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Klauber Dalcero Pompeo

ARQUITETURA MUSCULAR, FUNCIONALIDADE E REABILITAÇÃO EM MULHERES COM DOR PATELOFEMORAL

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ARQUITETURA MUSCULAR, FUNCIONALIDADE E REABILITAÇÃO EM MULHERES COM DOR PATELOFEMORAL

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BANCA EXAMINADORA

Prof. Dr. Bruno Manfredini Baroni – UFCSPA

Prof. Dr. Eduardo Lusa Cadore – UFRGS

Profª Drª Lilian Ramiro Felício – UFU

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“1% de inspiração e 99% de transpiração”

Thomas Edison

ARQUITETURA MUSCULAR, FUNCIONALIDADE E REABILITAÇÃO EM MULHERES COM DOR PATELOFEMORAL

RESUMO

A Dor Patelofemoral (DPF) caracteriza-se por uma dor difusa na articulação do joelho, com consequências negativas para a qualidade de vida e funcionalidade dos pacientes. A etiologia da DPF ainda não é totalmente compreendida, sendo considerada pouco conhecida. No entanto, o consenso é de que a DPF seja de origem multifatorial, incluindo fatores locais, proximais e distais ao joelho. O tratamento conservador para DPF tem apresentado bons resultados. No entanto, a abordagem terapêutica mais adequada ainda não está clara, e o índice de sujeitos não-responsivos ao tratamento é elevado. A literatura recente tem apontado que modelos de tratamento multiarticulares, ou seja, incluindo exercícios para os fatores proximais e/ou distais, além dos exercícios para os extensores do joelho, têm apresentado melhores resultados que a intervenção tradicional. Além disso, a literatura revela uma associação entre as alterações nos padrões de movimento distais e proximais em pacientes com a DPF, o que sugere que intervenções focadas nos fatores proximais ou distais poderiam ocasionar resultados semelhantes. Entretanto, não foram encontrados na literatura estudos que tenham investigado de maneira ampla os fatores relacionados com as alterações musculares estruturais (hipotrofia) em mulheres com DPF, assim como a relação entre a arquitetura muscular e força com as alterações no padrão de movimento do membro inferior em mulheres com DPF. Também, há uma carência de estudos que comparem os efeitos de protocolos de reabilitação baseados em exercícios físicos focados nos fatores proximais e distais, associados à intervenção com enfoque local, em mulheres com DPF. Com base no exposto, a presente tese tem como objetivos: (1) verificar a presença de alterações na massa muscular (hipotrofia) do membro inferior em mulheres com DPF em comparação a mulheres saudáveis; (2) verificar se existe correlação entre os parâmetros estruturais (espessura muscular) e funcionais (força) com o alinhamento do membro inferior durante o teste de agachamento unipodal em mulheres com DPF e (3) comparar o efeito de dois modelos de tratamento sobre as variáveis clínicas e biomecânicas em mulheres com DPF. A fim de atingir esse objetivo, a presente tese foi dividida em três capítulos/estudos. No primeiro estudo (Capítulo I), foi realizado um estudo transversal que teve como objetivo comparar a espessura dos músculos que atuam nas articulações do quadril (fator proximal), joelho (fator local), e tornozelo e pé (fator distal) em mulheres com DPF (n=20) em relação a mulheres assintomáticas para DPF (n=20). Os resultados demonstraram que mulheres com DPF apresentam alterações na espessura muscular nos fatores proximal (glúteo médio = -13%), local (vasto medial = -15%, quadríceps = -9%) e distal (gastrocnêmio medial = +9%, flexor curto dos dedos = -23%, flexores plantares = +6%; músculos do pé = -12%) em comparação a mulheres saudáveis. Tais diferenças na massa muscular podem auxiliar a explicar as possíveis alterações na força e no alinhamento do membro inferior previamente observados em sujeitos com DPF. No segundo estudo (Capítulo II), foi realizado um estudo transversal, que teve por objetivo verificar a associação entre o valgo dinâmico do joelho durante o teste de agachamento unipodal e a espessura muscular e a força em mulheres com DPF (n=55) e sem DPF (n=20). Os resultados apontam uma correlação negativa entre a espessura dos músculos tibial anterior (r= -0,28) e glúteo máximo (r= -0,32) e o valgo dinâmico. Além disso, observou-se que a espessura do glúteo máximo explicou 10% do valgo dinâmico nas mulheres com DPF. Os dados obtidos apontam que tanto fatores proximais quanto distais influenciam de modo similar o alinhamento dinâmico do membro inferior em mulheres com DPF. No terceiro estudo (Capítulo III), foi realizado um estudo longitudinal, que teve por objetivo comparar os efeitos de dois modelos de reabilitação com 12 semanas de duração para DPF, sendo um modelo focado nos fatores proximal e local (PLT, n=25) e o segundo focado nos fatores distal e local (DLT, n=25), sobre a dor, funcionalidade, valgo dinâmico, espessura muscular e força em mulheres com DPF. Os dois protocolos de reabilitação foram efetivos na redução da dor (PLT= -47%, DLT= -43%) e melhora na funcionalidade (PLT = 14%, DLT = 9%) sem diferenças entre os programas de reabilitação após 12 semanas. Além disso, ao final do tratamento, ambos protocolos foram efetivos no aumento da força, hipertrofia e realinhamento do membro inferior durante o agachamento unipodal. Os resultados obtidos na presente tese demonstram que: (1) mulheres com DPF apresentam simultaneamente alterações na espessura muscular nos níveis proximais, locais e distais em relação a mulheres saudáveis; (2) a espessura muscular de músculos proximais e distais está negativamente associada com a magnitude do valgo dinâmico durante a execução do agachamento unipodal em mulheres com DPF, quanto menor a espessura maior o valgo dinâmico e (3) a utilização de protocolos de intervenção multiarticulares, focados nos fatores proximais e distais em associação com o fator local, apresentam resultados semelhantes na reabilitação de mulheres com DPF. Este estudo foi aprovado no CEP da UFRGS (nº 2.089.328) e registrado no *Clinical Trials* (nº NCT03663595).

Palavras-Chave: Dor patelofemoral, espessura muscular, valgo dinâmico, reabilitação multiarticular.

MUSCLE ARCHITECTURE, FUNCTIONALITY AND REHABILITATION IN WOMEN WITH PATELLOFEMORAL PAIN

ABSTRACT

Patellofemoral pain (PFP) is characterized by diffuse pain around the knee joint with negative consequences in the patients' quality of life and functionality. PFP etiology is not fully understood, being considered an orthopedic enigma. However, the consensus is that etiology is multifactorial, including local factors, proximal factors, and distal factors. PFP is not a degenerative syndrome, and conservative treatments have offered good results. However, the most appropriated therapeutic approach is still unclear, and the rate of non-responders to treatment is high. The traditional intervention model focused only on strengthening knee extensor muscles, as the mechanism was thought to be localized exclusively at the knee joint. However, the recent literature has pointed out that multiarticular treatment models, including exercises for proximal or distal factors, in addition to exercises for the knee extensors, have shown better results than the traditional model. In addition, there is an association between changes in distal and proximal movement patterns in PFP subjects, which suggest that intervention programs focused in proximal or local factors may have similar effects. However, no previous studies evaluated, in a comprehensive manner, proximal, local and distal factors related to muscle structural changes (hypotrophy) in women with PFP, as well as the relationship between muscle architecture and muscle strength with abnormal lower limb movement patterns in women with PFP. There is a lack of studies comparing the effects of treatment models focused on proximal or distal factors, and that were associated with the knee, in women with PFP. Based on the above-mentioned aspects, the purpose of this thesis was to: (1) verify the presence of muscle mass loss (hypotrophy) in the lower limb of women with PFP compared to healthy women; (2) verify whether there is a correlation between structural (muscle thickness) and functional (strength) parameters with lower limb alignment during single-leg squat in women with PFP and (3) to evaluate two treatment models' effects on clinical and biomechanical properties in young women symptomatic for PFP through a randomized clinical trial. In order to achieve this goal, this thesis was divided into three chapters/studies. In the first study (Chapter I), a cross-sectional study was carried out, comparing muscle thickness of the muscles acting at the hip (proximal factor), knee (local factor), and ankle-foot (distal factor) joints in women with PFP (n=20) in comparison to healthy women (n=20). The results showed that women with PFP present changes in muscle thickness in the proximal (gluteus medius = -13%), local (vastus medialis = -15%, quadriceps = -9%) and distal (gastrocnemius medialis = +9%, flexor digitorum brevis = -23%, plantar flexors = +6%, foot muscles = -12%) factors compared to healthy women. Such differences in muscle mass can help explain the possible changes in strength and lower limb alignment previously observed in patients with PFP. In the second study (Chapter II), a cross-sectional correlational study was carried out to verify the association between the dynamic knee valgus during single leg squat with muscle thickness and muscle strength in women with PFP (n=55) and without PFP (n=20). We observed a negative association between muscle thickness of tibialis anterior (r=-0.28) and gluteus maximus (r=-0.32) and dynamic knee valgus. In addition, gluteus maximus muscle thickness explained 10% of the dynamic knee valgus in women with PFP. These results show that both proximal and distal factors have similar influence in lower limb alignment in women with PFP. In the third study (Chapter III), a longitudinal study was carried out to compare the effects of two 12-week treatment models, one focused in proximal and local factors (PLT, n=25) and the second focused in distal and local factors (DLT, n=25), on pain, functionality, dynamic valgus, muscle thickness and strength in women with PFP. Both rehabilitation programs were effective in reducing pain (PLT= -47%, DLT= -43%) and improving functionality (PLT= +14%, DLT= +9%) without significant differences between rehabilitation programs after 12 weeks. In addition, at the end of the treatment, both protocols were effective in increasing strength, hypertrophy and realignment of the lower limb during single leg squat. The results obtained in the present thesis demonstrated that: (1) women with PFP present changes in muscle thickness at proximal, local and distal-to-the-knee joints; (2) there is an association between muscle thickness and the magnitude of dynamic valgus index in single-leg squat in women with PFP; and (3) multiarticular intervention programs, focused on proximal or distal factors in association to local factors, present overall similar results in the rehabilitation of women with PFP. This study was approved at CEP of UFRGS (n°2.089.328) and registered in Clinical Trials (nº NCT03663595).

Keywords: patellofemoral pain, muscle thickness, dynamic valgus, multiarticular rehabilitation

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APRESENTAÇÃO

A Dor Patelofemoral (DPF) é caracterizada por uma dor retropatelar e/ou peripatelar na articulação do joelho, principalmente em atividades em que articulação do joelho é sobrecarregada em flexão, como por exemplo, agachar e subir e descer escadas[1]. A DPF é a condição clínica mais comumente observada na medicina esportiva afetando principalmente as mulheres[2,3], reduzindo a qualidade de vida e a performance funcional dos acometidos pela DPF[4,5]. A etiologia da DPF é multifatorial, com alterações biomecânicas nos chamados fatores proximais (relacionado a modificações ao nível do tronco e o quadril), fatores locais (relacionado a modificações nas estruturas que atuam diretamente na articulação do joelho) e fatores distais (relacionado a alterações ao nível do tornozelo e pé)[6]. A melhor compreensão desses fatores biomecânicos relacionados com a DPF e suas inter-relações se torna necessária para o desenvolvimento de programas de intervenção adequados e com alta taxa de sucesso de tratamento e, consequentemente, a reversão ou minimização dos efeitos deletérios produzidos pela DPF.

Dessa forma, a presente tese tem como objetivos: (1) verificar a presença de alterações na massa muscular (hipotrofia) do membro inferior em mulheres com DPF em comparação a mulheres saudáveis; (2) verificar se existe correlação entre os parâmetros estruturais (espessura muscular) e funcionais (força) com o alinhamento do membro inferior durante o teste de agachamento unipodal em mulheres com DPF e (3) comparar o efeito de dois modelos de tratamento sobre as variáveis clínicas e biomecânicas em mulheres com DPF.

Com base no exposto, a tese está dividida em uma introdução geral e 3 capítulos, sendo cada capítulo composto por um artigo original, escrito em língua inglesa e já elaborado no formato da revista a qual cada um dos artigos foi ou será submetido futuramente.

No capítulo I, intitulado *"Proximal, Local and Distal Muscle Morphology in Women with Patellofemoral Pain"*, através da técnica de ultrassonografia, avaliamos se mulheres com DPF apresentam diferenças na espessura muscular em músculos que atuam nas articulações do quadril, joelho, tornozelo e pé, em comparação a mulheres saudáveis. Os músculos analisados foram: tensor da fáscia lata, glúteo médio, glúteo máximo, reto femoral, vasto lateral, vasto medial, sóleo, gastrocnêmio, fibulares longo e curto, tibial anterior, flexor longo dos dedos, flexor curto dos dedos, flexor curto do hálux e abdutor do hálux. Além disso, comparamos a massa muscular, a partir do somatório das espessuras musculares de músculos que apresentam função semelhante. Os grupos musculares avaliados foram: posterolateral do quadril, quadríceps, flexores plantares e músculos do pé. Este estudo já foi submetido e se encontra aceito para publicação no *Journal of Diagnostic Medical Sonography.* Como resultados, observamos que mulheres com DPF apresentam simultaneamente alterações na espessura muscular em músculos proximais, locais e distais, em comparação a mulheres sem DPF. Tais alterações evidenciam a necessidade de um programa de intervenção com enfoque global no membro inferior em mulheres com DPF. Além disso, com base nos resultados obtidos no Capítulo 1, nos questionamos se essas modificações na espessura muscular presentes em mulheres com DPF poderiam estar associados ao desalinhamento dinâmico do membro inferior, mais especificamente, sobre o valgo dinâmico durante tarefas de descarga de peso. Com base no exposto, desenvolvemos o estudo presente no Capítulo II.

No Capítulo II, intitulado *"Proximal and Distal Muscle Thicknesses are Negatively Associated with Dynamic Knee Valgus During Single-Leg Squat in Women With Patellofemoral Pain",* buscamos observar se a espessura muscular e o torque de músculos que atuam na articulação do quadril, joelho e pé se correlacionam o Valgo Dinâmico durante a execução do Teste de Agachamento Unipodal em mulheres com DPF e mulheres saudáveis. Foram avaliadas as espessuras dos músculos glúteo médio, glúteo máximo, vasto lateral e tibial anterior, através da técnica de ultrassonografia. Além disso, o torque dos músculos abdutores e rotadores externos do quadril, extensores do joelho e inversores do pé foram avaliados através da técnica de dinamometria manual. Nossos resultados demonstraram que a espessura muscular de músculos proximais e distais, mais especificamente do glúteo máximo e tibial anterior, estão negativamente correlacionados com o valgo dinâmico em mulheres com DPF. Estes resultados novamente demonstram a necessidade de um programa de intervenção multiarticular com enfoque no fortalecimento e consequentemente hipertrofia muscular no membro inferior. No entanto, nenhum estudo se propôs a comparar os efeitos de modelos de intervenção focado nos músculos proximais ou músculos distais, associados aos músculos que atuam na articulação do joelho em mulheres com DPF. Com base no exposto, desenvolvemos o estudo presente no Capítulo III.

No Capítulo III, intitulado *“Targeting Proximal and Local Muscles is Better than Targeting Distal and Local Muscles in a Rehabilitation Program for Patellofemoral Pain? A double blind randomized clinical trial”,* comparamos os efeitos de dois modelos de reabilitação baseados em exercícios físicos em mulheres com DPF. O primeiro modelo de programa de reabilitação tinha como foco os exercícios para os músculos “proximais e locais” e, o segundo modelo, foco nos músculos “distais e locais”. O programa de reabilitação teve duração de 12 semanas, com avaliações ocorrendo em 3 momentos (pré-intervenção; após 6 semanas e após 12 semanas). Foram mensurados: níveis de dor, através da escala numérica de dor; funcionalidade, através do Questionário Kujala; massa muscular, através da ultrassonografia; índice de valgo dinâmico no Teste de Agachamento Unipodal; e força isométrica dos abdutores do quadril, rotadores externos do quadril, extensores do quadril, extensores do joelho, flexores do joelho, eversores do pé e inversores do pé, através da dinamometria manual. A partir dos dados obtidos, observamos que a utilização de um programa de reabilitação focado nos músculos proximais e locais, apresenta, de uma forma geral, resultados semelhantes aos obtidos quando aplicamos um programa de reabilitação com enfoque nos músculos distais e locais para mulheres com DPF.

INTRODUÇÃO

A Dor Patelofemoral (DPF) é caracterizada por uma dor retropatelar e/ou peripatelar na articulação do joelho, principalmente em atividades excêntricas em que articulação do joelho é sobrecarregada em flexão, como, por exemplo, agachar e descer escadas[1]. A DPF é uma das condições clínicas mais comumente observadas na prática clínica geral[7] e a condição clínica mais comum na medicina esportiva, representando 20% de todas as lesões na corrida e que afeta principalmente as mulheres[2,3]. Considerando dados de prevalência e incidência, observa-se que a incidência de DPF é 2,2 vezes maior nas mulheres que nos homens, com uma prevalência anual na população adulta geral de 22%, nas mulheres de 29% e nos homens de 15%[8], considerando apenas mulheres adultas jovens, com idade entre 18 e 35 anos, estima-se que a prevalência seja de 12-13%[9]. Além disso, mais de 90% dos sujeitos acometidos pela DPF apresentam sintomas até 20 anos após o início da DPF[10,11]. Tais sintomas trazem prejuízo na qualidade de vida[4,5] e na performance funcional[12] dos sujeitos acometidos pela DPF. Inclusive, a DPF tem sido sugerida como um dos fatores precursores da osteoartrite patelofemoral[13].

A etiologia da DPF ainda não é totalmente compreendida, uma vez que existe uma complexa relação entre as influências anatômicas, biomecânicas, psicológicas, sociais e comportamentais[14]. Considerando apenas as influências anatômicas e biomecânicas, o consenso é que a DPF seja de origem multifatorial, com déficits sendo observados nas articulações do tronco e quadril (fatores proximais), joelho (fator local) e tornozelo e pé (fatores distais)[6]. No entanto, tem sido observado que as alterações nesses fatores relacionados com a presença da DPF não ocorrem de maneira isolada, mas sim concomitantemente, envolvendo no mínimo dois desses fatores[15–17]. Por exemplo, Ferrari et al (2018)[16] observaram que todos os sujeitos analisados apresentavam alterações cinemáticas em pelo menos dois fatores (52%) ou então, nos três fatores (42%), enquanto Oliveira et al (2014)[17] observaram menor força de rotadores mediais do quadril (22%) e extensores do joelho (23%) em sujeitos com DPF comparados a sujeitos saudáveis.

A arquitetura muscular determina de maneira significativa a funcionalidade do músculo esquelético[18], e um dos parâmetros de arquitetura muscular que é positivamente correlacionado com a capacidade de produção de força máxima do músculo é a espessura muscular[19]. Uma das alterações mais comumente observadas em sujeitos com DPF é a presença de fraqueza muscular[15,20,21]. Além disso, uma menor espessura muscular tem sido relacionada com maiores níveis de dor[22], demonstrando que alterações na estrutura muscular afetam a funcionalidade e o *status* clínico de sujeitos acometidos pela DPF. No entanto, a presença de alterações na morfologia muscular tem apresentado resultados controversos, seja no fator local (músculo quadríceps)[23–27] ou em músculos proximais[22,28,29] (quadril e tronco). Em relação ao músculos intrínsecos e extrínsecos da articulação do pé (fator distal), um estudo observou uma menor área de secção transversa dos músculos do pé em sujeitos com pé pronado e com lesões por excesso de uso, entre elas a DPF[30]. Portanto, existe uma controvérsia na literatura em relação a presença ou não de alterações na morfologia muscular em sujeitos com DPF, além de uma escassez de estudos que se propuseram a avaliar a morfologia muscular nas articulações distais do membro inferior especificamente em sujeitos com DPF.

A presença de alterações na cinemática do membro inferior em tarefas funcionais de descarga de peso tem sido amplamente observada em sujeitos acometidos pela DPF[15,16,31,32]. A combinação de adução e rotação interna do quadril excessivas durante atividades de descarga de peso tem potencial para afetar a cinemática de todo o membro inferior, medializando o joelho em relação ao pé e fazendo com que a tíbia se movimente em abdução e o pé em pronação. O resultado final dessa combinação é chamado de valgo dinâmico[33]. Também tem sido proposto que alterações na dinâmica das articulações do tornozelo e pé, como por exemplo, a pronação excessiva, uma das possíveis alterações distais presentes em sujeitos com DPF[34], podem gerar movimentos compensatórios na articulação do quadril e, consequentemente, alterar a homeostase da mecânica patelofemoral, aumentando a compressão entre a patela e o fêmur, o que pode gerar dor nessa articulação[35].

A relação entre o valgo dinâmico do joelho e a força do quadril tem se mostrado dependente da tarefa. Por exemplo, durante o agachamento unipodal, somente a redução na força dos abdutores do quadril foi associada ao valgo dinâmico[36]. Por outro lado, o aumento de 20% na força dos abdutores do quadril normalizada pelo peso corporal, melhora em 4º o valgo do joelho[37], sendo essa diferença de 4º semelhante à encontrada na adução do quadril entre sujeitos saudáveis e com DPF[15].

