with the findings of Cibulka and Threlkel-Watkins (2005).[80] They used Thomas and Ober tests for measuring the flexibility of hip flexors and ITB in a patient with anterior right knee pain. Their results showed no significant difference between the left and right rectus femoris muscles, ITB, or hip flexor muscles.[80] These authors applyed exactly our methods and their findings also were in accordance with our results.

In addition, this finding is partly in agreement with the results were found by Piva et al. (2005).[95] They stated that no differences exist in flexibility of the iliotibial band/ tensor fascia lata (ITB/TFL) complex and strength of the hip external rotators and abductors between the patients with PFPS and healthy control subjects. However; they found less flexibility of quadriceps in the patients compared with control group. [95] One explanation for the difference in hip flexor flexibility that was found in their and our study may lies in the method of flexibility measuring. We used Thomas test for measuring flexibility of hip flexors and this test was done in the supine position, whereas they used a measurement of knee angle during passive knee flexion in prone position and measured only flexibility of quadriceps.

In contrast to our findings, some researchers stated that limited flexibility of the quadriceps, (ITB/TFL) complex and hamstrings have been associated with PFPS.[28,94] McConnel and Bennell (2006) stated that a tight TFL, through its attachment into the ITB, will cause lateral tracking of the patella, particularly at 20° of knee flexion when the band is at its shortest.[185]

Smith et al. (1991) showed that skaters with anterior knee pain had tighter quadriceps muscles and ITB than those without pain.[94] Maybe the age of the skaters in Smith's study explains the difference between their and our study. Their subjects were between 10-20 years old; however our subjects were between 20-30 years old.

Although some prior studies indicated that tightness in the ITB and quadriceps muscles may contribute to PFPS and knee pain by pulling the patella laterally, we didn't find any relationship between limited flexibility of hip flexor muscles and ITB with PFPS.

5.4.3. Treatment

McConnell (2002) indicated that stretching the tight lateral structures may decrease the tendency of the patella to track laterally and should enhance the position of the patella.[2] Tyler and et al. (2006) stated that increase the flexibility of the hip flexors and ITB would allow the pelvis to rotate posteriorly, create relative femoral external rotation and helping to align the patella in the trochlear groove of the femur.[61] Therefore, they performed a 6-week treatment program for patients with PFPS. They indicated that improvements in hip flexion strength combined with normalized ITB and iliopsoas flexibility were associated with excellent results for patients with PFPS.[61]

In the present study, knee and hip ROM as well as flexibility of hip flexor muscles and ITB was considered in the TC group to determine the effect of TC on flexibility and ROM, and then was compared with the patients and control group. The results showed no significance differences in ROM of knee flexion and extension, and hip flexion, extension, abduction, adduction, internal rotation and external rotation between the groups.

Although it has been reported that TC enhances balance, muscle function and flexibility,[186] no study considered the effect of TC training on improvement of flexibility and ROM in the patients with PFPS. However, Van Deusen and Harlowe (1987) indicated that TC exercise increase lower-extremity ROM in the patients with rheumatoid arthritis.[117]

To the author's knowledge, there was no study that investigated the relationship between TC and flexibility of hip flexors and ITB. Only Macfarlane et al. (2005) stated that TC trainings improve hamstring flexibility.[124]

Although Lan et al. (1996) didn't study the flexibility of lower-extremity, they found that TC practitioners had greater thoracic/ lumbar flexibility in comparison with the control group. [118]

It is considerable that these studies investigated TC group with control group of sedentary subjects or TC practitioners before and after TC trainings. These groups had no other sport activities. Therefore, it is predictable that TC improves flexibility in these groups. However, in the current study, we compared active athletes with a TC group. Our results showed that the control group had less flexibility in ITB than that of the TC group. This may suggest that TC training have an effect on flexibility of ITB.

Notwithstanding we found no significant differences in hip flexors and ITB flexibility in the TC group in compared with athletes with PFPS, this is an interesting point in our findings. Based on decreasing of flexibility and ROM with increasing age, [187] TC group had same flexibility in hip flexors and ITB as same as knee and hip ROM with the two other groups. This point indicates that TC improves flexibility and it may be recommended to the patients with PFPS who has limited flexibility.

6. Summary

Patellofemoral pain syndrome (PFPS) is a term for a variety of pathologies or anatomical abnormalities leading to a type of anterior knee pain and is the most common single diagnosis among runners and in sport medicine centers. Despite this high incidence, the exact cause of these disorders remains enigmatic.

The major complain of patients with PFPS is retropatellar pain during activities such as running, squatting, going up and down stairs, prolonged sitting, cycling, and jumping.

Some of risk factors in athletes with PFPS were considered and compared with athletes without PFPS in the present study. In addition, since Tai chi (TC) helps or reduces the load on the lower limbs joints, particularly in knee, a TC group was chosen to compare with the two other groups.

6.1.1. Risk factors

The results of the present study showed that the electrical activity of Vastus medialis oblique (VMO) at 30° and 45° angles of knee flexion was significantly higher in the patients than that of the control group. Based on the no significant differences in VMO/ VL (Vastus lateralis) and VMO/ TFL (Tensor fascia lata) ratios across all knee flexion angles between the two groups, and significant differences in VMO/ (TFL+ VL) ratio at 30° angle of knee flexion, it seems that the TFL and VL together produce lateral force on the patella. It may be assumed that high electrical activation of the VMO in the patients is an effort to counteract lateral force which produces by the VL and TFL and for preventing patella tracking. It is suggested that in consideration of lateral stabilizers of the patella, the TFL and VL should be assessed together. In addition, it may be assumed that 30° angle plays an important role for injuries occurring in runners.

Our findings demonstrated that decreased lumbar lordosis may be cited as a risk factor for PFPS, but there were no differences in posterior or anterior pelvic tilt between the patients with PFPS and control group. It is suggested that during the physical examination of patients with PFPS, the position of lumbar lordosis is also attended. If patients with PFPS posses decreased lumbar lordosis, training regimens may be effective for the improvement of patellar malaligment and the alleviation of PFPS.

Furthermore, this study provides evidence that abnormal biomechanics of lower limb, like as leg length difference (LLD), genu varum, genu valgus, foot pronation, flat and high arched foot may not place individuals at risk of PFPS; however individuals with PFPS may demonstrate one or more of the abnormal biomechanics. Although this result is helpful for runners with abnormal biomechanics, further research is needed in order to explore the actual effects of these abnormalities.

