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ALTERAÇÕES NEUROMUSCULARES DE MEMBRO INFERIOR E SUAS RELAÇÕES COM A CINEMÁTICA DURANTE TAREFAS UNIPODAIS DE DECARGA DE PESO NA SÍNDROME DA DOR PATELOFEMORAL

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LOWER LIMB NEUROMUSCULAR CHANGES AND THEIR RELATIONSHIP WITH KINEMATICS DURING SINGLE-LEG WEIGHT-BEARING TASKS IN THE PATELLOFEMORAL PAIN SYNDROME

Thesis submitted to the Graduate Program of Human Movement Science of the Universidade Federal do Rio Grande do Sul in partial fulfillment of the requirements for the degree of Philosophy Doctor in Human Movement Science.

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LOWER LIMB NEUROMUSCULAR CHANGES AND THEIR RELATIONSHIP WITH KINEMATICS DURING SINGLE-LEG WEIGHT-BEARING TASKS IN THE PATELLOFEMORAL PAIN SYNDROME

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Alterações neuromusculares de membro inferior e suas relações com a cinemática durante tarefas unipodais de descarga de peso na syndrome da dor patelofemoral

por
Rodrigo Rodrigues

Submetido ao Programa de Pós-graduação em Ciências do Movimento Humano da Universidade Federal do Rio Grande do Sul em 19 de julho de 2018 como requisito parcial para a obtenção do título de Doutor em Ciências do Movimento Humano

Resumo

A síndrome da dor patelofemoral (SDPF) é o diagnóstico mais comum em populações fisicamente ativas. A SDPF está relacionada com o mau alinhamento dos membros inferiores durante tarefas de descarga de peso, causando maior estresse e dor na articulação patelofemoral. Esse mau alinhamento está relacionado com um aumento da inclinação ipsilateral do tronco, adução do quadril, abdução do joelho e maior grau de rotação interna da tíbia durante atividades dinâmicas, como agachamento unipodal, corrida, salto e subir e descer escadas. Fatores anatômicos e biomecânicos estão relacionados a alterações ao redor da articulação femoropatelar, como menor força de extensão do joelho, atraso na ativação do vasto medial em relação ao vasto lateral e atrofia do músculo quadríceps. Recentemente, alterações do quadril (fatores proximais), tornozelo e pé (fatores distais) têm sido propostas como fatores contribuintes da SDPF. No entanto, as evidências sobre ativação e alteração da morfologia muscular dos membros inferiores, principalmente nos fatores proximais e distais, são escassas. Esta tese teve como objetivo verificar as alterações neuromusculares dos membros inferiores e determinar se algum parâmetro neuromuscular explicava a cinemática durante tarefas unipodais. Após a apresentação dos motivos para realização deste estudo (Capítulo I), no Capítulo II objetivamos verificar as alterações neuromusculares (ativação muscular e morfologia muscular) relacionadas aos fatores proximais e distais na SDPF por meio de uma revisão sistemática. As buscas foram realizadas nas bases de dados Medline (via PubMed), Scielo, Scopus, PEDro, Cochrane Central, Embase e ScienceDirect databases até abril de 2018 para estudos avaliando ativação muscular ou parâmetros de morfologia muscular das articulações do tronco, quadril e tornozelo/pé. Dois revisores independentes avaliaram cada trabalho para inclusão e qualidade. Dezenove estudos foram identificados (SDPF, n = 319; GC, n = 329). Três estudos investigaram os músculos ao redor das articulações do tronco e tornozelo/pé. Quinze estudos investigaram os músculos ao redor da articulação do quadril. As evidências foram inconclusivas sobre a ativação do transverso do abdome/oblíquo interno (TrA/OI) na SDPF durante atividades de alta velocidade. Os níveis de ativação, duração e atraso na ativação de Glúteo Médio (GMed), glúteo máximo (GMax), biceps femoral (BF) and semitendinoso (ST) foram inconclusivos nos estudos incluídos. Não foram observadas diferenças na ativação de gastrocnêmio lateral (GL), gastrocnêmio medial (GM), sóleo (SOL), tibial anterior (TA) e fibular longo (FIB). Apenas um estudo incluído avaliou parâmetros da morfologia muscular, sem alterações na espessura muscular e na intensidade do eco GMed e GMax. Com base na falta de evidências sobre alterações na ativação muscular em torno das articulações do quadril, tornozelo e pé durante tarefas dinâmicas, e no fato de que um único estudo avaliou os resultados da morfologia muscular (GMed e GMax) na SDPF, propusemos um artigo original (Capítulo III) que teve como objetivo comparar os parâmetros neuromusculares dos membros inferiores e a cinemática no plano frontal durante tarefas unipodais de descarga de peso em mulheres com SDPF e determinar se algum resultado neuromuscular explicava o índice dinâmico de valgo (IVD) durante as tarefas. Quinze mulheres com SDPF e quinze mulheres saudáveis pareadas por

idade (grupo controle - GC) foram comparadas com os seguintes testes: (1) questionário funcional; (2) espessura muscular ao redor do quadril (GMed e tensor da fáscia lata - TFL), joelho (VL e VM) e tornozelo/pé (TA e FIB); (3) IVD e ativação muscular durante agachamento e salto vertical unipodais; (4) torque isométrico máximo para abdução do quadril, extensão do joelho e eversão/ inversão do pé; e (5) ativação muscular durante testes isométricos e funcionais. Uma regressão linear múltipla (modelo *Stepwise)* foi usada para verificar se alguma variável neuromuscular explicava o IVD durante as tarefas unipodais. O tamanho de efeito (ES) foi usado para determiner a magnitude da diferença entre os grupos. Comparado ao GC, o grupo SDPF apresentou: (1) menor espessura do GMed (-10.02%; ES = -0.82) e maior espessura do TFL (+18.44%; ES = +0.92) e do FIB (+14.23%; ES = +0.87); (2) menor ativação do TA durante o agachamento unipodal (-59,38%; ES = -1.29); (3) menor ativação do GMed durante o salto vertical unipodal (-28.70%; ES = -1.35) e (4) maior ativação do GMed durante o teste isométrico de abdução de quadril (+34.40%; ES = +0.77). IVD durante o agachamento unipodal foi explicado pela ativação do VL durante a tarefa somente no GC, enquanto a espessura do TA no GC e o torque de eversores do pé no SDPF explicou o IVD durante o salto vertical unipodal. Com base em nossos resultados, as mulheres com SDPF apresentaram alterações neuromusculares significativas nas articulações do quadril e tornozelo/pé. No entanto, apenas fatores distais explicaram o IVD no grupo SDPF.

Palavras-chave: dor patelofemoral; tronco; quadril; tornozelo; EMG; atrofia muscular

Lower limb neuromuscular changes and their relationship with kinematics during single-leg weight-bearing tasks in the patellofemoral pain syndrome

by

Rodrigo Rodrigues

Submitted to the Graduate Program of Human Movement Science on July 19, 2018, in partial fulfillment of the requirements for the degree of Philosophy Doctor in Human Movement Science.

Abstract

Patellofemoral pain syndrome (PFPS) is the most common diagnoses in physically active populations. PFPS is related with lower limbs poor alignment during weight-bearing tasks, causing higher patellofemoral joint stress and pain. This poor alignment is related with an increase of ipsilateral trunk lean, hip adduction, knee abduction and greater tibial internal rotation during dynamic activities such as single-leg squat, running, jumping, and stepping tasks. Anatomical and biomechanical factors are related with unwanted changes around the patellofemoral joint, such as lower knee extension strength, delayed onset of vastus medialis activation relative to vastus lateralis and quadriceps muscle atrophy (knee joint muscles intrinsic changes). Recently, hip (proximal), ankle and foot (distal) changes have been proposed as PFPS contributing factors. However, the evidences about lower limb muscle activation and morphology changes, mainly in proximal and distal factors, are scarce. This thesis aimed to create clinical subgroups based in lower limb neuromuscular changes and determine if some neuromuscular outcome explained kinematics during single-leg tasks. After displaying the reasons to perform this study (Chapter I), in Chapter II we aimed to verify neuromuscular changes (muscle activation and muscle morphology) related to proximal and distal factors in PFPS through a systematic review. Medline (via PubMed), Scielo, Scopus, PEDro, Cochrane Central, Embase and ScienceDirect databases were searched until April 2018 only for retrospective studies evaluating muscle activation or muscle morphology parameters of trunk, hip and ankle/foot joints. Two independent reviewers assessed each paper for inclusion and quality. Twenty retrospective studies were identified (PFPS, n=319; CG, n=329). Three studies investigated muscles around trunk and ankle/foot joints. Fifteen studies investigated muscles around the hip joint. Evidences were inconclusive about transversus abdominis/internal oblique (TrA/IO) activation in PFPS during high-speed activities. Gluteus medius (GMed), gluteus maximus (GMax), bíceps femoris (BF) and semitendinous (ST) activation level, activation duration and activation onset were inconclusive in the included studies. No differences were observed in gastrocnemius lateralis (GL), gastrocnemius medialis (GM), soleus (SOL), tibialis anterior (TA) and fibularis (FIB) muscle activation. Only one included study evaluated muscle morphology parameters, without changes in the GMed and GMax muscle thickness and echo intensity. Based in the lack of evidences about muscle activation changes in PFPS patients' muscles around hip, ankle and foot joints during dynamic tasks, and in the fact that a single study evaluated muscle morphology outcomes (GMed), we proposed an original article (Chapter III) that aimed to compare lower limb neuromuscular parameters and frontal plane kinematics during single-leg tasks in women with PFPS, and determine if some neuromuscular outcome explained dynamic valgus index (DVI) during tasks. Fifteen PFPS women and fifteen healthy age-matched women (control group - CG) were compared with the following tests: (1) functional questionnaire; (2) hip (GMed and tensor fasciae latae - TFL), knee (VL and VM) and ankle/foot (TA and FIB) muscle thickness; (3) DVI and muscle activation during single-leg squat and vertical jump; (4) maximal isometric torque for hip abduction, knee extension and foot eversion/inversion; and (5) muscle activation during isometric and functional tests. A multiple-

stepwise regression analysis was used to test if neuromuscular outcomes explained DVI during single-leg tasks. Effect sizes (ES) were used to determine the magnitude of between-groups differences. Compared to the CG, PFPS showed: (1) smaller GMed (-10.02%; ES = -0.82) and greater TFL (+18.44%; ES = +0.92) and FIB muscle thickness (+14.23%; ES = +0.87); (2) lower TA muscle activation during single-leg squat (-59,38%; ES = -1.29); (3) lower GMed muscle activation during single-leg jump (-28.70%; ES = -1.35) and (4) greater GMed muscle activation during hip abduction isometric test (+34.40%; ES = +0.77). DVI during single-leg squat was explained by VL activation during this task only in CG, whereas lower TA muscle thickness in the CG and higher foot eversion torque in PFPS explained DVI during single-leg vertical jump. Based in our results, females with PFPS showed significant neuromuscular changes at the hip and ankle/foot joints. However, only distal factors explained DVI in the PFPS group.

Keywords: patellofemoral pain; trunk; hip; ankle; EMG; muscular atrophy

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CHAPTER I – BACKGROUND AND AIMS

Patellofemoral pain syndrome (PFPS) is characterized by retro or peripatellar pain, exacerbated during weight-bearing activities such as running, jumping, squatting and going up and down stairs [1]. It is one of the most common diagnoses among young, physically active populations [2], predominantly in females [3]. Therefore, it has a debilitating effect on PFPS patients' daily lives by reducing their ability to perform sporting and work-related activities pain free [4]. The most common responses observed in PFPS patient's dynamic tasks is related with frontal/transverse plane kinematic changes, such as ipsilateral trunk lean, hip adduction, knee abduction [5] and greater tibial internal rotation [6]. Additionally, many studies have evaluated patients after PFPS diagnoses and tried to observe kinetic, kinematic and neuromuscular changes compared to healthy participants [5, 7-10], thinking in rehabilitation programs to minimize pain and improve functionality.

Historically, anatomical and biomechanical factors related with PFPS focused in the structures around patellofemoral joint [11]. Lower knee extension strength [12], delayed activation onset of vastus medialis (VM) relative to vastus lateralis (VL) [13], and quadriceps muscle atrophy [14] pointed to the main neuromuscular changes related with the disease. Recently, proximal (related with hip [5, 8, 15] and trunk [8, 16]) and distal factors (related with ankle and foot joint changes [17, 18]) have been proposed as PFPS contributing factors, which might lead to lower limb poor alignment during weight-bearing tasks and cause higher patellofemoral joint stress and pain [9, 19].

Although interventions involving exercise are the most effective for these patients, many of them are not responsive to treatment, which is commonly explained by the changes observed in PFPS not being adequately addressed or not being the same for all patients [4]. Thus, the identification of which factors are present in PFPS patients can potentiate the intervention protocols effectiveness [4, 20, 21], such as the identification of aetiology subgroups [21]. Recent evidences demonstrated that the combination of hip and knee [22] and foot and knee exercises [23] in a rehabilitation exercise program is better than exercise focusing at the knee alone on pain severity and functionality in PFPS

patients. Even with the observed improvement on clinical outcomes, the mechanisms that better explain this condition or that need to be addressed are scarce.

The amount of published studies is a reflection of this recent attention given by researchers to proximal and distal factors. When we performed a simple search in PubMed database with terms "patellofemoral pain syndrome and hip" or "patellofemoral pain syndrome and ankle", we only observed 263 and 72 studies, respectively (until July 5th, 2018), while the search with "patellofemoral pain syndrome and knee" we observed 937 studies. Additionally, the consensus statement from the last International Patellofemoral Pain Research Retreat in September 2017 [24] pointed as one of the future directions a "greater understanding of potential mechanisms underpinning treatment effects". Thus, we believe that the identification of clinical subgroups based in detailed lower limb neuromuscular changes can help to explain poor lower limb aligment during weight-bearing tasks and improve exercise rehabilitation protocols.

Based on previous studies weakness to identify the mechanisms related with PFPS, this dissertation was subdivided in three sections. Chapter II is an original manuscript aimed to compare neuromuscular outcomes (muscle activation and muscle morphology) related to proximal and distal factors between PFPS patiens and healthy participants through a systematic review. Chapter III is an original article that aimed to compare lower limb neuromuscular parameters and frontal plane kinematics during single-leg tasks in women with and without PFPS and determine if some neuromuscular outcome explained dynamic valgus index (DVI) during tasks. Finally, in the last chapter we address our conclusion and future directions.

CHAPTER II - PROXIMAL AND DISTAL NEUROMUSCULAR CHANGES IN PATELLOFEMORAL PAIN SYNDROME: A SYSTEMATIC REVIEW

2.1 ABSTRACT

Introduction: Patellofemoral pain syndrome (PFPS) is a multifactorial disease related to neuromuscular changes at the trunk, hip, knee, ankle and foot joints. However, evidences about neuromuscular changes in trunk, hip, ankle and foot joints are scarce. **Purpose:** To verify neuromuscular changes (muscle activation and muscle morphology) related to proximal and distal joints in PFPS compared to healthy participants through a systematic review. **Methods:** Medline (via PubMed), Scielo, Scopus, PEDro, Cochrane Central, Embase and ScienceDirect databases were searched until April 2018 only for observational and clinical trials studies evaluating muscle activation or muscle morphology parameters of trunk, hip and ankle/foot joints. Two independent reviewers assessed each paper for inclusion and quality. Means and standard deviations were extracted from each included study to allow effect size calculations and results comparison. **Results:** Nineteen studies were identified (PFPS, n=319; CG, n=329). Three studies investigated muscles at the trunk and ankle/foot joints. Fifteen studies investigated muscles at the hip joint. Evidences were inconclusive about transversus abdominis/internal oblique (TrA/IO) activation in PFPS during high-speed activities. Gluteus medius (GMed), gluteus maximus (GMax), biceps femoris (BF) and semitendinosus (ST) activation level, activation duration and activation onset were inconclusive in the included studies. No differences were observed in gastrocnemius lateralis (GL), gastrocnemius medialis (GM), soleus (SOL), tibialis anterior (TA) and fibularis (FIB) muscle activation. Only one included study evaluated muscle morphology parameters but did not observe changes in the GMed and GMax muscle thickness and echo intensity. **Conclusion:** Our results failed to demonstrate neuromuscular changes in trunk, hip, ankle and foot joints related to PFPS. Future studies need to evaluate muscle morphology around trunk, hip and ankle/foot joints to help in the selection of the best exercises for PFPS rehabilitation programs.

Key-words: patellofemoral pain; trunk; hip; ankle; EMG; muscular atrophy

2.2 INTRODUCTION

Knee injuries are prevalent among a variety of competitive sports. Two of the most common sports-related knee injuries are patellofemoral pain syndrome (PFPS) and anterior cruciate ligament (ACL) injuries [25]. PFPS is the most common diagnoses in physically active populations [2], and is related with poor lower limbs alignment during weight-bearing tasks, which cause higher patellofemoral joint stress and pain [9, 19]. This poor alignment is related with an increase of ipsilateral trunk lean, hip adduction, knee abduction [8] and greater tibial internal rotation [6] during dynamic activities such as single-leg squat [8, 9], running [26], jumping [27, 28] and stepping tasks [9].

For a long time, clinicians believed that only local knee changes were related with PFPS. Evidence for this idea of an intrinsic relaton between changes at the knee joint and PFPS can be observed in exercise rehabilitation protocols, which focused only in the quadriceps muscle and on structures around the patellofemoral joint [29]. Possible reasons for that are related to neuromuscular changes around the patellofemoral joint observed in PFPS patients. A meta-analysis observed towards a delayed onset of vastus medialis oblique (VMO) relative to vastus lateralis (VL) in PFPS compared to healthy people during stair ascent and descent, which may adversely affect the tracking of the patella due to the fact that VMO act to avoid the lateralization of patella, thus contributing to the presence of pain [30]. Additionally, quadriceps atrophy is also observed in PFPS compared to healthy participants according to a meta-analysis [14], supporting the rationale for the use of quadriceps strengthening as part of a PFPS rehabilitation program.