Considerando que a espessura muscular apresenta correlação significativa com a força muscular[19], sugere-se que alterações na espessura muscular (hipotrofia), podem alterar negativamente a dinâmica do membro inferior durante tarefas funcionais. Segundo o nosso conhecimento, somente um estudo buscou verificar a relação entre a espessura muscular e o alinhamento do membro inferior em mulheres com DPF, não encontrando correlações significativas[38]. A partir do exposto, observa-se uma carência de estudos e a necessidades de novas investigações, a fim de elucidar a possível relação existente entre a espessura dos músculos que atuam nas articulações do membro inferior e o alinhamento do membro inferior durante tarefas funcionais em mulheres com DPF.

Os programas de reabilitação para DPF tradicionalmente focavam apenas na articulação do joelho, apresentando resultados efetivos na redução da dor e melhora na funcionalidade[39]. No entanto, observa-se que a adição de exercícios para os músculos proximais, em associação com os exercícios para os músculos que atuam diretamente no joelho, tem mostrado melhores resultados que os programas de intervenção focados somente no fortalecimento dos músculos do joelho[39–41]. Resultados semelhantes foram observados quando intervenções focadas nos fatores distais são associadas ao fortalecimento dos extensores do joelho, sendo que o grupo com intervenção multiarticular apresentou melhores resultados[34]. A partir dos resultados supracitados, observa-se que programas de reabilitação multiarticulares, ou seja, focados no fortalecimento de músculos proximais ou distais, em associação aos músculos que atuam diretamente no joelho apresentam melhores resultados que a intervenção tradicionalmente usada. Entretanto, até o momento nenhum estudo se propôs a comparar os efeitos de um protocolo de reabilitação para DPF utilizando-se exercícios focados nos músculos proximais e locais, em relação a utilização de exercícios focados nos músculos distais e locais. Levanta-se a hipótese, em função da associação observada entre a cinemática distal e proximal em sujeitos com DPF, que programas de reabilitação com enfoque nos fatores distais ou proximais possivelmente gerariam resultados semelhantes no tratamento da DPF[42]. No entanto, essa hipótese precisa ser investigada.

Com base no exposto anteriormente, três questões principais norteiam a presente tese: (1) existem diferenças na espessura muscular de músculos proximais, locais e distais em mulheres com DPF em comparação a mulheres saudáveis; (2) existe correlação entre a espessura muscular e a força com o alinhamento do membro inferior durante a execução de uma tarefa funcional de descarga de peso em mulheres com DPF; e (3) quais são os efeitos de dois modelos de protocolos de intervenção baseados em exercícios físicos com enfoque nos músculos proximais ou distais, em associação aos músculos que atuam na articulação do joelho em mulheres com DPF? Os capítulos 1, 2 e 3 da presente tese pretendem responder cada uma dessas perguntas, respectivamente.

CHAPTER 1 - PROXIMAL, LOCAL AND DISTAL MUSCLE MORPHOLOGY IN WOMEN WITH PATELLOFEMORAL PAIN

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1.1 Abstract

Objective: Compare proximal, local and distal muscle morphology in women with and without patellofemoral pain (PFP). **Materials and Methods:** Proximal, local and distal muscles' thicknesses (MT) were obtained by B-mode ultrasound images in healthy (control group - CG, n=20) and PFP (PFP group, n=20) women. Additionally, muscle mass was measured by the sum of the synergists' MT. Data were analyzed by independent t-test, Mann-Whitney U test, and by effect size. **Results:** PFP women had smaller gluteus medius (p=0.02, *d*=0.7), vastus medialis (p<0.01, *d*=1.0) and flexor digitorum brevis (p<0.01, *d*=1.0) and greater gastrocnemius medialis (p=0.04, *d*=0.6) MT than CG. Quadriceps muscle mass (p=0.01, *d*=0.8) and foot muscle mass (p=0.008, *d*= 0.9) were smaller while plantar flexors' muscle mass was greater in PFP group than CG (p=0.01, *d*=0.8). **Conclusion:** PFP women have proximal, local and distal MT alterations in comparison to CG that may explain possible changes in muscle strength and functionality.

Keywords: ultrasound, patellofemoral pain, women, muscle morphology

1.2 Introduction

Patellofemoral pain (PFP) is characterized by retropatelar and/or peripatelar pain, usually during activities involving knee flexion, such as squats and stair ascent and descent[1]. PFP is the most common clinical knee manifestation in sports medicine[3]. It has been related to 11-17% of all knee injuries[7,43] and 20% of all running-related injuries[3]. In addition, there is a higher PFP incidence in women[44], and more than 90% of people with PFP have persistent pain up to 20 years after the symptoms onset[10,11], which impairs the patients' functional performance and reduces their quality of life [4,5,12].

A common clinical finding on PFP is muscle weakness[15,20,21], and the mechanisms related to muscle strength deficits are commonly attributed to central (i.e., neural)[45] and peripheral (i.e., skeletal muscle) parameters[20]. One of the important skeletal muscle structural parameters is muscle thickness (MT), as it has a positive correlation to the maximum voluntary contraction[19]. In addition, a smaller MT was associated with higher levels of pain in PFP[22], demonstrating a clinical effect of PFP in skeletal muscle structural parameters that may affect functionality. However, although the knee extensor muscles are directly involved in PFP, muscle morphology studies in PFP patients revealed controversial results. While some studies found no difference between PFP and asymptomatic subjects for quadriceps muscle morphology (i.e., MT and cross-sectional area)[23,24], others reported significant deficits (i.e., volume, pennation angle and cross-sectional area) on the PFP group[25–27]. Similarly, while a smaller cross-sectional area of foot muscles was observed in individuals with pronated feet and symptomatic overuse injuries in the lower extremity (among them PFP)[30], controversial findings were observed in proximal muscles acting at the pelvis and hip joint[22,28,29]. While trunk muscles' (internal and external oblique) MT appears to be smaller in PFP[22], no differences were observed in the gluteus medius and gluteus maximus compared to asymptomatic subjects[28,29].

PFP etiology is multifactorial, with biomechanical deficits being observed at hip/trunk (proximal factors), knee (local factor) and ankle/foot (distal factors) in PFP patients[6]. Changes in MT of synergistic muscles may also change their impact on musculoskeletal biomechanical properties. In the quadriceps muscle, for example, a reduction in the vastus medialis (VM) relative to vastus lateralis (VL) size has been considered a factor responsible for the poor patellar tracking during knee flexion and extension movements[26,46]. This between-synergists size difference may lead to different pressure regions at the articular cartilage surface of the patella and the femur, which may cause cartilage degeneration, thereby leading to joint pain. Similarly, distal muscles are responsible for controlling the foot movements during functional tasks[30], and abnormal foot movements are linked to lower limb misalignment[35]. Intrinsic foot muscles can control foot posture and counteract the medial longitudinal arch deformation[30,47], which may also affect lower limb alignment. Therefore, changes in distal muscle structure may lead to abnormal limb function that may contribute to PFP.

Despite the above-mentioned evidence of the muscle structure deficits in PFP, to our knowledge, no previous studies made a comprehensive evaluation of the lower limb muscles' morphology encompassing muscles that act proximally to the knee (hip), locally at the knee and distally to the knee (ankle/foot) in PFP women. Thus, we aim to evaluate the lower limb muscle morphology and muscle mass of synergistic muscles in women with PFP and compare it to a matched healthy women control group (CG). We hypothesize that young women with PFP will have lower MT of individuals muscles and lower muscle mass of synergistic muscles at all lower limb joints compared to the healthy CG.

1.3 Materials and Methods

1.3.1 Study design

In this cross-sectional study, women with PFP and healthy women without PFP attended a single session of ultrasound (US) evaluations. CG subjects were recruited from the university where the study was conducted, whereas PFP patients were recruited through posted flyers at the university and social medial advertisements. The evaluations were developed between October of 2018 and May of 2019.

This study was approved by the University's Ethics Committee for Human Research (Protocol nr. 2.089.328), and prospectively registered on Clinical Trials (nr. NCT03663595). All participants were informed of the benefits and risks of the investigation before signing an institutionally approved informed consent document to participate in the study.

1.3.2 Participants

The sample size was determined a priori based on a previous study of our research group (unpublished data), which observed a 10% difference in quadriceps muscle mass between women with and without PFP (PFP= 4.7±0.6 cm; CG= 5.2±0.6 cm), with an effect size (ES) of 0.88, and observed power of 1-β >0.80 and alpha level equal to 0.05 using a statistical package (G*Power 3.1.3, Frauz Faur Universität Kiel, Germany)[48]. The quadriceps muscle mass was considered for sample size determination because the generalized quadriceps atrophy (and the resulting muscle weakness)[20,23,25,26,49–51] is the most evident factor in idiopathic PFP. In addition, muscle atrophy is directly related to muscle weakness, and quadriceps weakness is the only prospective risk factor for PFP with at least moderated evidence in the PFP population[50]. A minimum sample size of 17 subjects per group was indicated. However, due to possible losses, twenty participants per group were recruited in a total of 40 women between 18 and 42 years of age. Anthropometric characteristics of both groups and PFP clinical data are presented in Table 1.

1.3.3 Eligibility criteria

The CG group was composed of healthy women with similar characteristics (body mass, height, age, body mass index, physical activity level) as those of the PFP group, but with no pain symptoms at the knee joint and no history of lower limb injury. Also, CG subjects had no physical limitations at the lower limb that could affect the functionality during daily living activities or sports participation. A physiotherapist, with six years of clinical experience, evaluated PFP participants based on the following inclusion criteria: (1) self-report peripatelar or retropatelar pain in at least two of the following situations: squatting, running, kneeling, jumping, climbing or descending stairs, sitting for a long time, sitting with knees flexed; (2) present ongoing patellar pain for at least 3 months before the study start; (3) a minimum level of 3 out of a 10 numeric rating scale for knee pain, where 0 and 10 correspond to “no” and “intolerable pain discomfort”, respectively; (4) beginning of PFP not related to trauma; (5) not participating at any PFP treatment in the last 12 months; and (6) testing positive for the patellar grind test (Clarke's Sign, in which the patella is compressed against the trochlea manually while the clinician asks the patient to contract the quadriceps, and the test is positive if the patient reports pain). Participants were excluded from the PFP group if they presented signs or symptoms of (1) meniscal or other intra-articular pathologies; (2) signs of patellar apprehension; (3) history of hip, knee or ankle joint injury; (4) evidence of joint effusion; and (5) history of patellofemoral joint surgery.

1.3.4 Procedures

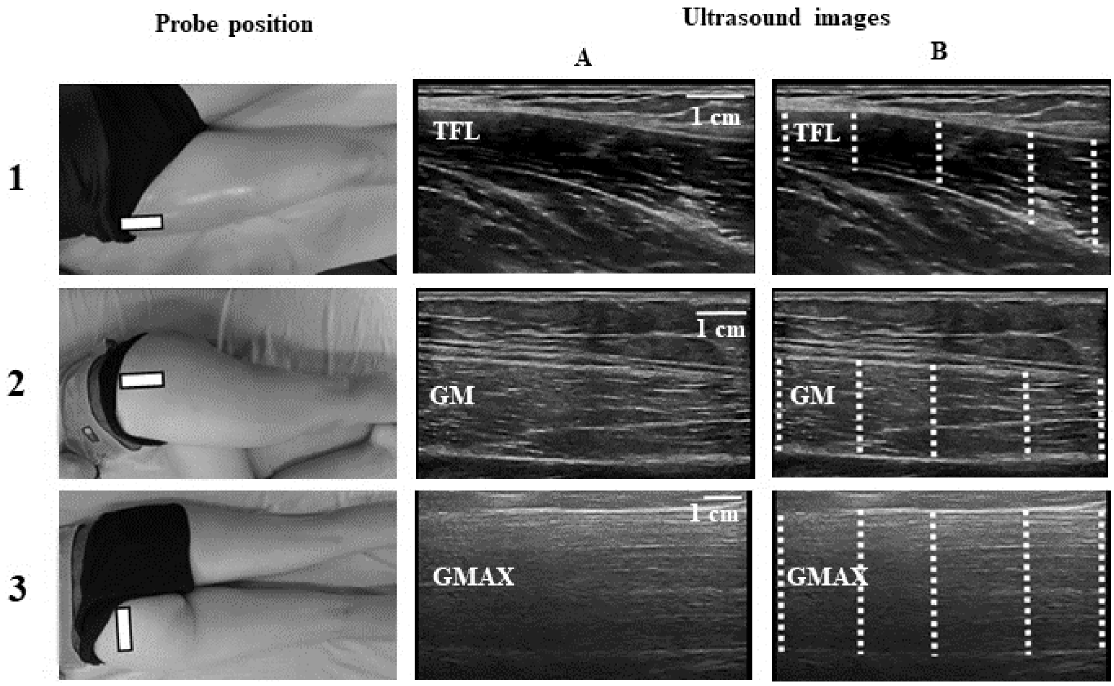
CG and PFP group subjects were instructed to not participate in any vigorous activity 48 hours before the tests. As previous studies did not observe a significant difference in muscle morphology between the dominant and non-dominant sides in healthy women or a group of healthy subjects (male/female)[24,52], only the dominant limb (used to kick a ball) was evaluated in CG. In PFP patients with unilateral pain, only the affected limb was assessed. In patients with bilateral pain, the evaluation was performed in the limb with the worst symptoms. We did not match PFP and CG based on dominance because only 32% of the subjects with unilateral PFP had symptoms in their dominant limb[23], and there is a significant difference in muscle morphology between the affected and unaffected side in women with PFP[20,24]. In addition, MT was negatively related to pain levels[22], and we expected that PFP subjects with bilateral symptoms would have significant muscle atrophy on the limb with the worst symptoms.

Before the US evaluations, the participants' physical activity level was measured using the short form of the 7-day self-administered International Physical Activity Questionnaire (IPAQ). Additionally, PFP participants were requested to complete the Kujala Questionnaire[53] for determining knee functionality level. This questionnaire has a functionality score (AKPS) ranging from 0 to 100, where the higher values indicated better functionality. Finally, a numeric rating scale was used to determine the PFP participants' knee pain level in the previous week.

1.3.4.1 Ultrasound assessment

A B-mode ultrasonography system (Logiq P6, GE Healthcare, Waukesha, Washington, United States of America) with a matrix linear-array probe (60mm linear array ML6-15, 5-15Mhz – GE Healthcare, Waukesha, Washington, United States of America) was used for US measurements. A researcher with 7 years of experience with the musculoskeletal US performed all measurements and data analyses. The researcher who conducted the US assessments was not blinded to the clinical status of the subjects (PFP or CG). All US images were obtained in a relaxed condition, as previously described in the literature[54–56], on a single session (~ 60 min), after the subjects laid down on a stretcher in a supine position for a period of 5 to 10 minutes to re-establish body fluids[57].

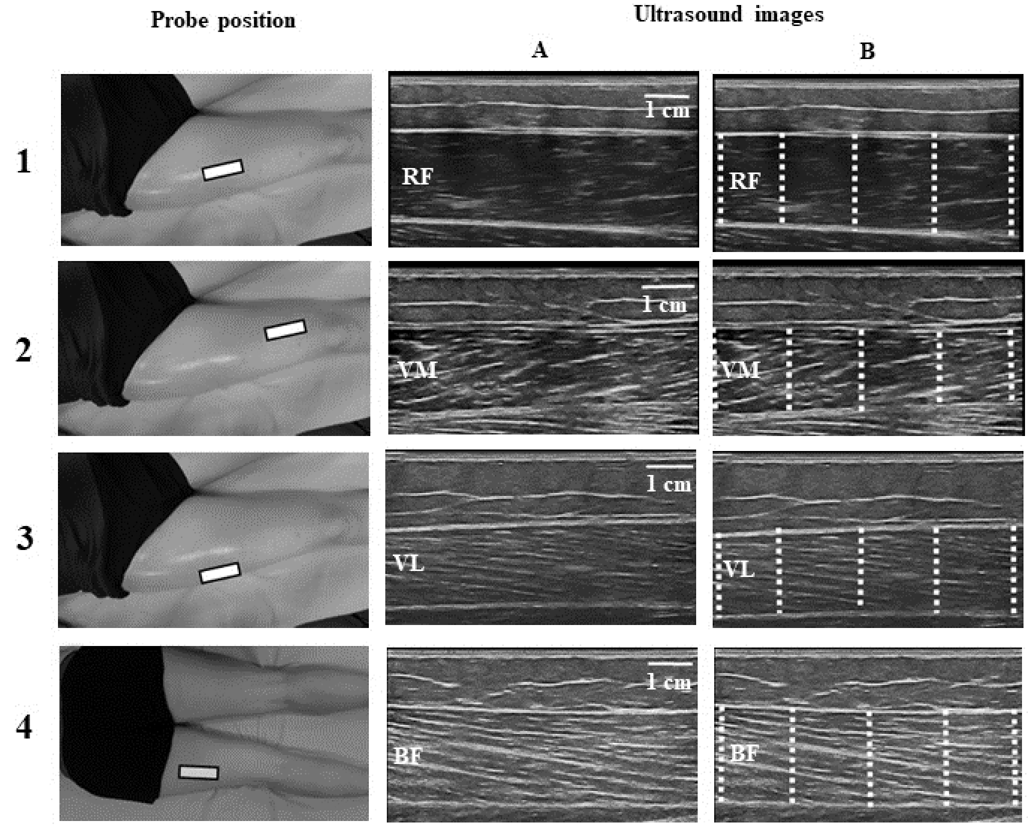
Muscle thickness (MT) of the proximal [tensor fasciae latae (TFL), gluteus medius (GM), gluteus maximus (GMAX)], local [rectus femoris (RF), vastus medialis (VM), vastus lateralis (VL), biceps femoris (BF)], and distal [peroneus longus and brevis (PLB), tibialis anterior (TA), gastrocnemius medialis (GMED), soleus (SOL), flexor digitorum longus (FDL), flexor digitorum brevis (FDB), flexor hallucis brevis (FHB) and abductor hallucis (ABH)] muscles to the knee joint was evaluated. Participants laid down in the supine position with hip, knee, ankle and foot at the neutral position for TFL, RF, VM, VL, TA, PLB, FLD, FDB and ABH evaluations. For GM, participants were placed in a lateral position, with the hip in the neutral position. And for GMAX, BF, GMED, and SOL, subjects were placed in a prone position with hip, knee, and ankle in the neutral position. Additional information about probe position and representative US images of proximal muscles are presented in Figure 1, local muscles in Figure 2 and distal muscles in Figure 3.



Legend: 1 – Tensor fascia latae (TFL), transducer was place in the axial plane over the anterior superior iliac spin; 2 – Gluteus medius (GM), transducer was place in the axial plane at the midway point between the proximal end of the iliac crest and the femur's greater trochanter; 3 – Gluteus maximus (GMAX), transducer was placed in the transversal plane at one-third of the distance between the posterior superior iliac spine and the greater trochanter. White rectangle represents the probe position, and dashed lines represent the MT assessment points.

Figure 1. Proximal muscles to the knee joint, with probe position and representative examples of US images (A) and their respective muscle thickness assessment points (B).

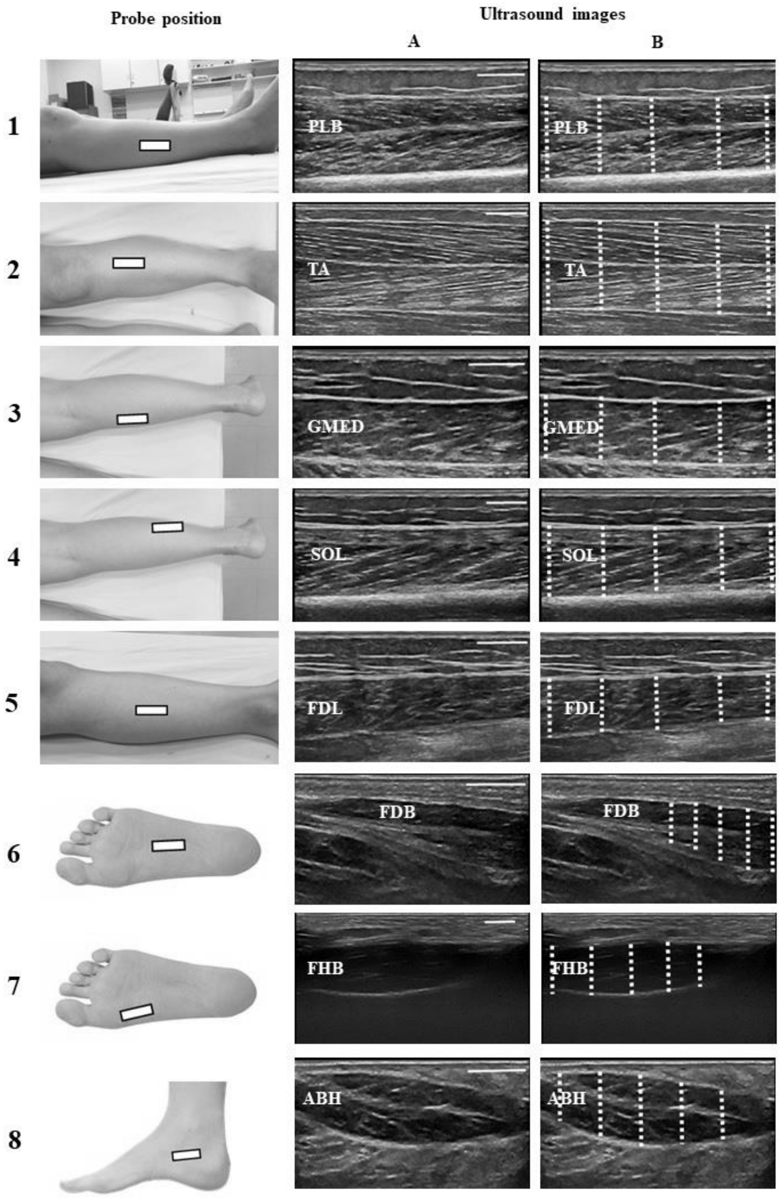
Muscle mass was obtained for different lower limb regions by summing the MTs from synergistic muscles (i.e., with similar function) in these regions[23,54,55]. Therefore, hip posterolateral muscle mass was obtained from GM and GMAX, quadriceps mass was obtained from RF, VM and VL, plantar flexor muscle mass from GMED and SOL, and foot muscle mass from FDB, FHB, and ABH.



