UNIVERSIDADE DE BRASÍLIA/FACULDADE DE CEILÂNDIA

PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIAS DA REABILITAÇÃO

CURSO DE MESTRADO ACADÊMICO

THE INFLUENCE OF HIP AND KNEE JOINT ANGLES ON QUADRICEPS MUSCLE-TENDON UNIT PROPERTIES DURING MAXIMAL VOLUNTARY ISOMETRIC CONTRACTION

Alessandra Martins Melo de Sousa

Brasília/DF, 2022

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Alessandra Martins Melo de Sousa

Orientadora: Profa. Drª. Rita de Cassia Maqueti Durigan

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"Tudo o que fizerem, façam de todo o coração, como para o Senhor, e não para os homens. "

"Colossenses 3.23"

DEDICATÓRIA

Dedico esta dissertação ao meu Deus, o maior orientador e sustentador da minha vida, em especial aos meus amáveis pais, Conceição Sousa e Francisco Paulo pelo incansável apoio na minha formação como ser humano, bem como, a todos os meus familiares e amigos que contribuíram para que este trabalho pudesse ser realizado.

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Primeiramente gostaria de agradecer a Deus, por me inspirar e permitir realizar este sonho para a Glória dele.

Aos meus pais que sempre me ensinaram “Em tudo o que for fazer, dê o seu melhor e o faça para Deus”. Minha gratidão a eles que nos momentos bons e nas adversidades sempre estiveram ao meu lado me encorajando a realizar este sonho. Agradeço também aos meus familiares e amigos por todo apoio durante todos esses anos.

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Agradeço ao meu grupo de pesquisa em Plasticidade Musculotendínea (GPLAST), alunos da Universidade de Brasília, Álvaro Ventura, Leandro Gomes e Dr. Ivo Neto pela colaboração nas coletas, estudos e análise dos dados, bem como as minhas amigas Mestre Isabella da Silva Almeida, Maria Augusta Araújo e Mestre Greyciane Castro por trilharem esta jornada comigo, dividindo as alegrias e compartilhando também os momentos difíceis.

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Por fim, gostaria de agradecer a Universidade de Brasília, Faculdade de Ceilândia e a Faculdade de Educação Física pela concessão do espaço para estudos e coleta dos dados, bem como a todos os voluntários da pesquisa por seus esforços e colaboração com a promoção da divulgação científica.

RESUMO

Os exercícios de extensão do joelho são comumente usados para tratar lesões no joelho. No entanto, não está claro qual é o posicionamento ideal para exercícios de força de extensão do joelho. 60º de flexão do joelho permite maior produção de força, mas 20º de flexão do joelho reduz o estresse articular. Além disso, o posicionamento sentado *versus* supino pode influenciar a função musculotendínea. Determinar como funciona a unidade musculotendínea do quadríceps femoral, de acordo com os ângulos das articulações do quadril e do joelho, pode ajudar na tomada de decisão clínica ao prescrever exercícios de extensão do joelho. Nosso objetivo foi determinar o efeito dos ângulos das articulações do quadril e joelho na estrutura e funcionamento neuromuscular de todos os constituintes da musculatura do quadríceps femoral e nas propriedades do tendão patelar. Vinte jovens do sexo masculino foram avaliados em quatro posições: sentado e supino em 20º e 60º de flexão do joelho (SIT20, SIT60, SUP20 e SUP60). A dinamometria computadorizada foi usada para determinar o pico de torque de extensão do joelho durante a contração voluntária isométrica máxima (CVIM). A ultrassonografia foi usada em repouso e durante a CVIM para caracterizar o músculo quadríceps femoral e a rigidez do complexo tendão aponeurose. Além disso, foram avaliadas as propriedades morfológicas, mecânicas e materiais do tendão patelar. Observamos que o pico de torque e a eficiência neuromuscular do quadríceps femoral foram maiores para as posições SUP60 e SIT60 em comparação com as posições SUP20 e SIT20. Encontramos maior comprimento do fascículo e menor ângulo de penação nas posições com o joelho fletido a 60º. A rigidez do complexo tendão aponeurose do quadríceps femoral, a força, a rigidez, o estresse e o módulo de Young do tendão patelar foram maiores em posições mais alongadas (60º) do que em posições encurtadas (20º). O alongamento do tendão patelar foi maior na posição SIT20 comparado ao SUP20. A atividade elétrica muscular do quadríceps femoral, comprimento, tensão e área de secção transversa do tendão patelar permaneceram inalterados entre as posições. Em conclusão, os clínicos devem considerar o posicionamento a 60° de flexão do joelho em vez de 20°, independente se sentado ou deitado, durante a reabilitação para gerar carga na unidade musculotendínea o suficiente para estimular a mecanotransdução. ClinicalTrials.gov (Identificador: NCT03822221).