Recently, trunk and hip changes [5, 8, 15] have been proposed as PFPS contributing factors, due to their function on pelvic stability and eccentric control of hip adduction in weight-bearing tasks [31]. Moreover, ankle and foot joint changes also contribute for PFPS, mainly due to excessive rearfoot eversion [17] and the lack of pronation control during tasks [32], which have been observed in PFPS patients and related with poor limb aligment. These proximal (trunk and hip joints) and distal

(ankle/foot joints) changes might lead to lower limb poor aligment during weight-bearing tasks and cause higher patellofemoral joint stress and pain [9, 19].

Even though proximal and distal changes seem to have a critical role in PFPS development, the evidence in support of these proximal and distal mechanisms, as being related with kinematic changes during dynamic tasks, is scarce. Nevertheless, two systematic reviews with meta-analysis have focused on changes at the hip joint in PFPS patients. Barton et al. [33] observed a delayed gluteus medius (GMed) activation and with shorter duration during stair ascent and descent, and during running in PFPS patients. Additionally, a lower hip strength was also observed in PFPS compared to a healthy control group (CG) [34]. These two results help to explain the contribution of proximal factors in PFPS development. We did not observe any systematic review related to the distal factors in PFPS patients, although kinematic changes have been observed in previous studies [17].

In summary, changes in quadriceps muscle activation and morpholgy were observed in PFPS. Systematic reviews involving proximal factors showed changes in hip muscle strength and gluteus activation. However, despite of the existence of proximal and distal factors being evaluated in PFPS patients, there is a lack of systematic reviews involving proximal and distal neuromuscular outcomes. Evaluation of these proximal and distal outcomes could help to explain the PFPS patients' poor limb alignment in functional tasks and help to determine the best exercises choice in a PFPS rehabilitation program. Thus, the aim of present study was to verify the existence of proximal (trunk and hip joints) and distal (ankle/foot joints) neuromuscular changes (muscle activation and muscle morphology) in PFPS studies through a systematic review.

2.3 METHODS

This is a systematic review of controlled trials following the PRISMA Statement recommendations and registered in the International Prospective Register of Systematic Reviews – PROSPERO (waiting for record register).

2.3.1 Search strategy

Studies indexed in Medline (via Pubmed), Scielo, Scopus, PEDro, Cochrane Central, Embase and ScienceDirect published until April 2018 were searched. References lists from the included studies were also searched to find other potential studies to be included in this review.

Mesh terms, Emtree terms, and keywords related to the subject of interest (patellofemoral pain syndrome) and the outcomes of interest (muscle activation, muscle morphology and muscle strength of trunk, hip, ankle and foot) were utilized combined with the Boolean operators "AND" and "OR". The complete description of the search strategy used in Medline via Pubmed database is shown below (Table 1).

Table 1: Complete description of the search strategy used in Medline via Pubmed database

("Patellofemoral Pain Syndrome"[Mesh] OR "Pain Syndrome, Patellofemoral" OR "Anterior Knee Pain Syndrome" OR "Patellofemoral Syndrome" AND "Electromyography"[Mesh] OR "Electromyographies" OR "Surface Electromyography" OR "Electromyographies, Surface" OR "Electromyography, Surface" OR "Surface Electromyographies" OR "Electromyogram" OR "Electromyograms" OR "muscle architecture" OR "muscle thickness" OR "muscle activation" OR "Muscle Strength"[Mesh] OR "muscle volume" OR "Muscular Atrophy"[Mesh])

2.3.2 Eligibility criteria

To be included, retrospective studies should address muscle activation or muscle morphology parameters of trunk, hip, ankle and foot joints in PFPS patients and compare outcomes with a healthy group. Participants should have PFPS (men or women), without other skeletal muscle diseases. Clinical trials involving rehabilitation programs were included and outcomes were obtained only in the pre-intervention period. Any parameter of muscle activation (muscle onset, activation duration, and activation magnitude) and muscle morphology (muscle thickness, anatomical cross section area, pennation angle, fascicle length, volume and echo intensity) was included. Studies investigating at least one of the outcomes of interest were included. Finally, only articles written in English, Spanish or Portuguese were considered.

2.3.3 Study selection

Results from each database were exported for further analysis of titles and abstracts by two independent authors. Duplicated studies were excluded. Titles and abstracts were analyzed to select potential studies to be included in the review and to exclude manuscripts that did not fill the eligibility criteria. Studies selected by at least one author were downloaded and the eligibility criteria were applied to them. Two independent authors performed full-text analyses, and discrepancies were solved by consensus.

2.3.4 Outcomes

The considered outcomes were muscle activation amplitude, muscle activation duration and muscle activation onset during any functional activity (running, squatting, stair-stapping, single-leg triple hop, walking, rehabilitation exercises, upward squatting and step up/step down exercises). Moreover, pennation angle, fascicle length, muscle thickness, echo intensity, CSA and muscle volume measured by ultrasonografy, magnetic resonance imaging and computed tomography scan were included outcomes.

2.3.5 Quality assessment

A modified version of the Downs and Black Quality Index [35] was used to access methodological quality. The modified version of the Downs and Black Quality Index is scored out of 15 items, with higher scores indicating higher-quality studies. Studies with scores of 10 or greater were considered of “high quality” and studies with scores below 10 were considered of “low quality”. We used the criteria used in a similar previous study [33]

2.3.6 Data extraction

Two authors used a standardized spreadsheet to extract data, and discrepancies were solved by consensus. Extracted data included publication info (author, year), participants' characteristics (number, sex, age), clinical characteristics (usual pain and symptoms duration), and outcomes mean and standard deviation values from both groups (PFPS and CG). If the study had more study groups (other skeletal disease or other intervention), only the data about the groups of interest were extracted. When a study performed a rehabilitation protocol, only the data before intervention was extracted. When the data were presented only in figures, we used Image J software (National Institutes of Health, Bethesda, Maryland) to estimate mean and standard deviation values. When studies presented a series of measures of the same outcome, results for either sexes, or measures of different parts of the muscle, we calculed the mean value for each group analysis.

2.3.7 Data analysis

Data analyses were planned to consider both qualitative and quantitative approaches. However, the large variety and diversity of described outcomes among studies, limited a quantitative assessment, as very few had similar outcomes. The main reason is related with different tasks performed among studies. Therefore, a qualitative analysis was performed considering the main characteristics, results, and limitations of each study in addition to the already mentioned quality assessment. Additionally, we calculed the between-groups outcome effect sizes if authors did not present them.

2.4 RESULTS

2.4.1 Description of studies

The initial search returned 1373 studies retrieved from the different databases. Duplicates were removed, and after title and abstract analysis performed by two reviewers, 117 full-texts were downloaded for analysis. After inclusion and exclusion criteria analysis, 19 studies fulfilled the

eligibility criteria for inclusion in this systematic review. The complete process of the studies searches and selection is depicted in Figure 1.

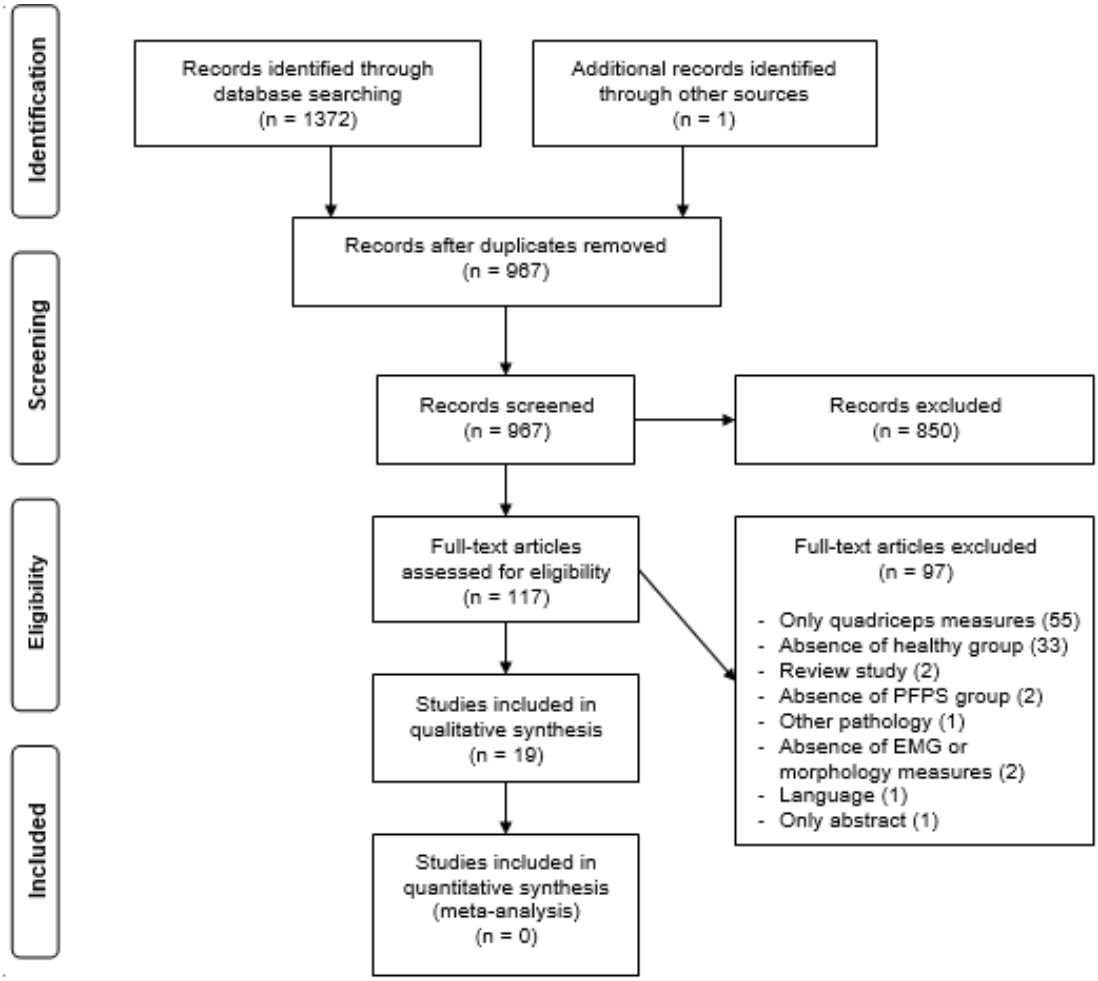

Figure 1. Flowchart of search and selection of the studies included in the systematic review.

2.4.2 Participants characteristics of the included studies

Two hundred and seventy-five women were evaluated in each group (PFPS and CG), while 44 men in PFPS group and 54 men in CG. The age of the participants in PFPS group and healthy participants range between 21 and 33 years. The symptoms duration of PFPS patients range between 9.5 and 58.8 months. However, it is important to note that only 8 studies included this information [7, 9, 10, 16, 36-39]. The mean pain measured by VAS was 44.6 mm, with 9 studies using this method [16, 27, 28, 36-41] Additionally, one study used a Pain Severity Scale [10] (Table 2).

2.4.3 Outcomes characteristics of the included studies

We observed that 19 studies measured some EMG parameter of trunk, hip or ankle/foot joints. Three studies performed an EMG analysis of some trunk muscles such as the transversus abdominis [40, 41], internal oblique [40, 41], external oblique [8], erector spinae [40, 41] and intercostalis [8]. Fifteen studies measured some hip joint muscles such as gluteus medius [5, 7, 9, 16, 26-28, 36-43], gluteus maximus [5, 26-28, 38, 39], biceps femoris [28, 44] and semitendinous [44]. Finally, three studies measured some ankle/foot joint muscle, such as tibialis anterior [45], fibularis longus [44], gastrocnemius medialis [44], gastrocnemius lateralis [45] and soleus [38].

Regarding the test type used to measure muscle activation, the most used were a type of stair-stepping task in seven studies [7, 9, 16, 36, 37, 42, 43], single-leg squat in four studies [5, 8, 39, 42], a type of jump test in three studies [7, 27, 28] and running in two studies [26, 38]. With respect to the EMG analysis, the most common outcome was the relative EMG amplitude (%MIVC) in 13 studies [5, 7-9, 26-28, 36, 38, 39, 44, 45].

We observed only one study that performed a measure of muscle morphology. The authors evaluated gluteus medius and gluteus maximus muscle thickness and echo intensity through an ultrasonografy system [10]. All outcomes characteristics of the included studies were presented in Table 2.

Table 2. Main characteristics of participants, neuromuscular outcomes and type of task performed in each included study.

Study	Participants					Main outcomes			
	Groups	Age	Number/ Gender	Usual pain (mm)	Duration of symptoms (months)	Muscle morphology	Muscle activation	Type of test	Outcome
Biabanimoghadam et al., 2016 [40]	CG PFPS	25.1±3.6 26.2±3.4	30 F 30 F	NE 55.3±11	NI NI	NE	GMed ES TrA/IO	Rise on to their toes as quickly and strongly as possible.	Onset
Bley et al., 2014 [27]	CG PFPS	23.1±3.3 23.5±2.1	20 F 20 F	NE 49±16	NI NI	NE	GMax GMed	Propulsion phase of SLTHT	%MIVC
Bolgla et al., 2011 [36]	CG PFPS	23.9±2.8 24.5±3.2	18 F 18 F	NE 44±15	NE 14.4±12.8	NE	GMed	Stair-stepping test	%MIVC
Boling et al., 2006 [37]	CG PFPS	24±6 23±2	5 M 9 F 5 M 9 F	NE 48±21	NE 22±25	NE	GMed	Stair-stepping task	Onset Duration
Cowan et al., 2008 [16]	CG PFPS	25.4±5.5 26±10.1	12 M 15 F 3 M 7 F	NE 40±10	NE 6±5	NE	GMed	Stair-stepping task	Onset
Dionísio et al., 2011[45]	CG PFPS	23.2±1.1 24.1±1.5	4 M 4 F 4 M 4 F	NE NI	NE NI	NE	BF ST GL TA	Upward squatting	%MIVC
Esculier et al., 2015 [38]	CG PFPS	33.2±6 34.1±6	15 F 5 M 16 F 5 M	NE 28±11	NE 38.1±45.5	NE	GMed GMax SOL	Stance phase of running	%MIVC
Kalytczak et al., 2016 [28]	CG PFPS	23.1±3.3 23.5±2	14 F 14 F	NE 50.5±16.3	NE NI	NE	GMed GMax BF	SLTHT	%MIVC
Liebensteiner et al., 2008 [44]	CG PFPS	25.7±3.9 25.2±4.1	11 F 8 M 11 F 8 M	NI NI	NI NI	NE	BF ST FIB GM	Eccentric leg-press action	%MIVC
Nakagawa et al., 2011 [7]	CG PFPS	22.7±2.5 23.3±5.2	10 F 9 F	NI NI	NE 52.1±46.7	NE	GMed	Walking, descending stairs and single-leg vertical jump	Onset %MIVC
Nakagawa et al., 2012a [5]	CG PFPS	22.7±2.5 22.6±3.2	20 F 20 M 20 F 20 M	NI NI	NI NI	NE	GMed GMax	Single-leg squat	%MIVC

Nakagawa et al., 2012b [9]	CG PFPS	22.6±3.3 23±3.2	20 F 20 M 20 F 20 M	NI NI	NE 34±21.8	NE	GMed	Stair-stepping task	%MIVC
Nakagawa et al., 2015 [8]	CG PFPS	22.3±3.0 22.7±3.4	20 F 10 M 20 F 10 M	NI NI	NI NI	NE	EO IC	Single-leg squat	%MIVC
Nunes et al., 2017 [10]	CG PFPS	23.2±2.8 24.3±4	27 F 27 F	NE 42.2±17.2*	NE 58.8±49.2	GMed GMax	NE	Ultrassonography	Muscle thickness Echo intensity
O'Sullivan et al., 2012 [42]	CG PFPS	21±1 23±4	12 F 12 F	NI NI	NI NI	NE	GMed	Wall-press Step-up and over Pelvic drop Single-leg squat	%MIVC
Rojhani et al., 2014 [41]	CG PFPS	26.3±3.2 26.5±3.5	27 F 27 F	NE 45±9.3	NI NI	NE	TrA/IO ES GMed	Unexpected perturbation applied to lateral side of the body	Onset Duration
Saad et al., 2011 [43]	CG PFPS	23.3±2.1 23.1±2.3	15 F 15 F	NI NI	NI NI	NE	GMed	Step-up Step-down	Integral of linear envelope
Song et al., 2015 [39]	CG PFPS	23.3±2.1 23.1±2.3	8 F 16 F	NE 41.6±11.1	NE 9.5±11.1	NE	GMed GMax	Single-leg squat	%MIVC
Wilson et al., 2011 [26]	CG PFPS	21.6±4.5 21.3±2.6	20 F 20 F	NI NI	NI NI	NE	GMed GMax	Running	%MIVC Onset Duration

CG: control group; PFPS: patellofemoral pain syndrome group; F: female; M: male; NI: not informed; NE: not evaluated; GMed: gluteus medius; GMax: gluteus maximus; EO: external oblique; IO: internal oblique; GL: gastrocnemius lateralis; GM: gastrocnemius medialis; SOL: soleus; TA: tibialis anterior: FIB: fibularis longus; ST: semitendinous; BF: biceps femoris; IC: iliocostalis; TrA: transversus abdominis; ES: erector spinae; SLTHT: single-leg triple hop test; %MIVC: percent of maximal isometric voluntary contraction; *Pain Severity Scale.