Legend: 1 – Rectus femoris (RF), transducer was placed in the axial plane at midway point between the great trochanter and the femur lateral condyle; 2 – Vastus medialis (VM), transducer was place in the axial plane at 25-30% between the great trochanter and the femur lateral condyle; 3 – Vastus lateralis (VL), transducer was place in the axial plane at midway point laterally to RF over VL between the great trochanter and the femur lateral condyle; 3 – Biceps femoris (BF), transducer was placed in the axial plane at midway point between ischial tuberosity and lateral condyle of tibia. White rectangle represents the probe position and dashed lines represent the MT assessment points.

Figure 2.Local muscles to the knee joint, with probe position and representative examples of US images (A) and their respective muscle thickness assessment points (B).

Mean values were obtained from three US images for each muscle to determine MT. US images were analyzed using the Image-J software (National Institute of Health, USA) according to procedures previously described[54]. MT was considered the distance between deep and superficial aponeuroses and was calculated through the mean value of 5 parallel lines drawn at right angles between the superficial and deep aponeuroses along each US image (Figures 1 to 3). Reliability analysis was conducted by having the same analyst reanalyzing the images in the same manner with an interval of 7-10 days after the first analysis.



Legend: 1 – Peroneus longus and brevis (PLB), transducer was placed in the axial plane at the midway point (50%) between the fibular head and the lateral malleolus' inferior border; 2 – Tibialis anterior (TA), transducer was placed proximally in the axial plane, at 30% of the line between the fibula's lateral malleolus and the femur's condyle; 3 – Gastrocnemius medialis (GMED), transducer was placed in the axial plane over the medial gastrocnemius head at 30% proximally between the popliteal crease and the lateral malleolus; 4 – Soleus (SOL), transducer was placed in the axial plane at the midway point between the popliteal crease and the lateral malleolus; 5 – Flexor digitorum longus (FDL), transducer was placed in the axial plane at the midway point between the medial tibial plateau and the medial malleolus' inferior border; 6 – Flexor digitorum brevis (FDB), transducer was placed perpendicular to a line from the calcaneus medial tubercle to the third toe; 7 – Flexor hallucis brevis (FHB), transducer was placed perpendicular to a line parallel to the muscle; 8 – Abbductor hallucis (ABH), transducer was placed along a line perpendicular to the long axis of the foot at the anterior aspect of the medial malleolus. White rectangle represents the probe position and dashed lines represent the MT assessment points.

Figure 3. Distal muscles to the knee joint, with probe position and representative examples of US images (A) and their respective muscle thickness assessment points (B).

1.3.5 Statistical analysis

All statistical tests were performed with SPSS (version 22.0; SPSS Inc., Chicago, IL). Shapiro-Wilk tests were used to verify data normality. An independent t-test or a Mann-Whitney U test was used to compare groups for age, anthropometric characteristics, physical activity level, and study outcomes. Fisher's exact test was used to test the difference in the assessed limb sides between the groups. The between-groups effect sizes (ES) were calculated through the Cohen's *d*, and classified as trivial (<0.2), small (>0.2), moderate (>0.5), large (>0.8), or very large (>1.3)[58].

An intraclass correlation coefficient (ICC) was applied to verify the intra-rater reliability in 10 participants (5 PFP group and 5 CG). The participants' selection for the reliability analysis was random. Intraclass correlation coefficient (ICC) values were classified as indicating no reliability for values between 0.00 to 0.25, poor reliability for 0.26 to 0.49, moderate reliability for 0.50 to 0.69, high reliability for 0.70 to 0.89, and very high reliability for values between 0.90 to 1.00[59]. The minimum detectable difference (MDD) was also used to define the smallest difference that can be detected that is not due to chance or systematic error. The MDD was calculated using the following equation: $MDD = 1.96 \times \sqrt{2} \times SEM$, where SEM means the standard error of measurement[59]. All statistical analyses used a significance level of $\alpha \leq 0.05$.

1.4 Results

PFP and CG participants were similar for age, anthropometric characteristics and physical activity level (Table 1). The PFP group's AKPS self-reported function was 70.5 points, the usual pain level was 4.7, and 95% of the patients had the symptoms' onset at least six months prior to the tests (Table 1). Eleven (55%) participants in the PFP group had pain symptoms or the worst symptoms in their dominant limb, and 55% of PFP patients had the right side assessed. In CG, 95% of participants had the right side assessed.

Except for BF MT's between-groups comparison, all analyses were made with an independent T-test. The MT of GM (-13.4%), VM (-15%) and FDB (-23.5%) was smaller in PFP compared to CG, with moderate to large ES (range: 0.7 to 1.0) (Table

2), while GMED's MT was greater (9.8%) in PFP compared to CG, with moderated ES (0.6).

Overall, high to very high intra-rater reliability values were found for all measurements (ICC's range: 0.70 to 0.99; Table 3). Additionally, for the outcomes with significant between-group differences values, all mean differences were greater than the measurements' MDD values.

Quadriceps muscle mass (-9%) and foot muscle mass (-12.3%) were lower in PFP than in CG, with moderated to large ES (range: 0.7 to 0.9; Table 4), while plantar muscle mass was greater in PFP compared to CG (6.7%), with large ES (0.8).

Table 1. PFP and CG participant's characteristics.

Characteristics	**Group**		**p-value**
	CG (n=20)	**PFP (n=20)**	
Age (years)*	28.5 ± 5.1	30.0 ± 5.6	0.36
Mass (kg)*	58.5 ± 4.3	59.1 ± 7.7	0.77
Height (m)*	1.64 ± 0.1	1.65± 0.1	0.71
BMI (Kg/m²)*	21.8 ± 1.3	21.8 ± 2.4	0.96
7-days IPAQ (MET-minutes/week)*	2962.5 ± 2883.1	2129.1 ± 1736.5	0.27
Dominant Limb			
Right limb (%)	95	90	
Left limb (%)	5	10	
Assessed Limb			
Right limb (%)	95	55	1.0
Left limb (%)	5	45	
Pain and functionality			
AKPS (0-100 points)†	NA	70.5 ±9.4	
Levels of usual pain (0-10)‡	NA	4.7 ±1.6	
Lower limb with the worst pain			
Unilateral (%)	NA	25	
Bilateral (%)	NA	75	
Onset of symptoms			
Up to 6 months (%)	NA	5	
Six months to one year (%)	NA	20	
More than 1 year (%)	NA	75	

Legend: AKPS, anterior knee pain score; BMI, body mass index; IPAQ, International Physical Activity Questionnaire - Short Form; NA, not applied. * Values are mean±SD; † Level of usual pain in the last 7 days measured by numeric rating scale; ‡ Kujala et al (1993).

Table 2. Comparison of lower limb muscle thickness (in cm) between the PFP group and CG.

Muscles	**PFP group (n=20)**	**Control group (n=20)**	**Mean difference (95% confidence interval)**	**% of the mean difference**	**p-value**	**ES**
Tensor Fascia Latae	1.7±0.3	1.6±0.3	0.1 (-0.3, 0.1)	7.0	0.23	0.4
Gluteus Medius	1.9±0.4	2.2±0.4	0.3 (0.04, 0.5)	13.4	**0.02†**	0.7
Gluteus Maximus	3.3±0.5	3.4±0.9	0.2 (-0.3, 0.6)	5.0	0.47	0.2
Rectus Femoris	1.6±0.3	1.8±0.3	0.2 (-0.2, 0.3)	8.5	0.07	0.6
Vastus Medialis	1.3±0.2	1.5±0.3	0.2 (0.1,0.4)	15.0	**<0.01†**	1.0
Vastus Lateralis	2.0±0.2	2.1±0.2	0.5 (-0.8, 0.2)	2.8	0.44	0.3
Biceps Femoris	1.0 (0.3)	2.0 (0.3)	0.9 (-0.2, 0.3)	4.5	0.49	0.2
Peroneus Longus and Brevis	1.7±0.3	1.7±0.3	0.1 (-0.3, 0.1)	4.8	0.34	0.3
Tibialis Anterior	2.4±0.2	2.4±0.2	0.1 (-0.1, 0.1)	0.0	1.00	0.0
Gastrocnemius Medialis	1.9±0.3	1.7±0.3	0.2 (-0.3, 0.0)	9.8	**0.04†**	0.6
Soleus	1.4±0.2	1.3±0.2	0.1 (-0.3, 0.2)	10.0	0.09	0.6
Flexor Digitorum Longus	1.3±0.3	1.4±0.3	0.6 (-0.1, 0.3)	4.4	0.56	0.2
Flexor Digitorum Brevis	0.9±0.2	1.1±0.3	0.2 (0.1, 0.3)	23.5	**<0.01†**	1.0
Flexor Hallucis Brevis	1.1±0.2	1.0±0.2	0.1 (-0.2, 0.4)	7.7	0.21	0.4
Abductor Hallucis	0.9±0.2	1.0±0.2	0.1 (-0.3, 0.2)	9.5	0.15	0.5

Legend: * Values are mean±SD (cm), except for the Biceps femoris muscle where the median (IQR) are shown; † indicates the between-groups differences (p<0.05); ES = Effect Size.

Table 3. Intrarater reliability of muscle morphology (MT) measures.

Muscles	**ICC**	**MDD**
Tensor of Fasciae Latae	0.82	0.44
Gluteus Medius	0.99	0.04
Gluteus Maximus	0.87	0.58
Rectus Femoris	0.98	0.09
Vastus Medialis	0.97	0.09
Vastus Lateralis	0.98	0.07
Biceps Femoris	0.99	0.09
Peroneus Longus and Brevis	0.98	0.08
Tibialis Anterior	0.97	0.12
Gastrocnemius Medilais	0.99	0.05
Soleus	0.94	0.15
Flexor Digitorum Longus	0.96	0.07
Flexor Digitorum Brevis	0.98	0.05
Flexor Hallucis Brevis	0.92	0.17
Abductor Hallucis	0.70	0.19

Legend: ICC, intraclass correlation coefficient; MDD, minimal detectable difference; MT, muscle thickness.

Table 4. Comparison of muscle mass (in cm) between CG and the PFP group for the different evaluated regions.

Regions	PFP group (n=20)*	CG (n=20)*	Mean difference (95% interval of confidence)	% of mean difference	P value	ES
Hip posterolateral muscle mass	5.1±0.6	5.6±1.1	0.5 (-0.1, 1.0)	-8.2	0.11	0.5
Quadriceps muscle mass	4.9±0.5	5.3±0.5	0.4 (0.1, 0.8)	-9.0	**0.01**†	0.8
Plantar flexor muscle mass	3.3±0.4	3.0±0.4	0.3 (-0.5, -0.6)	6.7	**0.01**†	0.8
Foot muscle mass	2.9±0.4	3.3±0.4	0.4 (0.1, 0.6)	-12.3	**<0.01**†	0.9

Legend: CG, control group; ES = Effect Size; PFP, patellofemoral pain. * Values are mean±SD; † indicates the between-groups differences ($p<0.05$).

1.5 Discussion

The main findings of the present study are that young women with PFP have simultaneous alterations in MT at the hip (proximal factor), knee (local factor) and ankle/foot (distal factor) in comparison to women without PFP, showing evidence that PFP is a complex and multifactorial clinical problem that should be treated more globally (i.e., proximally, locally and distally to the knee). More specifically, as expected, we observed a lower MT of GM (-13.4%), VM (-15%) and FDB (-23.5%), as well as lower quadriceps muscle mass (-9%) and foot muscles' mass (-12.3%) in PFP compared to CG. However, contrary to our preliminary hypothesis, the PFP group showed a higher MT of GMED (9.8%) and higher plantar flexor muscle mass (6.7%) than CG.

GM MT reduced (-13.4%) in PFP patients in comparison with healthy subjects. Previous studies that analyzed GM's MT in PFP patients did not observe significant alterations when compared to healthy subjects[28,29]. Methodological differences in sample characteristics and the number of measurement points used to determine MT may explain the between-studies controversial findings. Previous meta-analyses observed that reduced hip abduction strength is associated with dynamic knee valgus during single-leg squat tasks[36]. This dynamic knee valgus may be the result of femoral adduction (relative to the pelvis), tibial abduction (relative to the femur), or the combination of both during weight-bearing activities[33,60]. Also, dynamic knee valgus is positively associated with knee pain severity[61].The lower MT of GM observed in our study, combined with delayed and shorter duration of GM's activation[62], indicates that structural and neural deficits in women with PFP may explain the hip abductors' weakness observed in PFP, thereby explaining the dynamic knee valgus described in previous studies. In addition, a hip-abductor muscle-strengthening protocol has been shown to be effective in decreasing knee pain[63]. Similarly, a 20% increase in hip abductor strength (normalized to body weight) resulted in a 4.3º improvement in knee valgus[64], which has been reported as the difference in hip adduction angle between women with and without PFP[15]. Thus, effective interventions with a focus on hip muscle strengthening, with special attention to GM actions, are necessary to optimize the lower limb alignment and to decrease pain in PFP patients.

Contrary to a previous study[23], our results showed significant quadriceps muscle atrophy due to the lower mass (9%) in the PFP group compared to healthy subjects. Methodological differences in sample characteristics and the number of quadriceps' MT components added as representative of quadriceps muscle mass may explain the between-studies controversial findings. Giles et al[23] observed that all portions of the quadriceps muscle are reduced in patients with unilateral PFP in comparison with the asymptomatic limb, but not when compared with individuals without PFP. Conversely, in the present study, we observed smaller quadriceps muscle mass (-9%) and selective atrophy of the VM (-15%) in women with PFP in comparison to healthy women. Our results suggest that intervention programs should focus on knee extensor muscles' training, with special attention to VM during rehabilitation.

To the best of our knowledge, this is the first study to evaluate the plantar flexor muscle morphology in women with PFP in comparison to healthy women. Contrary to our expectations, PFP patients showed higher GMED MT (9.8%) and plantar flexor muscle mass (8.2%) compared to CG. The greater GMED's MT and plantar flexor muscle mass, and the smaller plantar flexion flexibility observed in PFP patients[65], may explain the lower ankle dorsiflexion range of motion previously observed in PFP patients[66]. The reduction in ankle dorsiflexion range of motion is associated with the increase in hip and knee movements in the frontal and transverse planes and with knee mobility reduction[67–69]. Additionally, a previous study observed that individuals with excessive dynamic knee valgus showed greater GMED activation during a squatting task[70]. This greater GMED activation can lead to a thicker GMED, which in turn can be a mechanism to reduce the mechanical demand over the knee extensors and the patellofemoral compression during weight bearing activities of the lower limbs when a greater contribution of the plantar flexors occurs[71].

The extrinsic and intrinsic foot muscles provide specific contributions for supporting the foot's medial longitudinal arch[72] and, consequently, for the maintenance of the neutral foot joints' alignment. The fact that FDB was the only foot muscle with significant MT reduction (-23.5%) in the PFP group, maybe is due to its anatomical and biomechanical characteristics. While FDL seems to be required to create greater supination moments at the ankle joint, FHB and ABH are directly related to the hallux's function, and their proximity to the medial foot arch may require them to work in the maintenance of the medial longitudinal arch. Their higher mechanical demands during foot function may explain why there was no between-groups difference in their MTs[56] compared to the FDB's lower MT. Interestingly, FDB's activation has a significant influence on calcaneal eversion, calcaneal abduction, and metatarsal adduction[47]. Therefore, FDB's lower MT may determine alterations in foot alignment (e.g., pronated foot) and the excessive calcaneal eversion previously observed in PFP patients[34,73]. Thus, as previously suggested in the literature[74], a distal strengthening program focused on foot muscle actions should be considered in PFP rehabilitation programs.

The novelty of the present study was that women with PFP have simultaneous alterations in muscle morphology at the hip (proximal factor), knee (local factor) and ankle/foot (distal factor) joints. However, some limitations should be taken into account when interpreting and applying this study results to clinical practice. First, our sample was composed exclusively of young women, which limits the extrapolation of our results to other groups (e.g., men, elderly) than young adult women with PFP. Although sex is not a risk factor for future development of PFP[50], women were chosen because they are 2.2 times more likely to develop PFP compared to men[44]. In addition, women demonstrated greater hip adduction compared to men with PFP during running and squatting, and, therefore, kinematic due to squatting and running is different between the sexes[75]. In addition, women with PFP have lower GM activation than healthy women, which may be related to their above-mentioned greater hip adduction. As such difference was not observed between men with and without PFP[15], activation differences between sexes may also change the desired outcomes. Taken altogether, these results demonstrate that men and women with PFP present different neuromechanical alterations, which is a confounding factor in a mixed sample. Therefore, we decided to evaluate muscle morphology first in women because of their higher PFP incidence and to avoid confounding factors determined by intrinsic sex neuromechanical differences. Second, all muscles' images were collected in a relaxed condition, which limits the extrapolation to contracted situations in which MT may change in different ways among the different muscles due to intrinsic architecture. However, despite MT may slightly increase during muscle contraction, we believe that changes in US images from the contracted to the relaxed conditions will probably maintain the same pattern observed for the relaxed state, which probably will not change the observed results. Third, the differences of dominance between the two groups might have contributed to the differences in the outcomes. More specifically, while in the PFP group 55% of the analyzed lower limbs were dominant limbs, in CG only the dominant limb was analyzed. Lower muscle mass was observed in the PFP symptomatic limb[20,24], demonstrating a higher atrophy than the asymptomatic one. However, muscle morphology was similar between-sides in healthy subjects (male/female)[24,52], and therefore our evaluation of only the dominant limb probably did not interfere in the results. Fourth, the researchers were not blinded to the subjects' condition (PFP or healthy), which may bring some bias to the results. However, all the methodological steps were carefully applied and similar among all the subjects, and therefore we hope that there was little or no interference in the obtained results. Finally, due to being a cross-sectional study, our findings cannot be pointed out as being the cause or effect of PFP in women. Further prospective studies are necessary with additional/different populations (i.e., men, older adults), based on the sex differences in kinematic alterations observed in PFP patients[75], and different contractile conditions (i.e., relaxed and contracted[22]) to clarify if muscle morphological alterations are the cause or the effect of PFP.

1.6 Conclusion

Women with PFP have proximal, local and distal muscle morphological alterations in comparison to healthy women without PFP, which may explain possible changes in muscle strength and functionality. Future PFP-treatment intervention programs should focus not only on strengthening the quadriceps muscle, but also on proximal and distal muscles to the knee joint when rehabilitating patients due to this complex multifactorial orthopedic disease.

CHAPTER 2 - PROXIMAL AND DISTAL MUSCLE THICKNESSES ARE NEGATIVELY ASSOCIATED WITH DYNAMIC KNEE VALGUS DURING SINGLE-LEG SQUAT IN WOMEN WITH PATELLOFEMORAL PAIN

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2.1 Abstract

Objective: To investigate the association between the proximal and distal-to-the-knee muscle properties [thickness and strength] and dynamic knee valgus (DKV) during the single-leg squat (SLS) in women with patellofemoral pain (PFP) and healthy women (CG). **Design:** Cross-sectional correlational study. **Setting:** Research laboratory. **Participants:** Fifty-five women with PFP (age: 29.11 ± 6.3 years; body mass: 62.56 ± 10.11 kg; height: 1.64 ± 0.07 m) and twenty healthy women (age: 28.50 ± 5.1 years; body mass: 58.50 ± 4.36 kg; height: 1.64 ± 0.67 m) volunteered to participate in the study. **Interventions:** Not applicable. **Main Outcome Measure(s):** We measured the muscle thickness (MT) of gluteus medius (GM), gluteus maximus (GMAX), vastus lateralis (VL) and tibialis anterior (TA) muscles by ultrasonography, the isometric maximum voluntary torque of hip abductors, hip external rotators, knee extensors and foot inversors, and DKV during SLS, in women with PFP and CG. Muscle properties (MT and strength) were associated with DKV during SLS in both groups. A multiple linear regression was used to evaluate if the muscular properties could explain the DKV on the PFP group. **Results:** We observed a significant negative association between GMAX MT and DKV (r = -0.32; p=0.01), and TA MT and DKV (r = -0.28; p=0.03). MT of GMAX explained 10% of DKV in PFP group. In CG, only MT of VL was correlated with DKV (r = 0.43; p=0.05). No significant correlations were observed between muscle torque and DKV in both groups. **Conclusion(s):** The association between proximal and distal MT and DKV during SLS suggests that PFP intervention programs should be multiarticular and focused on the strengthening of hip and ankle/foot muscles in women with PFP. Finally, our results suggest that muscle properties that influence DKV in PFP women are different from healthy women.