Palavras-chaves: Relação momento-ângulo, Comprimento do músculo, Propriedades mecânicas, Força de extensão do joelho, músculo quadríceps.

ABSTRACT

Knee extension exercises are commonly used to treat knee injuries. However, it is unclear what optimal positioning is for knee extension strength exercises. 60º of knee flexion allow greater force production, but 20º knee flexion reduces joint stress. Further, seated versus supine positioning may influence musculotendinous function. Determining how the quadriceps femoris musculotendinous unit functions, according to hip and knee joints angles may help with clinical decision making when prescribing knee extension exercises. We aimed to determine the effect of hip and knee joint angles on structure and neuromuscular functioning of all constituents of the quadriceps femoris musculature and patellar tendon properties. Twenty young males were evaluated in four positions: seated and supine in both 20º and 60º of knee flexion (SIT20, SIT60, SUP20, and SUP60). Computerized dynamometry was used to determine peak knee extension torque during maximal voluntary isometric contraction (MVIC). Ultrasound imaging was used at rest and during MVIC to characterize quadriceps femoris muscle and tendon aponeurosis complex stiffness. Additionally, patellar tendon morphological, mechanical, and material properties were evaluated. We found that peak torque and neuromuscular efficiency were higher for SUP60 and SIT60 compared to SUP20 and SIT20 position. We found higher fascicle length and lower pennation angle in positions with the knee flexed at 60º. The tendon aponeurosis complex stiffness of quadriceps femoris, force, stiffness, stress, and Young's modulus of patellar tendon were greater in more elongated positions (60º) than in shortened positions (20º). Stretching of patellar tendon was greater in SIT20 compared to SUP20. Muscle electrical activity of quadriceps femoris, length, strain, and CSA of patellar tendon remained unchanged between the positions. In conclusion, clinicians should consider positioning at 60° of knee flexion rather than 20°, regardless seated or supine, during rehabilitation to load the musculotendinous unit enough to stimulate a mechanotransduction. ClinicalTrials.gov (Identifier: NCT03822221).

Keywords: Moment-angle relationship, Muscle length, Mechanical properties, Knee extension force, quadriceps muscle.

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MVIC: Maximal voluntary isometric contraction