2.4.4 Neuromuscular outcomes in PFPS vs healthy participants

Table 3 describes the results and outcomes from each study. Regarding trunk outcomes, two studies demonstrated differences in EMG outcomes between PFPS and healthy participants. PFPS patients had an activation delay in TrA/IO when the participants perfomed a test where they needed to rise on to their toes as quickly and strongly as possible [40]. However, an early activation and greater activation duration of TrA/IO and ES were observed in PFPS patients after an unexpected perturbation was applied to the lateral side of the body [41]

GMed, GMax and BF muscle activation were greater in PFPS patients during single-leg triple hop [27] and stair-stepping task [36]. However, a lower activation during step down was observed in PFPS patients [43], while Nakagawa et al. [9] demonstrated that PFPS patients had a lower GMed only in 60º of knee flexion during stepping maneuver. Additionally, a delayed GMed muscle activation was observed in PFPS patients during stair-stepping task [16] and running [26]. A lower BF and ST activation was observed during the eccentric leg press action [44]. No between-groups differences were observed for muscle morphology [10].

Regarding ankle/foot EMG outcomes, no differences were observed between PFPS and healthy participants independently of the performed task. Only in one study was impossible to obtain results because the figure and values are very small and there is some overlapping [45]. Effect size values of each included study and outcomes are demonstrated in Table 3.

Table 3. Outcomes measured and results from each included study.

Study	Neuromuscular outcome	Type of test	Muscles	Results (Mean±SD)		Difference between-groups (p value)	Effect size
				CG	**PFPS**		
Biabanimoghadam et al., 2016 [40]	Muscle onset (ms)	Rise on to their toes as quickly and strongly as possible.	GMed	-42.3±118.4	-39.6±155.3	0.94	0.02
			TrA/IO	-15.3±141.3	91.4±179.2	**0.013**	0.67
			ES	119.0±188.5	109.3±182.8	0.84	0.05
Bley et al., 2014 [27]	Amplitude (%MIVC)	Propulsion phase of SLTHT	GMed	10.5±10.1	20.9±10.0	**0.002**	1.00
			GMax	10.1±9.3	20.4±11.9	**0.005**	1.00
			BF	8.5±12.5	15.9±7.2	**0.026**	0.70
Bolgla et al., 2011 [36]	Amplitude (%MIVC)	Stair-stepping test	GMed load	18.6±8.8	40.2±22.9	**0.001**	1.28
			GMed stance	8.1±5.0	21.5±15.9	**0.002**	1.17
			GMed pre-swing	5.4±3.6	7.5±5.6	0.602	0.45
Boling et al., 2006 [37]	Muscle onset (ms)	Stair-stepping test	GMed*	-86.9±55.4	-120.2±111.3	NI	0.39
	Activation duration (ms)		GMed*	492.6±149.0	480.6±79.9	NI	0.10
Cowan et al., 2008 [16]	Muscle onset (ms)	Stair-stepping test	GMed[#]	-21.5±13.3	20.3±19.0	**0.01**	2.87
Dionísio et al., 2011[45]	Amplitude (%MIVC)	Upward squatting	BF	NI	NI	>0.05	NI
			ST	NI	NI	>0.05	NI
			GL	NI	NI	>0.05	NI
			TA	NI	NI	>0.05	NI
Esculier et al., 2015 [38]	Amplitude (%MIVC)	Stance phase of running	GMed	74.3±28.3	60.1±25	0.09	0.55
			GMax	48.1±23.0	46.7±22.8	0.84	0.06
			SOL	226.4±85.7	183±70.0	0.08	0.57
Kalytczak et al., 2016 [28]	Amplitude (%MIVC)	SLTHT	GMed stance	10.9±5.2	11.6±5.2	0.72	0.14
			GMed conc	4.8±2.7	5.5±3.1	0.54	0.25
			GMed ecc	7.3±3.2	8.2±4.0	0.52	0.26
			GMax stance	12.8±8.6	12.5±5.1	0.69	0.04
			GMax conc	5.1±4.8	5.5±4.2	0.50	0.09
			GMax ecc	8.5±4.4	8.8±4.3	0.92	0.07
			BF stance	6.9±2.5	10.3±5.0	**0.04**	0.89
			BF conc	2.9±1.3	3.6±2.8	0.37	0.33
			BF ecc	4.4±2.5	6.4±3.1	0.07	0.74
Liebensteiner et al., 2008 [44]	Amplitude (%MIVC)	Eccentric leg-press action	BF[&]	100.5±30.0	82.0±23.0	**0.019**	0.71
			ST[&]	107.0±31.5	81.0±23.0	**0.009**	0.97
			FIB[&]	124.5±48.5	108.0±37.0	0.420	0.39
			GM[&]	121.5±48.0	106.0±79.0	0.252	0.24

Nakagawa et al., 2011 [7]	Muscle onset (ms)	Walking, descending stairs and single-leg vertical jump	GMed walk	NE	NE	NE	NE
			GMed stairs	-125.7±84.1	-103.5±79.3	0.17	0.29
			GMed jump	-169.2±112.6	-172.5±89.3	0.81	0.04
	Amplitude (%MIVC)		GMed walk	2.2±2.2	3.1±2.5	0.41	0.34
			GMed stairs	3.0±1.3	5.7±3.6	0.15	1.08
			GMed jump	10.1±8.0	14.4±10.7	0.33	0.49
Nakagawa et al., 2012a [5]	Amplitude (%MIVC)	Single-leg squat	GMed	23.2±7.6	20.8±6.8	>0.05	0.34
			GMax	21.7±7.1	22.3±6.1	>0.05	0.09
Nakagawa et al., 2012b [9]	Amplitude (%MIVC)	Stair-stepping task	GMed[§]	30.4±5.1	23.5±6.1	**<0.05 (only in 60º of knee flexion)**	1.24
Nakagawa et al., 2015 [8]	Amplitude (%MIVC)	Single-leg squat	EO	15.0±11.6	15.5±13.5	0.90	0.04
			IC	25.3±19.5	15.3±10.3	0.09	0.65
Nunes et al., 2017 [10]	Muscle thickness	Ultrassonography	GMed	2.3±0.2	2.2±0.3	0.61	0.13
			GMax	2.4±0.3	2.4±0.2	0.55	0.15
	Echo intensity		GMed	100.5±23.3	113.3±31.5	0.09	0.46
			GMax	123.1±22.7	128.1±26.6	0.46	0.20
O'Sullivan et al., 2012 [42]	Amplitude (%MIVC)[#]	Wall-press	GMed[1]	87.9±22.8	90.3±18.0	>0.05	0.12
		Step-up and over	GMed[2]	85.0±26.0	83.8±21.2	>0.05	0.05
		Pelvic drop	GMed[3]	85.1±27.1	82.8±15.6	>0.05	0.11
		Single-leg squat	GMed[4]	89.3±25.8	89.4±23.9	>0.05	0.00
Rojhani et al., 2014 [41]	Muscle onset (ms)	Unexpected perturbation applied to lateral side of the body	TrA/IO	45.9±22.6	26.1±12.7	**<0.001**	1.10
			ES	83.2±54.1	43.0±29.8	**0.001**	0.94
			GMed	47.7±25.6	69.5±41.3	**0.025**	0.65
	Activation duration (ms)		TrA/IO	188.5±61.0	254.6±139.7	**0.031**	0.62
			ES	196.2±76.1	253.5±113.4	**0.035**	0.60
			GMed	290.2±103.7	380.0±283.4	0.132	0.43
Saad et al., 2011 [43]	Integral of linear envelope (mV)	Step-up	GMed step up	0.79±0.15	0.7±0.1	>0.05	0.73
		Step-down	GMed step down	0.68±0.1	0.56±0.1	**0.01**	1.24
Song et al., 2015 [39]	Amplitude (%MIVC)	Single-leg squat	GMed	61.5±15.8	64.4±15.8	>0.05	0.19
			GMax	28.0±18.1	23.5±7.4	>0.05	0.40
Wilson et al., 2011 [26]	Amplitude (%MIVC)	Running	GMed	64.8±30.9	81.4±29.8	>0.05	0.56
	Muscle onset (ms)		GMed	59.7±32.6	35.2±32.3	**<0.05**	0.77
	Activation duration (ms)		GMed	193.6±38.7	151.2±57.5	**<0.05**	0.89
	Amplitude (%MIVC)		GMax	56.1±30.1	51.6±27.3	>0.05	0.16
	Muscle onset (ms)		GMax	56.3±32.3	60.9±58.1	>0.05	0.10
	Activation duration (ms)		GMax	200.6±53.3	185.6±67.6	>0.05	0.25

* mean of ascending and descending; # mean of GMed subdivisions; & mean of unstable and stable conditions; § mean of male and female and ascending and descending phases; [1]Wall-press; [2]Step-up and over; [3]Pelvic drop; [4]Single-leg squat; CG: control group; PFPS: patellofemoral pain syndrome group; GMed: gluteus medius; GMax: gluteus maximus; EO: external oblique; IO: internal oblique; GL: gastrocnemius lateralis; GM: gastrocnemius medialis; SOL: soleus; TA: tibialis anterior: FIB: fibularis longus; ST: semitendinous; BF: biceps femoris; IC: iliocostalis; TrA: transversus abdominis; ES: erector spinae; %MIVC: percent of maximal isometric voluntary contraction; conc: concentric; ecc: eccentric; ms: milliseconds; mV: millivolts; NE: not evaluated; NI: impossible to obtain results

2.4.5 Quality assessment

Included studies methodological quality assessment through the modified version of the Downs and Black Quality Index [35] was performed according to a similar previous study [33]. We observed that only four studies [7, 36, 43, 45] were classified as having "low quality" based on the index criteria. All methodological quality results are presented in the Table 4.

Table 4. Modified Downs and Black scale.

Study	1	2	3	5	6	7	10	11	12	15	16	18	20	21	25	Total
Biabanimoghadam et al., 2016 [40]	1	1	1	1	1	1	1	U	U	U	1	1	1	0	0	**11/15**
Bley et al., 2014 [27]	1	1	1	1	1	1	1	U	U	U	1	1	1	1	0	**12/15**
Bolgla et al., 2011 [36]	1	1	1	1	1	1	1	U	U	U	1	1	1	0	0	**9/15**
Boling et al., 2006 [37]	1	1	1	2	1	1	1	U	U	0	1	1	U	1	1	**12/15**
Cowan et al., 2008 [16]	1	1	1	2	1	1	1	U	U	1	1	1	1	1	1	**14/15**
Dionísio et al., 2011 [45]	0	1	1	1	1	1	1	U	U	U	1	1	1	U	0	**9/15**
Esculier et al., 2015 [38]	1	1	1	2	1	1	1	U	U	U	1	1	1	0	0	**11/15**
Kalytczak et al., 2016 [28]	1	1	1	2	1	1	1	U	U	U	1	1	1	0	0	**11/15**
Liebensteiner et al., 2008 [44]	1	1	1	1	1	1	1	U	U	U	1	1	1	1	0	**11/15**
Nakagawa et al., 2011 [7]	1	1	1	1	1	1	1	U	U	0	1	1	U	0	0	**9/15**
Nakagawa et al., 2012a [5]	1	1	1	1	1	1	1	U	U	0	1	1	1	0	0	**10/15**
Nakagawa et al., 2012b [9]	1	1	1	1	1	1	1	U	U	0	1	1	1	0	0	**10/15**
Nakagawa et al., 2015 [8]	1	1	1	1	1	1	1	U	U	0	1	1	1	0	0	**10/15**
Nunes et al., 2017 [10]	1	1	1	1	1	1	1	U	U	0	1	1	1	0	0	**10/15**
O'Sullivan et al., 2012 [42]	1	1	1	2	1	1	1	U	U	0	1	1	1	0	0	**11/15**
Rojhani et al., 2014 [41]	1	1	1	2	1	1	1	U	U	0	1	1	1	1	0	**12/15**
Saad et al., 2011 [43]	1	0	0	0	1	1	0	0	U	0	1	1	U	0	0	**5/15**
Song et al., 2015 [39]	1	1	1	2	1	1	1	U	U	0	1	1	1	0	0	**11/15**
Wilson et al., 2011 [26]	1	1	1	1	1	1	1	0	U	0	1	1	1	1	U	**11/15**

Caption of itens: 1: Clear aim/hypothesis; 2: Outcome measures clearly described; 3: Patient characteristics clearly described; 5: Confounding variables described; 6: Main findings clearly described; 7: Measures of random variability provided; 10: Actual probability values reported; 11: Participants asked to participate representative of entire population; 12: Participants prepared to participate representative of entire population; 15: Blinding of outcome measurer; 16: Completed analysis was planned; 18: Appropriate statistics; 20: Valid and reliable outcome measures; 21: Appropriate case-control matching; 25: Adjustment made for confounding variables. For items 1–3, 6, 7, 10–12, 15, 16, 18, 20, 21 and 25: 0 (no); 1 (yes); U (unable to determine). For item 5: 0 (no); 1 (partially); 2 (yes)

2.5 DISCUSSION

In this systematic review, we analyzed retrospective studies that compared proximal (hip or trunk joints) and distal (ankle or foot joints) neuromuscular outcomes between PFPS patients and healthy participants in the CG. We considered studies that, among other characteristics, performed muscle activation or muscle morphology evaluations. Our main findings concern 20 studies, with 19 focusing on muscle activation parameters. Three studies compared trunk joint muscle activation, 15 compared hip joint muscle activation, and three compared ankle/foot joints muscle activations. Only four studies were classified with low quality. Another significant issue is the fact that only one study evaluated muscle morphology outcomes. Based in the included studies, it is still not clear whether proximal and distal neuromuscular outcomes are different between PFPS and healthy participants.

The main results failed to demonstrate a consensus regarding proximal muscle activation differences between PFPS patients and the CG. A possible reason is related to different tasks evaluated in the included studies. We observed three studies that evaluated muscles around trunk joints. One study observed that PFPS patients presented a delay muscle activation of TrA/IO compared to the CG during the rise phase on to their toes as quickly and strongly as possible [40] (ES = 0.67) and an early muscle activation of TrA/IO when an unexpected perturbation was applied to the lateral side of the body [41] (ES = 1.10). Additionally, Nakagawa et al. [8] failed to demonstrate differences in EO and IC (whereas a moderate effect size has been observed favouring the healthy participants) during single-leg squat. Based in these results, deep muscles are needed in high-speed activities, mainly in PFPS patients.

Muscles related to hip joints were evaluated in 15 included studies, with GMed measured in all of them. Previous systematic reviews and meta-analysis demonstrated evidences of an impairment in hip abductor muscle strength [34] and GMed activation during stair-stepping activities [33] in PFPS patients. Based in these results, hip joint changes appear to be present in PFPS patients. GMed muscle activation of our included studies were greater in PFPS patients during single-leg triple hop

(ES = 1.00) [27] and during the load phase (ES = 1.28) and the stance phase (ES = 1.17) of stair-stepping task [36]. However, a lower GMed activation during step down was observed in PFPS patients (ES = 1.24) [43], while Nakagawa et al. [9] demonstrated that PFPS patients had a lower GMed activation only in 60º of knee flexion during stepping maneuvers (ES = 1.24). Nevertheless, no differences were observed in activation level during running (ES = 0.56) [26], while a delayed GMed muscle activation was observed in PFPS during stair-stepping task (ES = 2.87) [16] and running (ES = 0.77) [26], and an early activation was observed after unexpected perturbation (ES = 0.65) [41]. Changes in hip abductor muscles neuromuscular function is related to poor lower limb alignment during dynamic tasks [5, 9] due to their function on pelvic stability and eccentric control of hip adduction in weight-bearing tasks [31]. Only one of our included studies demonstrated between-groups differences in the GMax activation. Bley et al. [27] observed a greater muscle activation in PFPS patients during the propulsion phase of single-leg triple hop test (SLTHT). Authors justified the results due to the GMax function to avoid the greater hip internal rotation observed in PFPS patients in weight-bearing tasks [5] and assisting the quadriceps in the task execution.

Four included studies investigated BF and ST muscle activation [27, 28, 44, 45]. While two studies observed a greater BF muscle activation in PFPS patients during SLTHT propulsion phase [27] (ES = 0.70) and during SLTHT stance phase [28] (ES = 0.89), a lower BF (ES = 0.71) and ST (ES = 0.97) activation to the same group was observed during eccentric leg press action [44]. Additionally, no between-groups differences were observed during upward squatting [45]. The BF greater activation observed is hypothesized as being due to a compensatory strategy for the deficient dynamic alignment in the high-demand tasks placed on the knee [27, 28]. However, a smaller hamstrings activation, observed in PFPS during the eccentric phase of the leg-press action, might also be part of a neuromuscular deficit that contributes to PFPS development [44].

Three included studies evaluated muscle activation of distal factors (ankle/foot joints) [38, 44, 45]. No between-groups differences were observed for GL and TA during upward squatting [45], for SOL during running stance phase (ES = 0.57) [38], GM (ES = 0.24) and FIB (ES = 0.39) during

eccentric leg-press action [44]. Previous study observed that excessive hip adduction, knee flexion and knee abduction [6] are related with the lack of pronation control during daily tasks [32]. Furthermore, excessive rear foot eversion is thought to be a risk factor for PFPS development [17], due to the resultant greater tibial internal rotation [6]. Based on the results of our included studies, although changes in foot kinematics are related with poor lower limb alignment during dynamic tasks, the mechanisms may not be related with distal muscle activation.

Another factor that could be related with poor lower limb alignment is related to muscle morphology parameters. Previous studies demonstrated quadriceps atrophy in PFPS participants [46]. Our study aimed to observe evidences about proximal and distal muscle morphology outcomes in PFPS participants. Surprisingly, only one included study looked at muscle structure, and the authors did not observed differences in GMed (ES = 0.13) and GMax (ES = 0.15) muscle thickness and echo intensity (GMed; ES = 0.46; GMax; ES = 0.20) [10]. Muscle thickness has been shown to be a good predictor of intrinsic muscle force because muscle force is dependent on the number of parallel sarcomeres [47], while echo intensity is related to the amount of non-contractile muscle tissue [10]. Even though a hip strength impairment was observed through a meta-analysis [34], this result might not be related only to glutei muscle morphology parameters.