In the present study, no differences were found in knee and hip range of motion (ROM) and flexibility of hip flexors and iliotibial band between the two groups. These results showed that the restricted ROM of knee and hip joints as well as shortness of hip flexors and iliotibial band may not be intermediate factors in creation PFPS.

6.1.2. Treatment

There is no agreement about treatment of PFPS, however, some methods such as patellar taping, physical therapy, muscle strengthen and stretching was suggested.

In our study, in accordance with the benefits of TC on knees, we compared TC group with the patients with PFPS and control group. We found no significant differences in electrical activity of VL, VMO and TFL muscles in TC group compared with the two other groups. Additionally, there were no significant differences in VMO/ VL, VMO/ TFL and VMO/ (TFL+ VL) ratios across all knee flexion angles. In regard to the higher age of the TC group than that of the patients and control group, it was expected that TC group had lower amplitude than that of the younger athletes, due to muscle atrophy in higher age. However, our results showed no significant differences in electrical activation of VMO and VL between the young athletes and TC group. It may be assumed that TC training affects the quality of the EMG signals.

In addition, the findings of this study indicated no significant differences in the angle of lumbar lordosis between TC group and the patients as well as TC and control groups. However, the degree of anterior pelvic tilt in TC group was significantly less than that of the patients and control group. Based on the age of the TC group, the results of the present study suggest that TC is an effective training method to prevent pelvic drop. It may be suggested that patients with PFPS, who have anterior pelvic tilt causing pain in their knee, use TC exercises to improve their pelvic drop and subsequently alleviate pain.

Additionally, our findings showed significant differences in LLD between the TC group and the patients as well as TC and control groups. Most of the TC group had no LLD. This finding emphasizes that TC exercises have an affect on equal length of legs and can help to decrease of presence of this problem in runners.

No significant differences were found in genu valgum, genu varum, foot pronation, flat and high arch foot, knee and hip ROM and flexibility of hip flexors between the TC group and the two other groups. However, significant difference was found in flexibility of ITB between TC and control groups. In regard to age differences between groups, it may be resulted that TC training is useful for posture alignment and flexibility. Maybe it helps patients with PFPS in improvement of their posture alignment.

In the current study, we only compared TC group with the patients and control group. For clearing the effect of TC exercise on improvement of PFPS, further research is needed with emphasis on performing the TC training on the patients with PFPS.

All of results were summarized in follow table:

Groups / Risk Factors	Patients and Control group	Patients and Tai chi group	Control and Tai chi groups	Explanation
Amplitude Of VMO at 15° angle	No	No	No	No significant differences in VL and TFL at 15°
Amplitude Of VMO at 30° angle	Yes	No	No	No significant differences in VL and TFL at 30°
Amplitude Of VMO at 45° angle	Yes	No	No	No significant differences in VL and TFL at 45°
VMO/ VL ratio across all knee flexion angle	No	No	No	—
VMO/ TFL across all knee flexion angle	No	No	No	—
VMO/ (TFL+VL) ratio at 30° angle	Yes	No	No	No significant differences in this ratio at 15° and 45° angles
Lumbar lordosis	Yes	No	No	—
Pelvic tilt	No	Yes	Yes	—
Leg length discrapancy	No	Yes	Yes	—
Knee deformities	No	No	No	—
Foot pronation	No	No	No	—
Arch index	No	No	No	—
Range of motion	No	No	No	—
Flexibility of hip flexors	No	No	No	—
Flexibility of ITB	No	No	Yes	—

7. References

1. Reid D. Sports injury assessment and rehabilitation. Chapter 12: Anterior knee pain and the patellofemoral pain syndrome. *Churchill Livingstone*. New York. 1992.

2. McConnell J. The physical therapist's approach to patellofemoral disorders. *Clinics in Sports Medicine.* 2002; 21(3):363-387.

3. Green S.T. Patellofemoral syndrome. *Journal of Bodywork and Movement Therapies*. 2005; 9:16-26.

4. Dixit S, Difiori JP. Management of patellofemoral pain syndrome. *American Family Physician*. 2007; 75(2).

5. Banovetz JM, Banovetz SL, Albright JP. Basic science and conservative care of patellofemoral dysfunction: a review of the literature. *The Lowa Orthopaedic Journal*. 1996; 16:88-96.

6. Holt G, Nunn T, Allen RA, et al. Variation of the vastus medialis obliquus insertion and its relevance to minimally invasive total knee arthroplasty. *The journal of Arthroplasty*. 2008; 23(4):600-604.

7. McConnell J. Management of patellofemoral problems. *Manual Therapy*.- 1996; 1:60-66.

8. Benninghoff A. Anatomie; makroskopische Anatomie, Embryologie und Histologie des Menschen. Part 1. Untere Extremität. *Urban, Schwarzenberg*.1994; 345-352.

9. Fredericson M, Guillet M, DeBenedictis L. Quick solution for iliotibial band syndrome. *The Physician and Sports Medicine.* 2000; 28(2).

10. Mosher TJ. Knee, extensor mechanism injuries (MRI). Dec 16, 2008. Available at: http://emedicine.medscape.com/article/401001

11. Fredericson M, Cookinham CL, Chaudhari A, et al. Hip abductor weakness in distance runners with iliotibial band syndrome. *Clinical Journal of Sport Medicine*. 2000; 10(3):169-175.

12. Puniello MS. Iliotibial band tightness and medial patellar glide in patients with patellofemoral dysfunction. *The Journal of Orthopaedic and Sports Physical Therapy.* 1993; 17:144-8.

13. Reilly DT, Martens M. Experimental analysis of the quadriceps muscle force and patello-femoral joint reaction force for various activities. *Acta Orthopaedica Scandinavica*. 1972; 43:126-37.

14. Waryasz GR, McDermott AY. Patellofemoral pain syndrome (PFPS): a systematic review of anatomy and potential risk factors. Dynamic medicine. 2008; 7:9. Available at: http://www.dynamic-med.com/content/7/1/9.

15. Witvrouw E, Lysens R, Bellemans J, et al. Intrinsic risk factors for the development of anterior knee pain in an athletic population. *The American Journal of Sports Medicine.* 2001; 28:480-489.

16. Stefanyshyn DJ, Stergiou P, Lun VM, Meeuwisse WH, Worobets JT. Knee angular impulse as a predictor of patellofemoral pain in runners. *The American Journal of Sports Medicine* 2006; 34(11).