RF: Rectus femoris

VM: Vastus medialis

VL: Vastus lateralis

VI: Vastus intermedius

L_f: fascicle length

Θp: pennation angle

TAC: Tendon aponeurosis complex

EMG: surface electromyography

CONSORT: Consolidated Standards of Reporting Trials

SUP60: supine with 60º of knee flexion

SIT60: seated with 60º of knee flexion

SUP20: supine with 20º of knee flexion

SIT20: seated with 20º of knee flexion

RMS: Root mean square

CSA: Cross sectional area

CI: Confidence interval 95%

ANOVA: Analysis of variance

η_ρ^2: eta squared

ICC: Intra-class correlation

APRESENTAÇÃO

O presente manuscrito da Defesa de Dissertação é proveniente de um grande projeto "*What is the best knee and hip angle to optimize the neuromuscular and tendinous adaptations induced by the electrical stimulation of the quadriceps femoris muscle*?",que foi desenvolvido durante o mestrado do pesquisador MsC. Jonathan Galvão Tenório Cavalcante e que resultou em 3 publicações científicas, das quais sou co-autora dos 2 respectivos artigos: *"Hip and knee joint angles determine fatigue onset during quadriceps neuromuscular electrical stimulation"*publicado na Revista *Applied Bionics and Biomechanics* (2022), bem como *"The effects of knee and hip joint angles on patellar tendon loading during quadriceps neuromuscular electrical stimulation"* publicado na Revista *Translational Sports Medicine* (2021). Nesses estudos houve a participação dos pesquisadores internacionais, Professora Dra. Karin Silbernagel do *Muscle and tendon Performance Laboratory* da *University of Delaware* (USA), bem como com a colaboração do Professor Dr. Patrick Corrigan da *Saint Louis University* (USA).

O início da minha trajetória na pesquisa acadêmica deu-se ainda no período da graduação (2015 – 2018), quando fui aluna da Iniciação Científica no Projeto "Pilates para hipertensas" da Universidade Católica de Brasília (UCB), sob direção e apoio da Professora Dra. Yomara Lima Mota, Prof. Mestre Leticia de Souza Andrade e minha amiga e prof. Mestre Isabella da Silva Almeida, que me apresentou aos professores pesquisadores da Universidade de Brasília (UnB). Sendo assim, entrei em contato com os responsáveis pelo grupo de pesquisa, a Profa. Rita de Cássia Marqueti Durigan e o Prof. João Luiz Quaglioti Durigan demonstrando interesse pela área acadêmica e desta forma, a convite dos mesmos ingressei no Grupo de Pesquisa em Plasticidade Musculotendínea (GPlast). Inicei colaborando no projeto do MsC. Jonathan Galvão para entender o desenho do estudo, bem como aprender a realizar as avaliações de torque, eletromiografia e da arquitetura musculotendínea em adultos jovens. Posteriormente ao momento de aprendizado auxiliei no mesmo projeto como avaliadora das variáveis de torque, atividade elétrica, arquitetura muscular do quadríceps femoral e propriedades do tendão patelar.

Por conseguinte, a Profa. Rita de Cássia e o Prof. João Durigan em conjunto iniciaram o desenho do meu pré-projeto de mestrado com as mesmas avaliações citadas acima, entretanto na população com osteoartrite de joelho. Em março de 2020 fui aprovada como aluna regular do mestrado do Programa de Pós-Graduação em Ciências da Reabilitação da Universidade de

Brasília – Faculdade de Ceilândia (UnB/FCE), sob orientação da Profa. Rita de Cassia Marqueti Durigan. Sendo assim, o projeto osteoartrite de joelho seria submetido ao Comitê de Ética da UnB/FCE. Entretanto, devido ao cenário da pandemia pelo novo coronavírus (COVID-19), o Distrito Federal decretou estado de quarentena e isolamento, desenvolvendo ao longo das semanas diferentes medidas de contenção da pandemia, dentre elas o fechamento de Universidades, paralisando por tempo indeterminado as atividades presenciais, incluindo a utilização dos laboratórios. Neste cenário, o laboratório de treinamento de Força da Faculdade de Educação Física - Universidade de Brasília (FEF/UnB), onde as coletas estavam sendo realizadas, seguiu as recomendações e paralisou as suas atividades. Com essa medida, a realização do projeto inicialmente proposto ficou comprometida e uma vez que o projeto original não poderia ser executado, pela inviabilidade de coleta, parte do projeto de mestrado do MsC Jonathan Galvão em que as análises foram realizadas com contrações voluntárias tornou-se o meu atual projeto de mestrado culminando no manuscrito apresentado a seguir, que foi desenvolvido durante o período de Pandemia pela COVID-19.

O período de suspensão das atividades presenciais, devido ao contexto da pandemia foi desafiador para o prosseguimento do trabalho de dissertação, e além disto, receber 1 mês após a qualificação do mestrado, o diagnóstico de 3 doenças, sendo elas a Síndrome de Sjogren Severa, a Polineuropatia Inflamatória desmielinizante crônica e a Hipertensão intracraniana benigna, tornaram esta jornada ainda mais árdua. Embora, a trajetória não tenha sido como esperada, o sustento de Deus, o apoio incansável dos meus pais, a ajuda dos meus orientadores e professores, o suporte dos meus amigos e o auxílio da equipe médica que me acompanha até hoje foram essenciais para que este manuscrito a seguir pudesse ser apresentado.