Another important aspect is the methodological quality of the included studies. 80% of included studies (16/20) were considered as having high quality. Even though some parameters were well-controlled in the studies, blinding of outcome measurer, for example, was performed by only one included study [16], which can cause an elevated risk of bias. From the studies included in the present review, it is possible to observe that proximal and distal neuromuscular changes related to PFPS is unclear. Additionally, TrA/IO apparently presented an early activation in PFPS during high-speed tasks. GMed, GMax, BF and ST results demonstrated a lack of consensus in muscle activation outcomes (muscle onset, contraction duration and level of activation), whereas GMed and GMax muscle morphology was not affected in PFPS patients. Finally, muscle activation around ankle/foot joints presented results like those observed in healthy participants. The lack of evidences might be

related to different tasks used to compare PFPS and healthy participants. Stair-stepping was the most common task (5/20 studies) observed in the included studies, followed by single-leg squat (4/20 studies) and single-leg jump (3/20 studies).

Our results revealed a lack of consensus among the revised studies. The evidences demonstrated improvement in clinical outcomes when proximal exercise rehabilitation is included in classical intrinsic PFPS management (exercise focusing in knee alone) [48]. Studies also showed that the addition of foot targeted exercises and foot orthoses for 12 weeks was more effective than knee targeted exercises alone in individuals with patellofemoral pain [23]. Therefore, future studies need to verify neuromuscular changes of other proximal and distal muscles, such as tensor fascia latae (due to hip abductor and internal rotator actions [49]) and intrinsic foot muscles (due to action in the foot arch [50]) and their relationship with excessive rearfoot eversion. Furthermore, the muscle morphology measures are necessary in future studies involving PFPS patients, because they might help to identify more clearly neuromuscular changes and determine the correct choice for the best exercises in a PFPS rehabilitation protocol.

2.6 CONCLUSIONS

Based in our results, responses of muscles around trunk, hip and ankle/foot joints are limited. Conflicting findings may be due to methodological and sex differences, and/or the multifactorial nature of PFPS, despite the high methodological quality observed in most studies. Additionally, future studies need to evaluate muscle morphology around trunk, hip and ankle/joints to help define the best exercises in PFPS rehabilitation programs.

CHAPTER III - LOWER LIMB NEUROMUSCULAR CHANGES AND THEIR RELATIONSHIP WITH KINEMATICS DURING SINGLE-LEG WEIGHT-BEARING TASKS IN THE PATELLOFEMORAL PAIN SYNDROME

3.1 ABSTRACT

Introduction: Patellofemoral Pain Syndrome (PFPS) is a multifactorial disease that has been related with changes at the hip, knee, ankle and foot. The identification of which factors are present in PFPS patients can potentiate the effectiveness of the exercise protocols in rehabilitation programs. **Purpose:** To compare lower limb neuromuscular parameters and frontal plane kinematics during single-leg tasks between women with PFPS healthy women, and to determine if some neuromuscular outcome explains dynamic valgus index (DVI) during two functional tasks. **Methods:** Fifteen PFPS women and fifteen healthy age-matched women (control group - CG) were compared with the following tests: (1) functional questionnaire; (2) hip (gluteus medius and tensor fasciae latae), knee (vastus lateralis and vastus medialis) and ankle (fibularis [longus + brevis] and tibialis anterior) muscle thickness; (3) DVI and muscle activation during single-leg squat and vertical jump; (4) maximal isometric torque for hip abduction, knee extension and foot eversion/inversion; and (5) muscle activation during isometric and functional tests. A multiple-stepwise regression analysis was used to test if neuromuscular outcomes explained DVI during single-leg tasks. **Results:** Compared to the CG, PFPS showed: (1) smaller gluteus medius (-10.02%; ES = -0.82) and greater tensor fasciae latae (+18.44%; ES = +0.92) and fibularis muscle thickness (+14.23%; ES = +0.87); (2) lower tibialis anterior muscle activation during single-leg squat (-59.38%; ES = -1.29); (3) lower gluteus medius muscle activation during single-leg jump (-28.70%; ES = -1.35) and (4) greater gluteus medius muscle activation during hip abduction isometric test (+34.40%; ES = +0.77). Higher DVI during single-leg squat was explained by higher vastus lateralis activation during the task only in CG, whereas lower tibialis anterior muscle thickness in the CG and higher foot eversion torque in PFPS are related with higher DVI during single-leg vertical jump. **Conclusion:** Females with PFPS showed significant neuromuscular changes at the hip and ankle/foot joints. However, only distal factors explained DVI in the PFPS group.

Key-words: patellofemoral pain; hip; extrinsic foot muscles; kinematics; vertical jump

3.2 INTRODUCTION

Patellofemoral pain syndrome (PFPS) is characterized by retro or peripatellar pain, exacerbated during weight-bearing activities such as running, jumping, squatting and going up and down stairs [1], being one of the most common diagnoses among young, physically active populations [2], predominantly in females [3]. PFPS aetiology is a complex interplay among various anatomical, biomechanical, psychological, social and behavioral factors [51]. Anatomical and biomechanical factors are related with local changes (around the patellofemoral joint [11]), such as lower knee extension strength [12] and delayed onset of vastus medialis activation relative to vastus lateralis [13]. Recently, hip [5, 8, 15], ankle and foot changes [18, 52] have been proposed as PFPS contributing factors, which might lead to lower limb poor alignment during weight-bearing tasks and cause higher patellofemoral joint stress and pain [9, 19].

Changes in neuromuscular function at the hip joint, mainly abductor muscles weakness [53], is observed in PFPS patients [34]. These changes are critical due to these muscles' role on pelvic stability and eccentric control of hip adduction during weight-bearing tasks [31]. This is probably the reason why the focus of previous studies has been in glutei muscles [10, 33]. However, tensor fasciae latae (TFL) is also an important hip abductor and internal rotator [49]. Thus, changes in the TFL neuromuscular parameters in PFPS patients could explain the higher hip internal rotation observed during dynamic tasks [9]. Even though the relationship between GMed and TFL function is critical for hip stability in weight-bearing activities [54], there is a lack of evidences about TFL neuromuscular responses in PFPS.

Additionaly, previous studies observed that excessive hip adduction, knee flexion and knee abduction [6] is related with the lack of foot pronation control during daily tasks [32]. Furthermore, excessive rearfoot eversion is thought to be a risk factor for PFPS development [17], due to the resultant greater tibial internal rotation [6]. Despite this significant foot effect in PFPS development, there is a lack of studies about the neuromuscular responses at the ankle and foot joints in this syndrome, and well-designed experiments aimed at understanding the neuromuscular changes at

these distal joints might help to explain distal kinematic changes observed in PFPS patients during dynamic tasks [55].

Investigations about kinetic and kinematic responses during jump is essential in PFPS patients due to the large patellofemoral joint stresses caused by this activity [56]. A prospective study demonstrated that greater knee valgus displacement during the drop jump landing was a predictor factor for PFPS development in adolescent women athletes [57]. Even though lower hip abductor strength, lower passive hip internal rotation range of motion (ROM) and lower shank-forefoot alignment are predictor factors for the knee frontal plane projection angle (FPPA) during landing tasks [58], neuromuscular parameters related with lower limb kinetic and kinematic changes remain unclear.

These gaps in the literature led us to the following questions: (1) are there neuromuscular differences in TFL muscle and foot eversion and inversion muscles in PFPS patients compared to healthy participants? (2) Knowing that greater knee valgus displacement was a predictor factor for PFPS development in adolescent female athletes in a prospective study [30], can proximal, local and distal neuromuscular outcomes explain dynamic valgus during single-leg tasks in women with and without PFPS?

3.3 METHODS

3.3.1 Participants

Twenty-nine women with knee pain contacted us to participate in the study after the project disclosure at the University campus and social networks. The inclusion criteria included women aged between 18 and 40 years, presence of retropatellar or peripatellar pain (minimum of three points on the visual analog scale), for at least two months, in at least two of the following tasks: squatting, up and down stairs, running, jumping, kneeling and prolonged sitting [59]. Additionally, absence of pain during patellar tilt test, hip and ankle injury and no lower limb surgery were also inclusion parameters. After these criteria were applied, seven women were excluded due to lower limb surgery history, three were excluded due to patellar instability (positive in patellar tilt test) and other four volunteers

dropped out due to incompatibility with our data collection schedule. Thus, 15 women were included in the PFPS group. In the cases of bilateral pain, the limb with highest self-reported pain was evaluated. Fifteen healthy women, age-, body size and level of physical activity-matched to the PFPS patients, were recruited as a control group (CG). Dominant limb was evaluated in this group. A written informed consent was obtained from all participants before starting the experiment. The study was approved by the University's Ethical Research Committee (registration number CAAE 61489016.9.0000.5347) and was conducted respecting the ethical standards of the Resolution of Federal University of Rio Grande do Sul (114/2014).

Initially, the participants answered the IPAQ and Anterior Knee Pain Scale (AKPS) [60] to determine physical activity level and functional capacity, respectively. After that, measurement of muscle thickness, EMG sensors placement and skin markers positioning for kinematic evaluation were performed and were followed by the assessment of single-leg tests and maximal isometric strength tests.

3.3.2 Muscle thickness evaluation

A B-mode ultrasonography system (SSD-4000; Aloka Inc., Tokyo, Japan) with a linear-array probe (60 mm, 7.5 MHz) was used to determine GMed, TFL, vastus lateralis (VL), vastus medialis (VM), fibularis longus and brevis (FIB) and tibialis anterior (TA) muscle thickness. The same investigator, with extensive experience in ultrasonography, performed all ultrasound measurements. The ultrasonography probe was covered with water-soluble transmission gel and oriented parallel to muscle fascicles and perpendicular to the skin. Muscle thickness was considered the distance between deep and superficial aponeuroses and was calculated through the mean value of five parallel lines drawn at right angles between the superficial and deep aponeuroses along each of three ultrasonography images. Ultrasonography images were digitized and analyzed with Image J software (National Institutes of Health, Bethesda, Maryland) [61].

For GMed, participants were placed side lying with the test-leg facing up. The test-leg's hip was positioned in neutral flexion/extension and rotation, and the test-leg's knee was positioned in full

extension. The probe was placed on the lateral aspect of the hip, on the lower half of a coronal line located between the top of the greater trochanter and a point at 25% of the distance between the anterior-superior iliac spine (ASIS) and the posterior-superior iliac spine (PSIS) [62] (Figure 2A). For the TFL, the probe was placed in the axial plane over the ASIS. The TFL short tendon was then visualized in the sagittal plane. The transducer was shifted down over the muscle belly, laterally and caudally to the anterior border of the fasciae latae [63] (Figure 2B).

For VL, scans were taken at the midpoint between the greater trochanter and the femur's lateral condyle (Figure 2C), while VM scans were performed distally at 70-75% of the same line, but medially over the muscle belly. The transducer orientation relative to the longitudinal axis of the thigh was different between participants due to their individual anatomical characteristics [61] (Figure 2D). For FIB, the probe was placed at 50% of the distance between the fibular head and the inferior border of the lateral malleolus [50] (Figure 2E). For TA, after identification and marking of the proximal and distal muscle insertions, the probe was positioned perpendicular to the dermal surface along the midsagittal plane of the TA muscle, at the site corresponding to the muscle's thickest portion [64] (Figure 2F).

3.3.3 Maximal isometric strength evaluations

Maximal isometric muscular strength was measured with a Biodex System 3 dynamometer (Biodex Medical Systems, Shirley, NY, USA). Volunteers were positioned on the dynamometer according to the manufacturer's recommendations for hip abduction, knee extension, and foot eversion and inversion evaluations. Participants performed an additional warm-up protocol consisting of 10 submaximal repetitions at an angular velocity of $90°.s^{-1}$. Participants were previously instructed to execute all tests with the highest possible effort, developing maximal strength "as fast as possible", and verbal encouragement was provided throughout the tests [61]. After a familiarization to maximal tests, hip abduction test was performed at 10° of hip abduction (0° = hip neutral position) [65], while knee extensor test at 60° of knee flexion (0° = full knee extension) [61]. For foot eversion and

inversion isometric tests, we performed a pilot study with dynamic contractions to determine the angle of peak torque. Thus, foot eversion test was performed at 30º of foot inversion and foot inversion at 10º of foot eversion (0º = foot neutral position). Three trials of 5-seconds maximal contraction were performed for each isometric test. A 2-min interval was observed between successive contractions in each test. The isometric tests' peak torque was normalized to body mass and used in the statistical analysis.

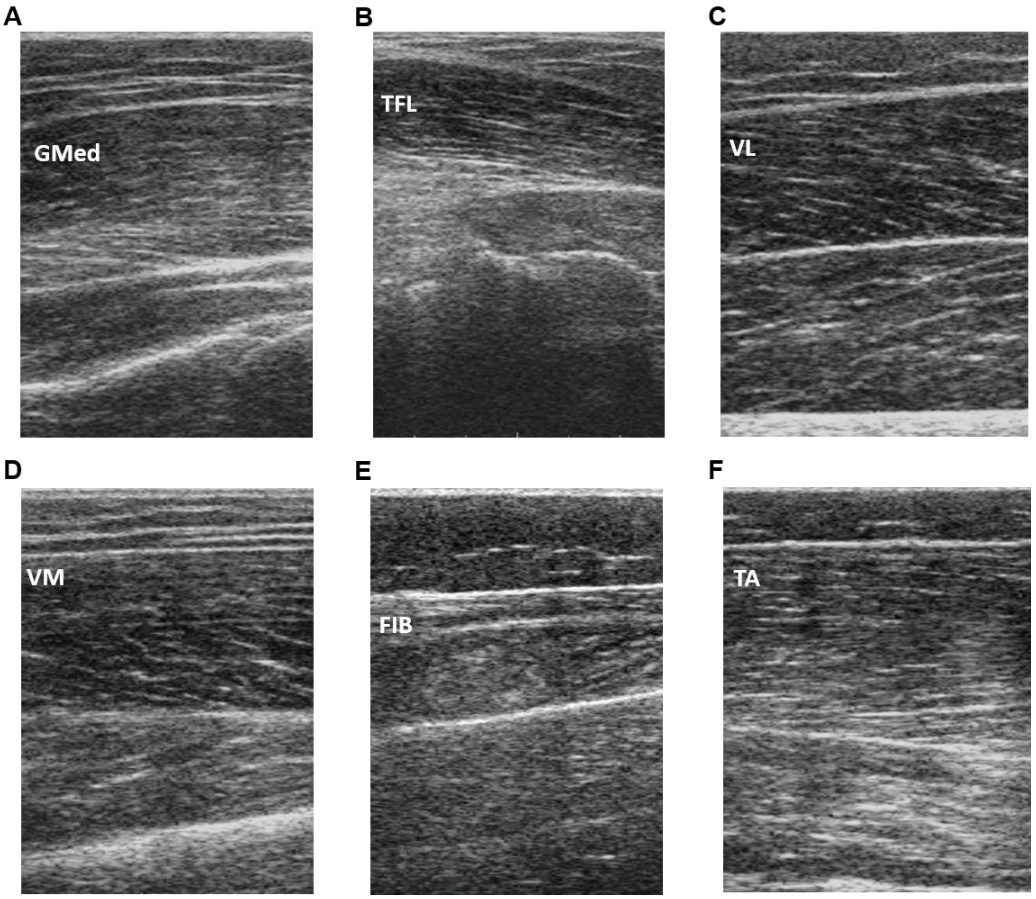

Figure 2: Ultrasound images from a representative subject used for muscle thickness analysis of GMed (A), TFL (B), VL (C), VM (D), FIB (E) and TA (F).

3.3.4 Kinematic measures during single-leg tasks

Two-dimensional (2D) data were captured while participants completed single-leg squat and vertical jump. PFPS patients performed the tests with their involved limb, while CG participants performed the test with their preferred limb. Skin markers were attached with double-faced adhesive

tape at the following locations: ASISs; greater trochanter; lateral femoral epicondyle; patella center; lateral malleolus; and midpoint between medial and lateral malleoli. Two-dimensional data were captured with two GoPro Hero 4 cameras (GoPro Inc, California, US) with 90 Hz of sample rate. The first camera was positioned in the frontal plane to determine the participants' hip adduction and knee abduction displacement during tasks, while the second camera was positioned in the sagittal plane and was used to determine the knee peak flexion during both tasks. Both cameras were synchronized with a light signal, and data were processed with Kinovea software (Kinovea Organization, France).

All participants were instructed to flex the contralateral knee, cross arms in the trunk and squat the maximum as possible in the both tasks. Participants were oriented to avoid trunk flexion during tasks. During single-leg squat, participants performed five repetitions with cadence controlled by a metronome (2 seconds-per-phase). During single-leg vertical jump, all participants were instructed to squat (more quickly and deeply as possible) and jump the highest as possible. Participants performed three single-leg jumps. All 2D angles were measured from the frontal and sagittal plane views by one investigator. In the sagittal plane, the angle between the greater trochanter and the lateral femoral epicondyle was used to determine the eccentric phase depth from each test. In the frontal plane, a line drawn between markers placed on the anterior superior iliac spines defined the pelvic segment. A line drawn from the midpoint of the knee, bisecting the thigh, defined the thigh segment. A line drawn from the midpoint of the knee to the midpoint of the ankle defined the shank segment. For all analyses, we used the angular displacement between the start (participants in the standing position and contralateral knee flexed) and the end of the eccentric phase (peak of knee flexion). The hip FPPA was calculated as initial angular position minus the angle between the pelvis segment and the thigh segment. A positive hip FPPA indicated apparent hip adduction. The knee FPPA angle was calculated as initial angular position minus the angle between the thigh segment and the shank segment. A positive knee FPPA angle indicated apparent knee abduction.

Dynamic valgus index (DVI) was measured using lower limb kinematic parameters during the single-leg tasks. This measure was performed based on a previous study with PFPS patients during

single-leg squat [66] and was proposed because it is a 2D variable that combines the hip and knee angles that might be a more comprehensive representation of the entire lower-extremity movement pattern than the knee FPPA alone (Figure 3). DVI was calculated as the sum of the hip and the knee FPPAs of each single-leg squat and vertical jump, and the mean between both tests in each task was used for statistical analysis. After the single-leg tasks, the discomfort level was evaluated with a 0-100 mm visual analogue scale (VAS), where 0 and 100 mm corresponded to no discomfort and worst perceived discomfort, respectively.