KEYWORDS: patellofemoral pain, dynamic knee valgus, single-leg squat, muscle thickness, muscle torque

2.2 Introduction

Patellofemoral Pain (PFP) is characterized by retropatellar and/or peripatellar pain, usually during activities that involve knee flexion, such as squats and stair ascent and descent[1,40]. PFP subjects show altered lower limb alignment during weight-bearing activities, such as the single-leg squat (SLS)[15,32,76,77]. Moreover, greater abnormal movement at the knee joint (e.g. knee external rotation) was associated with greater pain in PFP during SLS[78]. A combination of hip adduction, hip internal rotation, and knee abduction leads to an excessive medial movement of the knee, characterizing the dynamic knee valgus (DKV)[33]. Additionally, alterations at the ankle/foot joints during weight-bearing activities have the potential to alter the correct patellofemoral joint alignment in the frontal and transverse planes[35,67–69]. These lower limb kinematics alterations can increase the stress placed on the patellofemoral joint that can contribute to nociception[14].

Hip strength deficits, especially at the hip abductors and hip external rotators, may increase the hip adduction and internal rotation range of motion during weight-bearing activities, which can elevate joint stresses at the patellofemoral joint[33]. In addition, hip abductors and external rotators strengths are correlated with DKV[64,79]. However, there are conflicting results in the literature, with a recent meta-analysis only observing a negative relationship between hip abduction strength and DKV in SLS, but not for hip external rotators and extensors strength[36]. In addition, rearfoot eversion was associated with tibial internal rotation and greater hip adduction[42], suggesting a relationship with lower limb alignment, while higher midfoot mobility was associated with DKV[80]. Overall, these evidences suggest that changes in the structure and strength of muscles proximal and distal to the knee may change the mechanical loads at the knee, thereby contributing to the development of PFP.

Gluteus medius (GM) and gluteus maximus (GMAX) are primary contributors to hip abduction and hip external rotation, respectively[81]. These proximal muscles are responsible for preventing the excessive hip adduction and hip internal rotation, and have a significant role in lower limb frontal plane stability during weight-bearing tasks[33]. Distally, tibialis anterior (TA) acts as a primary contributor to foot inversion and to supporting the medial longitudinal arc[82–84], thus avoiding excessive eversion movements and great midfoot mobility. The aforementioned deficits in structure and function of GM, GMAX and TA has the potential to contribute to an excessive DKV. However, to our knowledge, only one study has previously tested together the relationship between MT and strength and lower limb alignment during SLS in women with PFP, and failed to observe significant correlations[38]. However, no primary contributor of hip external rotation was evaluated (i.e. GMAX), since excessive hip internal rotation influence the DKV and was previously observed that GMAX activation is negatively associated with knee valgus[85]. In addition, quadriceps weakness is considered a risk factor for PFP[50] and the quadriceps' line of action angle has the potential to alter the quadriceps muscle activation in women. More specifically, greater knee flexion is required during SLS, as the quadriceps' line of action angle gets larger, and muscle activation is increased in the lateral head of the muscle (i.e., vastus lateralis, VL)[86]. Therefore, the evaluation of GMAX and one representative muscle of the knee extensor muscles (i.e., VL) is necessary to try to establish the relationship between structure and function of these muscles with DKV in PFP.

Assuming that muscle architecture is related to the force level during a contraction[18,87], and to the performance in functional tasks[88], we hypothesize that changes in MT will influence the capacity of muscles to maintain a good lower limb alignment during SLS and a lower MT will be negatively correlated with DKV in PFP women. Based on the lack of studies investigating the association between proximal and distal muscle properties with DKV, our aim is to verify the association between lower limb alignment during SLS and proximal and distal muscle strength and thickness in women with PFP.

2.3 Materials and Methods

2.3.1 Participants

The sample size was estimated using G*Power (3.1.3, Frauz Faur Universität Kiel, Germany), based on a previously determined correlation between hip abduction strength and lower limb alignment in the frontal plane in women during single leg squat of r= 0.46[37], with an alpha level of 0.05 and power of 0.80. A minimum sample size of 12 subjects per group was indicated. However, we also made a multiple linear regression to identify if any selected variable can explain the DKV in PFP group and therefore a higher sample size was needed in PFP group compared to Control Group

(CG). Healthy women (CG) and symptomatic for PFP between 18 and 42 years of age were recruited. The CG group had similar characteristics (body mass, height, age and body mass index) as those of the PFP group, but with no pain symptoms at the knee joint and no history of lower limb injury. The inclusion criteria for PFP group were: (I) presence of peripatelar or retropatelar pain in at least two functional tasks (squatting, running, kneeling, jumping, climbing or descending stairs, sitting for a long time, sitting with knees flexed), (II) present ongoing patellar pain for at least 3 months, (III) present PFP a minimum of 3 out of 10 points in the numeric rating scale for knee pain (0= “no pain” and 10= “intolerable pain”), (IV) start PFP not related to trauma, (V) did not participate in any PFP treatment in the last 12 months and (VI) compatibility with data collection schedule. All subjects signed an informed consent form agreeing to participate in the study, whose protocol was approved by the University’s Ethics Committee for Human Research (Protocol nr. 2.089.328; Clinical Trials nr. NCT03663595).

2.3.2 Procedures

2.3.2.1 Questionnaires and knee pain evaluation

Participants were instructed to not participate in any vigorous activity 48 hours before the tests. If the subjects had bilateral PFP, the limb with the worst symptoms was evaluated. Before the evaluations’ start, anthropometric and PFP symptoms were identified by anamneses. Additionally, participants completed the Kujala Questionnaire [53] for knee functionality level, which has a score of functionally (Anterior Knee Pain Score - AKPS) ranging from 0 to 100, where higher values indicated better functionality. Pain level was assessed as “mean pain during the previous week” using a numeric rating scale from 0 to10, where 0 and 10 correspond to “no” and “intolerable pain discomfort”, respectively.

2.3.2.2 Kinematic evaluation

DKV were evaluated using 2D videos recorded with a digital camera (Go Pro-Hero 4, GoPro Inc, California, *USA*; sampling rate = 90 Hz). The digital camera was positioned in the frontal plane, 2 m in front of the participant, at a height of 45 cm. A standardized testing procedure was adopted, based on previous studies[37,89]. For DKV evaluation, skin markers with double-sided adhesive tape were placed at the anterior superior iliac spines, at the midpoint of the femoral condyles, and anteriorly at the midpoint between the lateral and medial ankle malleoli in the tested limb[32]. DKV was defined as the angle formed between the line connecting the anterior superior iliac spines (ASIS) with the midpoint of the knee and a second line connecting the midpoint of the knee with the midpoint between lateral and medial ankle malleoli (Figure 4)[76] . Participants stood in front of a height-adjustable plinth, with the foot of the tested limb parallel to a standardized reference line. SLS peak depth was standardized to 60º of knee flexion, indicated when the participants' buttocks touched the plinth[37]. The SLS depth was previously verified using a goniometer.

All participants received the same instructions on how to perform the SLS, but without instructions about trunk, hip, knee, or ankle/foot joints' position. They were instructed to stand on their tested limb, with the trunk upright and contralateral leg in approximately 20º of hip flexion, knee fully extended, and toes off the floor. Participants then initialized the SLS lowering down until the buttocks contacted the plinth and returned to the starting position, taking 4 seconds in total (2 s – descending phase and 2 s – ascending phase). An online metronome was used to control the velocity during the SLS (60 bpm). Each participant performed 5 consecutive trials of SLS without interval between the executions.

DKV was analyzed at the peak SLS depth (60º of knee flexion). DKV was calculated with the equation: DKV = 180º - θ, where 0° was assumed a neutral position of the knee joint. Positive values indicated knee valgus and negative values indicated knee varus[85]. DKV was processed using the Kinovea software (Kinovea Organization, France).

Figure 4. A representative subject of the sample during a single leg squat at initial position (upper images) and at peak squat depth (lower images) in sagittal and frontal planes. The DKV (right images) is represented as the angle between the femur (A-B) and tibia (B-C).

2.3.2.3 Muscle thickness

MT was measured by a B-mode ultrasonography system (Logiq P6, GE *Healthcare, Waukesha, Washington, USA*) with a matrixial linear-array probe (60mm *linear array* ML6-15, 5-15Mhz – GE *Healthcare, Waukesha, Washington, USA*). All images were obtained after the participant resting in a supine position on a stretcher for a period of 5 to 10 min to re-establish body fluids[57]. The MT of GM, GMAX, VL and

TA were analyzed with the muscles in a relaxed condition as previously described in the literature [90]. Mean values were obtained from three images for each muscle, which were analyzed using the Image-J software (National Institute of Health, USA) according to procedures previously described[91]. More details about MT assessment are present in FIGURE 5.

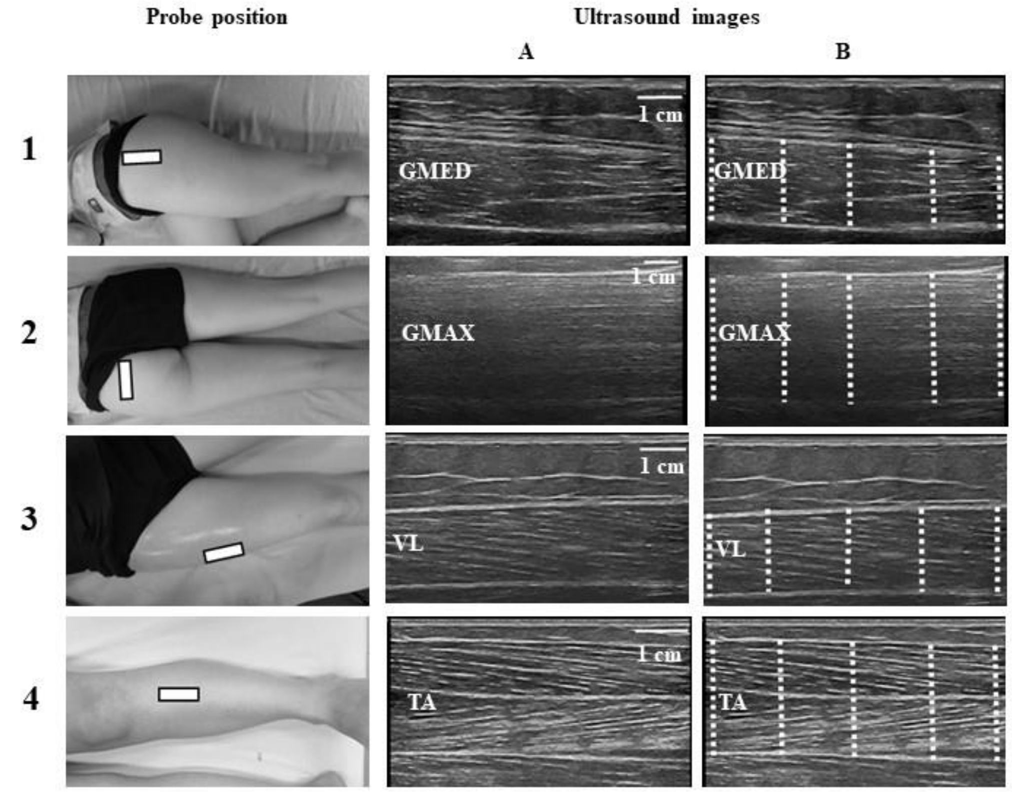

Figure 5. Muscles' measurement sites, with probe position, image samples (A) and muscle thickness assessment points (B). 1 – Gluteus medius (GM): transducer was place in the axial plane, at the midway point between the proximal end of the iliac crest and the greater trochanter. 2 – Gluteus maximus (GMAX): transducer was placed in the transversal plane, at one-third of the distance between the posterior superior iliac spine and the greater trochanter. 3 – Vastus lateralis (VL): transducer was place in the axial plane at midway point over VL between the great trochanter and the femur lateral condyle. 4 – Tibialis anterior (TA): transducer was placed proximally in the axial plane, at 30% of the line between the fibula's lateral malleolus and the femur's condyle. White rectangle represents the probe position, and dashed lines represent the MT assessment points.

2.3.2.4 Torque evaluation

Isometric muscle torques for hip abduction, hip external rotation, knee extension and foot inversion were measured with a handheld dynamometer (Microfeet 2, Hoggan Health, United States of America). To reduce the investigator's influence in the torque measurements, a strap was used during the strength tests. Before the measured trials, participants performed one practice trial, followed by a 1-min resting period. All participants were instructed to push the dynamometer as hard as they could for 5 seconds. Three trial tests were performed, with 1-minute rest between each test and 2 minutes between muscle groups. Force was converted to torque (torque [Nm] = N X moment arm [m]) and normalized to body mass: (torque [Nm] = N X body mass [kg] X 100)[92]. Only the peak torque was used for statistical analysis.

Subject and dynamometer positions were adapted from previous studies[93,94]. Hip abduction torque was measured with the participant in a side-lying position, with the hip at 10º of abduction and knee fully extended (Figure 6A). The contralateral limb stayed with the hip in the neutral position and the knee at 90º of knee flexion. The dynamometer was positioned 5 cm proximal to the lateral malleolus midpoint. The moment arm was determined as the distance from the femur's great trochanter to the dynamometer center. Hip external rotation torque was measured with the subjects seated on the stretcher, with the hip and knee flexed to 90º (Figure 6B). The dynamometer was positioned distally over the tibia's medial surface, 5 cm proximal to the medial malleolus midpoint. The moment arm was determined as the distance from the medial femoral condyle to the dynamometer center[94]. Knee extension torque was measured with the subject seated, with the hip and knee flexed in 90º (Figure 6C). The dynamometer was positioned over the anterior aspect of the lower leg, 5 cm proximal to the lateral malleolus midpoint[95]. The foot inversion torque was measured with the subject in side-lying position, with the hip, knee and ankle maintained in the neutral position (Figure 6D). The contralateral limb stayed with the hip abducted and externally rotated, and the knee at 90º of knee flexion. The dynamometer was positioned over the head of the first metatarsal bone. The moment arm was determined as the distance from the head of the first metatarsal bone to the medial malleolus point[93].

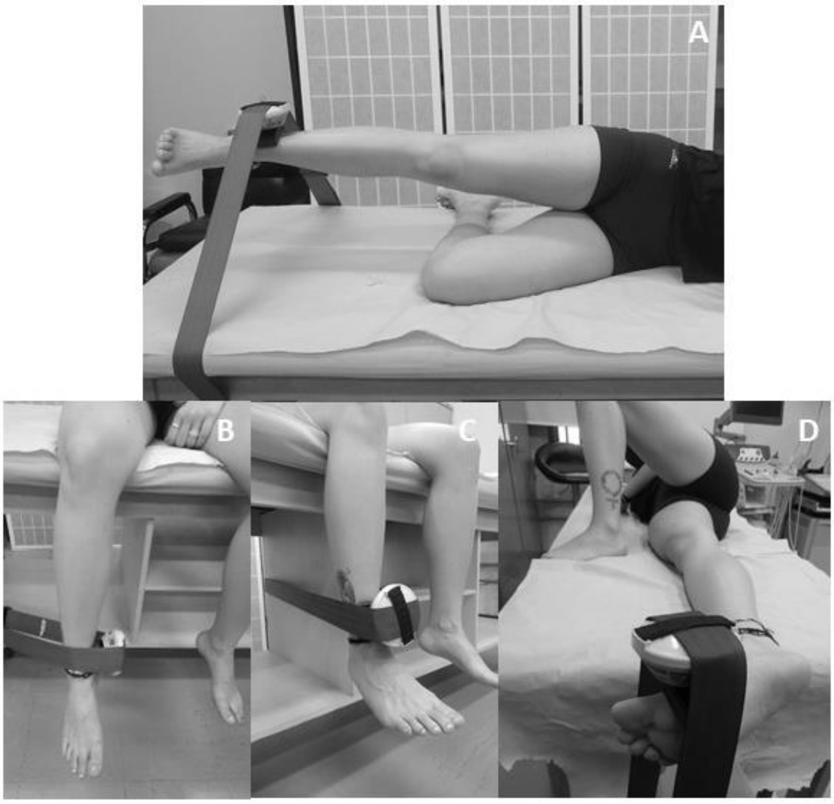

Figure 6. A representative position of the participants during an isometric peak torque measurement for (A) hip abductors, (B) hip external rotators, (C) knee extensors and (D) foot inversors, and respective dynamometer positions.

2.3.4 Statistical analysis

All statistical tests were performed with SPSS (version 22.0; SPSS Inc., Chicago, IL). Shapiro-Wilk tests were used to verify data normality. An independent t-test was used to compare groups for age and anthropometric characteristics. An intraclass correlation coefficient (ICC) was applied to verify the intra-rater reliability in 11 subjects of the sample, and the assessments were separated by 7 days. ICC values were classified as 0.00 to 0.25 indicating no reliability; 0.26 to 0.49, poor reliability; 0.50 to 0.69, moderate reliability, 0.70 to 0.89, high reliability and 0.90 to 1.00, very high reliability[59]. Additionally, the standard error of measurement (SEM) was used to determine the precision for all dependent analyses. Pearson correlation coefficient were used to analyze possible correlations between DKV with isometric torque and MT in both groups. The magnitudes of the correlation coefficients were interpreted as weak (0.1 - 0.35), moderate (0.36 - 0.67) or strong (0.68 - 1)[96]. When significant correlations were found in more than one muscle variable, multiple linear regression analyses were performed in order to investigate which of the muscular parameters could explain the excursion of DVI. All statistical analyses used a significance level of $\alpha \leq 0.05$.

2.4 Results

Twenty subjects in CG and fifty-five subjects in PFP group were recruited. Groups were similar for age and anthropometric characteristics, and further details about PFP volunteers' are described in Table 5. The flow of participants through the study are shown in Figure 7.

DKV values, as well as the values of MT and isometric torque for both groups, are described in detail in Table 6. PFP exhibited greater TA MT (+0.15 cm; p=0.04) than CG. DKV (+4.5º, p=0.05), hip abductor (+35.6 Nm; p=0.003), hip external rotator (+24,0 Nm; p<0.001) and knee extensor torque (+49.3 Nm; p<0.001) were greater in CG than PFP.

We observed a significant negative weak association between MT of GMAX and DKV (r = -0.32; p=0.01), and between TA MT and DKV (r = -0.28; p=0.03) in PFP. In CG, MT of VL had a moderate association with DKV (r = 0.43; p=0.05). We did not observe any significant correlation between isometric muscle torque and DKV in both groups (p>0.05). The values of the correlation's magnitude measures are described in detail in Table 7. The multiple regression analysis revealed that only GMAX muscle thickness was a significant DKV predictor, explaining 10% of the variance in DKV (r^2= 0.10; p=0.017), resulting in the following equation DKV= {[-4,199) * GMAX MT] +21,685}). Overall, high to very high intra-rater reliability was found for all measurements (ICC's range: 0.89 to 0.99; Table 8).

Table 5 Characteristics of the participants.

Characteristics	Group		p-value
	CG (n=20)	**PFP (n=55)**	
Age (years)*	28.5 ± 5.1	29.0 ± 6.3	0.75
Mass (kg)*	58.5 ± 4.3	62.4 ± 10.0	0.09
Height (m)*	1.64 ± 0.1	1.64 ± 0.1	0.94
BMI (Kg/m^2)*	21.8 ± 1.3	23.2 ± 3.5	0.08
Pain and functionality			
AKPS (0-100 points)†	NA	69.5± 11.3	
Levels of usual pain (0-10)‡	NA	5.2 ± 1.5	
Lower limb with the worst pain			
Unilateral (%)	NA	33	
Bilateral (%)	NA	67	
Onset of symptoms			
Up to 6 months (%)	NA	13	
Six months to one year (%)	NA	15	
More than 1 year (%)	NA	72	

AKPS, anterior knee pain score; BMI, body mass index; NA, not applied. * Values are mean±SD; † Level of usual pain in the last 7 days measured by numeric rating scale; ‡ Kujala et al (1993).