17. Taunton JE, Ryan MB, Clement DB, et al. A retrospective case-control analysis of 2002 running injuries. *British Journal of Sports Medicine*. 2002; 36:95-101.

18. Drozd S. Patellofemoral pain syndrome ("Runner's knee"). August 2004. Available at: http://www.runnersworld.com/article/1,7124,s6-241-285--7773-0,00.htm Accessed: 24.03.2010.

19. Bolling MC, Padua DA, Marshall SW, et al. A prospective investigation of biomechanical risk factors for patellofemoral pain syndrome. The joint undertaking to monitor and prevent ACL injury (JUMP-ACL) cohort. The *American Journal of Sports Medicine* 2009; 37(11):2108-2116.

20. Brukner PD, crossley KM, Morris H, et al. Recent advances in sports medicine. *MJA Practice Essential-Sports Medicine.* 2006; 184(4):20.

21. Fulkerson JP. Diagnosis and treatment of patients with patellofemoral pain. *The American Journal of Sports Medicine.* 2002; 30(3):447-456

22. Fulkerson JP, Hungerford DS. Disorders of the patellafemoral joint. Williams and Wilkins, 1997.

23. Cowan S, Bennell K, Hodges W. Therapeutic Patellar Taping Changes the Timing of Vasti Muscle Activation in People With Patellofemoral Pain Syndrome. *Clinical Journal of Sports Medicine* 2002; 12(6):339-347.

24. Crossley K, Bennel K, Green S, et al. Physical Therapy for Patellofemoral pain: a randomized, doble-blined, placebo-controlled trail. *The American Journal of Sports Medicine.* 2002; 30:857-865.

25. Owings TM, Grabiner MD. Motor control of the vastus medialis obliquus and vastus muscles is disrupted during eccentric contractions in subjects with patellofemoral pain. *The American Journal of Sports Medicine.* 2002; 30:483-87.

26. Fulkerson JP. Common Patellofemoral problems. *American Academy of Orthopaedic Surgeons*. 2004.

27. Wilk KE, Davise Gj, Mangine RE, et al. Patellofemoral disorders: a classification system and clinical guidelines for non-operative rehabilitation. The *Journal of Orthopaedic and Sports Physical Therapy.* 1998; 28:307-22.

28. Fredericson M, Yoon K. Physical examination and patellofemoral pain syndrome. *American Journal of Physical Medicine & Rehabilitation.* 2006; 85:234-43.

29. Miller J, Sedory D, Croce R. Leg rotation and vastus medialis obliquus/vastus lateralis electromyography activity ratio during closed chain kinetic exercises prescribed for patellofemoral pain. *Journal of Athletic Training.* 1997; 32:216-220.

30. Souza D, Gross M. Comparison of vastus medialis obliquus, vastus lateralis muscle integrated electromyographic ratios between healthy subjects and patients with patellofemoral pain. *Physical Therapy.* 1991; 71:310-20.

31. Gilleard W, McConnell J, Parsons D. The effect of patellar taping on the onset of vastus medialis obliquus and vastus lateralis muscle activity in persons with patellofemoral pain. *Physical Therapy.* 1998; 78(1):25-32.

32. Ahmad CS, Shubin Stein BE, Matuz D, et al. Immediate Surgical Repair of the Medial Patellar Stabilizers for Acute Patellar Dislocation, A Review of Eight Cases. *The American Journal of Sports Medicine.* 2000; 28:804-810.

33. Mosher TJ, Jackson J. Overview of the knee extensor mechanism. 2007. Available at: emedicine.medscape.com.

34. Nicole JC, Kathleen AS, Swanik CB, et al. Effects of plyometric training on muscle-activation strategies and performance in female athletes. *Journal of Athletic Training.* 2004; 39(1):24-31.

35. Recondo J, Salvador E, Villanua J, et al. Lateral stabilizing structures of the knee: Functional anatomy and injuries assessed with MR imaging. *Radiographics.* 2000; 20:S91-S102.

36. Insall J. Current concepts review: patellar pain. The *Journal of Bone and Joint Surgery* (AM). 1982; 64: 147-152.

37. Grabiner MD, Koh TJ, FMiller G. Fatigue rates of vastus medialis obliquus and vastus lateralis during static knee extension. *Journal of Orthopaedic Research.* 1991; 9(2):391-397.

38. Boucher JP, King MA, Lefebvre R, et al. Quadriceps femoris muscle activity in patellofemoral pain syndrome. *American Journal of Sports Medicine.* 1992; 20:527-532.

39. Karst GM, Willett GM. Onset timing of electromyographic activity in the vastus medialis obliquus and vastus lateralis muscles in subjects with and without patellofemoral pain syndrome. *Physical Therapy*. 1995; 75(9):813-23.

40. Cowan S, Bennell KL, Hodges PW, et al. 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; 82:183-189.

41. Mellor R, Hodges PW. Motor unit synchronization is reduced in anterior knee pain. *The Journal of Pain.* 2005; 6(8).

42. McClinton S, Donatell G, Weir J, et al. Influence of step height on quadriceps onset and activation during stair ascent in individuals with patellofemoral pain syndrome. *The Journal of Orthopaedic and Sports Physical Therapy*. 2007; 37(5):239-244.

43. Moraes Santos G, Gramani Say K, Pulzato F, et al. Integrated electromyographic ratio of the vastus medialis obliquus and vastus lateralis longus muscles in gait in subjects with and without patellofemoral pain syndrome. *Rev Bras Med Esporte*. 2007; 13(1).

44. Santos EP, Bessa SNF, Lins CAA, et al. Electromyographic activity of vastus medialis obliquus and vastus lateralis muscles during functional activities in subjects with patellofemoral pain syndrome. *Rev Bras Fisioter*. 2008; 12(4).

45. Van Tiggelen D, Cowan S, Coorevits P, et al. Delayed vastus medialis obliquus to vastus lateralis onset timing contributes to the development of patellofemoral pain in previously healthy men. *The American Journal of Sports Medicine*. 2009; 37(6): 1099-1105.

46. Smith KL. Recurrent patellofemoral subluxation. *Journal of Manual & Manipulative Therapy.* 1997; 5(2):63-79.

47. Wheatly M, Jahnke W. Electromyographic study of the thigh and hip muscles in normal individuals. *Archives of Physical .Medicine.* 1951; 32:508-515.

48. Gregersen CS, Hull ML, Hakansson NA. How changing the inversion/aversion foot angle affects the non-driving intersegmental knee moments and the relative activation of the vastii muscles in cycling. *Journal of Biomechanical Engineering*. June 2006; 128:391-398.