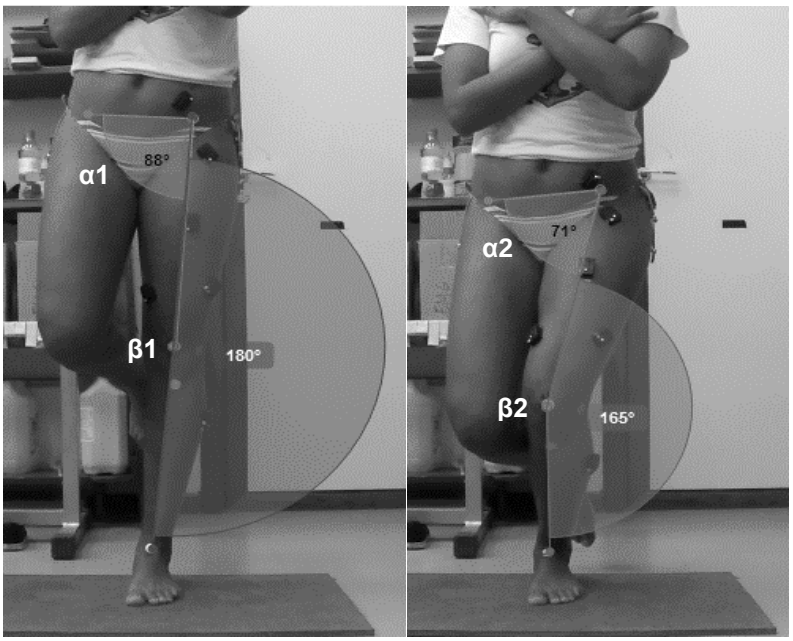

Figure 3: Representative image of dynamic knee valgus angular measures. Hip FPPA was calculated through the angle between the pelvis segment and the thigh segment (α1 – α2). Knee FPPA was calculated through the angle between the thigh segment and the shank segment (β1 – β2). The sum of Hip FPPA and Knee FPPA was considered the Dynamic Valgus Index (DVI) [66].

3.3.5 Muscle activation evaluation

A 16-channel Delsys EMG system (EMG Trigno Wireless Trigno Base Station, Delsys Inc., Natick, Massachussets, USA) was used for muscle activation data collection. For each muscle, an individual sensor was used. For GMed, the sensor was placed at 50% on the line from the iliac crest to the great trochanter. For TFL, the sensor was placed in the proximal 1/6 on the line from the ASIS to the lateral femoral condyle. VM sensor was placed at 80% on the line between the ASIS and the

joint space in front of the anterior border of the medial collateral ligament, while VL sensor was positioned at 2/3 on the line from the ASIS to the lateral side of the patella. For FIB longus, the sensor was placed at 25% on the line between the tip of the fibula head to the tip of the lateral malleolus. For TA, the sensor was placed at 1/3 on the line between the tip of the fibula and the tip of the medial malleolus. Skin preparation and electrode positioning for EMG evaluation followed standard procedures [67].

A Butterworth band-pass filter, with cut-off frequencies of 20 and 500 Hz, was used in all evaluations. During all isometric tests, muscle activation was measured. For isometric tests, root mean square (RMS) values were calculated from 3-sec in the middle of the EMG signals obtained during the isometric tests. These values were considered 100% of each muscle activation and were used for the muscle activity normalization during single-leg tasks. For the analysis, we used the percent of maximal isometric activation from each muscle during eccentric phase of both tasks [68]. All EMG data were synchronized with an accelerometer system, which could identify eccentric and concentric phases. EMG analysis was performed in LabChart software (ADInstruments, Brazil).

3.3.6 Statistical Analysis

Data normality was tested through the Shapiro-Wilk test. Data sphericity was tested by Mauchly test, and Greenhouse-Geisser correction factor was used when the sphericity was violated. An independent Student t-test (or Mann-Whitney U test) was used to compare all between-group outcomes. A 5% significance level was adopted for all analyses and all statistical procedures were performed in SPSS 20.0. Effect size (ES) was calculated for all analyses. We adopted the Cohen's criteria for the analysis (>0.2: small; >0.50: moderate; >0.80: large) [69]. Positive ES values indicate that outcomes in PFPS were higher than CG.

A multiple-stepwise linear regression model was used to identify if lower limb neuromuscular parameters (predictor variables) were able to explain DVI (criterion variables) in each group. The goodness-of-fit model, which indicates how well the linear combination of the variables predicted the

functional states, was given by the squared multiple correlation (R^2) [70]. The predictors' relative importance was estimated with the part correlations (part r), which provides the correlation between a predictor and the criterion after removing the effects of all other predictors in the regression equation from the predictor, but not the criterion. A positive part correlation indicates that the predictor and the criterion are directly related, whereas a negative sign denotes an inverse relation [70]. A p-value ≤0.05 was used for regression and partial correlation analysis.

3.4 RESULTS

3.4.1 Participants characteristics

PFPS patients displayed impaired function measured by the AKPS and higher VAS after single-leg tasks compared to controls. No between-groups differences were observed in other clinical characteristics (Table 5).

Table 5: Participants characteristics.

	CG (n=15)	PFPS (n=15)	p-value
Age (years)	29.00 ± 5.23	26.33 ± 4.18	0.135
Body mass (Kg)	62.16 ± 7.83	65.98 ± 13.08	0.341
Height (m)	1.64 ± 0.06	1.63 ± 0.06	0.766
Body Mass Index (Kg/m²)	23.12 ± 3.31	24.51 ± 3.61	0.281
IPAQ (met.min.week)	2053.23 ± 1648.42	2131.94 ± 1824.35	0.902
AKPS (points)	N.A	76.26 ± 10.18	N.A
Duration of symptoms (years)	N.A	5.24 ± 2.10	N.A
VAS pain after squat (mm)	1.42 ± 3.51	22.31 ± 12.55	**<0.001**
VAS pain after jump (mm)	2.32 ± 4.13	30.54 ± 21.10	**<0.001**

CG = Control Group; PFPS = Patellofemoral Pain Syndrome Group; IPAQ = International Physical Activity Questionnaire; AKPS = Anterior Knee Pain Score; VAS = Visual Analog Scale; N.A = not applicable

3.4.2 Kinetic and kinematic parameters

No between-groups differences were observed for hip abduction (-5.6%), knee extension (-14.53%), foot eversion (-7.69%), inversion isometric strength (+6.25%) and DVI during single-leg squat (+69.65%) and single-leg vertical jump (+30.71%). Nevertheless, proximal (hip) and distal

(foot) isometric strength presented a small effect size, while local (knee) isometric strength and DVI during both tasks showed a moderate effect size (Table 6).

Table 6: Between-groups hip, knee and foot isometric torque and DVI data (mean ± SD).

	CG (n=15)	PFPS (n=15)	p-value	ES
Hip Abduction (Nm/Kg)	1.23 ± 0.31	1.16 ± 0.32	0.569	-0.23
Knee Extension (Nm/Kg)	2.82 ± 0.67	2.41 ± 0.63	0.100	-0.65
Foot Eversion (Nm/Kg)	0.39 ± 0.18	0.36 ± 0.11	0.557	-0.23
Foot Inversion (Nm/Kg)	0.32 ± 0.06	0.34 ± 0.12	0.473	0.28
Peak of knee flexion in the squat (º)	57.73 ± 8.63	63.80 ± 8.63	0.081	0.73
Peak of knee flexion in the jump (º)	54.93 ± 6.39	59.20 ± 8.20	0.123	0.60
DVI during squat (º)	18.20 ± 10.52	26.13 ± 13.73	0.084	0.67
DVI during jump (º)	15.40 ± 6.03	20.13 ± 9.31	0.110	0.62

CG = Control Group; PFPS = Patellofemoral Pain Syndrome Group; ES = effect size; DVI = Dynamic Valgus Index.

3.4.3 Muscle thickness

Compared to the CG, PFPS patients showed lower GMed muscle thickness (-10.02%) and greater TFL (+18.44%) and FIB (+14.23%) muscle thickness. No differences were observed in VL (+2.10%), VM (+6.93%) and TA (-1.35%) muscle thickness (Figure 4).

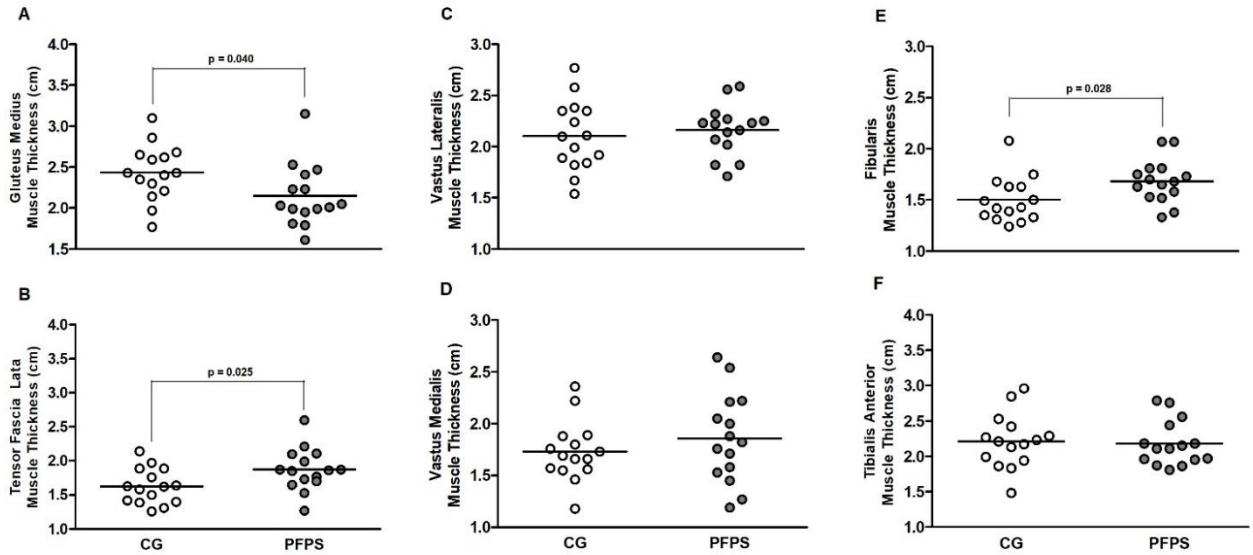

Figure 4: Muscle thickness of GMed (A), TFL (B), VL (C), VM (D), FIB (E) and TA (F). CG = control group; PFPS = patellofemoral pain syndrome group. Each dot represents one subject; solid line represents the group mean value.

3.4.4 Muscle activation

Regarding to muscle activation during maximal isometric tests, compared to CG, PFPS patients presented greater GMed activity (+34.40%). No differences were observed in the other muscles. During single-leg squat, PFPS patients presented lower TA muscle activity (-59.38%). No differences were observed for other muscles. Finally, a lower GMed activity (-28.70%) during the eccentric phase of the single-leg vertical jump was observed. No differences were observed in the other muscles (Table 7).

Table 7: Between-groups muscle activation during maximal and single-leg tasks.

		CG (n=15)	PFPS (n=15)	p value
Gluteus Medius	MIVC (mV)	0.43 ± 0.11	0.58 ± 0.25*	**0.044**
	SLS (%MIVC)	71.28 ± 14.62	56.66 ± 30.21	0.107
	SLJ (%MIVC)	83.72 ± 16.81	58.04 ± 22.09*	**0.001**
Tensor Fasciae Latae	MIVC (mV)	0.14 ± 0.05	0.15 ± 0.10	0.631
	SLS (%MIVC)	18.74 ± 9.33	21.93 ± 15.97	0.510
	SLJ (%MIVC)	26.13 ± 10.39	27.35 ± 18.84	0.827
Vastus Lateralis	MIVC (mV)	0.95 ± 0.29	0.94 ± 0.49	0.960
	SLS (%MIVC)	78.76 ± 25.40	72.75 ± 30.11	0.559
	SLJ (%MIVC)	26.13 ± 10.39	27.35 ± 18.84	0.827
Vastus Medialis	MIVC (mV)	0.79 ± 0.29	0.68 ± 0.32	0.331
	SLS (%MIVC)	63.55 ± 32.25	71.96 ± 41.53	0.540
	SLJ (%MIVC)	71.65 ± 35.49	77.78 ± 48.07	0.694
Fibularis Longus	MIVC (mV)	0.51 ± 0.26	0.52 ± 0.39	0.974
	SLS (%MIVC)	113.05 ± 74.13	73.05 ± 28.06	0.066
	SLJ (%MIVC)	116.41 ± 43.12	122.17 ± 53.60	0.748
Tibialis Anterior	MIVC (mV)	0.74 ± 0.32	0.84 ± 0.35	0.422
	SLS (%MIVC)	133.44 ± 54.82*	79.25 ± 27.81	**0.002**
	SLJ (%MIVC)	108.24 ± 51.92	87.90 ± 44.77	0.260

CG = Control Group; PFPS = Patellofemoral Pain Syndrome Group; MIVC = maximal isometric voluntary contraction; SLS = single-leg squat; SLJ = single-leg jump; mV = millivolts; %MIVC = percent of maximal isometric voluntary contraction

Figure 5 demonstrates the effect size of muscle thickness and muscle activation during both single-leg tasks. We observed a large effect size for GMed, TFL and FIB, small for VL and VM and trivial for TA muscle thickness (Figure 5A). For maximal activation during isometric tests, a moderate effect size was observed for GMed, small for VM and TA and trivial for TFL, VL and FIB (Figure 5B). Regarding muscle activation during single-leg squat (Figure 5C), a large effect size was observed for TA, moderate for GMed and FIB, small for TFL and VM and trivial for VL. Finally, during single-leg jump, a large effect was observed for GMed, small for TA and trivial for TFL, VL, VM and FIB longus muscle activity (Figure 5D).

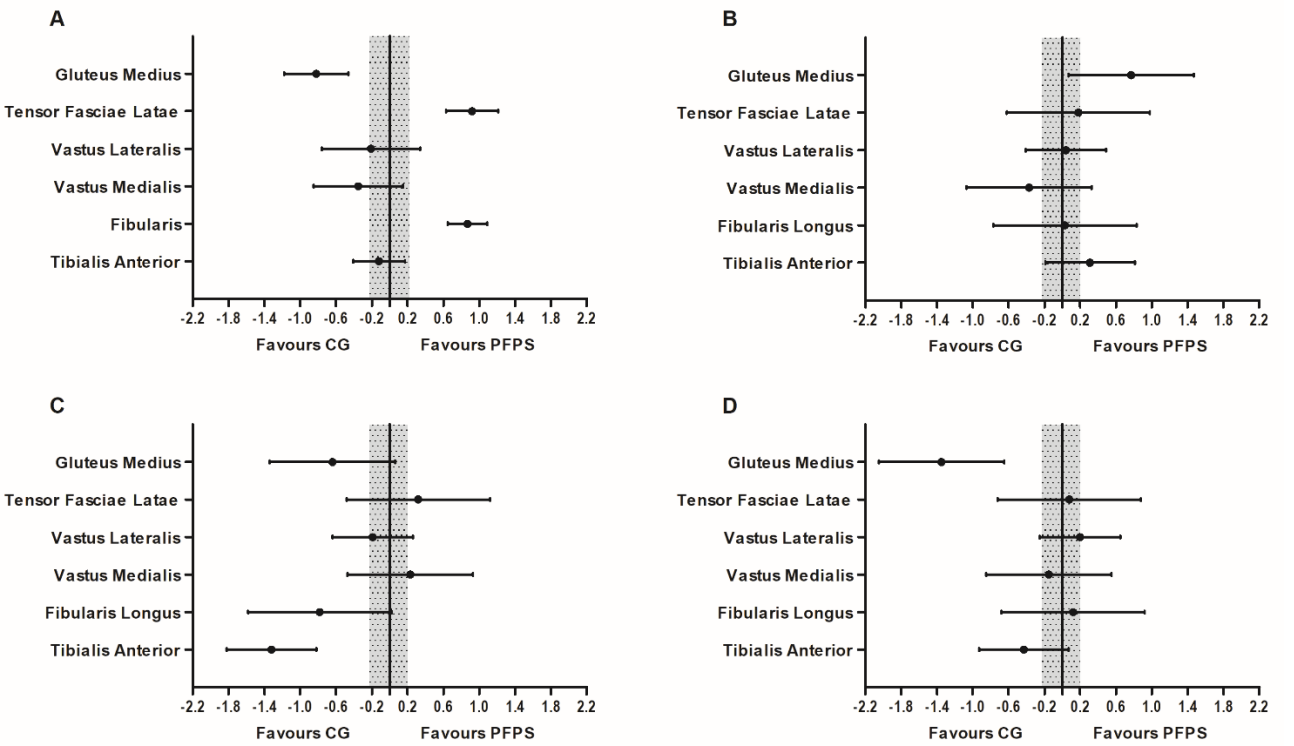

Figure 5: Effect size of muscle thickness (A), maximal muscle activation (B), muscle activation during single-leg squat (C) and muscle activation during single-leg vertical jump (D) between groups. CG = control group; PFPS = patellofemoral pain syndrome group. Grey zone indicates a trivial effect size.