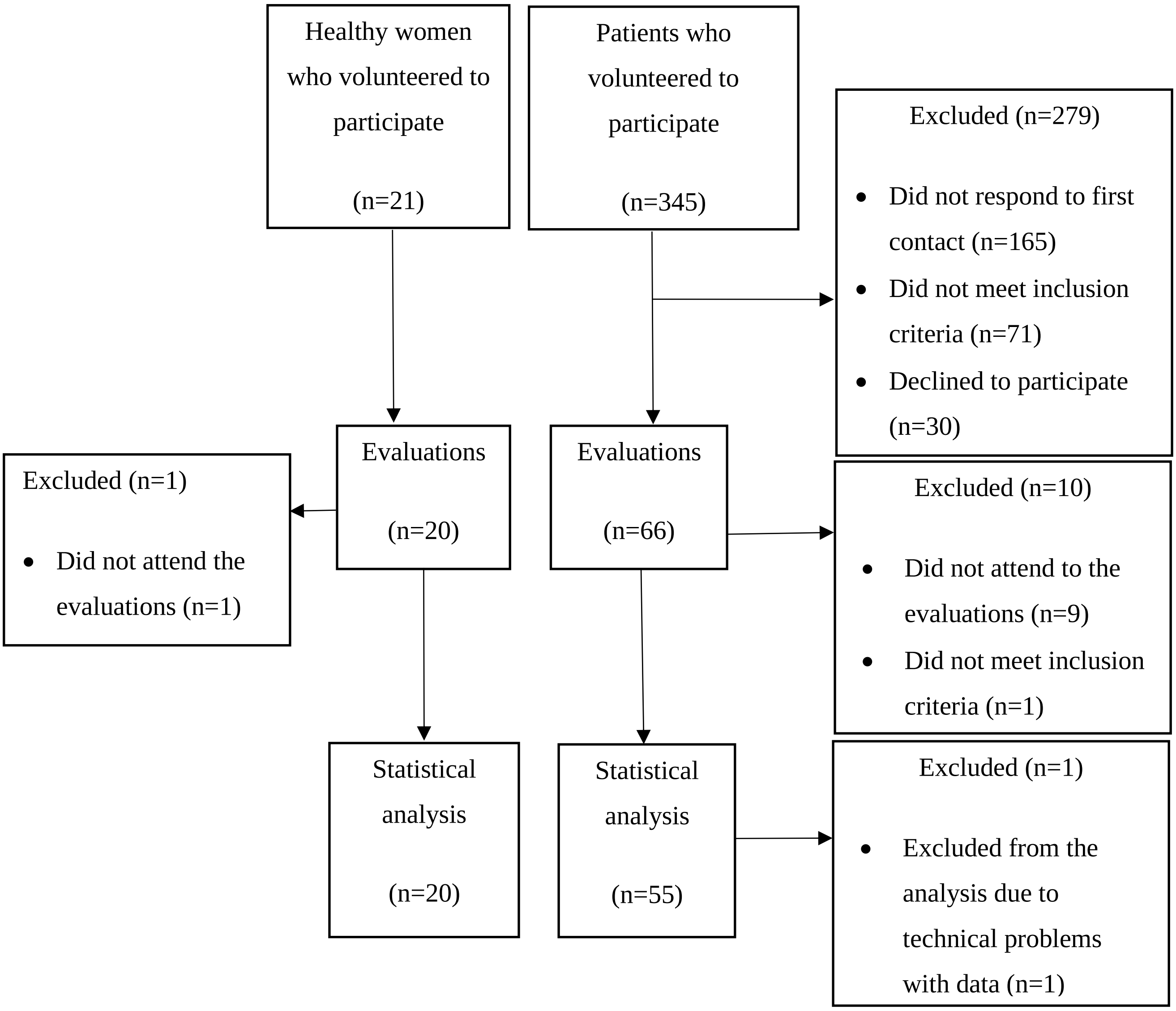

Figure 7. The flow of the participants through the study.

Table 6. Mean ± standard deviation values for kinematic variables during SLS, isometric torque and muscle thickness.

	PFP	CG	p value (95% CI)
SLS - Kinematic (º)			
DKV	7.78 ± 9.0	12.30 ± 8.40	0.05* (-9.10 to 0.10)
Isometric torque (Nm/Kg X 100)			
Hip abductors	134.87 ± 32.66	170.56 ± 45.57	0.003* (-58.5 to -12.88)
Hip external rotators	65.22 ± 12.84	89.26 ± 19.97	<0.01* (-33.86 to -16.21)
Knee extensors	188.50 ± 42.34	237.84 ± 66.66	<0.01* (-75.26 to -23.4)
Foot inversors	37.84 ± 9.43	38.84 ± 8.13	0.67 (-5.75 to 3.73)
Muscle thickness (cm)			
Gluteus medius	2.16 ± 0.45	2.16 ± 0.39	1.0 (-0.23 to 0.23)
Gluteus maximus	3.30 ± 0.68	3.41 ± 0.86	0.57 (-0.50 to 0.27)
Vastus lateralis	2.17 ± 0.30	2.10 ± 0.22	0.26 (-0.06 to 0.23)
Tibialis anterior	2.50 ± 0.30	2.35 ± 0.18	0.04* (0.0 to 0.28)

Abbreviations: DKV = dynamic knee valgus; SLS = single leg squat; * indicated significant difference between groups (p≤0.05).

Table 7. Correlations between dynamic knee valgus (DKV), muscle torques and muscle thickness.

	DKV			
Muscle torque	PFP group	p value	CG	p value
Hip abductors	0.15	0.25	-0.18	0.44
Hip external rotators	0.03	0.83	-0.07	0.74
Knee extensors	-0.07	0.60	-0.12	0.60
Foot inversors	0.00	1.0	-0.24	0.29
Muscle thickness				
Gluteus medius	-0.17	0.21	0.07	0.75
Gluteus maximus	-0.32*	0.01	0.13	0.56
Vastus lateralis	-0.10	0.47	0.43*	0.05
Tibialis anterior	-0.28*	0.03	0.24	0.30

Abbreviations: DKV = dynamic knee valgus; * indicated significant correlation ($p \leq 0.05$)

Table 8. Intra-rater reliability.

	ICC	**SEM**
MT of Gluteus Medius	0.98	0.06
MT of Gluteus Maximus	0.94	0.13
MT of Vastus lateralis	0.99	0.02
MT of Tibialis Anterior	0.98	0.03
DKV	0.89	0.50

Abbreviations: DKV, dynamic knee valgus; ICC, intraclass correlation coefficient; MT, muscle thickness; SEM, standard error of measurement

2.5 Discussion

The main finding of our study is that we observed a negative correlation between MT of proximal and distal muscles with DKV in PFP women. More specifically, PFP women with lower MT of GMAX and TA displayed greater DKV. In addition, the MT of GMAX was a significant predictor of DKV, explaining 10% of the DKV in the PFP group. In CG, only VL MT was significantly correlated with DKV. In addition, CG exhibited greater DKV, hip abductor, hip external rotator and knee extensor torques and lower TA MT than PFP.

Our results demonstrated different significant correlations between MT with DKV in PFP and healthy women. In PFP, proximal and distal muscles were negatively associated with DKV, whereas in healthy women, the local muscle (i.e., VL) is associated with DKV. Interestingly, contrary to commonly observed[32,38], PFP exhibited lower DKV than CG during SLS. VL MT was the only variable with significant correlation with DKV in CG. As previously reported, in healthy women, as the quadriceps' line of action angle increases during squatting tasks, the activation ratio between the more lateral rectus femoris and VL muscles relative to vastus medialis became greater, that is, as the quadriceps' line of action angle gets larger, muscle activation increases in the more lateral muscles[86]. Based on greater DKV observed in our CG, we hypothesize that a greater demand over VL happens in healthy women with greater DKV, which possibly help us to explain the observed correlation between the VL MT and DKV.

Due to the low value of significant correlations between MT and DKV in PFP, our findings should be interpreted with caution. To the best of our knowledge, this is the first study that established a relationship between MT of proximal and distal muscles to kinematic patterns during SLS in PFP women. Only one study previously tried to established a relation between lower limb alignment in the frontal plane and MT in PFP women, and the authors did not observe a relationship between MT and lower limb kinematics[38]. However, MT of a primary hip external rotator was not evaluated. GMAX plays a significant role in the lower limb frontal plane stability[33], and is the most potent hip external rotator, especially the middle fibers, from 0 to 90° of hip flexion[81,97]. Also, as previously observed, PFP women display a greater GMAX recruitment compared to healthy women, which can reflect on an attempt to recruit a weakened muscle in an effort to stabilize the hip joint during weight-bearing tasks[98], which also suggest a poor neuromuscular economy of GMAX in PFP women during SLQ[99]. In addition, a negative association between GMAX activation and DKV has been already observed in women[85]. The novelty of our study is that we observed a significant negative correlation between GMAX MT and DKV. Our results suggest that PFP women with higher MT of GMAX display a better lower limb alignment during SLS. In addition, GMAX MT can predict 10% of DKV in PFP. We suggest that PFP women with higher GMAX MT will probably have more capacity to counteract the excessive adduction and internal rotation of the femur during SLQ, thereby avoiding the medialization of the knee (i.e., knee valgus). Although this finding explained only a minor part of the DKV, this result highlights the importance of GMAX on the lower limb movement homeostasis in PFP women.

We also obtained a negative correlation between MT of TA and DKV. The extrinsic and intrinsic foot muscles provide specific contributions for supporting the foot medial longitudinal arch[72]. As previously observed in a nerve block condition of intrinsic foot muscles, the TA was able to provide support to the foot's longitudinal arch in the frontal plane[82]. In people with a flat-arched foot, a greater peak of TA activation was observed, which may reflect on a greater demand over TA to control the flat-arched foot[83,84]. Considering the theorized relation between distal joints alignment and DKV[35], we hypothesized that PFP woman with higher MT of TA would have more strength to support the foot's longitudinal arch in the frontal plane and counteract the excessive foot pronation, which can increase the medialization of the knee. We observed a greater TA MT in the PFP group. Similar to our findings, previous studies already observed greater peroneus[38] and gastrocnemius medialis[90] muscles in women with PFP. We suggest that these greater MTs of distal muscles observed in PFP women may be the result of greater demand over these muscles to maintain the correct foot alignment and, consequently, the good alignment of the lower limb during dynamic tasks.

Hip abduction and external rotation strength have been previously associated with DKV[64,79]. Contrary to aforementioned study, we did not observe an association between hip strength and DKV in both groups. A possible explanation for our results is that we evaluated the isometric maximum torque of the hip muscles, while during the

SLS these muscle groups act eccentrically at submaximal levels to avoid the excessive medialization of the lower limb. However, isometric strength has already shown a significant correlation with DKV[64] in women. Nevertheless, methodological differences may explain the contradictory results. For example, in our study we analyzed the peak torque during strength tests, while the average score of three maximum contractions was used previously[64].

Based on our results, clinicians should focus in strengthening of the hip posterolateral muscles and extrinsic foot muscles during rehabilitation for PFP women in order to reestablish a good lower limb alignment. Our results seem to corroborate with a previous study that suggested that intervention programs target at hip or ankle/foot in PFP women may have similar effects on lower limb kinematic pattern during SLS[42].

However, some factors should be taken into account when interpreting the results of this study. First, our sample was composed by PFP women, which limits these results extrapolation for other populations, as men, for example. Second, due to being a case-control study, our findings cannot be pointed out as PFP cause or effect in women. Third, we evaluated a limited number of joints, muscles, and only isometric torque, and due to the multifactorial etiology of PFP, further studies with more comprehensive evaluations are necessary to clarify the relationship between muscle morphology and strength to DKV. Fourth, we did not evaluate muscle activation during SLS, since previous studies had already observed a significant correlation between frontal plane movements of the lower limb and activation of quadriceps[86] and GMAX[85] muscles. Therefore, this variable may have influenced our findings. Finally, our results suggested a different influence of muscle properties (MT and strength) in PFP compared to healthy women. Although, we evaluated a larger number of subjects in PFP than CG, the number of subjects in CG was greater than our sample size estimation for the correlation analyses. Therefore, we believe that PFP sample size did not interfere in our results.

In conclusion, we observed different correlations between muscle structure and DKV during SLS in healthy compared to PFP women. Our study observed a negative correlation between MT of proximal and distal muscles (i.e., GMAX and TA) while in healthy women only MT of VL was correlated with lower limb kinematic during SLS.

However, despite differences in muscle structure would suggest differences in muscle strength between the two groups, isometric muscle torque was not associated with kinematic parameters during SLS in PFP and healthy women.

CHAPTER 3 - TARGETING PROXIMAL AND LOCAL MUSCLES IS BETTER THAN TARGETING DISTAL AND LOCAL MUSCLES IN A REHABILITATION PROGRAM FOR PATELLOFEMORAL PAIN? A DOUBLE BLIND RANDOMIZED CLINICAL TRIAL

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3.1 Abstract

Background: Multiarticular rehabilitation is considered better than knee-targeted alone for Patellofemoral Pain (PFP). However, no previous study compared the effect of adding proximal or distal-targeted exercises in association to knee-targeted exercises in rehabilitation for women with PFP. **Methods:** Fifty young women diagnosed with PFP were randomized into two groups submitted to proximal and local-targeted (PLT) or distal and local-targeted (DLT) exercises for a twelve-week rehabilitation program. Pain, functionality, muscle mass, dynamic valgus index (DVI) and muscle strength were measured at baseline and after six and twelve weeks of the program start. Data were analyzed by ANOVA with repeated measures. **Findings:** PLT and DLT rehabilitation programs had similar effects after 6 and 12 weeks, with significant improvements in pain (6 weeks: PLT=37%, DLT=30%; 12 weeks: PLT=47%, DLT=43%), functionality (6 weeks: PLT=7%, DLT=4%; 12 weeks: PLT=14%, DLT=8%), DVI (12 weeks: PLT=29%, DLT=23%), posterolateral hip muscle mass (6 weeks: PLT=6%, DLT=11%;12 weeks: PLT=12%, DLT=21%), quadriceps muscle mass (6 weeks: PLT=6%, DLT=4%; 12 weeks: PLT=DLT=7%), and knee extension strength (6 weeks: PLT=5%, DLT=9%; 12 weeks: PLT=8%, DLT=5%). Hip abduction (12 weeks: 10%) and hip extension strength (6 weeks: 8%; 12 weeks: 11%) increased only in patients submitted to the PLT rehabilitation, whereas foot muscle mass increased only at the DLT rehabilitation (6 weeks: 6%; 12 weeks: 8%). **Interpretation:** Multiarticular rehabilitation targeting proximal or distal muscles, in association with knee-targeting, improve in a similar way the clinical status, reduce knee valgus and increase muscle mass and muscle strength in women with PFP after 12 weeks.

Keywords: patellofemoral pain, women, multiarticular rehabilitation, proximal muscles, distal muscles.

3.2 Introduction

Patellofemoral pain (PFP) is considered one of the most common clinical condition in sports medicine and general practice[2,3,7]. Previous studies observed that targeting hip and core muscles reduced the pain levels earlier than knee-targeted rehabilitation program[100,101]. Also, hip muscles' strengthening associated to knee-targeted exercises resulted in clinical benefits for PFP patients in comparison with a non-treatment group[39] and was better than knee-target rehabilitation alone[39–41] even at 1 year of follow-up[102].

Distally-targeted interventions are also recommended for PFP[74], and physiotherapy plus foot orthoses use was effective in the short-term reduction of pain[103]. Also, similar to what was observed with the addition of hip strengthening to knee-targeted exercises, the addition of foot-targeted exercises and foot orthoses with knee-targeted exercises promoted better improvements than knee-targeted exercises alone in PFP patients[34]. The inclusion of distal muscles' strengthening may be clinically important for some PFP patients, being, in some instances, more effective than foot orthoses[74]. However, the paucity of studies evaluating the efficacy of distal muscles strengthening in PFP highlights the necessity of developing new studies in this area[74].

Abnormal movements of the foot may interfere with the hip joint motion, and, consequently, may alter patellofemoral tracking. It has been proposed that the excessive rearfoot eversion during the gait stance phase may result in increased tibial internal rotation, creating a compensatory hip internal rotation movement. This combination changes the patellofemoral mechanics, increasing the compression between the patella and the femur, which may produce PFP symptoms[35]. A significant association between greater rearfoot eversion range of motion and greater hip adduction peak and range of motion was observed in PFP patients[104]. These data corroborate the theoretical association between proximal and distal joints during weight-bearing tasks, and may indicate that rehabilitation programs targeting proximal (pelvis, hip), local (i.e., the knee) and distal (ankle, foot) factors may have similar overall effects on lower limb motion and, consequently, in PFP clinical outcomes[104]. In this direction, a recent study observed similar success rates with foot orthoses treatment, compared with hip exercises in patients with PFP[105].

However, to our knowledge, no previous study compared the effects of proximal or distal-targeted rehabilitation programs composed exclusively by exercises in women with PFP. Therefore, the aim of the present study is to compare the effects of two rehabilitation programs focused in (1) proximal and local muscles and (2) distal and local muscles in women with PFP.

3.3 Methods

3.3.1 Study design

In this randomized clinical trial study, women with PFP performed a rehabilitation program for 12 weeks. This is a double-blind study in which the researchers responsible by the assessments were blinded to the patients' allocation in the two rehabilitation programs, and the researchers (trainers) that conducted the rehabilitation programs were blinded to the evaluations. Methodological quality was determined by the PEDro scale. A 6/10 points on the PEDro scale was obtained, and our study was classified as "high quality"[106].

This study was approved by the University's Ethics Committee for Human Research (Protocol nr. 2.089.328), and prospectively registered on Clinical Trials (nr. NCT03663595). All participants were informed of the benefits and risks of the investigation before signing an institutionally approved informed consent document to participate in the study.

3.3.2 Participants and recruitment

Sample size was determined *a priori* based on the 13 points difference in the Anterior Knee Pain Score (AKPS), with a standard deviation of 12.8[39] after hip and knee-targeting rehabilitation and a difference of 2 points in a numeric pain rating scale (NPRS), with an assumed 2 points of standard deviation, power of $1-\beta>0.80$, and an alpha level equal to 0.05, using a statistical package Action Stat 3.7 (Estatcamp, São Paulo, Brazil, 2020). The NPRS and AKPS have shown a minimal clinically important difference (MCID) of 2[107] and 13[53,108] points, respectively. A minimum sample size of 20 subjects for AKPS and 21 for NPRS per group was indicated.

Women with PFP between 18 and 42 years were recruited from the university where the study was conducted and from the general population through posted flyers and social medial advertisements. Potential patients contacted the researchers through an e-mail, and the researchers determined the eligibility based on the inclusion criteria. After that, the selected patients were invited to visit the laboratory for a clinical examination. A physiotherapist evaluated PFP participants' eligibility based on following criteria: (1) presence of peripatelar or retropatelar pain in at least two functional tasks (squatting, running, kneeling, jumping, climbing or descending stairs, sitting for a long time, sitting with knees flexed), (2) presenting ongoing patellar pain for at least 3 months, (3) presenting PFP with a minimum of 3 out of 10 points in the numeric rating scale for knee pain (0 = "no pain",10 = "intolerable pain"), (4) beginning of PFP symptom's not related to trauma and (5) not participating in any PFP treatment in the last 12 months. Participants were excluded if they presented signs or symptoms of (1) meniscal or other intra-articular pathologies; (2) signs of patellar apprehension; (3) history of hip, knee or ankle joint injury; (4) evidence of joint effusion; and (5) history of patellofemoral joint surgery.

3.3.3 Procedures

Baseline, and post-6 and post-12 weeks of the rehabilitation program assessments were performed in two sessions (≈ 60 to 90 min) separated by at least 48h between sessions. The first session was composed by measurements of: (a) anthropometric characteristics; (b) patients-reported clinical status and (c) ultrasound evaluations of muscle mass. Additionally, physical activity level was measured only at baseline by the short form of the 7-day self-administered International Physical Activity Questionnaire (IPAQ). The second evaluation session was composed by measurements of: (a) dynamic valgus index and (b) muscle strength. The affected knee in patients with unilateral PFP or the most affected (painful) knee in patients with bilateral PFP were assessed. Patients were instructed to not participate in any vigorous activity 48 hours before the tests. After baseline assessment, the patients were submitted to one of the following rehabilitation protocols for 12 weeks, targeting (1) proximal and local muscles or (2) distal and local muscles. The patients were allocated by blocks in one of the two rehabilitation protocols (1:1) by one of the researchers not involved in the evaluations.

3.3.3.1 Primary outcome measures

3.3.3.1.1 Patients-reported clinical status

Pain level was assessed as “the mean pain during the previous week” using a NPRS from 0 to10, where 0 and 10 correspond to “no” and “intolerable pain discomfort”, respectively.

Self-reported function was assessed using the Kujala Questionnaire (AKPS)[53], a reliable 13-item questionnaire ranging from 0 to 100, evaluating subjective symptoms and functional limitations associated with PFP, where the higher values indicated better functionality and 100 indicating no disability[4].

3.3.3.2 Secondary outcome measures

3.3.3.2.1 Ultrasound assessment

A B-mode ultrasonography system (Logiq P6, GE Healthcare, Waukesha, Washington, United States of America) with a matricial linear-array probe (60mm linear array ML6-15, 5-15Mhz – GE Healthcare, Waukesha, Washington, United States of America) was used for ultrasound (US) measurements. A researcher with 7 years of experience with musculoskeletal US performed all measurements and data analyses. All US images were obtained in a relaxed condition, as previously described in the literature[90].

Muscle thickness of the following muscles was evaluated: gluteus medius (GM), gluteus maximus (GMAX), rectus femoris (RF), vastus medialis (VM), vastus lateralis (VL), flexor digitorum brevis (FDB), flexor hallucis brevis (FHB) and abductor hallucis (ABH). Quadriceps mass was obtained by the summing the MT from RF, VM and VL, Hip posterolateral muscle mass was obtained from GM and GMAX and Foot muscle mass from FDB, FHB, and ABH[90].