CONTEXTUALIZAÇÃO

A eficácia contrátil de um músculo e a geração de torque é influenciada em grande parte por variáveis como, a atividade elétrica, a arquitetura muscular (Folland e Williams, 2007) e pelas propriedades morfológicas, materiais e mecânicas do tendão, incluindo as propriedades do complexo tendão aponeurose (Maganaris et al., 1999; Bohm et al., 2015; Tas et al., 2016; Grob et al., 2016). Cabe ressaltar que esses fatores, podem variar durante contrações voluntárias isométricas máximas (CVIMs), com a mudança no comprimento da unidade músculo-tendão (Lanza et al., 2017; Kubo et al., 2006). Tendo em vista as características de origem e inserção da musculatura do quadríceps femoral, as alterações nos ângulos das articulações do quadril e joelho têm implicações fisiológicas e estruturais para a produção de força (Herzog et al., 1990). Sabe-se que há um consenso geral, no qual o torque é comumente maior em ângulos de flexão do joelho próximos a 60º (Pincivero et al., 2004, Lanza et al., 2017 e Cavalcante et al., 2021), no entanto, em relação ao ângulo da articulação do quadril, a discussão permanece aberta (Garnier et al., 2022).

Concernente a atividade elétrica do músculo, sabe-se que em posições mais encurtadas, a musculatura do quadríceps femoral tem maior ativação do que em posições alongadas (Babault et al., 2003), bem como um maior valor de ativação poderia ser esperado na posição sentada versus supina para os músculos superficiais do quadríceps femoral (Maffiuletti e Lepers, 2003). Além de compreender o comportamento neural do quadríceps, estudos também são necessários para entender as adaptações que ocorrem na arquitetura muscular durante a contração, por meio da ultrassonografia (Kubo et al., 2006; Blazevich et al., 2006), como o aumento da espessura do músculo e do ângulo de penação e a redução do comprimento do fascículo, que são de extrema importância, pois dizem respeito sobre a função de uma fibra muscular (Blazevich, Gill, e Zhou 2006). Outra variável que pode ser observada através da ultrassonografia é o deslocamento do complexo tendão-aponeurose (TAC) que reflete a capacidade dos componentes do tecido tendíneo de resistir e alongar ao armazenar e transferir energia (Kubo et al., 2006; Burgess et al., 2009).

Além da unidade contrátil, do sistema músculo-esquelético, cabe ressaltar a importância dos tendões que possuem como função primária, transferir a força do músculo para o osso (Giusti e Pepe 2016; Blalock et al. 2015) estando diretamente ligados na realização do movimento articular (Bohm, Mersmann, e Arampatzis 2015). Os tendões respondem tanto à atividade quanto à inatividade e sabe-se que suas propriedades morfológicas, mecânicas e materiais não mudam igualmente de acordo com as condições em que as cargas são aplicadas, incluindo o ângulo articular, tendo em vista que afeta a deformação do tendão (Pearson et al., 2017) e o braço do momento (Bohm et al., 2015). Sabe-se que após o treinamento isométrico, a rigidez do tendão é maior em músculos posicionados de formas mais alongadas em comparação aos músculos em posições mais encurtadas (Kubo et al. 2006) e que o aumento da capacidade de produção de força, rigidez e resistência ao estresse do tendão (Guzzoni, et al. 2018) é benéfico para a remodelação do tecido.