3.4.5 Stepwise Multiple Regression Analysis

The linear stepwise multiple regression analysis was performed to demonstrate if neuromuscular outcomes could explain DVI in both tasks and both groups. For single-leg squat, regression analysis

demonstrated that VL muscle activation during task explained 32.4% of DVI in the CG. For PFPS, DVI was not explained by any neuromuscular outcome. The partial correlations (part r), due to the multiple regression results, demonstrated a significant association between VL activation during task and DVI in CG (r = 0.569; p = 0.027), but not in PFPS (r = -0.094; p = 0.739) (Figure 6A). Regarding to single-leg vertical jump, the stepwise model showed that foot eversion torque and TA muscle thickness explained 44% and 32.7% of DVI in the PFPS and CG, respectively. The partial correlations (part r), due to the multiple regression results, demonstrated a significant association between foot eversion torque and DVI in PFPS (r = 0.663; p = 0.007), but not in CG (r = -0.030; p = 0.917) (Figure 6B), and TA muscle thickness and DVI in CG (r = -0.572; p = 0.026), but not in PFPS (r = -0.034; p = 0.904) (Figure 6C).

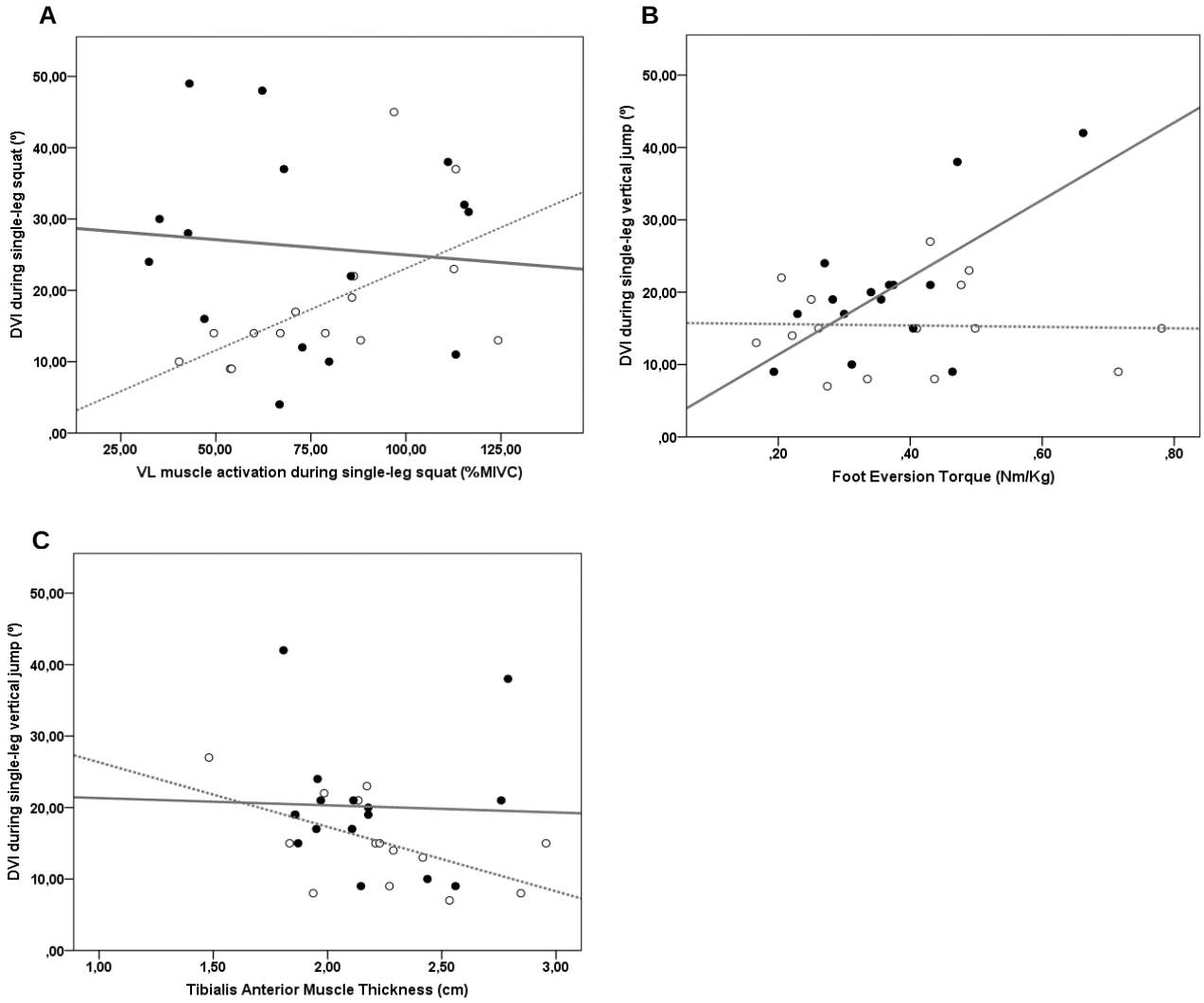

Figure 6: Partial correlation analysis between DVI during single-leg squat and VL muscle activation during task (A), DVI during single-leg vertical jump and foot eversion torque (B) and tibialis anterior muscle thickness (C) White dots = CG; Black dots = PFPS. Dashed line = CG; Solid line = PFPS.

3.5 DISCUSSION

Our PFPS patients showed (1) a lower GMed muscle thickness and activation during single-leg vertical jump; (2) a greater TFL and FIB muscle thickness; (3) a greater GMed muscle activation during maximal isometric contraction; (4) a lower TA muscle activation during single-leg squat. Additionally, we observed that DVI during single-leg squat can be predict by VL muscle activation only in the CG group, while DVI during single-leg vertical jump was explained by foot eversion torque in PFPS patients and TA muscle thickness in the CG. A very interesting result was that only in the CG a neuromuscular outcome was related with DVI during single-leg squat, whereas distal (ankle-foot) parameters were related to DVI during single-leg vertical jump in both groups.

Our study did not demonstrate a significant between-groups difference in DVI in both single-leg tasks, although a moderate effect size favoring the PFPS group was observed for this index (i.e. apparently DVI is a little larger in PFPS). Our results differ from a previous study that demonstrated greater DVI values than ours in the PFPS group during single-leg squat (31.14º vs 26.13º) [66]. Additionally, the mean DVI values observed in the CG were similar to our results (18.30º vs 18.20º). Regarding the single-leg vertical jump, we did not find previous studies that evaluated DVI using this functional task.

These kinematic changes in PFPS patients might be explained by changes in neuromuscular outcomes (muscle activity and muscle morphology) during weight-bearing tasks. However, previous studies did not demonstrate changes on GMed activation during activities that demanded great neuromuscular control, such as vertical jump [71] and single-leg triple hop [28]. Our results demonstrated a smaller GMed activation during the single-leg vertical jump in the PFPS group (-28.70%) compared to the CG, different that was observed in previous studies during the propulsion phase of the single-leg hop test [27]. The smaller GMed activation during the single-leg vertical jump apparently affected the hip control in the frontal plane in our PFPS patients. The greater PFPS patients' GMed activity in previous studies [27, 28] is explained as an attempt to stabilize the lower limb in dynamic tasks. Therefore, further investigations are needed to clarify this point.

No between-groups difference was observed for GMed activation during single-leg squat in our study, agreeing with the results by O'Sullivan et al. [42] and Kedroff et al. [72], but not with Nakagawa et al. [5]. One possible explanation for this lack of consensus is that single-leg squat is a submaximal task, and the clinical differences might not be so evident when comparing PFPS patients with healthy participants in this functional task.

Our study also failed to demonstrate between-groups differences in distal muscle activation during the single-leg vertical jump. Furthermore, we did not find studies envolving PFPS and distal muscle activation patterns during jump. We were able to find only one study investigating TA muscle activation during dynamic task in PFPS [80], and no between-groups difference was observed during the concentric phase of the double-leg squat. Nevertheless, a smaller TA activation (-59.38%) was observed in our study during single-leg squat in PFPS patients. TA has the important function of resisting foot pronation [73]. Thus, the lower TA activation observed in our study might explain the association between excessive rear foot eversion and greater tibial internal rotation observed during over-ground walking in PFPS patients [6]. However, we did not evaluate knee movements in the transverse plane.

The main novelty of our study is related to changes in muscle thickness observed in the PFPS group, since muscle thickness can be related with physiological cross-sectional area [74], which is directly related to muscle strength [47]. The evidences about changes in PFPS patients muscle morphology is limited to the quadriceps muscle [46]. Until now, we observed only one study involving measures of muscle thickness of proximal factors in PFPS patients. Nunes et al. [10] did not observe differences in GMed muscle thickness and echo intensity between PFPS and a CG. Our results showed a smaller GMed muscle thickness (-10.02%) and greater TFL (+18.44%) in the PFPS group. Hip stability in weight-bearing activities [54] is related with GMed and TFL function [49]. This greater TFL muscle thickness observed in PFPS patients might be a compensatory mechanism to the smaller GMed muscle thickness, since both TFL and GMed are hip abductors. However, TFL is also a hip internal rotator. Thus, the greater TFL muscle thickness observed in PFPS patients also

would explain the higher hip internal rotation observed during dynamic tasks [9]. The smaller GMed muscle thickness might explain the greater activation observed for this muscle during maximal isometric contraction compared to CG (+34.40%) and might be a neural mechanism to compensate the smaller muscle structure. These neuromuscular compensatory changes observed for the hip abductor muscles in the PFPS patients might explain the absence of between-groups difference for the hip abduction isometric torque.

FIB muscle thickness was greater in the PFPS group (+14.23%) compared to the CG, showing evidence of distal changes involved in the PFPS group. Previous studies observed that foot muscles morphology was a predictor factor for asymptomatic over-pronated feet [75], and smaller FIB thickness was observed in pes planus [50]. Thus, the greater FIB muscle thickness in our PFPS group can lead to excessive rearfoot eversion [17] and greater tibial internal rotation previously observed in the PFPS group [6], and might constitute a risk factor for PFPS development [17]. However, a previous study observed that hip abduction fatigue caused an elevation in the FIB longus EMG amplitude and earlier activation onset during landing [76]. This seems to demonstrate a compensatory mechanism caused by impairment in the ability to control frontal and transverse plane hip motion. This, in turn, should cause an eccentric overload at the muscles that control foot inversion/eversion that need to compensate this hip abductor weakness by controlling lower limb balance, which might justify the greater FIB muscle thickness in the PFPS group. However, this hypothesis needs to be tested by further investigations.

Previous studies did not observed an impairment on knee extensor [77] and foot inversor [52] isometric strength in PFPS patients, agreeing with our results. Quadriceps muscle is highly used during basic daily life activities. Furthermore, we hypothesized that our PFPS group was classified as moderately active, a level of physical activity similar to the one observed for the CG, might explain the between-groups similarity for the knee extensor muscles. Another aspect that that should be evaluated in PFPS patients is the maximal capacity of force production in different muscle actions. It

is possible that isometric strength is not the optimal clinical measure of hip strength, since weight-bearing tasks need eccentric (not isometric) contractions to control movements [78].

Prospective studies observed that greater knee valgus displacement in the landing of a drop jump was a predictor factor for PFPS development in adolescent female athletes [57] and for pain severity [79]. Thus, trying to explain DVI during weight-bearing tasks through neuromuscular outcomes might help in the exercises choice of rehabilitation protocols. The stepwise multiple regression analysis demonstrated that DVI was explained by VL muscle activation during single-leg squat (32.4%) and by TA muscle thickness during single-leg vertical jump (32.7%) only in CG. The fact that foot eversion torque (44%) explained DVI in the PFPS group further supports the idea that something happened with the PFPS patients foot inversors (i.e. tibialis anterior), who recruited the eversors (FIB) probably to control foot inversion excentrically, determining the abovementioned higher FIB muscle thickness in the PFPS group. The moderate, significant and positive association observed between DVI and VL muscle activation during single-leg squat in the CG further strengthens this relationship. Similarly, the moderate, significant and positive association observed between foot eversion torque and DVI in the PFPS group strengthens the relationship between foot eversors structure and functional tasks, despite the fact that our study did not show between-group differences in foot eversion maximal isometric torque.

In the CG, a moderate, significant and negative association was observed between TA muscle thickness and DVI. TA has an important role in resisting foot pronation during weight-bearing tasks [80]. According to the above results, greater VL muscle activation during, greater foot eversion or smaller TA muscle thickness explain greater DVI during single-leg squat and vertical jump, respectively.

One of the main limitations of the study was that only isometric tests were used to evaluate muscular strength. Eccentric tests might help to explain different aspects of functional impairment [81]. Furthermore, a lack of intrinsic foot muscles morphology evaluation, due to their function on longitudinal and mediolateral arc control [82], could have helped to explain changes in kinematic

parameters caused by excessive rearfoot eversion [17]. Nevertheless, the novelty of our study was to demonstrate hip and ankle-foot morphological adaptations in PFPS patients, which help to explain kinematic changes during weight-bearing tasks. Thus, exercise protocols that cause excessive TFL activation compared to GMed and foot evertor muscles may be counterproductive in the treatment of PFPS patients.

3.6 CONCLUSION

PFPS patients have a smaller GMed and greater TFL and FIB muscles thickness and greater GMed muscle activity during maximal hip abduction isometric contraction, smaller TA and GMed muscle activity during the single-leg squat and the vertical jump, respectively. DVI during single-leg squat was not explained by neuromuscular outcomes in PFPS and distal factors explained DVI during single-leg vertical jump. This was the first study that aimed to verify muscle morphology of proximal (TFL) and distal (TA, FIB) muscles in PFPS patients. Based in our results, exercise rehabilitation programs focused in distal factors need to be included in PFPS patients due to their relationship with lower limb poor alignment.

4. CONCLUSION AND FUTURE DIRECTIONS

This thesis aimed to identify lower limb neuromuscular changes and their relationship with single-leg weight-bearing tasks in PFPS patients. The systematic review (Chapter II) included only studies that measured muscle activation or muscle morphology outcomes in trunk, hip and foot/ankle joints. Based in our results, limited evidence demonstrated an early activation of TrA/IO in high-speeds activity, while the responses of muscles around hip and ankle/foot joints are limited. Additionally, only one study evaluated muscle morphology of some muscle related to proximal or distal factors until now. These limited evidences about neuromuscular changes in proximal and distal factors contrast with the observed improvement when hip or foot exercises are combined with knee strengtening on clinical and functionality outcomes in PFPS patients.

Thus, the needed to better understand lower limb neuromuscular changes led to an original study to verify lower limb neuromuscular parameters and frontal plane kinematics during single-leg tasks in women with PFPS and determine if some neuromuscular outcome explained dynamic valgus index. Our study evaluated muscle activation and morphology of GMed, TFL, VL, VM, FIB and TA. Our results demonstrated that women with PFPS showed significant neuromuscular changes at the hip and ankle/foot joints. Also, we performed an additional study which aimed to associate neuromuscular outcomes of lateral trunk flexors (external and internal oblique muscle thickness, external oblique muscle activation during single-leg tasks) and time until task failure during side plank with knee and hip FPPA during single-leg tasks (Appendix A, manuscript in Portuguese). This study was performed by Kelli Daiana Klein in a partial fulfillment of the requirements for the degree of Bacelor in Physical Education. The results demonstrated: (i) negative association between the external oblique muscle thickness and the hip FPPA during the single-leg jump test in the CG ($p=0.027$, $r=-0.521$; moderate); (ii) negative association between the time until task failure during the side plank and the degree of knee abduction ($p=0.037$, $r=-0.543$, moderate); (iii) negative association between the internal oblique muscle thickness and the degree of knee abduction during the single-leg squat in the PFPS ($p=0.004$; $r=-0.701$; strong). The lower IO thickness and the low LFT muscles

resistance are associated with higher degrees of knee valgus. Based in our results, PFPS exercises in rehabilitation programs should focus in proximal and distal factors due to their relationship with poor lower limb alignment in functional tasks.

We would like to recommend some future directions regarding patellofemoral pain investigations. Regarding neuromuscular changes, the evaluation of intrinsic foot muscles can help to explain poor lower limb aligment during dynamic tasks. Finally, the investigation of neuromuscular changes after rehabilitation programs might help to explain the improvement in pain and functionality in PFPS patients.

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APPENDIX A – ADDITIONAL MANUSCRIPT

ASSOCIAÇÃO ENTRE A FUNÇÃO NEUROMUSCULAR DE FLEXORES LATERAIS DE TRONCO E A CINEMÁTICA NO PLANO FRONTAL DURANTE TAREFAS FUNCIONAIS EM MULHERES COM SÍNDROME DA DOR PATELOFEMORAL

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Resumo

O objetivo desse estudo foi verificar a associação entre parâmetros neuromusculares dos músculos flexores laterais do tronco (FLT) e o grau de adução do quadril e abdução de joelho durante os testes de agachamento e salto unipodal em mulheres com Síndrome da Dor Patelofemoral (SDPF). Trinta mulheres [SDPF, n=15 (idade: 26,33±4,18 anos; IMC: 24,51±3,61 kg/m²); grupo controle (GC), n=15 (idade: 29,00±5,23 anos; IMC: 23,12±3,31 kg/m²)] foram submetidas às seguintes avaliações: grau de adução do quadril, valgo do joelho, ativação muscular do oblíquo externo (OE) durante os testes de agachamento e salto unipodal; espessura dos músculos OE e oblíquo interno (OI) em repouso; tempo até a exaustão na prancha lateral. Correlação de Pearson (α=5%) avaliou a associação entre as variáveis neuromusculares dos FLT e os parâmetros cinemáticos durante o agachamento e o salto unipodal. Foram observadas associações negativas entre a espessura do OE e o grau de adução de quadril durante o salto unipodal no GC (p=0,027; r=-0,521; moderada), entre o tempo até a exaustão durante a prancha lateral e o grau de abdução do joelho durante o agachamento unipodal no SDPF (p=0,037; r=-0,543; moderada), e entre a espessura do OI e o grau de abdução do joelho durante o agachamento unipodal no SDPF (p=0,004; r=-0,701; forte). A menor espessura do OI e a baixa resistência muscular dos FLT estão associadas com maiores graus do valgo do joelho, sugerindo que este grupo muscular deve ser levado em consideração em programas de reabilitação em pacientes com SDPF.

Palavras-chave: síndrome da dor patelofemoral; tarefas funcionais; estabilidade do core.