Mean values were obtained from three US images for each muscle to determine MT. Ultrasound images were analyzed using the Image-J software (National Institute of Health, USA) according to procedures previously described[54]. MT was considered the distance between deep and superficial aponeuroses, and was calculated through the mean value of 5 parallel lines drawn at right angles between the superficial and deep aponeuroses along each US image. A previous study assessed the reliability of these measures and observed a high to very-high reliability, with intraclass correlation coefficients (ICC's) ranging from 0.7 to 0.99[90].

3.3.3.2.2 Dynamic valgus index during Single-leg squat

Dynamic valgus index (DVI) was evaluated during single-leg squat (SLS) using 2D videos recorded with a digital camera (Go Pro- Hero 4, GoPro Inc, California, USA; sampling rate = 90 Hz). The digital camera was positioned perpendicular to the frontal plane, 2 m in front of the participant at a height of 45 cm. A standardized testing procedure was adapted from previous studies[89,109]. Participants were barefoot and wore shorts and short-sleeved t-shirts to allow visualization of anatomic landmarks. Anatomical markers were placed at the anterior superior iliac spines, at the midpoint of the patella, and anteriorly at the midpoint between the lateral and medial ankle malleoli in the tested limb. Participants stood in front of a height-adjustable plinth, with the foot of the tested limb parallel to a standardized reference line. SLS depth was standardized to 60º of knee flexion for each subject, and indicated when the participants' buttocks touched the plinth. The single-leg squat depth was verified using a goniometer applied to the lateral aspect of the knee.

All participants received the same verbal instructions on how to perform the SLS, without instructions about hip, knee, or ankle/foot joints' position. They were instructed to stand on their tested limb, with the trunk upright and contralateral leg in approximately 20º of hip flexion, knee fully extended, and toes off the floor (starting position). This position was held for at least 1 second. Participants then initialized the SLS by lowering down until the buttocks contacted the plinth and returned to the starting position, taking 4 seconds in total. An online metronome was used to control the frequency during the SLS (60 bpm). Each participant performed 5 consecutive trials of SLS without intervals.

Hip frontal plane projection angle (HFPPA) and knee frontal plane projection angle (KFPPA) were recorded and analyzed at the peak depth (60º of knee flexion). The DVI was calculated as the sum of HFPPA and KFPPA as previously described[109]. Hip and knee FPPA analysis was performed in the Kinovea software (Kinovea

Organization, France) and the average of 5 repetitions of SLS was used in the statistical analysis.

3.3.3.2.3 Muscle strength

Isometric muscle strength of hip (abduction, extension, external rotation), knee (extension and flexion) and foot (eversion and inversion) were measured by a handheld dynamometer (Microfeet 2, Hoggan Health, USA). To eliminate the investigator's influence in the generated force, a strap was used during the strength tests. Before measured trials, participants performed one practice trial, and rested for 1 minute. All participants were instructed to push the dynamometer as hard as they could for 5 seconds. Three trial tests were performed, with 1-minute rest between each test and 2 minutes rest between muscle groups. Isometric strength was measured in Newtons (N) and posteriorly converted into Kilograms of force (Kg.f) and normalized to body mass (Kg): (isometric strength = Kg.f/Kg). Only the highest normalized force value was used for statistical analysis.

Hip abduction strength was measured with the participant in side lying position with the hip at 10º of abduction and knee fully extended. The contralateral limb stayed with the hip in the neutral position, and the knee positioned at 90º of knee flexion. The dynamometer was positioned 5 cm proximal to the lateral malleolus midpoint. Hip extension strength was measured with the participant at the prone position, with the hip in neutral position, and the knee fully extended. The contralateral limb stayed with the hip and knee in neutral position. The dynamometer was positioned at the posterior aspect of the lower leg, 5 cm proximal to the lateral malleolus midpoint. Hip external rotation strength was measured with the subjects seated, with the hip and knee flexed in 90º. The dynamometer was positioned over the distal-medial aspect of the tibia, 5 cm proximal to the medial malleolus midpoint[94].

Knee extension strength was measured with the subject seated, with the hip and knee flexed in 90º. The dynamometer was positioned over the anterior aspect of the lower leg, 5 cm proximal to the lateral malleolus midpoint[95]. Knee flexion strength was measured with the participant in the prone position, with the hip in neutral position and knee fully extended. The contralateral limb stayed with the hip and knee in neutral position. The dynamometer was positioned at the posterior aspect of the lower leg, 5 cm proximal to the lateral malleolus midpoint[110].

Foot eversion strength was measured with the subject in side-lying position, with hip, knee and ankle maintained in the neutral position. The contralateral limb stayed with the hip and knee flexed. The dynamometer was positioned over the head of the fifth metatarsal bone. Foot inversion strength was measured with the subject in side-lying position with the hip, knee and ankle joints maintained in the neutral position. The contralateral limb stayed with the hip abducted and externally rotated and the knee flexed. The dynamometer was positioned over the head of the first metatarsal bone[93].

3.3.4 Rehabilitation program

Each participant was allocated in one rehabilitation program, composed by conventional strengthening and stretching exercises, targeting proximal and local muscles here called "proximal and local rehabilitation program (PLT)", or distal and local muscles here called "distal and local rehabilitation program (DLT)". The two rehabilitation programs were composed by 24 sessions (≈ 60 to 90 min of duration), applied twice a week, with at least 48 h between sessions. The rehabilitation sessions were supervised by three researchers. The rehabilitation programs were composed by two mesocycles of 12 sessions, and each mesocycle was divided into three microcycles of four sessions. At the beginning of each mesocycle, a maximum repetition's tests was used to define the overload used in each exercise. Details about maximum repetition's tests can be found at the SUPLEMENTARY MATERIAL 1. Both rehabilitation programs used a progressive overload through microcycles previously determinate based on the maximum repetition's tests for each exercise.

Both rehabilitation programs targeted the strength and flexibility of knee extensor and flexor muscles (local-focused). Additionally, PLT also targeted core, hip abductors, hip external rotators and hip extensor muscles, while DLT also targeted foot inversors, ankle plantar flexors, ankle dorsiflexors, and intrinsic foot muscles. Specific details of each rehabilitation program can be found at the SUPLEMENTARY MATERIAL 2. Representative images of each exercise can be found at the SUPLEMENTARY MATERIAL 3.

3.3.5 Statistical analysis

All statistical tests were performed using SPSS (version 22.0; SPSS Inc., Chicago, IL). Only the patients who completed the baseline evaluations and at least 10% of the training sessions were included in the statistical analysis. Missing data were replaced using the last score carried forward. Shapiro-Wilk tests were used to verify data normality. An independent t-test or U Mann Whitney test was used to compare groups for age, anthropometric characteristics, physical activity level and adherence to the rehabilitation program. Chi Square test was used for testing the between-groups difference in the assessed limb sides, presence of unilateral or bilateral symptoms, or the PFP symptoms starting time and treatment success. Two-way repeated measures ANOVAs, followed by Bonferroni post-hoc tests, were also used to identify the effect of rehabilitation program (PLT vs. DLT) and moment (baseline, after 6 weeks and 12 weeks) on patients-reported clinical status (pain and AKPS), DVI, muscle mass and isometric muscle strength. The between-moments effect sizes (ES) from baseline to after 6 weeks and from baseline to after 12 weeks were calculated through the Cohen's d, and classified as trivial (<0.2), small (>0.2), moderate (>0.5), large (>0.8), or very large (>1.3)[58]. All statistical analyses used a significance level of $\alpha \leq 0.05$.

We also calculated the *treatment success* adapted from Ferber (2015)[100], and patients were classified as "successful" if: (1) Pain level decreased >2 points and/or whose AKPS score increased by ≥8 points.

3.4 Results

From January to September of 2019, 345 patients volunteered to participate in the study. From those, 66 patients met the inclusion criteria and agree to participate in the study, and 50 were included in the statistical analyses. The flow of the patients through the study is shown in Figure 8.

Patients at PLT and DLT were similar for age, anthropometric characteristics and physical activity level. More details about patients' characteristics are shown in Table 9.

The average adherence was similar in both rehabilitation programs (78.4%). Two adverse events were reported involving an increase of knee pain symptoms during an execution of leg press and leg curl exercises in two different patients. With the adaptation of these exercises, leg press 45º to leg press 90º and from seated leg curl to prone leg curl exercise, these participants continued in the rehabilitation program. We observe that 80% and 68% of the patients were successful in PLT and DLT, respectively. The results of all outcome measures are described below and shown in Table 10.

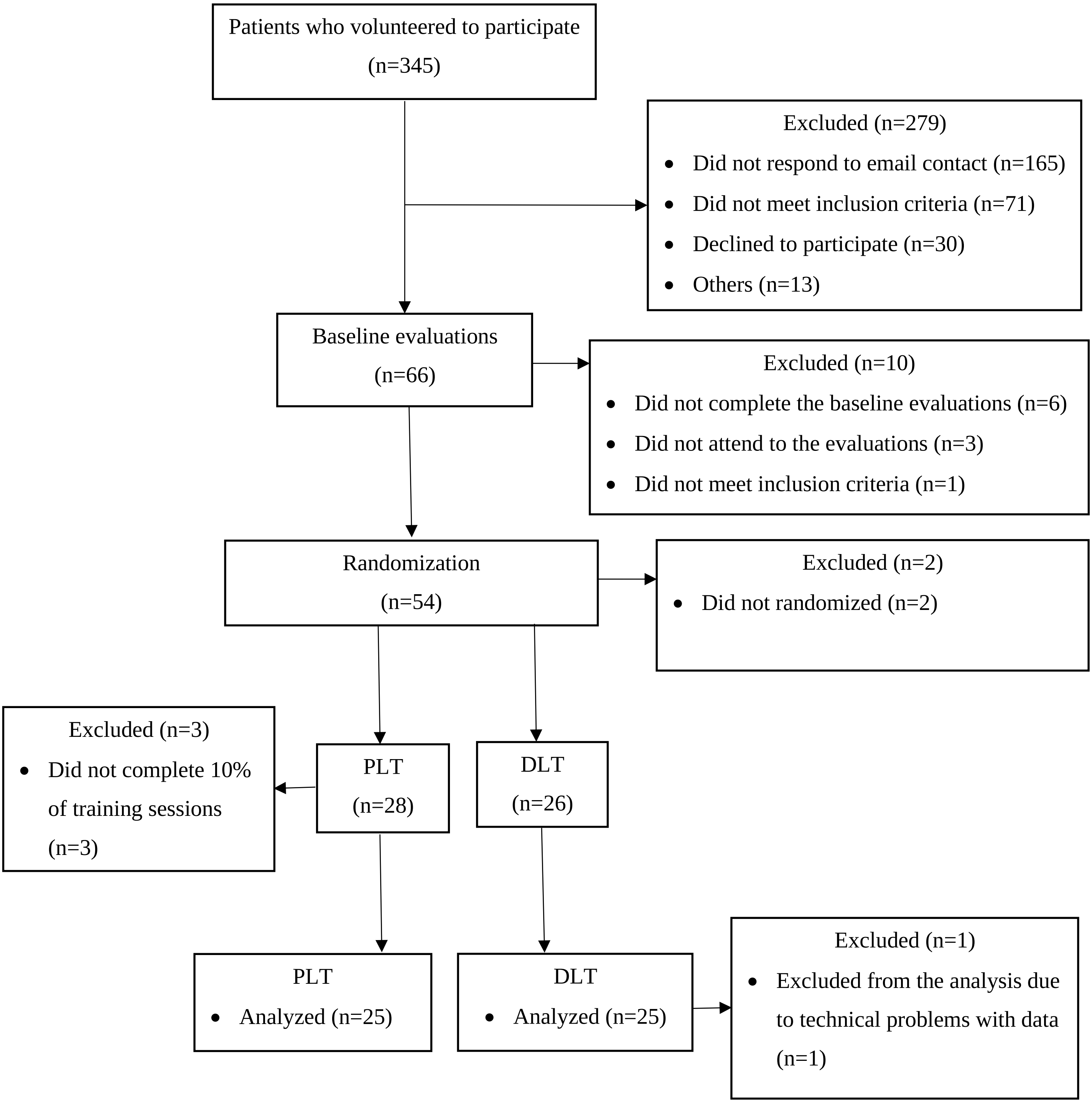

Figure 8. Flow chart of patients through the study steps.

Table 9. PFP and CG participant's characteristics.

Characteristics	Rehabilitation program		p-value (95% of CI)
	PLT	**DLT**	
Age (years)*	28.72±6.37	28.28±6.21	0.80 (-3.13;4.01)
Mass (kg)*	60.70±7.43	62.88±10.78	0.43 (-7.35;3.17)
Height (m)*	1.64±0.06	1.64±0.07	0.73 (-0.04;0.02)
BMI (Kg/m²)*	22.71±2.46	23.34±3.87	0.52 (-2.46;1.21)
7-days IPAQ (MET-minutes/week)#	1200 (2315)	1050 (3082)	0.45 (-0.76)‡
Assessed Limb			
Right limb (%)	52	56	0.25
Left limb (%)	48	44	
Lower limb with the worst pain			
Unilateral (%)	40	32	0.40
Bilateral (%)	60	68	
Onset of symptoms			
Up to 6 months (%)	16	12	0.72
Six months to one year (%)	8	24	
More than 1 year (%)	76	64	

Legend: BMI, body mass index; IPAQ, International Physical Activity Questionnaire - Short Form; * Values are mean±SD; #Values are median (IQR); ‡Values are p and Z.

3.4.1 Patients-reported clinical status

We did not observe a main effect of group or interaction for pain level and AKPS. There was a significant main effect of moment (p<0.001) for pain level and AKPS. Pain level was lower after 6 weeks (PLT: -37.7%, ES: 1.23; DLT: -30%, ES: 0.93; p<0.001) and after 12 weeks (PLT: -47.4%, ES: 1.53; DLT: -43.3%, ES: 1.46; p<0.001) than baseline values. We also observed lower pain after 12 weeks (PLT: -23.8%; DLT: -19%; p=0.01) compared to 6 weeks. After 12 weeks, we observed a very large ES in both groups.

AKPS improved after 6 weeks (PLT: +7.3%, ES: 0.45; DLT: +3.8%, ES: 0.22; p=0.003) and 12 weeks (PLT: +14.1%, ES: 0.80; DLT: +8.8%, ES: 0.50; p<0.001) compared to baseline values, and after 12 weeks (PLT: +6.3%; DLT: +4.7%; p=0.02) compared to 6 weeks. After 12 weeks we observed a moderate ES in both groups.

3.4.2 Muscle mass

We did not observe a main effect of group or interaction for posterolateral hip muscle mass and quadriceps muscle mass. However, there was a significant main effect of moment (p<0.001). Posterolateral hip muscle mass was greater after 6 weeks (PLT: +6.2%, ES: 0.41; DLT: +11.4%, ES: 0.58; p<0.001) and 12 weeks (PLT: +12.3%, ES: 0.82; DLT: +21.7%, ES: 1.10; p<0.001) than baseline values. After 12 weeks, we observed a large ES in both groups. Also, posterolateral hip muscle mass was greater after 12 weeks (PLT: +5.7%; DLT: +9.2%; p<0.001) compared to 6 weeks. Quadriceps muscle mass was greater after 6 weeks (PLT: +6.7%, ES: 0.46; DLT: +4.2%, ES: 0.28; p<0.001) and after 12 weeks (PLT: +7.3%, ES: 0.50; DLT: +7.2%, ES: 0.46; p<0.001) than baseline values. After 12 weeks, we observed a small ES in both groups.

We observed a main effect of moment (p=0.01) and group-moment interaction (p=0.04) in foot muscle mass. In PLT, there was no difference between the moments. However, in DLT, foot muscle mass was greater after 6 weeks (+6.4%, ES: 0.53; p=0.02) and after 12 weeks (+8.7%, ES: 0.66; p=0.00) than baseline values with moderate ES.

3.4.3 Dynamic valgus index

We did not observe a main effect of group or interaction for DVI. However, there was a significant main effect of moment (p<0.01). DVI was lower after 12 weeks (PLT: -29.7%, ES: 0.38; DLT: -34.5%, ES: 0.32; p=0.01) than baseline values. After 12 weeks we observed a small ES in both groups.

3.4.4 Isometric muscle strength

We did not observe a main effect of group or moment for hip abduction and hip extension strength. However, there a significant main group-moment interaction in hip abduction (p=0.04) and hip extension (p<0.01). Hip abduction in PLT was greater after 12 weeks (+ 10%, ES: 0.36; p=0.03) than baseline values with small ES, and hip extension was greater after 6 weeks (+8.8%, ES: 0.32; p=0.03) and after 12 weeks (+11.7%, ES: 0.44; p=0.02) than baseline values with small ES. In addition, hip extension in PLT was greater after 12 weeks than DLT (+15%; p=0.02). In DLT, we did not observe significant differences between the moments for hip strength.

In knee extension, we did not observe a main effect of group or interaction, but we found a significant main effect of moment (p<0.01). Knee extension was greater after 6 weeks (PLT: +5.2%, ES: 0.19; DLT: +9.1%, ES: 0.41; p=0.03) and after 12 weeks (PLT: +8.7%, ES: 0.28; DLT: +5.4%, ES: 0.29; p=0.01) than baseline values. After 12 weeks we observed a small ES in both groups.

In hip external rotators, knee flexors, foot eversors and foot inversors we did not observe any significant difference for isometric muscle strength.

Table 10. Mean and standard deviation values (with effect size within parentheses) of patients-reported clinical status, muscle mass, dynamic valgus index and muscle strength at Baseline, After 6 weeks and After 12 weeks of the rehabilitation program start.

	Baseline		**After 6 weeks**		**After 12 weeks**	
	PLT	**DLT**	**PLT**	**DLT**	**PLT**	**DLT**
Patient-Reported Clinical Status*						
Pain level (0-10)	5.40±1.55	4.80±1.35	3.36±1.75 (1.23)[a]	3.36±1.73 (0.93)[a]	2.56±2.11 (1.53)[ab]	2.72±1.49 (1.46)[ab]
AKPS (0-100)	68.12±9.95	72.32±11.85	73.12±12.19 (0.45)[a]	75.12±13.53 (0.22)[a]	77.72±13.75 (0.80) [ab]	78.68±13.44 (0.50) [ab]
Muscle mass*						
Hip posterolateral muscles (cm)	5.60±0.87	5.34±0.94	5.95±0.85 (0.41)[a]	5.95±1.14 (0.58)[a]	6.29±0.81 (0.82)[ab]	6.50±1.16 (1.10)[ab]
Quadriceps muscle (cm)	5.19±0.80	5.26±0.73	5.54±0.71 (0.46)[a]	5.48±0.85 (0.28)[a]	5.57±0.73 (0.50)[a]	5.64±0.90 (0.46)[a]
Foot muscles (cm)	3.07±0.36	2.97±0.33	3.07±0.41 (0.0)	3.16±0.38 (0.53)[a]	3.09±0.36 (0.06)	3.23±0.45 (0.66)[a]
Dynamic valgus index*						
DVI (º)	19.95±15.75	18.56±14.94	15.88±16.84 (0.25)	13.98±15.71(0.30)	14.01±15.56 (0.38)[a]	14.16±12.31 (0.32)[a]
Isometric muscle Strength*						
Hip abduction (Kgf/Kg)	0.20±0.05	0.20±0.06	0.21±0.06 (0.18)	0.19±0.04 (0.20)	0.22±0.06 (0.36)[a]	0.19±0.05 (0.18)
Hip extension (Kgf/Kg)	0.34±0.09	0.35±0.09	0.37±0.10 (0.32)[a]	0.34±0.07 (0.12)	0.38±0.09 (0.44)[ac]	0.33±0.08 (0.33)[c]
Hip external rotation (Kgf/Kg)	0.20±0.04	0.19±0.04	0.21±0.05 (0.22)	0.19±0.03 (0.0)	0.20±0.06 (0.0)	0.19±0.04 (0.0)
Knee extension (Kgf/Kg)	0.57±0.15	0.55±0.10	0.60±0.17 (0.19)[a]	0.60±0.14 (0.41)[a]	0.62±0.20 (0.28)[a]	0.58±0.11 (0.29)[a]
Knee flexion (Kgf/Kg)	0.38±0.09	0.36±0.10	0.37±0.09 (0.11)	0.36±0.08 (0.0)	0.38±0.09 (0.0)	0.36±0.09 (0.0)
Foot eversion (Kgf/Kg)	0.23±0.08	0.24±0.08	0.25±0.06 (0.28)	0.25±0.06 (0.14)	0.25±0.06 (0.28)	0.26±0.06 (0.28)
Foot inversion (Kgf/Kg)	0.31±0.08	0.32±0.08	0.31±0.09 (0.0)	0.33±0.08 (0.13)	0.32±0.10 (0.11)	0.33±0.08 (0.13)

Legend: DLT: distal and local muscle rehabilitation program; PLT: proximal and local muscle rehabilitation program. *Values are mean±SD (effect size); [a] significant different from baseline ($p < 0.05$); [b] significant different from after 6 weeks ($p < 0.05$); [c] significant different between groups ($p < 0.05$).

3.5 Discussion

The main findings of our study are that 12 weeks of PLT or DLT improved the self-reported clinical status, hip posterolateral muscle mass, quadriceps muscle mass, knee extension strength and DVI in a similar way. However, specific adaptations also occurred according to the rehabilitation program, such as the hip strength increased only in patients of PLT, while foot muscle mass increased only in DLT patients.