Embora saibamos que os tecidos musculares e tendíneos possuem papel importante para a geração do torque na CVIM, bem como o treinamento isométrico com contrações voluntárias pode ser útil na reabilitação de articulações lesionadas e com disfunções (Fitzgerald et al., 2003), ainda não é claro para os clínicos qual o melhor posicionamento a ser adotado na reabilitação de pacientes que possuem dores na articulação do joelho, quando se objetiva o fortalecimento muscular e o remodelamento tecidual. Um estímulo mecânico (causado pela contração muscular) é uma ferramenta poderosa capaz de atuar no remodelamento tecidual, devido ao mecanismo denominado de mecanotransdução. Por esse mecanismo, têm-se que sinais mecânicos podem ser convertidos em sinais biológicos a fim de promover adaptação celular e consequentemente a recuperação tecidual (Huwang et al., 2013). Nessa lógica, encontrar o melhor ângulo articular ou o melhor posicionamento do paciente em reabilitação, pode associar-se à forma mais apropriada da geração do estímulo mecânico e acelerar o processo de reparo tecidual. É necessário também levar em consideração que embora posições próximas a 60º de flexão do joelho, como vistas anteriormente sejam benéficas para maior produção de força (Pincivero et al., 2004, Lanza et al., 2017 e Cavalcante et al., 2021), as forças compressivas patelofemoral e tibiofemoral aumentam à medida que o joelho flexiona (Escamilla, 2001). Em contrapartida, quando o paciente é posicionado em decúbito dorsal com o joelho totalmente estendido, há contato mínimo entre o fêmur e a patela (Cox et al., 2021), o que consequentemente reduz o estresse articular. Portanto, investigar posições nas quais o estresse articular é menor, pode auxiliar os clínicos na escolha do posicionamento dos indivíduos com dor severa no joelho. Deste modo, o atual projeto pretende contribuir na compreensão de como a unidade músculotendínea atua de acordo com os ângulos da articulação do quadril e joelho, a partir de uma explicação baseada na biomecânica e na fisiologia.

As informações acima são relevantes e trazem um questionamento importante sobre como modificações no posicionamento e alterações biomecânicas podem ser cruciais para a reabilitação. Desta forma, a fim de ser útil na prática clínica, nosso estudo visa auxiliar os clínicos na construção de melhores estratégias de reabilitação para indivíduos com dores no joelho.

OBJETIVOS:

Objetivou-se avaliar a influência dos ângulos articulares do quadril (0º ou 85º) e joelho (60º ou 20º) no pico de torque extensor do joelho durante a CVIM juntamente com a eletromiografia de superfície (EMG), eficiência neuromuscular, arquitetura muscular, rigidez do TAC dos quatro constituintes do quadríceps femoral e propriedades do tendão patelar em indivíduos saudáveis do sexo masculino.

HIPÓTESES:

Hipotetizamos que: (1) o pico de torque de extensão do joelho durante a CVIM será maior a 60º de flexão do joelho comparado a 20º, assim como maior na posição sentada comparada à supina; (2) maior atividade do músculo quadríceps femoral a 20º de flexão do joelho comparado a 60º; (3) maior eficiência neuromuscular nas posições de 60º; (4) em repouso e durante a CIVM, o comprimento do fascículo (Lf) será maior e o θp será menor quando o joelho estiver a 60º; (5) a rigidez do TAC e do tendão patelar seriam maiores em posições mais alongadas em comparação com as posições encurtadas. Este estudo é importante, pois proporcionará um maior entendimento de como as variáveis musculotendíneas se comportam em diferentes ângulos, que podem ser futuramente úteis na construção de melhores exercícios isométricos para os programas de reabilitação.

THE INFLUENCE OF HIP AND KNEE JOINT ANGLES ON QUADRICEPS MUSCLE-TENDON UNIT PROPERTIES DURING MAXIMAL VOLUNTARY ISOMETRIC CONTRACTION

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Keywords: Moment-angle relationship, Muscle length, Mechanical properties, Knee extension force, quadriceps muscle.