1. INTRODUÇÃO

A síndrome da dor patelofemoral (SDPF) é uma patologia de natureza multifatorial que se caracteriza por uma dor difusa retropatelar e/ou peripatelar na articulação do joelho, exacerbada por atividades de sobrecarga na articulação patelofemoral realizadas em flexão de joelho (Fulkerson, 2002). Essa dor é muito comum na medicina esportiva entre adolescentes e adultos jovens, com maior predominância em mulheres (Willson & Davis, 2008). Os sintomas que resultam na SDPF diminuem a capacidade funcional do membro inferior e dificultam as atividades de vida diárias como subir e descer escadas, atividades com saltos, agachamentos e corridas (Fulkerson, 2002).

Alterações cinemáticas (i.e. assimetria do alinhamento do membro inferior) são observadas nessa síndrome durante atividades de descarga de peso. Há um aumento do grau de adução do quadril e de abdução do joelho, causando aumento do estresse patelofemoral e, consequentemente, desconforto e dor (Nakagawa et al., 2012; Nakagawa et al., 2015). Esse desalinhamento do membro inferior tem sido associado a fatores (ou alterações) proximais (no tronco e quadril), locais (no joelho) e distais (no tornozelo e pé) ao local da dor em pacientes com SDPF.

Alterações na função neuromuscular da articulação do quadril, como, por exemplo, uma fraqueza dos músculos abdutores do quadril, pode ser um fator desencadeador da SDPF. Como os abdutores têm a função de estabilizar a cintura pélvica e controlar excentricamente a adução do quadril em tarefas de descarga de peso (Ferber et al., 2011), uma fraqueza desse grupo muscular levaria a um aumento da adução do quadril, da abdução do joelho e o consequente aumento do valgo do joelho e estresse na articulação patelofemoral.

Da mesma forma, alterações no controle neuromuscular ao nível do tronco também têm sido associadas ao desenvolvimento da SDPF (Baldon et al., 2015). A estabilidade do *core* (centro do corpo), por exemplo, pode ser definida como a base do controle dinâmico lombar e pélvico, permitindo a produção de força e o controle do movimento, que é transferido para toda a cadeia cinética do membro inferior durante o movimento funcional (Shirazi et al., 2014). Essa estabilidade é instantânea e requer um funcionamento eficiente, integrando a musculatura adequada para garantir que as variáveis de força, resistência e controle neuromuscular possam ser devidamente aplicadas em atividades funcionais (Akuthota & Nadler, 2004; Blaiser et al., 2018). Essa integração garante a estabilidade e alinhamento entre os membros, ou seja, a musculatura do *core* fornece uma base estável para um movimento funcional mais controlado, contribuindo para a estabilidade dinâmica das articulações (Zazulak et al., 2007).

A importância dos músculos flexores laterais de tronco em sujeitos acometidos pela SDPF é relatada em alguns estudos (Cowan et al., 2008; Earl & Hoch, 2011; Nakagawa et al., 2014; Shirazi et al., 2014). Conforme mencionado anteriormente, um prejuízo na força, resistência e controle

neuromuscular desses músculos do tronco está associado a uma menor estabilidade do *core*, podendo gerar mudanças na mecânica dos membros inferiores, aumentando assim, o risco de desenvolver lesões no joelho (Earl & Hoch, 2011; Leetun et al., 2004). Cowan e colaboradores (2008) relataram a redução de força no teste de resistência de flexão lateral de tronco (prancha lateral) em sujeitos com SDPF ao compará-los com sujeitos saudáveis. Redução na força máxima e na força sustentada (resistência à fadiga) da musculatura lateral do tronco pode reduzir a capacidade funcional de pessoas acometidas pela SDPF na estabilização do quadril e do tronco no plano frontal (Nakagawa et al., 2012). Embora esta redução na resistência e na força da musculatura abdominal tenha sido descrita, não foram encontradas evidências sobre possíveis alterações na ativação ou na morfologia dos músculos responsáveis pela estabilização do *core* em indivíduos com SDPF. Da mesma forma, não encontramos estudos que buscaram associar os parâmetros neuromusculares dos flexores laterais de tronco e a cinemática no plano frontal em atividades funcionais. Portanto, o objetivo do presente estudo foi verificar a associação entre as variáveis neuromusculares de flexores laterais do tronco [como o tempo até exaustão em prancha lateral, a espessura do oblíquo externo (OE), a espessura do oblíquo interno (OI) e a ativação excêntrica do OE] com o grau de adução do quadril e abdução de joelho durante os testes de agachamento e salto unipodal em mulheres com SDPF.

2. MATERIAIS E MÉTODOS

2.1 Sujeitos

Vinte e nove mulheres com dor no joelho participaram do estudo após a divulgação do projeto no campus da Universidade e nas redes sociais. Foram incluídas no estudo mulheres com idade entre 18 e 40 anos, com avaliação positiva no teste clínico de compressão e negativa no teste de apreensão patelar (Tavares et al., 2011), com presença de dor retropatelar ou peripatelar (mínimo de três na escala analógica visual) em no mínimo duas tarefas funcionais (agachamento, subida e descida de escadas, corrida, salto, ajoelhar e sentar prolongado) (Jan et al., 2009) há pelo menos dois meses. Além disso, as participantes não deveriam ter sido submetidas a cirurgia ou acometidas por lesão na articulação do joelho, quadril e tornozelo. Após a aplicação dos critérios, sete mulheres foram excluídas devido à história de cirurgia do membro inferior, três devido à instabilidade patelar e quatro desistiram pois não puderam comparecer no momento da coleta. Assim, 15 mulheres foram incluídas no grupo SDPF. Quinze mulheres saudáveis, pareados com as pacientes com SDPF por idade, massa corporal, estatura e nível de atividade física, foram recrutadas como grupo controle (GC) (Tabela 1). Um consentimento escrito foi obtido de todas as participantes antes de iniciar o experimento. Este estudo foi aprovado pelo Comitê de Ética em Pesquisa da Universidade (número de registro CAAE 61489016.9.0000.5347) e foi conduzido respeitando os padrões éticos da Reunião da Assembleia Geral da Declaração de Helsinque (outubro de 2008).

Inicialmente, os sujeitos responderam ao Questionário Internacional de Atividade Física (IPAQ) e à Escala de Dor Anterior do Joelho (EDAJ) (Cunha et al., 2013) para determinar o nível de atividade física e a capacidade funcional, respectivamente. Após, foram submetidos aos seguintes procedimentos: (1) medidas da espessura dos músculos OE e OI; (2) colocação de sensores de eletromiografia (EMG) no músculo OE; (3) posicionamento dos marcadores cutâneos para avaliação cinemática; (4) realização do agachamento unipodal; (5) realização do salto unipodal; (6) aferição do tempo até a exaustão dos músculos flexores laterais de tronco no teste de prancha lateral. Os avaliadores não foram cegados em relação à alocação dos sujeitos nos grupos.

2.2 Avaliação da espessura muscular de OE e OI

A ultrassonografia foi utilizada por meio de um equipamento de ecografia B-mode (SSD 4000, 51 Hz, *ALOKA Inc., Tokyo, Japan*) e uma sonda de arranjo linear (60mm - 7,5 MHz) para determinar a espessura dos músculos OE e OI. Um único pesquisador foi responsável pela coleta das imagens de ultrassonografia. A sonda de ultrassonografia foi coberta com gel de transmissão solúvel em água e colocada paralelamente aos fascículos musculares, perpendicular à pele. A espessura muscular foi mensurada pela distância entre as aponeuroses profunda e superficial, a partir do cálculo do valor

médio de cinco medidas de linhas paralelas desenhadas em ângulos retos entre as aponeuroses superficiais e profundas em imagens ultrassonográficas (Figuras 1-B e 1-C). As imagens foram analisadas com o software Image J (National Institutes of Health, Bethesda, Maryland) (Baroni et al 2013). Para o OE e OI, a sonda foi posicionada em um ângulo de 60 graus em relação a uma linha vertical, entre a cicatriz umbilical e a crista ilíaca, aproximadamente na mesma linha de orientação das fibras musculares do OE (Figura 1-A).

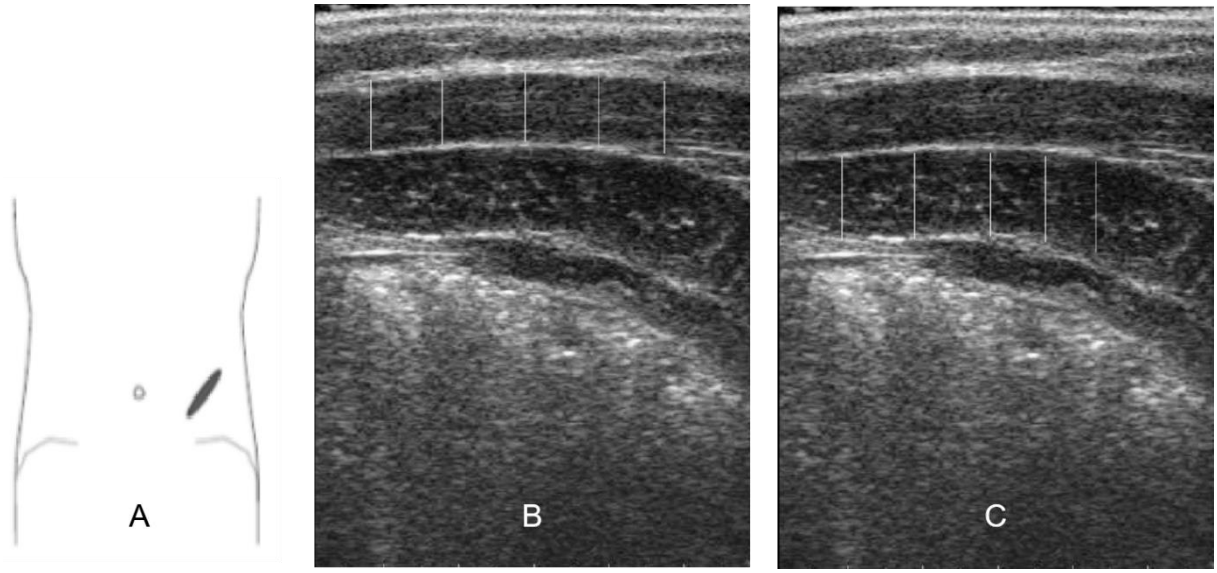

Figura 1: A – Imagem representativa de posicionamento da sonda de ultrassom (US). B e C – Imagens de arquitetura muscular em repouso de um sujeito da amostra, obtidas através da US, para a análise de espessura muscular (média de cinco linhas) do OE e OI, respectivamente.

2.3 Avaliação da ativação muscular

Um sistema de EMG Delsys de 16 canais (estação base EMG Trigno Wireless Trigno, Delsys Inc., Natick, Massachussets, EUA) foi usado para a coleta de dados de ativação do músculo OE. O sensor foi posicionado obliquamente aproximadamente 45 graus (paralelo a uma linha que conecta o ponto mais inferior da margem costal das costelas e o tubérculo púbico contralateral) acima da espinha ilíaca anterossuperior (EIAS) ao nível do umbigo (Escamilla et al., 2006). Um filtro Butterworth passa-banda, com frequências de corte de 20 e 500 Hz, foi utilizado em todas as avaliações para eliminar possíveis ruídos. Para normalizar os sinais EMG durante o agachamento e o salto unipodal, foram realizadas contrações voluntárias isométricas máximas para estabelecer a ativação muscular máxima. Para a realização do teste, os sujeitos foram posicionados em decúbito dorsal, com quadris e joelhos flexionados em 90 graus, e pés apoiados. Os participantes foram orientados para flexionar e girar o tronco para o lado oposto ao do OE onde estava posicionado o sensor. A resistência ao movimento foi aplicada no peito e ombros (Escamilla et al., 2006). Foram

realizadas três contrações voluntárias máximas, e um intervalo de 2 minutos foi observado entre as contrações. Os sujeitos foram previamente instruídos a executar o teste com o maior esforço possível para desenvolver a força máxima, e incentivo verbal foi fornecido ao longo dos testes (Baroni et al., 2013). A ativação muscular foi medida pelo teste isométrico, e valores *Root Mean Square* (RMS) foram calculados a partir de 3 segundos no meio dos sinais de EMG obtidos nos testes. Esses valores foram considerados 100% de cada ativação muscular e foram utilizados para normalização da atividade muscular durante o agachamento e o salto unipodal. Para análise, usamos a porcentagem de ativação máxima do músculo OE (Winter, 2005) durante a fase excêntrica do agachamento e salto unipodal. Todos os dados EMG foram sincronizados com o sistema de acelerometria do sistema Delsys, o qual permitiu identificar as fases excêntricas e concêntricas durante os testes. A análise EMG foi realizada no software LabChart (ADInstruments, Brasil).

2.4 Cinemática durante o teste de agachamento e salto unipodal

Dados bidimensionais foram capturados enquanto os participantes completaram o agachamento e salto unipodal. Os participantes com SDPF realizaram o agachamento e o salto no membro envolvido, enquanto os participantes do GC realizaram o teste com o membro preferido. Marcadores cutâneos com fita adesiva dupla-face foram fixados nos seguintes locais: espinhas ilíacas anterossuperiores (EIAS); trocânter maior; epicôndilo femoral lateral; centro da patela; maléolo lateral e ponto médio entre o maléolo medial e lateral. Dados bidimensionais foram capturados com uma câmera GoPro Hero 4 (GoPro Inc, Califórnia, EUA) com uma taxa de amostragem de 120 Hz. A primeira câmera foi posicionada no plano frontal ao participante para determinar a adução do quadril e a abdução do joelho durante o teste de agachamento e do salto, enquanto a segunda câmera foi posicionada no plano sagital e foi usada para determinar a profundidade de movimento de cada repetição. Ambas as câmeras foram sincronizadas com um sinal luminoso para posterior análise das imagens. Os dados foram processados com o software Kinovea (Kinovea Organization, France).

Para o agachamento unipodal, todos os sujeitos foram instruídos a flexionar o joelho contralateral, cruzar os braços no tronco e agachar o máximo possível. Eles realizaram cinco agachamentos unipodais com cadência controlada por um metrônomo (2 segundos por fase). Para o salto unipodal, todos os sujeitos foram instruídos a flexionar o joelho contralateral, cruzar os braços sobre o tronco, agachar-se (mais rápida e profundamente possível) e saltar o mais alto possível. Os participantes realizaram três saltos unipodais, e um intervalo de dois minutos foi observado entre as repetições.

Os ângulos foram medidos a partir do plano frontal e sagital por um investigador cegado a alocação dos sujeitos nos grupos. No plano sagital, o ângulo entre o trocânter maior e o epicôndilo femoral lateral (flexão do joelho) foi utilizado para determinar a profundidade do agachamento. No

plano frontal, o ângulo entre os marcadores colocados nas EIAS e no centro da patela, foi usado para medir o grau de adução do quadril. O ângulo entre os marcadores colocados na EIAS do membro avaliado e o marcador colocado no ponto médio entre os maléolos medial e lateral foi usado para medir o grau de abdução do joelho (Holden et al., 2017; Wyndow et al., 2016; Scholtes & Salsich, 2017) (Figura 2). Para todas as análises, utilizou-se o deslocamento angular entre início (participantes em posição ortostática e flexão contralateral do joelho) e final da fase excêntrica (pico de flexão do joelho).

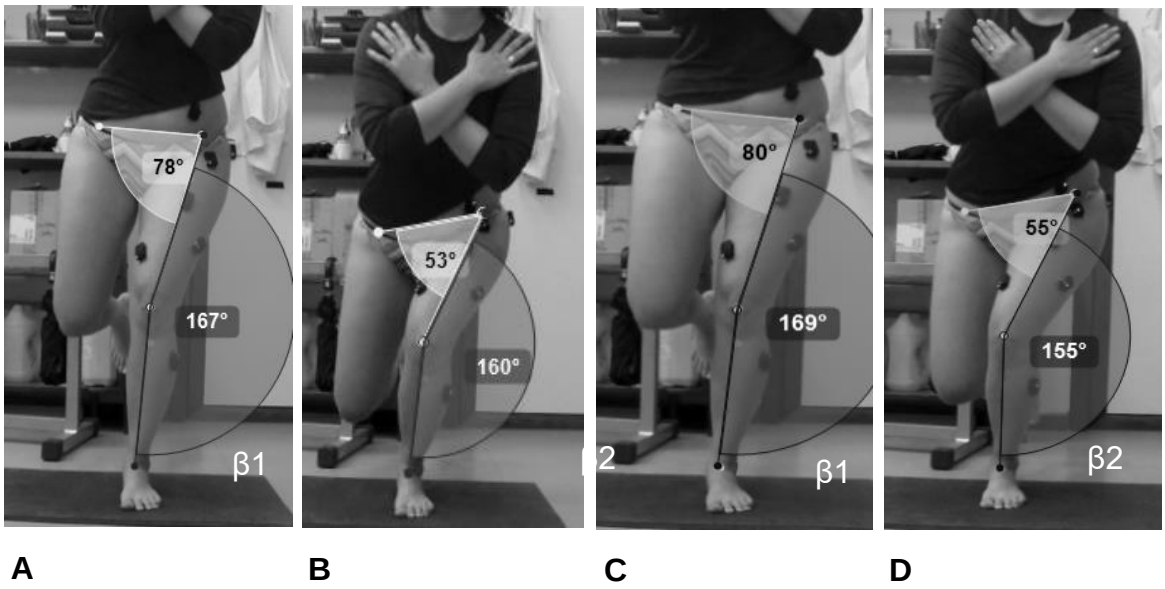

Figura 2: As figuras A e B representam a posição inicial e final, respectivamente, durante o teste de agachamento unipodal, enquanto as figuras C e D representam a posição inicial e final, respectivamente, durante o teste de salto unipodal. A adução do quadril foi calculada através do ângulo formado entre a pelve e a coxa (α2 - α1). O valgo do joelho foi calculado através do ângulo formado entre a coxa e a perna (β2 - β1).