Similar to previously observed[34,39,100,101], our two multiarticular rehabilitation programs were effective to reduced pain and improve the self-reported functionality in PFP women. We observed that adding proximal or distal exercises to knee-focused rehabilitation has similar effects on pain and functionality in PFP women, and has a treatment success of 68 to 80%. To our knowledge, this is the first study to evaluate the effects of distally-targeted exercises associated to knee-targeted exercises in a PFP rehabilitation program. A previous study observed that the addition of foot exercises and foot orthoses to knee strengthening exercises is better than knee strengthening alone for PFP patients[34]. When screened for excessive calcaneal eversion, 60% of the patients had successful outcomes[34]. In our study, 68% of the patients had treatment success, but methodological differences in sample characteristics and outcomes measures between the studies make it difficult to compare results. Our results demonstrated that PFP women obtain significant improvement in clinical status when submitted to DLT, which corroborated with a previous clinical practice guide that suggest the use of foot strengthening in a rehabilitation program for PFP[74].

We observed significant improvements on quadriceps muscle and posterolateral hip muscle mass in both groups, and on foot muscle mass only at DLT, which demonstrated that our rehabilitation programs are effective to generate hypertrophy. We point out that our post training values of quadriceps and posterolateral hip muscles' mass in both groups are greater than previously reported for young healthy women, while foot muscle mass at DLT was similar to that observed in healthy women[90].

Our two rehabilitation programs were effective in reducing DVI in PFP women by 30% and 34% in PLT and DLT, respectively. As previously reported, a 10% increase in Q-angle may increase patellofemoral contact pressure by about 45%[111]. Although the DVI is a form of dynamic knee valgus measurement and is different than Q-angle, dynamic knee valgus can be considered a dynamic correspondent of Q-angle, and excessive knee valgus resulting from hip adduction and/or tibial abduction would increase Q-angle, as the patella would be displaced medially[33]. Based on a previously observed greater pain in exaggerated dynamic knee valgus condition in PFP women[112], the reduction in DVI possibly reduced the pressure at the patellofemoral joint, which can contribute to pain reduction. Our results for the pain levels and AKPS give support to this idea, as both rehabilitation programs reduced DVI and improved pain symptoms.

A previous meta-analysis suggested that rehabilitation programs focused in hip and knee muscles, with an average duration of 6 weeks, are effective to reduce pain without changes in muscle strength in PFP patients, when compared with no exercise/placebo or with knee strengthening alone. Also, rehabilitation programs with 8-12 weeks show better results in increasing muscle strength[40]. Our results corroborated with this meta-analysis, since both groups increased the knee-extensors muscle strength, and PLT increased hip abduction and hip extension strength. Interestingly, knee extension strength increased after 6 and 12 weeks in both rehabilitation programs, while hip extension increased after 6 weeks and 12 weeks only in PLT. These earlier increases observed in muscle strength are possibly due to the progressive resistance applied in both rehabilitation programs and the greater exercises' volume.

Based in our results, exercises targeting proximal or local muscles, in addition to knee-targeted muscles, have similar overall effects for women with PFP. A feature that should be highlighted of the present study is the use of a low cost, and with high practical applicability, rehabilitation protocol that can be used in clinical practice by clinicians. However, some limitations should be taken in account when interpreting our results. First, our samples were composed exclusively by PFP women, which limit these results extrapolation for other populations, as men with PFP, for example. Second, the absence of a control group prevents us from observing whether the results obtained after the rehabilitation programs are similar to those observed in healthy subjects. Third, our local-focused exercises, although were designed for targeting the muscles that act at knee joint, we recognized that some exercises involved other muscle groups that act at the hip and ankle/foot joints (i.e., leg-press and lateral step-up), and not isolated at the knee joint muscles. However, the exercises used in our study focused at the knee joint muscles were adapted from protocols previously used for targeting knee muscles[39,100,101,113]. In addition, both groups performed the same protocol for knee joint muscles, and therefore we believe they did not interfere on the obtained results.

3.6 Conclusion

Our study concluded that exercises targeting proximal or distal muscles, combined with muscles acting locally at the knee joint, have similar overall effects, being effective to improve the clinical status, muscle strength, muscle mass and dynamic knee valgus in women with PFP.

3.7 Supplementary Files

3.7.1 Supplementary file 1 – Description of maximum load assessments tests

Exercises	Maximum load assessment tests
Resisted Side step with elastic band	15 MR's with elastic band (Borg RPE Scale > 15)
Front plank	Maximum time in the correct exercise position
Bilateral Side plank	Maximum time in the correct exercise position
Hip ER in side lying position with elastic band ("*clam exercise*")	15 MR's with elastic band (Borg RPE Scale > 15)
Isometric hip at 10° of ABD with elastic band	Maximum time in the correct exercise position with elastic band (Borg RPE Scale > 15)
Hip EXT with elastic band	15 MR's with elastic band (Borg RPE Scale > 15)
Walking lunge	MR's**
Dorsiflexion with elastic band	15 MR's with elastic band (Borg RPE Scale > 15)
Plantarflexion eccentric exercise with elastic band	15 MR's with elastic band (Borg RPE Scale > 15)
Leg-press	Maximum 5 MR's
Lateral Step-up (20cm box height)	MR's**
Single limb squat ("*Pistol*")	MR's**
Seated leg curl	Maximum 5 MR's
Short foot exercise	MR's**
Foot inversion with elastic band	15 MR's with elastic band (Borg RPE Scale > 15)

Legend: MR's: maximum repetition; ER: external rotation; ABD: abduction; EXT: extension; RPE: rating of perceived exertion. ** If the subject exceeds 20 MR's, an overload of 5% to 10% of body mass will be added.

3.7.2 Suplementary file 2 – Rehabilitation programs

3.7.2.1 Proximal-targeted protocol

SESSIONS	MICROCYCLES	EXERCISES	SERIES	REPETITIONS OR TIME(S)	REST (s)	VOLUME LOAD
1st# to 4th	1	Resisted side step with EB	2	12	60	MR's
		Front plank	2	80%*	60	Maximum time
		Bilateral side plank	2	80%*	60	Maximum time
		"Clam exercise" with EB	2	12	60	MR's
		Isometric hip ABD at 10º with EB	2	80%*	60	Maximum time#
		Hip EXT with EB	2	12	60	MR's
5th to 8th	2	Resisted side step with EB	3	13	60	MR's
		Front plank	3	90%*	60	Maximum time
		Bilateral side plank	3	90%*	60	Maximum time
		"Clam exercise" with EB	3	13	60	MR's
		Isometric hip ABD at 10º with EB	2	90%*	60	Maximum time#
		Hip EXT with EB	3	13	60	MR's
9th to 12 th	3	Resisted side step with EB	3	15	60	MR's
		Front plank	3	100%*	60	Maximum time
		Bilateral side plank	3	100%*	60	Maximum time
		"Clam exercise" with EB	3	15	60	MR's
		Isometric hip ABD at 10º with EB	2	100%*	60	Maximum time#

		Hip EXT with EB	3	15	60	MR's
13th# to 16th	4	Resisted side step with EB	3	12	60	MR's
		Front plank	3	85%*	60	Maximum time
		Bilateral side plank	3	85%*	60	Maximum time
		"Clam exercise" with EB	3	12	60	MR's
		Isometric hip ABD at 10º with EB	3	80%*	60	Maximum time#
		Hip EXT with EB	3	12	90	MR's
17th to 20th	5	Resisted side step with EB	3	13	60	MR's
		Front plank	3	90%*	60	Maximum time
		Bilateral side plank	3	90%*	60	Maximum time
		"Clam exercise" with EB	3	13	60	MR's
		Isometric hip ABD at 10º with EB	3	90% *	60	Maximum time#
		Hip EXT with EB	3	13	60	MR's
21th to 24th	6	Resisted side step with EB	3	15	60	MR's
		Front plank	4	100%*	60	Maximum time
		Bilateral side plank	4	100%*	60	Maximum time
		"Clam exercise" with EB	3	15	60	MR's
		Isometric hip ABD at 10º with EB	3	100%*	60	Maximum time#
		Hip EXT with EB	3	15	60	MR's

Legends: ABD, abduction; EB, elastic band; EXT, extension; MR's: maximum repetition; RPE: rating of perceived exertion. * % referring to the maximum time in seconds in the load test assessment; ** plus Borg RPE Scale greater than 15; # at 1st and 13th sessions a maximum load assessments tests were developed

3.7.2.2 Local-targeted protocol

SESSIONS	MICROCYCLES	EXERCISES	SERIES	REPETITIONS OR TIME(S)	REST (s)	VOLUME LOAD
1st# to 4th	1	Stationary bicycle	1	300 s	-	70-90 RPM
		Seated leg curl	2	12	60	80% MR's
		Lateral Step-up	2	60%	60	MR's
		Walking lunge	2	60%	60	MR's
		Single limb squat ("*pistol*")	2	80%	60	MR's
		Quadriceps stretching	2	30	60	Pain threshold
		Hamstring stretching	2	30	60	Pain threshold
5th to 8th	2	Stationary bicycle	1	300 s	-	70-90 RPM
		Seated leg curl	2	12	60	90% MR's
		Lateral Step-up	2	60%	60	MR's plus 5% to 10% of overloading*
		Walking lunge	2	60%	60	MR's plus 5% to 10% of overloading*
		Single limb squat ("*pistol*")	2	90%	60	Pain threshold
		Quadriceps stretching	2	30	60	Pain threshold
		Hamstring stretching	2	30	60	
9th to 12 th	3	Stationary bicycle	1	300 s	-	70-90 RPM
		Seated leg curl	2	10	60	100% MR's
		Leg-press	3	15	60	80% MR's
		Lateral Step-up	2	70%	60	MR's
		Walking lunge	2	70%	60	MR's
		Single limb squat ("*pistol*")	2	100%	60	MR's

		Quadriceps stretching	2	40	60	Pain threshold
		Hamstring stretching	2	40	60	Pain threshold
13th to 16th	4	Stationary bicycle	1	300 s	-	70-90 RPM
		Seated leg curl	3	12	60	80% MR’s
		Leg-press	3	12	60	80% MR’s
		Lateral Step-up	3	60%	60	MR’s
		Walking lunge	3	60%	60	MR’s
		Single limb squat (“*pistol*”)	3	80%	60	MR’s
		Quadriceps stretching	3	30	60	Pain threshold
		Hamstring stretching	3	30	60	Pain threshold
17th to 20th	5	Stationary bicycle	1	300 s	-	70-90 RPM
		Seated leg curl	3	12	60	90% MR’s
		Leg-press	4	10	60	90% MR’s
		Lateral Step-up	3	60%	60	MR’s plus 5% to 10% of overloading*
		Walking lunge	3	60%	60	MR’s plus 5% to 10% of overloading*
		Single limb squat (“*pistol*”)	3	90%	60	Pain threshold
		Quadriceps stretching	3	30	60	Pain threshold
		Hamstring stretching	3	30	60	
21th to 24th	6	Stationary bicycle	1	300 s	-	70-90 RPM
		Seated leg curl	3	10	60	100% MR’s
		Leg-press	4	10	60	100% MR’s
		Lateral Step-up	3	70%	60	MR’s
		Walking lunge	3	70%	60	MR’s
		Single limb squat (“*pistol*”)	3	100%	60	MR’s

		Quadriceps stretching	4	40	60	Pain threshold
		Hamstring stretching	4	40	60	Pain threshold

Legends: MR's: maximum repetition; RPE: rating of perceived exertion. * overloading of 5% to 10% of body mass that produce a Borg RPE Scale greater than 15; # at 1st and 13th sessions a maximum load assessments tests were developed.

3.7.2.3 Distal-targeted protocol

SESSIONS	MICROCYCLES	EXERCISES	SERIES	REPETITIONS OR TIME(S)	REST (s)	VOLUME LOAD
		Foot inversion with EB	2	12	60	MR’s
		Shortfoot exercise	2	80%	60	MR’s[#]
		Plantarflexors eccentric exercise with EB	2	15	60	MR’s
		Toe curl	2	15	60	Borg RPE Scale > 15*
1st[#] to 4th	1	Dorsiflexion with EB	2	12	60	MR’s
		Soleus stretching	2	30	60	Pain threshold
		Foot inversion with EB	3	12	60	MR’s
		Shortfoot exercise	2	90%	60	MR’s[#]
		Plantarflexors eccentric exercise with EB	3	15	60	MR’s
5th to 8th		Toe curl	2	15	60	Borg RPE Scale > 15*
	2	Dorsiflexion with EB	2	13	60	MR’s*
		Soleus stretching	2	30	60	Pain threshold
		Foot inversion with EB	3	15	60	MR’s
		Shortfoot exercise	2	100%	60	MR’s[#]
		Plantarflexors eccentric exercise with EB	2	12	60	MR’s
		Toe curl	3	15	60	Borg RPE Scale > 15*
9th to 12th	3	Dorsiflexion with EB	2	15	60	MR’s
		Soleus stretching	2	40	60	Pain threshold
		Foot inversion with EB	3	12	60	MR’s
		Shortfoot exercise	3	80%	60	MR’s[#]

		Plantarflexors eccentric exercise EB	3	12	60	MR's
13th# to 16th	4	Toe curl	4	15	60	Borg RPE Scale > 15*
		Dorsiflexion with EB	3	12	60	MR's*
		Soleus stretching	3	30	60	Pain threshold
		Foot inversion with EB	3	13	60	MR's
		Shortfoot exercise	3	90%	60	MR's#
		Plantarflexors eccentric exercise EB	3	10	60	MR's
17th to 20th	5	Toe curl	4	20	60	Borg RPE Scale > 15*
		Dorsiflexion with EB	3	13	60	MR's
		Soleus stretching	3	30	60	Pain threshold
		Foot inversion with EB	4	15	60	MR's
		Shortfoot exercise	4	100%	60	MR's#
		Plantarflexors eccentric exercise EB	4	10	60	MR's
21th to 24th	6	Toe curl	4	25	60	Borg RPE Scale > 15*
		Dorsiflexion with EB	3	15	60	MR's
		Soleus stretching	4	30	60	Pain threshold

Legends: EB: elastic band; MR's: maximum repetition; RPE: rating of perceived exertion. ** If the subject exceeds the number of MR's with an Borg RPE Scale lower than 15 an overload was added to reached the RPE; # If the subject exceeds 20 MR's an overload of 5% to 10% of body mass will be added; # at 1st and 13th sessions a maximum load assessments tests were developed

3.7.3 Supplementary File 3 - Exercises

3.7.3.1 Proximal-targeted exercises

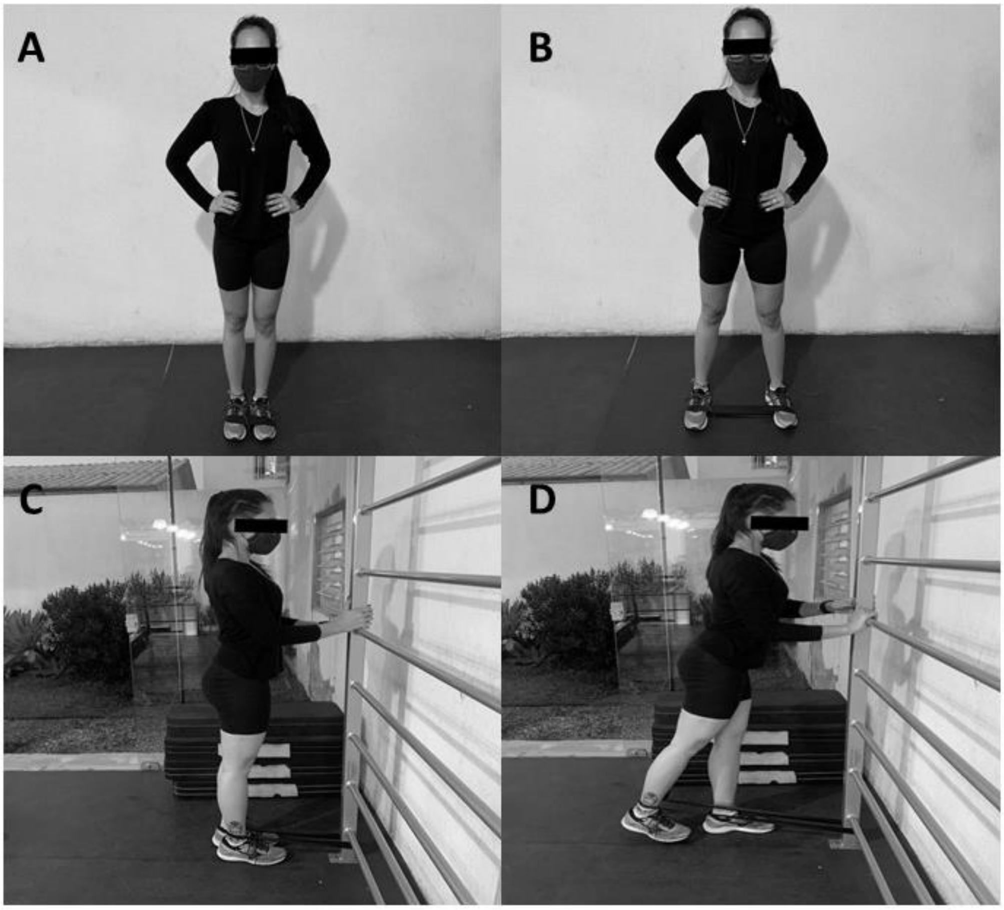

Figure 9. A representative image of the participants in “resisted side step with elastic band” (A and B) and “hip extension with elastic band” (C and D); Left images (A and C) represents the subject in initial position and right images (B and D) the final position of the exercise.

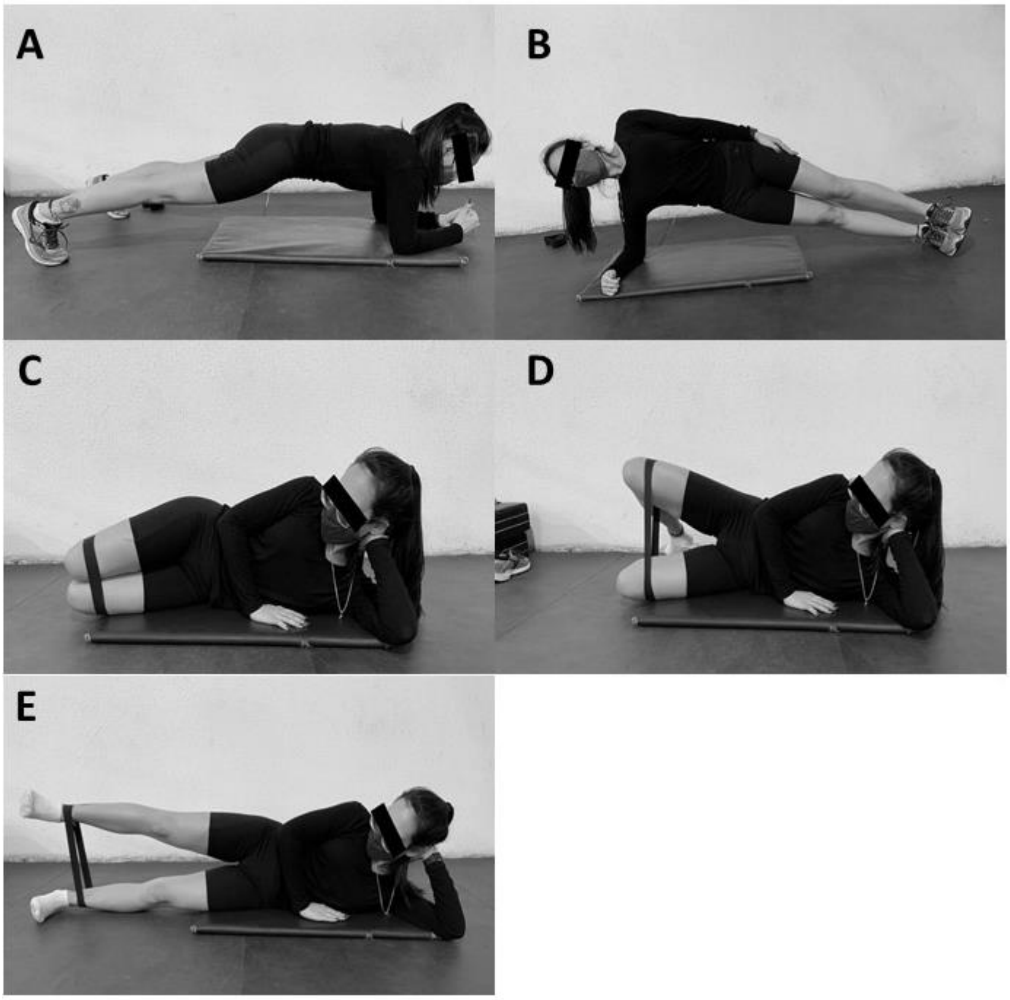

Figure 10. A representative image of the participants in “front plank” (A), one side of “bilateral plank” (B), “clam exercise with elastic band” (C and D) and “isometric hip abduction at 10º with elastic band” (E); A, B and E represents the subject in the sustained positions; C represent the subject at initial position and D the final position of the exercise.