49. McGorry RW, Hsiang SM. A method for dynamic measurement of lumbar lordosis. *Journal of Spinal Disorders*. 2000; 13(2):118-123.

50. Youdas JW, Garrett TR, Egan KS, et al. Lumbar lordosis and pelvic inclination in adults with chronic low back pain. *Physical Therapy*. 2000; 80(3):261-275.

51. Goncalves da Rocha RC, Nee R, Hall T, et al. Treatment of persistent knee pain associated with lumbar dysfunction: a case report. *NZ journal of Physiotherapy*. 2006; 34(1):31-35.

52. Watson AW. Sports injuries in footballers related to defects of posture and body mechanics. The *Journal of Sports Medicine and Physical Fitness*. 1995; 35(4):289-94.

53. Dvorak J, Junge A. Football injuries and physical symptoms. The American Journal of Sports Medicine. 2000; 28(5):S3-S9.

54. Erkula G, Demirkan F. Hamstring shortening in healthy adults. *Journal of Back and Musculoskeletal Rehabilitation.* 2002; 16: 77-81.

55. Murata Y, Takahashi K, Yamagata M, et al. The knee-spine syndrome: association between lumbar lodosis and extension of the knee*. The Journal of Bone and Joint Surgery.* 2003; 85-B: 95-9.

56. Press J, Young J. Rehabilitation of patellofemoral pain syndrome. In: Kibler, B. (ED), functional rehabilitation of sports and musculoskeletal injuries. *Aspen publications, Gaithersburg*. 1998; 254-264.

57. Tsuji T, Matsuyama Y, Goto M, et al. Knee-spine syndrome: correlation between sacral inclination and patellofemoral joint pain. *Journal of Orthopaedic Science*. 2002; 7(5):519-523.

58. Hruska R. Pelvic stability influences lower-extremity kinematics. *Biomechanics.* 1998; 5:23-29.

59. Sathe VM, Ireland ML, Byllantyne BT, et al. Acute effects of the protonics system on patellofemoral alignment: an MRI study. *Knee Surgery, Sports Traumatology, Arthroscopy*. 2002; 10:44-48.

60. Plastaras CT, Rittenberg JD, Rittenberg KE, et al. Comprehensive functional evaluation oft he injured runner. *Physical Medicine and Rehabilitation Clinics of North America*. 2005; 16:623-649.

61. Tyler T, Nicholas S, Mullaney M, et al. The Role of Hip Muscle Function in the Treatment of Patellofemoral Pain Syndrome. *American Journal of Sports Medicine.* 2006; 34:630-634.

62. Sweeting K, Mock M. Gait and posture, Assessment in general practice. *Australian Family Physician.* 2007; 36(6): 398-405.

63. Thomee R, Augustsson J, Karlsson J. Patellofemoral pain syndrome: a review of current issues. *Sports Medicine*. 1999; 28(4):245-262.

64. Asplund CC, St Pierre CP. Knee pain and bicycling: fitting concepts for clinicians. *The Physician and Sports Medicine*. 2004; 32(4).

65. Wen DY, Puffer JC, Schmalzried TP. Lower extremity alignment and risk of overuse injuries in runners. *Medicine & Science in Sports & Exercise*.1997; 29(10):1291-1298.

66. Wilk k, Reinold M. principles of patellofemoral rehabilitation. *Sports Medicine and Arthroscopy Review.* 2001; 9(4): 325-336.

67. Christopher M, Powers C. The influence of altered lower-extremity kinematics on patellofemoral joint dysfunction: a theoretical perspective. *Journal of Orthopaedic & Sports Physical Therapy.* 2003; 33(11): 639-646.

68. Gurney Burke. Leg length discrepancy. *Gait and posture.* 2002; 15: 195-206.

69. Beattie P, Isaacson K, Riddle DL, et al. Validity of derived measurements of leg-length differences obtained by use of a tape measure. *Physical therapy* 1990; 70(3):150-157.

70. Behave A, Paley D, Herzenberg JE. Improvement in gait parameters after lengthening for the treatment of limb-length discrepancy. The *Journal of Bone and Joint Surgery (Am).* 1999; 81:529-534.

71. Gurney AB, Mermier CM, Robergs RA, et al. Effects of leg length discrepancy on gait economy and lower extremity muscle activity in older adults. The *Journal of Bone and Joint Surgery (Am).* 2001; 83:907-915.

72. Messier S, Davis S, Curl W, et al. Etiologic factors associated with patellofemoral pain in runners*. Medicine Science in Sports and Exercise.* 1991; 23(9): 1008-1014.

73. Reid DC. The myth, mystic and frustration of anterior knee pain. *Clinical Journal of Sports Medicine*. 1993; 3:139-143.

74. Duffey M, Martin D, Canon W, et al. Etiologic factors associated with anterior knee pain in distance runners. *Medicine and Science in Sports and Exercise* 2000; 1825-1832.

75. Neely F.G. Biomechanical risk factors for exercise-related lower limb injuries. *Sports Medicine.* 1998; 26(6): 395-413.

76. Milgrom C, Kerem E, Finestone A, et al. Patellofemoral pain caused by overactivity. A prospective study of risk factors in infantry recruits*.* The *Journal of Bone and Joint Surgery (Am).* 1991; 73A*:*1041 –1043.

77. Doucette SA, Goble EM. The effect of exercise on patellae tracking in lateral patellar compression syndrome. *The American journal of Sports Medicine*. 1992; 20(4):434-440.

78. Cowan D, Jones B, Frykman P, et al. Lower limb morphology and risk of overuse injury among male infantry trainees. *Medicine & Science in Sports & Exercise*. 1996; 28(8):945-952.

79. Lun V, Meeuwisse WH, Stergiou P, et al. Relation between running injury and static lower limb alignment in recreational runners. *British Journal of Sports Medicine*. 2004; 38:576-580.

80. Cibulka MT, Threlkeld-Watkins J. Patellofemoral pain and asymmetrical hip rotation. Physical Therapy. 2005; 85(11):1201-1207.

81. Bonci CM. Assessment and evaluation of predisposing factors to anterior cruciate ligament injury. *Journal of Athletic Training*. 1999; 34(2): 155-164.

82. Messier SP and Pittala KA. Etiologic factors associated with selected running injuries. *Medicine and Science in Sports Exercise*. 1988; 20: 501–505.