Abstract

Knee extension exercises are commonly used to treat knee injuries. However, it is unclear what optimal positioning is for knee extension strength exercises. 60º of knee flexion allow greater force production, but 20º knee flexion reduces joint stress. Further, seated versus supine positioning may influence musculotendinous function. Determining how the quadriceps femoris musculotendinous unit functions, according to hip and knee joints angles may help with clinical decision making when prescribing knee extension exercises. We aimed to determine the effect of hip and knee joint angles on structure and neuromuscular functioning of all constituents of the quadriceps femoris musculature and patellar tendon properties. Twenty young males were evaluated in four positions: seated and supine in both 20º and 60º of knee flexion (SIT20, SIT60, SUP20, and SUP60). Computerized dynamometry was used to determine peak knee extension torque during maximal voluntary isometric contraction (MVIC). Ultrasound imaging was used at rest and during MVIC to characterize quadriceps femoris muscle and tendon aponeurosis complex stiffness. Additionally, patellar tendon morphological, mechanical, and material properties were evaluated. We found that peak torque and neuromuscular efficiency were higher for SUP60 and SIT60 compared to SUP20 and SIT20 position. We found higher fascicle length and lower pennation angle in positions with the knee flexed at 60º. The tendon aponeurosis complex stiffness of quadriceps femoris, force, stiffness, stress, and Young's modulus of patellar tendon were greater in more elongated positions (60º) than in shortened positions (20º). Stretching of patellar tendon was greater in SIT20 compared to SUP20. Muscle electrical activity of quadriceps femoris, length, strain, and CSA of patellar tendon remained unchanged between the positions. In conclusion, clinicians should consider positioning at 60° of knee flexion rather than 20°, regardless seated or supine, during rehabilitation to load the musculotendinous unit enough to stimulate a mechanotransduction. ClinicalTrials.gov (Identifier: NCT03822221).

1 Introduction

Quadriceps musculature weakness has been associated with the initiation, progression and severity of knee osteoarthritis (Vincent and Vincent, 2012), as well as, it may be caused by arthrogenic muscle inhibition, that remains a significant barrier to effective rehabilitation in patients with knee injuries and following surgery (Rice et al., 2010). While the above-mentioned conditions are of concern, exercise has been identified as a powerful intervention for many ailments and has often been used to treat knee injuries, with isometric training being one of the modalities used in rehabilitation programs (Fitzgerald et al., 2003).

The quadriceps femoris musculature is mainly responsible for the knee extension torque. The aponeuroses of these muscles are joined distally to form the quadriceps tendon, and, lastly, the patellar tendon, as the final force-transmission structure (Bohm et al. 2015, Grob et al. 2016). Due to origin characteristics of the rectus femoris muscle (RF) , changes in hip joint angles have physiological and structural implications for knee force production (Herzog et al. 1990). There is a general consensus on influence of knee joint angle on knee extensor torque during MVICs. However, regarding the hip joint angle, the discussion remains open (Garnier, et al, 2022). Knee extension torque during MVIC is commonly greater at knee flexion angles closer to 60º (Pincivero et al. 2004, Lanza et al. 2017 and Cavalcante et al., 2021). When comparing the supine and seated hip positions with the knee flexed to 90º (Maffiuletti and Lepers, 2003) and 70º (Ema et al. 2017), the MVIC may be reduced (Bampouras et al. 2017) or not (Cavalcante et al., 2021). Accordingly, it is necessary to elucidate the biomechanical advantages of different hip joint angles for clinical practice.

Extracting evidence from muscle groups in vivo is difficult because many factors interact to generate force during a particular joint movement. Strength production depends on morphological (muscular structure) and neural (electrical activity) parameters (Folland and Williams, 2007). In shortened positions, quadriceps femoris musculature has greater activation than in elongated positions (Babault et al. 2003), and a higher value for activation could be expected in the seated versus supine position for Vastus medialis (VM), Vastus lateralis (VL) and Rectus femoris (RF) muscles (Maffiuletti and Lepers, 2003).

Although positions closer to 60º knee flexion are beneficial for greater force production (Pincivero et al. 2004, Lanza et al. 2017 and Cavalcante et al., 2021), patellofemoral and tibiofemoral compressive forces increase as the knee flexes (Escamilla, 2001). Moreover, when positioned in supine with the knee fully extended, there is minimal contact between the femur and the patella (Cox et al., 2021). Therefore, investigating positions with greater patellofemoral compressive forces can be effective by producing greater mechanotrasnduction.