3.7.3.2 Local-targeted exercises

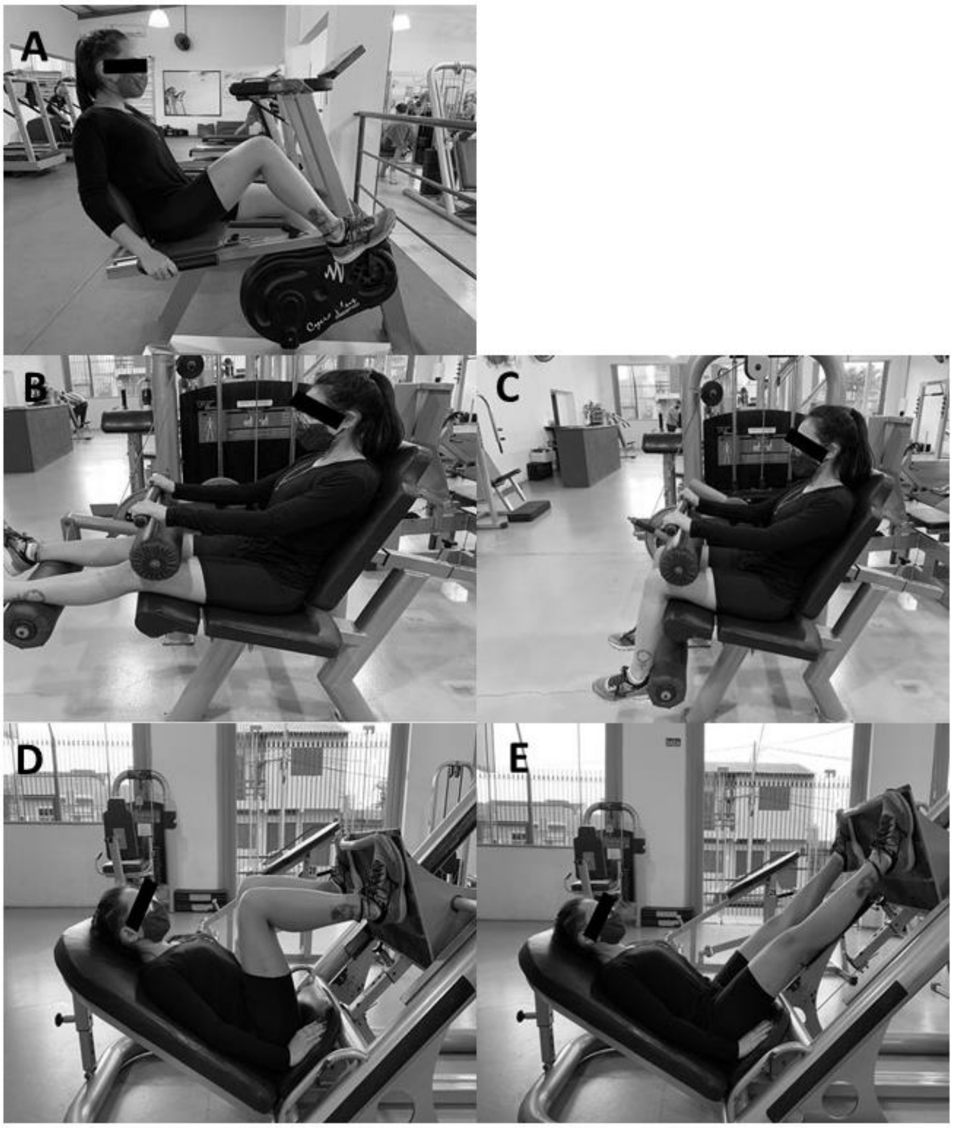

Figure 11. A representative image of the participants in “warmup at stationary bicycle” (A), “leg curl” (B and C) and “leg press” (D and E); Left images (B and D) represent the subject in initial position and D and E in final position of the exercise.

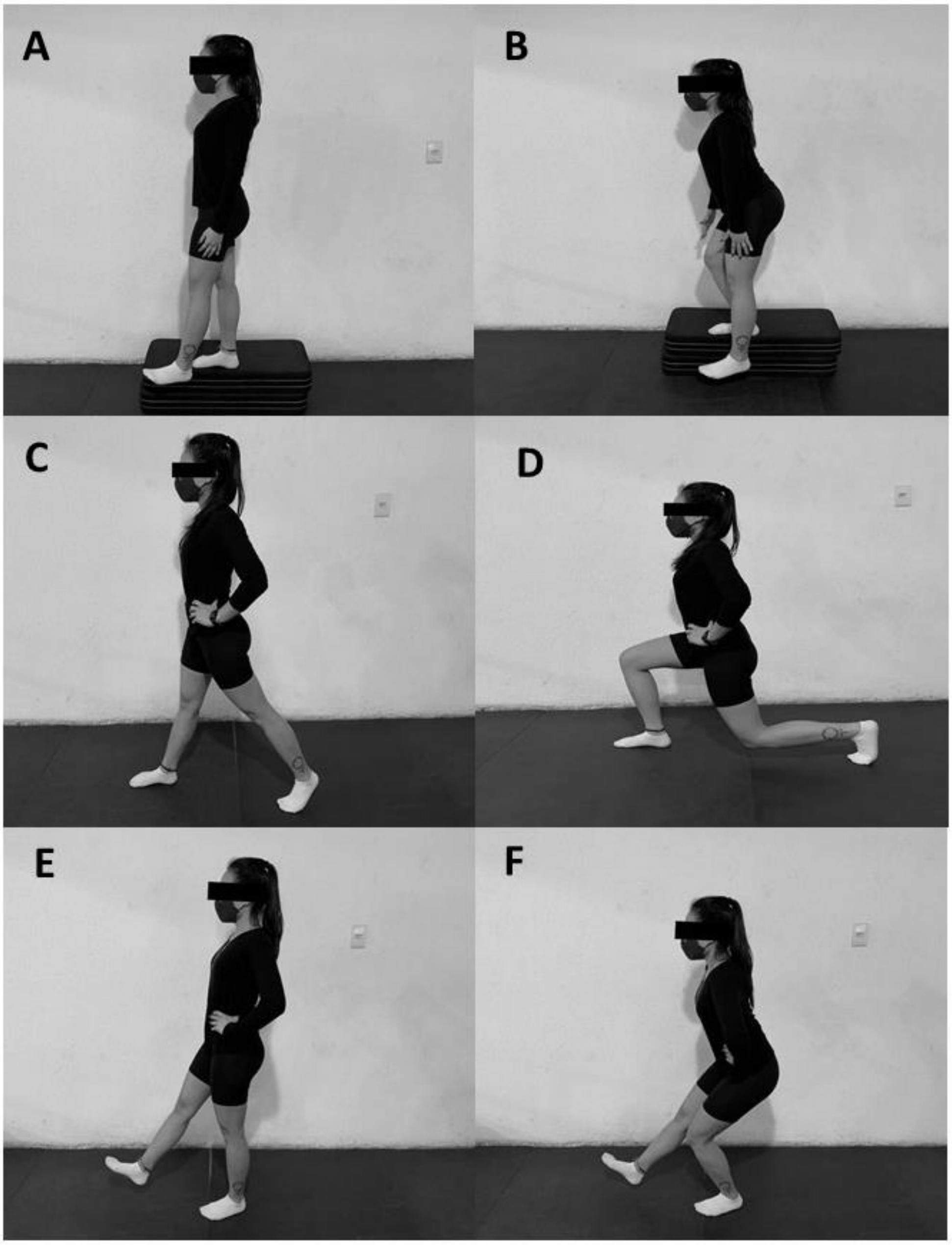

Figure 12. A representative image of the participants in “lateral step-up” (A and B), “walking lunge” (C and D) and “pistol” (E and F). Left images (A, C and E) represent the subject in initial position and right images (B, D and F) in final position of the exercise.

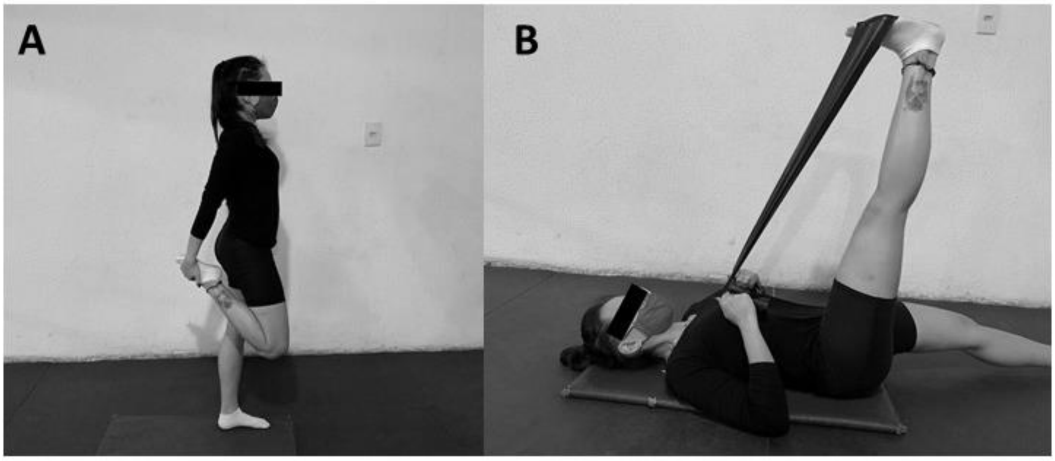

Figure 13. Representative image of subject in the sustained position at “quadriceps stretching” (A) and “hamstring stretching” (B).

3.7.3.3 Distal-focused exercises

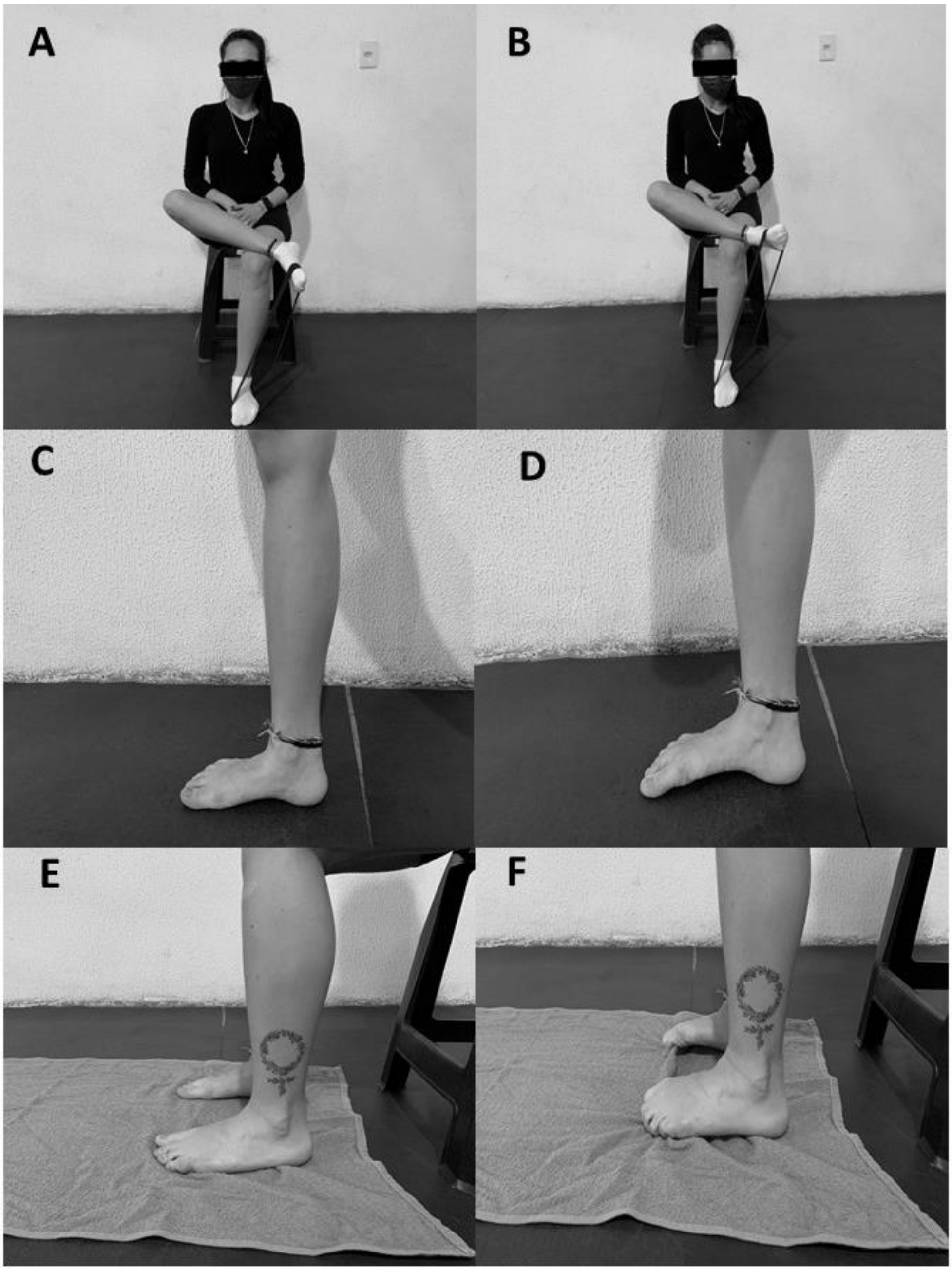

Figure 14. A representative image of the participants in “foot inversion with elastic band” (A and B), “shortfoot exercise” (C and D) and “toe curl” (E and F). Left images (A, C and E) represent the subject in initial position and right images (B, D and F) in final position of the exercise.

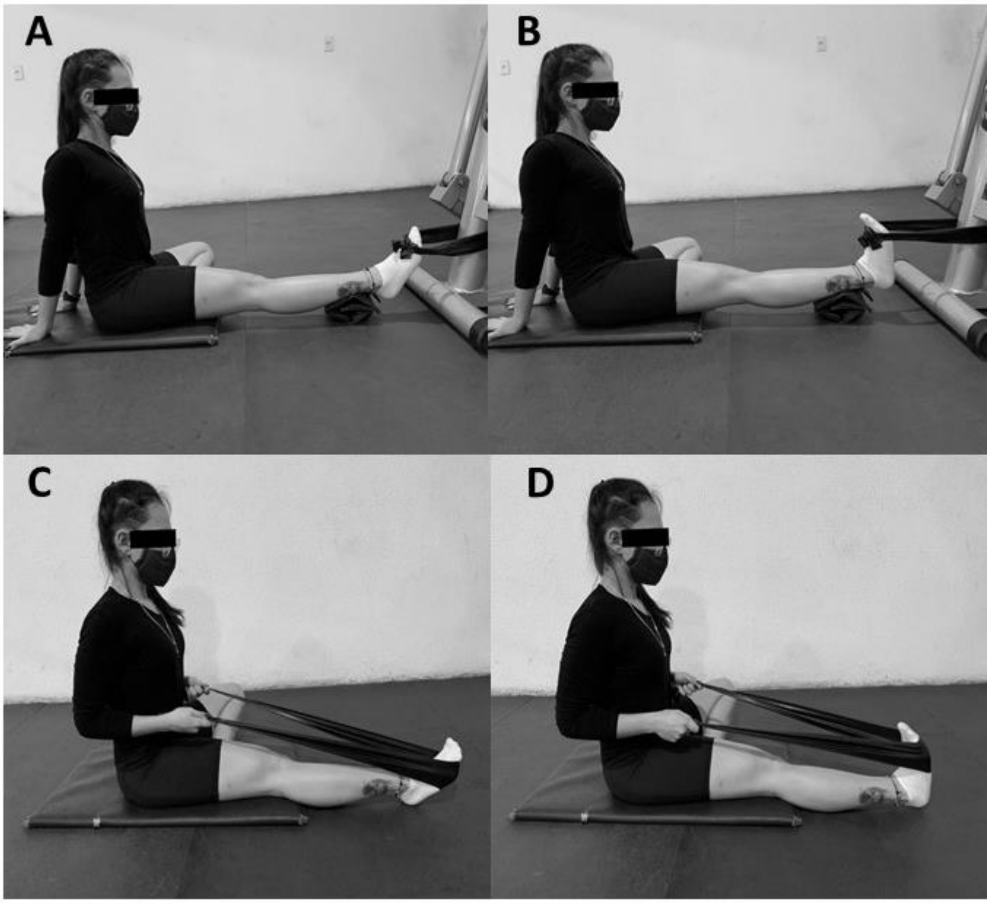

Figure 15. A representative image of the participants in “dorsiflexion with elastic band” (A and B) and “plantarflexors eccentric exercise elastic band” (C and D). Left images (A and C) represent the subject in initial position and right images (B and D) in final position of the exercise.

Figure 16.Representative image of subject in the sustained position at “soleus stretching” (A).

CONSIDERAÇÕES FINAIS DA TESE

A presente tese teve como objetivos principais: (1) verificar a presença de alterações na massa muscular (hipotrofia) no membro inferior em mulheres com DPF em comparação a mulheres saudáveis; (2) verificar se existe correlação entre os parâmetros estruturais (espessura muscular) e funcionais (força) com o alinhamento do membro inferior durante o teste de agachamento unipodal em mulheres com DPF e (3) comparar o efeito de dois modelos de tratamento sobre as variáveis clínicas e biomecânicas em mulheres com DPF.

No Capítulo I da tese, verificamos a presença de alterações na massa muscular em mulheres portadoras de DPF, em comparação a mulheres saudáveis. Menor espessura muscular foi observada no glúteo médio, vasto medial e flexor curto dos dedos no grupo DPF. Já o gastrocnêmio medial apresentou maior espessura no grupo DPF. Além disso, também observamos que mulheres com DPF apresentam redução na massa muscular no quadríceps e nos músculos do pé, e maior massa muscular nos flexores plantares. Dessa forma, foi possível observar que mulheres com DPF apresentam simultaneamente alterações estruturais nos músculos proximais, locais e distais em comparação a um grupo controle composto por mulheres saudáveis. Tais alterações evidenciam a necessidade de um programa de intervenção com enfoque global no membro inferior, com objetivo de fortalecimento muscular e, consequentemente, hipertrofia.

Com base na observação das alterações estruturais musculares observadas no Capítulo I, nosso objetivo no Capítulo II foi verificar se a espessura muscular dos músculos do membro inferior se correlacionava com o alinhamento dinâmico do membro inferior durante a execução de uma tarefa funcional de descarga de peso (agachamento unipodal). Nossos resultados demonstraram que a espessura do glúteo máximo (músculo proximal) e do tibial anterior (músculo distal) apresentam correlação negativa com o valgo dinâmico, ou seja, quanto menor a espessura muscular maior o valgo dinâmico durante o agachamento unipodal. Além disso, a espessura do glúteo máximo foi capaz de explicar 10% do valgo dinâmico em mulheres com DPF.

Com base em estudos prévios, que demonstram que programas de reabilitação multiarticulares apresentam melhores resultados que um programa focado exclusivamente no fortalecimento de músculos que atuam na articulação do joelho, e, a partir das observações dos resultados nos Capítulos I e II, da presença concomitante de fatores proximais e distais relacionados com as alterações na estrutura muscular e funcionalidade do membro inferior, surgiu o seguinte questionamento: existiriam diferenças nos resultados de dois protocolos de intervenção terapêutica baseados em exercícios físicos com enfoque nos músculos proximais e locais, em comparação a utilização de exercícios com enfoque nos músculos distais e locais? Para tentar responder esse questionamento, realizamos o estudo do Capítulo III.

Observamos que a utilização de um programa de reabilitação de 12 semanas focado nos músculos proximais e locais, apresenta, de uma forma geral, resultados semelhantes aos obtidos quando aplicamos um programa de reabilitação com enfoque nos músculos distais e locais para mulheres com DPF. Ambos os programas de reabilitação foram efetivos na redução da dor, melhora da funcionalidade, aumento da força, hipertrofia e redução do valgo dinâmico, com uma taxa de sucesso de tratamento entre 68% e 80%. Interessantemente, com apenas 6 semanas de reabilitação já foi possível observar uma redução significativa na dor e melhora na funcionalidade em ambos os grupos de tratamento.

A partir dos resultados da presente tese, foi possível observar que mulheres portadoras da DPF apresentam alterações estruturais nos fatores proximais, locais e distais, e que a redução na massa muscular pode estar relacionada com o alinhamento do membro inferior durante atividades de descarga de peso. Além disso, programas de reabilitação multiarticular com enfoque nos músculos proximais ou distais, associados aos músculos que atuam na articulação do joelho, são efetivos e apresentam resultados similares em mulheres com DPF.

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ANEXOS

Anexo 1 - E-mail de aceite do artigo 1 (Capítulo I)

Journal of Diagnostic Medical Sonography <onbehalfof@manuscriptcentral.com> dom., 11 de out. às 01:42
Para: kdpompeo@yahoo.com.br
Cc: evans.36@osu.edu

11-Oct-2020

Dear Dr. Pompeo,

Your manuscript entitled "Proximal, Local and Distal Muscle Morphology in Women with Patellofemoral Pain" (Manuscript JDMS-20-07-085-OR.R1) has been reviewed and accepted for the Journal of Diagnostic Medical Sonography (JDMS).

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Editor-in-Chief, Journal of Diagnostic Medical Sonography