83. Eng JJ, Pierrynowski MR. Effect of foot orthotics on the kinematics of the knee joint. In: Proceedings of the 12th International congress of biomechanics.1989; June 26-30; Los Angeles, California.

84. Powers CM, Chen PY, Reischl SF, et al. Comparison of foot pronation and lower extremity rotation in persons with and without patellofemoral pain. *Foot and ankle International*. 2002; 23:634-640.

85. Cheung RTH, Ng GYF, Chen BFC. Association of footwear with patellofemoral pain syndrome in runners. *Sports Medicine*. 2006; 36(3):199-205.

86. Hetsroni I, Finestone A, Milgrom C, et al. A prospective biomechanic study of the association between foot pronation and the incidence of anterior knee pain among military recruits. The *Journal of Bone and Joint Surgery [Br].* 2006; 88-B:905-8.

87. Thjis Y, De Clercq D, Roosen P, et al. Gait-related intrinsic risk factors for patellofemoral pain in novice recreational runners. British Journal of Sports Medicine. 2008; 42:466-471.

88. Kaufman KR, Brodine SK, Shaffer RA, et al. The effect of foot structure and range of motion on musculoskeletal overuse injuries. The *American Journal of Sports Medicine*. 1999; 27:585.

89. Esterman A and Pilotto L. Foot shape and its effect on functioning in royal Australian air force recruits, part 1: prospective cohort study. *Military Medicine*. 2005; 170(7):623-628.

90. Van Mechelen W, Hlobil H, Zijlstra WP, et al. Is range of motion oft he hip and ankle joint related to running injuries? A case-control study. *International Journal of .Sports Medicine* 1992; 13:605-610.

91. Thomee R, Renström P, Karlson J, et al. Patellofemoral pain syndrome in young women, I:a a clinical analysis of alignment, common symptoms and functional activity level. *Scandinavian of Medicine and Science in Sports.* 1995; 5:237-244.

92. Ferber R, McClay Davis I, Williams III DS. Gender differences in lower extremity mechanics during running. *Clinical Biomechanics*. 2003; 18:350-357.

93. Willson JD, Davis IS. Lower extremity jumping mechanics of female athletes with and without patellofemoral pain before and after exertion. *The American Journal of Sports Medicine*. 2008; 36(8):1587-1596.

94. Smith AD, Stroud L, Mcqueen C. Flexibility and anterior knee pain in adolescent elite figure skaters. *Journal of Pediatric orthopedics.* 1991; 11(1): 77-82.

95. Piva SR, Goodnite E, Childs J. Strength around the hip and flexibility of soft tissues in individuals with and without patellofemoral pain syndrome. *Journal of Orthopaedic & Sports Physical Therapy.* 2005; 35(12):793-801.

96. White LC, Dolphin P, Dixon J. Hamstring length in patellofemoral pain syndrome. *Physiotherapy*. 2009; 95(1):24-28.

97. Maurer SS, Carlin G, Butters R, Scuderi GR. Rehabilitation of the patellofemoral joint. In: Scuderi GR, ed. The patella. New York: Springer-Verlag; 1995: 143-165.

98. Eng JJ, Pierrynowski MR. Evaluation of soft foot orthotics in the treatment of patellofemoral pain syndrome. Physical therapy. 1993; 73(2): 62-68.

99. Cerny K. Vastus medialis obliquus/ vastus lateralis muscle activity ratios for selected exercises in persons with and without patellofemoral pain syndrome. *Physical Therapy*. 1995; 75(8): 672-683.

100. Tang SFT, Chen CK, Hsu R, et al. Vastus medialis obliquus and vastus lateralis activity in open and closed kinematic chain exercise in patients with patellofemoral pain syndrome: an electromyographic study. *Archives of Physical Medicine and Rehabilitation.* October 2001; 82:1441-445.

101. Crossly K, Bennell K, Green S, et al. Physical therapy for treatment pain. *The American Journal of Sports Medicine*. 2002; 30(6): 857.

102. Cowan SM. Physical therapy alters recruitment of the vasti in patellofemoral pain syndrome. *Medicine & Science in Sports & Exercise*. 2002; 34(12):1879-1885.

103. Mascal CL, Landel R, Powers C. Management of patellofemoral pain targeting hip, pelvis, and trunk muscle function: 2 case reports. *Journal of Orthopaedic & Sports Physical Therapy*. 2003; 33(11): 647-660.

104. Post WR. Patellofemoral pain: results of non-operative treatment. *Clinical Orthopaedics & Related Research*. 2005; 436: 55-59.

105. C.N.Sacco ID. Konno GK, Rojas GB, et al. Functional and EMG responses to a physical therapy treatment in patellofemoral syndrome patients. *Journal of Electromyography and Kinesiology*. 2006; 16: 167-174.

106. Cowan SM, Hodges PW, Crossley KM, et al. Patellar taping does not change the amplitude of electromyographic activity of the vasti in a stair stepping task. *British Journal of Sports Medicine*. 2006; 40: 30-34.

107. Fagen V, Delahunt E. Patellofemoral pain syndrome: a review on the associated neuromuscular deficits and current treatment options. The *Journal of Sports Medicine*. 2008; 42: 789-795.

108. Ng GYF, Zhang AQ, Li CK. Biofeedback exercise improved the EMG activity ratio of the medial and lateral vasti muscles in subjects with patellofemoral pain syndrome. *Journal of Electromyography and Kinesiology.* 2008; 18(1): 128-133.

109. Kuramoto AM. Therapeutic benefits of Tai chi exercise: research review. *Wisconsin Medical Journal*. 2006; 105(7): 42-46.

110. Yan JH, Downing JH. Tai chi: an alternative exercise form for seniors. *Journal of Aging and Physical Activity.* 1998; 6:350-362.

111. Wang C, Collet JP, Lau J. The effect of Tai chi on health outcomes in patients with chronic conditions: a systematic review. *Archive Internal Medicine.* 2004; 164:493-501.

112. Tsang WWN, Hui-Chan CWY. Effects of Tai chi on joint proprioception and stability limits in elderly subjects. *Medicine and Science in Sports and Exercise*. 2003; 35(12):1962-1971.

113. Taylor-Piliae RE; Haskell WL, Stotts NA, et al. Improvement in balance, strength, and flexibility after 12 weeks of Tai chi exercise in ethnic Chinese adults with cardiovascular disease risk factors. *Alternative Therapies in Health and Medicine*. 2006; 12(2): 50-8.