Compared to shortened positions, elongated and mid-range of the quadriceps femoris muscles have greater fascicle length (Lf) (Fukunaga et al., 1997a), and lower pennation angle (θp) (Fukunaga et al., 1997a). These alterations directly imply that force production: a) under isometric conditions, a muscle with longer fascicles may be expected to develop torque more quickly (i.e., higher shortening velocity) (Maden-Wilkinson et al., 2021); and b) the decrease of the pennation angle, at the elongated positions, implies a mechanical advantage for force generation (Fukunaga et al., 1997b). Tendon mechanical properties and their change also too so of paramount importance for muscular function and integrity (Wiesinger et al., 2020). Muscle work can be affected by connective tissue disorders (Suydam et al., 2015), periods of insufficient loading (de Boer et al., 2007, Kubo et al., 2012), or positioning of the joint (shortened muscle length) (Kubo et al., 2006). It is known that tendon stiffness is greater at longer muscle length than at shorter muscle length, after isometric training (Kubo et al., 2006) and resistance training increases the capacity of producing strength, stiffness, and resistance to stress (Guzzoni et al., 2018), which is beneficial for remodeling tissue. The tendon aponeurosis complex (TAC) stiffness indicates the elongation of the deep aponeurosis to the distal free tendon in response to transmitting muscle strength to the bones (Kubo et al., 2006; Burgess KE, 2009). It is well known that joint angles in elongated positions remove the slack of the TAC (increasing its stiffness) and, optimize muscle length for greater force production seem to be ideal for speeding up adaptation (Fukutani et al., 2017; Massey et al., 2018). Also, the increased tension of the TAC in stretched conditions favors better force transmission with less effort (Abellaneda et al., 2009; Raiteri, 2018).

Determining how the muscle-tendon unit acts according to hip and knee joint angles may help clinicians choose joint angles for knee extension exercises throughout rehabilitation. Therefore, we aimed to study and understand the the influence of hip (0º or 85º) and knee (60º or 20º) joint angles on the knee extensor MVIC along with surface electromyography (EMG), neuromuscular efficiency, muscle architecture, TAC stiffness of the four quadriceps femoris constituents, and patellar tendon properties in healthy male subjects. Specifically, we hypothesized that: (1) peak knee extension torque during MVIC would be greater at 60º of knee flexion compared to 20º, as well as greater in the seated compared to the supine; (2) greater quadriceps femoris muscle activity should be observed at 20º of knee flexion compared to 60º; (3) a higher neuromuscular efficiency should be observed on 60º positions; (4) at rest and during

MVIC, the Lf would be greater, and the θp would be lower when the knee is at 60º; (5) the TAC stiffness and the patellar tendon stiffness would be greater at more elongated positions compared to shortened positions. This study is important because it will inform how the muscle-tendon unit acts according to differents hip and knee joint angles during MVICs, which could be important for understanding and creating better rehabilitation proposals.

2. Material and methods

2.1. Trial design

This was a randomized, repeated-measures study. This is a sub-study to a larger trial that is aimed at gaining a better understanding of muscle-tendon behavior according to hip and knee joint angles. The full protocol is available on ClinicalTrials.gov (Identifier: NCT03822221). Participants were informed about the purposes, benefits, and risks before enrollment, and all provided written consent. Approval was obtained (protocol number 94388718.8.0000.8093) from the Research Ethics Committee at the University of Brasília/Faculty of Ceilândia following the Helsinki Declaration of 1975. This study was reported according to the Consolidated Standards of Reporting Trials (CONSORT) Statement for Randomised Trials of Nonpharmacologic Treatments (Schulz et al. 2010). All the procedures were performed in the Laboratory of Strength of the Faculty of the Physical Education at the University of Brasília.

2.2 Participants

Twenty male participants (age 24 ± 4.6 years; height 177 ± 6.3 cm, and body mass 77 ± 9.3 kg) were recruited through flyers and verbal invitation. The inclusion criteria were: healthy male, aged 18 to 30 years, and physically active. The exclusion criteria were: not engaged in systematic lower limb strengthening or sports competitions in the previous six months, any musculoskeletal injury, motor control disorder, or systemic diseases that could affect performance or safety on tests.