2.5 Nível de dor após os testes funcionais

Após os testes de agachamento e salto unipodal, o nível de dor foi avaliado com uma escala visual analógica de 0-100 mm (EVA), onde 0 e 100 mm corresponderam a ausência de dor e dor intolerável, respectivamente.

2.6 Avaliação de resistência da musculatura lateral de tronco

A resistência da musculatura do tronco foi definida como o tempo em que o sujeito conseguiu permanecer na posição estática pré-definida. Para a avaliação da resistência dos flexores laterais de tronco (prancha lateral), os sujeitos foram orientados a elevar a cintura pélvica e sustentar o corpo em linha reta, apoiado somente pelo antebraço do lado de apoio e os pés. O membro superior do lado

contralateral permaneceu ao lado do tronco (Figura 3). Os testes foram interrompidos quando os sujeitos não foram capazes de sustentar a posição. Foi realizada uma repetição e a duração do tempo em segundos foi utilizada para as análises (Baldon et al., 2015).

Figura 3: Prancha lateral para avaliação da resistência muscular dos flexores laterais de tronco. Fonte: Imagem obtida da Internet.

2.7 Análise estatística

O teste de Shapiro-Wilk foi usado para verificar a normalidade dos dados. Para a comparação das variáveis de caracterização da amostra foi realizado um teste t de Student para amostras independentes. Uma correlação produto-momento de Pearson foi realizada entre as variáveis neuromusculares (espessura e ativação) e o tempo até a exaustão na prancha lateral e os parâmetros cinemáticos durante o salto e o agachamento unipodal (grau de adução do quadril e valgo do joelho). Para classificar o grau de associação entre as variáveis foi utilizado o seguinte critério: correlações (positivas ou negativas) acima de 0,9 indicaram uma correlação muito forte; de 0,7 a 0,9 indicaram uma correlação forte; de 0,5 a 0,7 indicaram uma correlação moderada; de 0,3 a 0,5 indicaram uma correlação fraca e de 0 a 0,3 indicaram uma correlação desprezível. O nível de significância adotado foi de 5%. As análises foram realizadas no software SPSS 20.0.

3. RESULTADOS

3.1 Características Clínicas

Os pacientes com SDPF apresentaram função prejudicada medida pela pontuação de dor no joelho EDAJ e maior dor relatada após os testes em comparação aos sujeitos saudáveis (GC). Não foram observadas diferenças em outras características clínicas entre os grupos (Tabela 1).

Tabela 1: Características dos sujeitos da amostra.

	GC (n=15)	**SDPF (n=15)**	**Valor de p**
Idade	29,00 ± 5,23	26,33 ± 4,18	0,135
Massa corporal (Kg)	62,16 ± 7,83	65,98 ± 13,08	0,341
Estatura (m)	1,64 ± 0,06	1,63 ± 0,06	0,766
IMC (Kg/m²)	23.12 ± 3.31	24.51 ± 3.61	0,281
IPAQ (met.min.week)	2053,23 ± 1648,42	2131,94 ± 1824,35	0,902
Pontuação de dor no joelho (pontos)	N.A.	76,26 ± 10,18	N.A.
Duração dos sintomas (anos)	N.A.	5,24 ± 2,10	N.A.
Profundidade do salto (º)	54,93 ± 6,39	59,20 ± 8,20	0,123
Dor após salto (EVA) (mm)	2,3 ± 4,1	30,5 ± 21,11	**<0,001**
Profundidade do agachamento (º)	57,73 ± 8,63	64,80 ± 7,11	0,089
Dor após agachamento (EVA) (mm)	1,4 ± 3,5	22,23 ± 12,50	**<0,001**

GC = Grupo controle; SDPF = Grupo com Síndrome da Dor Patelofemoral; IMC = Índice de Massa Corporal; IPAQ = Questionário Internacional de Atividade Física; EDAJ = Escore de Dor Anterior no Joelho; EVA = Escala Visual Analógica; N.A. = Não Aplicável

3.2 Associação dos Desfechos

Quanto à associação entre os desfechos neuromusculares e os parâmetros cinemáticos, observamos uma associação negativa, moderada e significativa (r=-0,521; p=0,027) entre a espessura do OE e o grau de adução de quadril durante o salto unipodal no GC. Não foi observada associação entre estas duas variáveis para o grupo SDPF (r=0,112; p=0,693) (Figura 4). Ainda, houve uma associação negativa, moderada e significativa (r=-0,543; p=0,037) entre o tempo até a exaustão durante a prancha lateral e o grau de abdução do joelho durante o agachamento unipodal para o grupo SDPF, fato este não observado para o GC (r=-0,185; p=0,516) (Figura 5). Por fim, observamos uma associação negativa, forte e significativa (r=-0,701; p=0,004) entre a espessura do OI e o grau de abdução do joelho durante o agachamento unipodal para o grupo SDPF, diferente do observado para o GC (r=0,070; p=0,794) (Figura 6). Não observamos associação entre as demais variáveis para ambos os grupos.

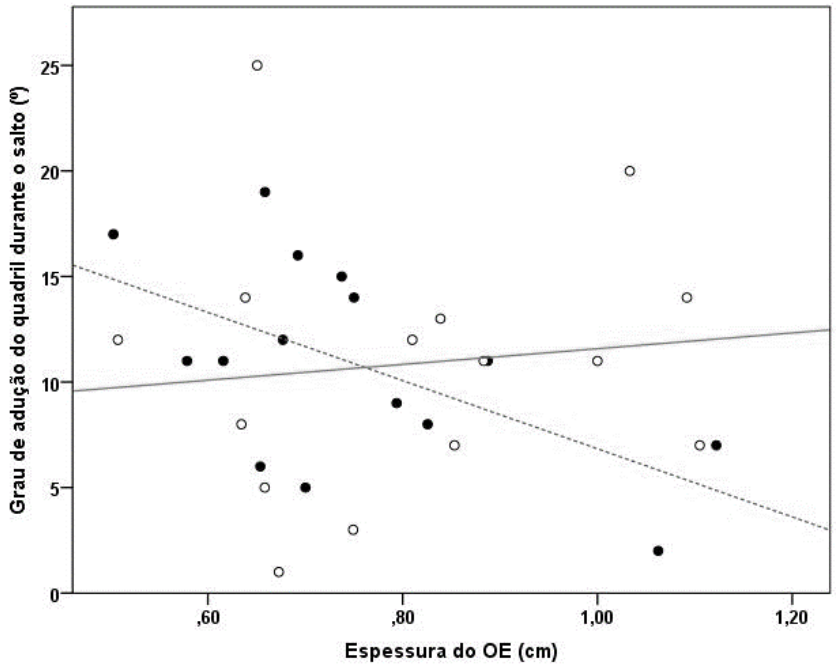

Figura 4: Associação entre o grau de adução do quadril durante o salto e a espessura muscular do OE. Pontos pretos (GC); pontos brancos (SDPF); linha tracejada (GC); linha sólida (SDPF).

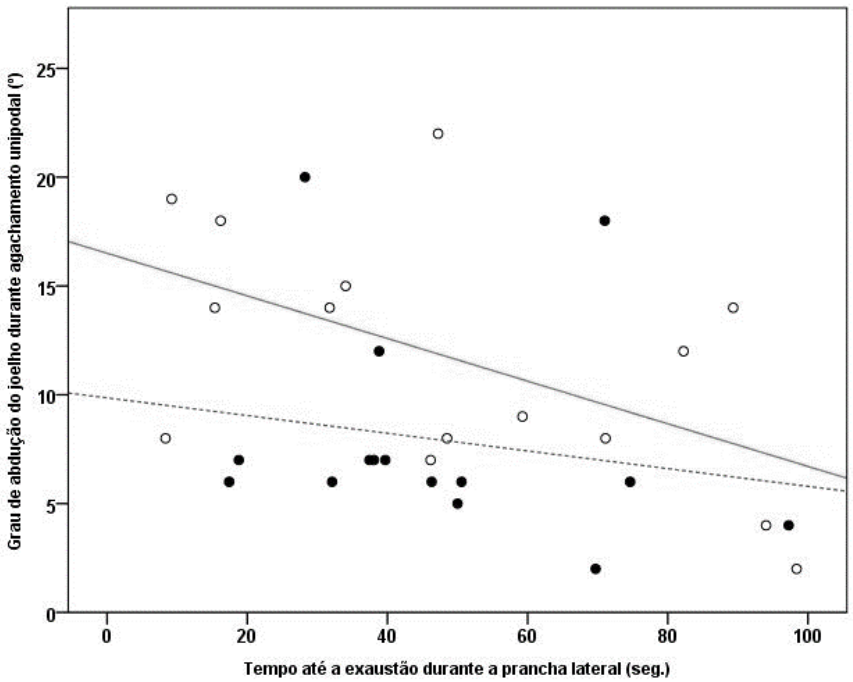

Figura 5: Associação entre o grau de abdução do joelho (valgo do joelho) durante o agachamento o tempo até a exaustão durante a prancha lateral. Pontos pretos (GC); pontos brancos (SDPF); linha tracejada (GC); linha sólida (SDPF)

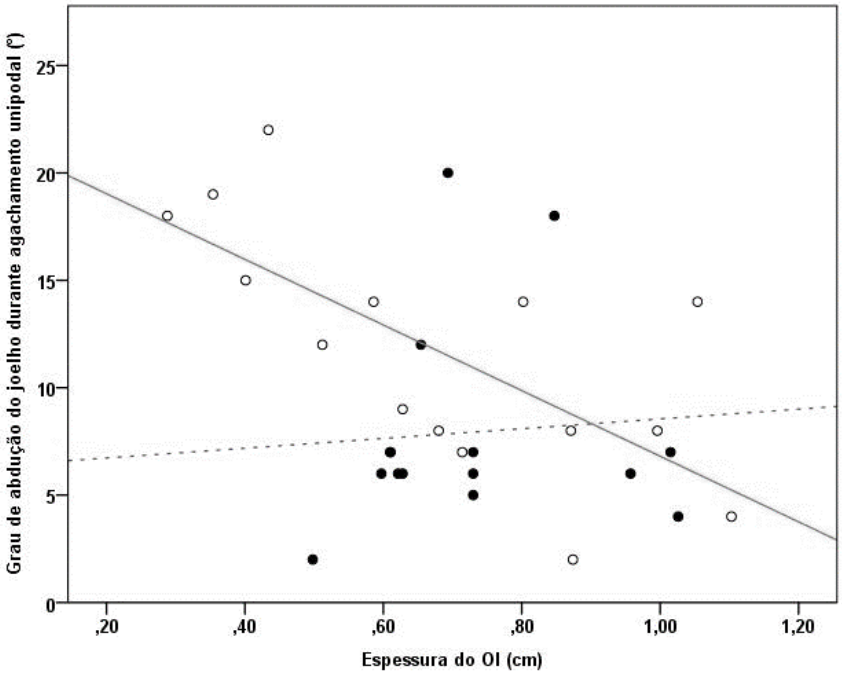

Figura 6: Associação entre o grau de abdução do joelho (valgo do joelho) durante o agachamento e a espessura do OI. Pontos pretos (GC); pontos brancos (SDPF); linha tracejada (GC); linha sólida (SDPF).

4. DISCUSSÃO

Conforme demonstrado pelos resultados, e a partir da hipótese formulada para o presente estudo, observamos que os parâmetros estruturais e funcionais dos flexores laterais do tronco estão associados com as variáveis cinemáticas no plano frontal durante o salto e o agachamento unipodal. Curiosamente, observamos que os grupos apresentam um comportamento diferente. Assim, observamos uma associação forte e significativa entre a espessura do OI e o grau de abdução do joelho no grupo SDPF. Desta forma, quanto menor foi a espessura de OI, maior era o grau de abdução de joelho durante o agachamento unipodal. Este resultado também foi observado para o tempo de exaustão em prancha lateral. Para o GC, houve uma associação entre a espessura muscular de OE e o grau de adução do quadril durante o salto unipodal. Não foram encontradas diferenças entre as demais variáveis para ambos os grupos.

A estabilidade do *core* depende da função adequada da musculatura do tronco, e é fundamental para uma funcionalidade eficiente entre os membros (Blaiser et al., 2018). A perda da estabilidade nessa musculatura pode ser um fator de risco para a perda do movimento adequado em atividades do dia a dia e perda da funcionalidade (Zazulak et al., 2007). Essas perdas, por sua vez, podem levar ao desenvolvimento de lesões nas extremidades inferiores (Blaiser et al., 2018). Nosso estudo demonstrou uma associação das variáveis neuromusculares com a cinemática no GC. Menores espessuras do OE estavam associadas com o aumento do grau de adução do quadril durante o salto unipodal. Esse resultado sugere que uma incapacidade do OE de controlar a pelve durante a fase excêntrica do salto leva a adução aumentada do quadril (Nakagawa et al., 2014). Portanto, parece existir uma importante relação da estrutura do OE com o controle do movimento do quadril durante atividades de descarga de peso.

Como observado no estudo de Nakagawa e colaboradores (2015), maiores graus de adução do quadril e abdução do joelho observados no grupo SDPF estão relacionados a um aumento no estresse patelofemoral e dor. Apesar de que fatores proximais estão relacionados a este controle das articulações do membro inferior durante atividades de descarga de peso, não observamos estudos prévios que tivessem investigado alterações da morfologia dos músculos do tronco nestes sujeitos. A associação de menor espessura muscular de OI com o maior grau de abdução de joelho no agachamento unipodal no grupo SDPF pode ter relação com os pontos de origem e inserção do OI e a anatomia funcional ou cinesiologia desse músculo. A origem do músculo está localizada na fáscia toracolombar e parte dorsal da crista ilíaca, enquanto sua inserção se dá da oitava à décima cartilagem costal, chegando à linha Alba (Carpes et al., 2011). Apesar de a função dos músculos abdominais ser geralmente explicada a partir dos movimentos do tronco sobre a pelve, os movimentos da pelve sobre o tronco também são produzidos por essa musculatura. Além disso, a estabilização da pelve pelos músculos do core, conforme mencionado anteriormente, é fundamental para fornecer estabilidade

para os movimentos do membro inferior (Neumann, 2002), e o músculo OI, por conectar a espinha ilíaca às costelas lateralmente em relação à articulação do quadril, é um importante músculo no posicionamento adequado da fossa do acetábulo durante atividades dinâmicas. Apesar de a literatura da cinesiologia estabelecer essa relação entre a musculatura abdominal como um importante fator de estabilização da pelve para a execução adequada dos movimentos do quadril, poucos são os estudos que apresentam evidências dessa relação. Uma redução na espessura do OI reduz a capacidade de sustentação da cintura pélvica e pode desencadear um pico de inclinação do tronco, adução de quadril e abdução do joelho quando pacientes com SDPF realizam o agachamento unipodal (Nakagawa et al., 2015), alterando, portanto, o alinhamento do membro inferior.

Outro componente da estabilidade do *core*, a resistência muscular, é representada pela capacidade de manter a força da musculatura axial em contração isométrica prolongada. Estudos anteriores relatam a incapacidade de produção de força resistida dos músculos flexores laterais de tronco na prancha lateral isométrica em sujeitos com SDPF comparados com sujeitos saudáveis (Cowan et al., 2008), o que vai ao encontro com os resultados do nosso estudo. Houve uma associação entre um menor tempo de resistência na prancha lateral e um maior grau de abdução do joelho durante o agachamento unipodal. Tanto o músculo OE quanto o OI são responsáveis pelo movimento de flexão lateral do tronco (Neumann, 2002; Carpes et al., 2011). Desta forma, como também observamos que a morfologia destes músculos apresenta associação com parâmetros cinemáticos, alterações deletérias neste grupo muscular podem desencadear desalinhamentos nos membros inferiores, compensação de musculaturas sinergistas e uma maior abdução de joelho.

A baixa capacidade de resistência dos flexores laterais pode estar ligada a uma maior adução de quadril e abdução de joelho em atividades dinâmicas (Cowan et al., 2008; Nakagawa et al., 20015). Um programa de fortalecimento da musculatura do *core* em mulheres com SDPF determinou uma melhora na capacidade funcional e diminuição da dor. Isso sugere que o fortalecimento de abdutores de quadril e flexores laterais do tronco pode estar relacionado com menores ângulos de abdução de joelhos em atividades funcionais (Earl & Hoch, 2011). Portanto, um fortalecimento da musculatura flexora lateral do tronco deve ser incluída em programas de reabilitação destes pacientes visando uma maior estabilidade dos membros inferiores durante as tarefas funcionais.

Uma das limitações do estudo foi o fato de que somente a prancha lateral foi mensurada no teste de resistência. O teste de prancha frontal para mensurar a resistência dos flexores anteriores de tronco seria importante, visto que eles também são importantes na estabilidade do *core* (Earl & Hoch, 2011). Com isso, estudos futuros devem investigar também parâmetros neuromusculares deste grupo para determinar se toda a musculatura abdominal sofre um comprometimento e determinar sua possível relação com a ausência de controle neuromuscular em atividades dinâmicas funcionais. A ultrassonografia também foi utilizada somente com a musculatura em repouso. Apesar de dificuldades

metodológicas, a fixação da sonda de ecografia na parede lateral do tronco, imediatamente acima da fossa do acetábulo, e a realização dos testes funcionais com a avaliação dinâmica da espessura dos músculos abdominais, também forneceriam mais informações sobre a relação entre a estrutura dos músculos do core e a sua função durante atividades funcionais.

5. CONCLUSÃO

Nossos resultados demonstraram que a menor espessura do OI e a baixa resistência muscular dos flexores laterais de tronco estão associadas com maiores graus de abdução do joelho. Assim, essa musculatura parece ser importante para a estabilidade do tronco e do quadril em atividades de descarga de peso e atividades funcionais em pessoas com SDPF. Essas informações, devem ser levadas em consideração em programas de reabilitação com enfoque no aumento de força e da resistência dos músculos envolvidos no core em pacientes com SDPF.

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