114. Fransen M, Nairn L, Winstanley J, et al. Physical activity for osteoarthritis management a randomized controlled clinical trail evaluating hydrotherapy or Tai chi classes. *Arthritis & Rheumatism (Arthritis Care & Research)* 2007; 57(3):407-414.

115. Savio LY, Renström AFH, Arnoczky SO. Tendinopathy in athletes. *Blackwell Publishing Company*. 2007: 212

116. Bryant G, James L. Simply Tai chi, vitality, relaxation, balance. Barca M. Australia. Hinkler books pty ltd, 2003.

117. Van Deusen J, Harlowe D. The efficacy of the ROM dance program for adults with rheumatoid arthritis. The *American Journal of Occupational Therapy*. 1987; 41: 90-5.

118. Lan C, Lai JS, Wong MK, Yu ML. Cardiorespiratory function, flexibility, and body composition among geriatric Tai chi chuan practitioners. *Archives of Physical Medicine and Rehabilitation*. 1996; 77(6):612-616.

119. Lan C, Lai JS, Chen SY, et al. 12-month Tai chi training in the elderly: its effect on health fitness. *Medicine & Science in Sports & Exercise:* 1998; 30(3):345-351.

120. Ross MC, Bohannon AS, Davis DC, et al. The effects of a short- term exercise program on movement, pain and mood in the elderly. Results of a pilot study. *Journal of Holistic Nursing.* 1999;17:139

121. Hong Y, Li JX, Robinson PD. Balance control, flexibility, and cardiorespiratory fitness among older Tai chi practitioners. *British Journal of Sports Medicine.* 2000; 34:29-34.

122. XU D, Hong Y, Li J, Chan K. Effect of Tai chi exercise on proprioception of ankle and knee joints in old people. *British Journal of Sports Medicine*. 2004; 38: 50-54.

123. Tsang WWN and Hui-chan CWY. Comparison of muscle torque, balance, and confidence in older tai chi and healthy adults. *Medicine and Science in Sports and Exercise.* 2005; 37(2): 280-289.

124. Macfarlane D, Chou KL, Cheng WK. Effects of Tai chi on the physical and psychological well-being of Chinese older women. *J Exerc Sci Fit*. 2005; 3(2):87-94.

125. Brismee JM, Paige RL, Chyu MC, et al. Group and home-based tai chi in elderly subjects with knee osteoarthritis: a randomized controlled trail. *Clinical Rehabilitation*. 2007; 21: 99-111.

126. Soo Lee M, Pittler MH, Ernst E. Tai chi for osteoarthritis: a systematic review. Journal of *Clinicical Rheumatology.* 2008; 27:211-218.

127. Shen CL, JamesCR, Chyu Mc, et al. Effects of Tai chi on gait kinematics, physical function, and pain in elderly with kne osteoarthritis- a pilot study. *Am J Clin Med*. 2008; 36(2): 219-32.

128. Rainoldi A, Melchiorri G, Caruso I: A method for positioning electrodes during surface EMG recordings in lower limb muscles. *Journal of Neuroscience Methods. 2004;* 134(1):37-43.

129. Hermans HJ, Freiks B. SENIAM; The state of the art on sensors and sensor placement procedures for surface ElectroMyoGraphy: A proposal for sensor placement procedures. Available at: http://www.seniam.org. 1997

130. Mayer TG, Tencer AF, Kristoferson S, et al. Use of noninvasive techniques for quantification of spinal range of motion in normal subjects and chronic low back dysfunction patients. *Spine.* 1984; 9: 588-95.

131. Ng J, Kippers V, Caroliyn A, parnianpour M. Range of motion and lordosis of the lumbar spine: reliability of measurement and normative values. *Spine.* 2001; 26(1): 53-60.

132. Sullivan S, Donegan L, Riddle D. The relationship of lumbar flexion to disability in patients with low back pain. *Physical Therapy*. 2000; 80(3): 240-250.

133. Adams MA, Dolan P, Marx C, et al. An electronic inclinometer technique for measuring lumbar curvature. *Clinical Biomechanics.* 1986; 1: 130-134.

134. Walker ML, Rothstein JM, Finucance SD, et al. Relationships between lumbar lordosis, pelvic tilt, and abdominal muscle performance. *Phys Ther*. 1987; 67(4): 512-516.

135. Hertel J, Dorfman J, Braham R. Lower extremity malalignments and anterior cruciate ligament injury history. *Journal of Sports Science and Medicine.* 2004; 3: 220-225.

136. Potter Nancy, Rothstein Jules. Intertester reliability for selected clinical tests of the sacroiliac joint. *Physical Therapy.* 1985; 65(11):1671-1675.

137. Cibulka MT, Delitto A, Koldehoff RM. Changes in innominate tilt after manipulation of the sacroiliac joint in patients with low back pain: an experimental study. *Phys Ther*.1988; 68:1359–1363.

138. Hreljac A, Marshal R, Hume P. Evaluation of lower extremity overuse injury potential in runners. *Medicine and Science in Sports and Exercise.* 2000; 32(9):1635-1664.

139. Razeghi M, Batt M. Foot type classification: a critical review of current methods. *Gait and posture.* 2002; 15(3):282-291.

140. Fusco M.A. Footprint: morphologic evaluation and functional evaluation. Comparison between two methods. *http://www.Mariantoniettafusco.com*

141. Miller PJ. Assessment of joint motion. In: Rothstein JM, ed. Measurement in physical therapy. New York, NY. Churchill Livingstone Inc. 1985: 103-106

142. Ryf C, Weymann A. Range of motion – Ao neutral-0 method, measurement and documentation. AO Publ. 1999.

143. Reese NB, Bandy WD. Joint range of motion and muscle length testing. Philadelphia, PA: Saunders Co; 2002.

144. Hoppenfeld S. Physical examination of the spine and extremities. Norwalk, CT: Appleton and Lange; 1976.

145. Thomas HO. Diseases of the hip, knee and ankle joints, with their deformities: treated by a new and efficient method (enforced, uninterrupted, and prolonged rest). 2^{nd} ed. Liverpool, England: Dobb, 1876.

146. Gleim GW, Stachenfeld NS, Nicholas JA. The influence of flexibility on the economy of walking and jogging. *Journal of Orthopaedics Research*. 1990; 8:814-823.

147. Kanamiya T, Whiteside L, Nakamura T, et al. Effect of selective lateral ligament release on stability in knee Arthroplasty. *Clinical Orthopaedics and Related Research*. 2002; 404:24-31.

148. Reider B, Marshall JL, Warren RF. Clinical characteristics of patellar disorder in young athletes. The *American Journal of Sports Medicine*. 1993; 9:270-4.

149. Berger R.A, Crossett L.S, Jacobs J.J, et al. Malrotation causing patellofemoral complications after total knee arthroplasty. *Clinical Orthopaedics and Related Research.* 1998; 356:144-153.

150. Ireland ML, Willson JD, Ballantyne BT; et al. Hip strength in females with and without patellofemoral pain. The *Journal of Orthopaedics and Sports Physical Therapy*. 2003; 33:671-676.

151. Powers CM. Patellar kinematics, past I: The influence of vastus muscle activity in subjects with and without patellofemoral pain. *Physical Therapy*. 2000; 80(10):956-964

152. Roberts TJ, Gabaldon AM. Interpreting muscle function from EMG: lessons learned from direct measurements of muscle force. *Integrative and Comparative Biology.* 2008; 48(2):312-320.

153. Orchard J, Fricker P, Abud A, et al. Biomechanics of iliotibial band friction syndrome in runners. The *American Journal of Sports Medicine*. 1996; 24(3):375-379

154. Besier TF, Lloyd DG, Cochrane JL, et al. External loading oft he knee joint during running and cutting maneuvers. *Medicine and Science in Sports and Exercise*. 2001; 33(7): 1168-1175.

155. Braddom R. Physical medicine and rehabilitation. In: Casazza B, Young J, editors. Musculoskeletal disorders of the lower limbs. 2nd ed. Philadelphia: WB Saunders. 2000: 834-7

156. Wise HH, Fiebert IM, Kates JL. EMG biofeedback as treatment of patellofemoral pain syndrome. The *Journal of Orthopaedics and Sports Physical Therapy.* 1984; 6:95-103.

157. Myeong SL, Pittler MH, Edzard E. Tai chi for osteoarthritis: a systematic review. Journal of *Clinical Rheumatology.* 2008; 27:211-218.

158. Alder PA, Roberts BL. The use of tai chi to improve health in older adults. *Orthopaedic Nursing.* 2006; 25:122-126.

159. Taylor SK. Tai chi for chronic pain and arthritis. *Tech Orthop* 2003; 18:110-114.

160. Tseng SC, Liu W, Finley M, et al. Muscle activation profiles about the knee during Tai chi stepping movement compared to the normal gait step. *Journal of Electromyography and Kinesiology.* 2007; 17(3):372-380.

161. MacGregor K, Gerlach S, Mellor R, et al. Cutaneous stimulation from patella tape causes a differential increase in vasti muscle activity in people with patellofemoral

pain. Journal of Orthopaedic research. 2004. Available at: www.elsevier.com/locate/orthres. Accepted: 19.07.2004.

162. Christou EA. Patellar taping increases vastus medialis oblique activity in the presence of patellofemoral pain. *Journal of Electromyography and Kinesiology*. 2004; 14(4):495-504.

163. Hanten WP, Schulthies SS. Exercise effect on electromyographic activity of the vastus medialis obliquus and vastus lateralis muscles. *Physical Therapy.* 1990; 70:561-5.

164. Mirzabeigi E, Jordan C, Gronley JK, et al. Isolation oft he vastus medialis oblique muscle during exercise. *The American Journal of Sports Medicine*. 1999; 27(1): 50-53.

165. Hinman RS, Cowan SM, Crossley KM, et al. Age-related changes in electromyographic quadriceps activity during stair descent. *Journal of Orthopaedic Research*. 2006; 23(2): 322-326.

166. Dixon J, Howe TE. Activation of vastus medialis oblique is not delayed in patients with osteoarthritis of the knee compared to asymptomatic participants during open kinetic chain activities. *Manual Therapy*. 2007; 12(3):219-225.

167. Nicolas JA, Grossman RB, Hershman EB. The importance of a simplified classification of motion in sports in relation to performance. The *Orthopedic Clinics of North America.* 1977; 8:499-532.

168. Nadler SF, Wu K, Galski T, et al. Low back pain in college athletes: A prospective study correlating lower extremity overuse or acquired ligamentous laxity with low back pain. *Spine.* 1997; 23(7): 828-833.

169. Rocha G, Nee R, Hall T, et al. Treatment of persistent knee pain associated with lumbar dysfunction: a case report*. New Zealand Journal of Physiotherapy.* 2006; 34(1): 31-35.

170. Deusinger RH. Biomechanical considerations for clinical application in athletes with low back pain. *Clinics in Sports Medicine*. 1989; 8: 703-715.

171. Gajdosik RL, Albert CR, Mitman JJ. Influence of hamstring length on the standing position and flexion range of motion oft he pelvic angle, lumbar lordosis and thoracic angle. The *Journal of Orthopaedics and Sports Physical Therapy.* 1994; 20(4): 213-9.

172. Sol C. Impact forces at the knee joint- A comparative study on running styles. Scientific research & pose method. 2001. Availabel at: www.posetech.com/library/cs-05-2001.html. Assessment 12.03.09.

173. Chen KM, Snyder M. R research-based use of Tai chi/ movement Therapy as a nursing intervention. *Journal of Holistic Nursing*. 1999;17:267

174. Gallagher B. Tai chi chuan and qigong: physical and mental practice for functional mobility. *Topics in Geriatric Rehabilitation.* 2003; 19(3):172-182.

175. Gelb DE, Lenke LG, Bridwell KH, et al. An analysis of sagittal spinal alignment in 100 asymptomatic middle and older aged volunteers. *Spine*. 1995; 20: 1351-8.

176. Huang A. Complete Tai chi, the definitive guide to physical and emotional self-improvement. Part I: how to learn and practice Tai chi. Buston. Tuttle publishing. 1993

177. Tai chi health. Deconstructing Tai chi: biomechanics, kinesiology, therapeutic and applications. Available at: http://romdance.com/Deconstructing%20Tai%20Chi%20poster.pdf.

178. Lowe Whitney. Leg length discrepancy and low back pain. *Massage Today.* 2008; 8(1).

179. McCaw ST. Leg length inequality: implications for running injury prevention. *Sports Medicine*. 1992; 14:422-429.

180. Kujala UM, Friberg O, Aalto T, et al. Lower limb asymmetry and patellofemoral joint incongruence in the etiology of knee exertion injuries in athletes. *International Journal of Sports Medicine.* 1987; 8: 214-20.

181. Schulthies SS, francis RS, Fisher AG, et al. Does the Q angle reflect the force on the patella in the frontal plane? *Physical Therapy*. 1995; 75: 24-30.

182. Li F, Harmer P, Fisher KJ, et al. Tai chi and fall reductions in older adults: A randomized controlled trial. *Journal of Gerontology: Medical Sciences*. 2005; 60A(2):187-194.

183. McGibbon C, Krebs D, Wolf S, et al. Tai chi and vestibular rehabilitation effects on gaze and whole body stability. *Journal of Vestibular Resarch.* 2004; 14:467-78.

184. Wu G, Liu W, Hitt J, et al. Spatial, temporal and muscle action patterns of Tai chi gait. *Journal of Electromyography and kinesiology*. 2004; 14:343-54.

185. McConnell J, Bennell K. Conserative management of anterior knee pain: the McConnell program. Anterior knee pain and patellar instability. *Springer.Londodn.* 2006; 167-184.

186. Department of health. Osteoarthritis. *Non-communicable diseases watch*. 2009; 2(5).

187. Daley MJ, Spinks WL. Exercise, mobility and aging. *Sports Med*icine. 2000; 29(1): 1-12.

8. Attachment

Universität Bielefeld

Fakultät für Psychologie und Sportwissenschaft
Abteilung Sportwissenschaft
AB I „Sportmedizin - Gesundheit und Training“

Universität Bielefeld | Postfach 10 01 31 | 33501 Bielefeld

Prof. Dr. med. Elke Zimmermann
Lehrstuhl für Sportmedizin

Raum: E0-110
Tel.: 0521.106-6109
Fax: 0521.106-6129
elke.zimmermann@uni-bielefeld.de
www.uni-bielefeld.de/sport

Bielefeld,
Seite 1 von 1

Einverständniserklärung

Name:

Geburtsdatum:

Hiermit erkläre ich mich einverstanden, dass bei mir/meiner Tochter/meinem Sohn im Rahmen einer Studie des Arbeitsbereiches Sportmedizin der Abteilung Sportwissenschaften der Universität Bielefeld ein Oberflächen-EMG und eine orthopädische Untersuchung durchgeführt werden.

Die Anonymisierung der Daten im Falle einer Publikation wird gewährleistet.

Datum

Unterschrift

Fragebogen

Nr.	Der Name von EMG Ordner:
Name:	Vorname:
Alter:	Gewicht:
Größe:	

- Ich bin:
  Rechtshänder ☐ Linkshänder ☐
- Welche Sportart betreiben Sie?
- Wie lange betreiben Sie Sport?
- Haben Sie Schmerzen im Kniegelenk?
  Ja ☐ Nein ☐
- Seit wann haben Sie Schmerzen im Kniegelenk?
- Die Schmerzen sind im:
  rechten Knie ☐ linken Knie ☐ beiden ☐
- Haben Sie eine Kniescheiben-Verletzung gehabt?
  Ja ☐ Nein ☐
- Hatten Sie eine Operation am Knie?
  Ja ☐ Nein ☐
- wenn ja,Welche?
- Verschlechtern sich Ihre Schmerzen beim Laufen?
  Ja ☐ Nein ☐
- Verschlechtern sich Ihre Schmerzen beim längeren Sitzen mit gebeugten Knien?
  Ja ☐ Nein ☐

• Fühlen Sie Schmerzen, wenn Sie Treppen steigen oder beim Bergsteigen? Ja ☐ Nein ☐
• Fühlen Sie Schmerzen, wenn Sie die Treppen runtergehen oder beim Bergabstieg? Ja ☐ Nein ☐
• Fühlen Sie ein Reiben in Ihrem Knie beim Gehen oder Laufen? Ja ☐ Nein ☐
• Üben sie oft Kniende Tätigkeiten aus? Ja ☐ Nein ☐
• Wenn ja, wie viele Stunden pro Tag?

Physical examination

Nr.	Name:

- Foot:
  Flat ☐ Normal ☐ High arch ☐
- Back foot axis:
  pronation ☐ Normal ☐ Supination ☐
- Leg axis:
  Valgum ☐ Normal ☐ Varum ☐
- Leg length minus:
  Right ☐ None ☐ Left ☐
- Pelvic tilt:

  Right side:
  Anterior ☐ Normal ☐ Posterior ☐

  Left side:
  Anterior ☐ Normal ☐ Posterior ☐
- Lumbar lordosis:

  Positive ☐ Negative ☐
- Knee ROM:
  E/F: Right Left
- Hip ROM:
  E/F: Right Left

  Ab/Ad: Right Left

  ER/IR: Right Left
- Thomas test:
  Positive ☐ Negative ☐
- Ober test:
  Positive ☐ Negative ☐

- The projction of pain::

  Medial ☐ Lateral ☐ Underneath the patella ☐

  Others ☐

Acknowledgment

I would like to take the opportunity to thank those people who spent their time and shared their knowledge for helping me to complete my thesis with the best possible result.

I am heartily thankful to my supervisor, Prof. Dr. med. Elke Zimmermann, whose encouragement and guidance from the initial to the final level enabled me to develop an understanding of the subject.

I am grateful to Prof. Dr. Stephan Starischka, who kindly supported me in EMG examinations.

I would like to express my thanks to Dr. Christian Vobejda and Dr. Reinhard von Piechowski who always provided me with useful advice.

A big thanks to all my colleague, Marlies Trenner, Petra Borgsen and Tim Wortmann, who always help me.

Finally, my special thanks to:

My mother, who taught me the meaning of life and showed me the best way of life, and my father; I never forget his kindness. Unfortunately, he passed away a few years ago and he wasn’t with me in the shining days of my life,

My sister, who taught me to work hard,

My husband, Majid, for his helping in examination and his encouragement and great guidance,

And my son, Andisheh, who accepted to be my model and presented to me calmness with his smile.

I am forever indebted to them.

Erklärung

Hiermit versichere ich, die vorliegende Dissertationsschrift mit dem Title

„Comparison of electrical activity of lateral and medial stabilizers of the patella and further diagnostically relevant risk factors in athletes with and without patellofemoral pain and in Tai Chi group"

Selbständig verfasst und keine, außer den angegebenen Hilfsmitteln und Quellen, verwendet zu haben. Zitate wurden als solche kenntlich gemacht. Die Dissertation lag weder in dieser noch in einer anderen Fassung einer anderen Universität oder Fakultät vor.

Bielefeld, 18.06.2010

Khoshraftar

Nahid Khoshraftar Yazdi