2.3 Randomization, allocation concealment, and blinding

Testing was performed in four positions (Figure 1): Supine and seated were considered 0º and 85º of hip flexion, respectively. A fully extended knee was considered as 0º of knee flexion. Order of the testing positions was randomized for each participant. Randomization was guaranteed by having participants blindly remove four small square paper sheets from an opaque envelope. Researchers and participants could not be blinded to the assessment positions.

2.4 Experimental procedures

The protocol consisted of five laboratory visits (Figure 1), including a familiarization visit and four experimental visits. Each visit lasted 2-3 hours and was performed seven days after the previous visit. We instructed participants to abstain from alcohol and stimulants (e.g., caffeine, chocolate, and performance supplements) for at least 24 hours before visits, avoid strenuous exercise 36 hours before the visits, and maintain their regular diet. We obtained anthropometrics (body mass and height) during the familiarization visit, and participants practiced ramped MVICs in each position. The four positions were tested separately in each experimental session and consisted of 12 MVICs to complete all ultrasound imaging and electromyography exams (two for EMG, two for patellar tendon properties, and eight for muscle architecture).

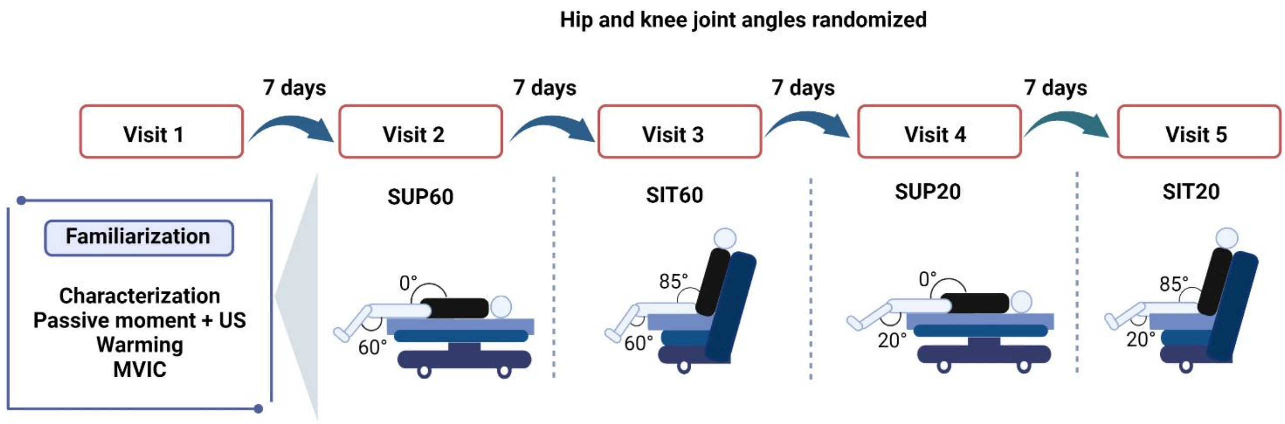


Figure 1 – Experimental design example: Participants took part in five sessions at least 7 days apart, a familiarization and four experimental sessions to randomly test four combinations of hip and knee joint angles during quadriceps femoris musculature evaluations (QF). Twelve MVICs were required at each visit. Legend: MVIC: Maximal Voluntary Isometric Contraction; SUP60: supine with 60º of knee flexion; SIT60: seated with 60º of knee flexion; SUP20: supine with 20º of knee flexion; SIT20: seated with 20º of knee flexion.

2.5 Outcomes

We measured the peak knee extension torque during MVIC in each position, along with Root Mean Square (RMS) values by EMG of the quadriceps musculature. Moreover, the muscle architecture (θ_p and L_f) and the tendon-aponeurosis complex (TAC) stiffness were measured from the four quadriceps femoris musculature, and the morphological (resting length and cross-sectional area (CSA)), mechanical (force, elongation, and stiffness), and material properties (stress, strain, and Young's Modulus) were measured from the patellar tendon.

2.5.1 Torque assessment

A computerized dynamometer (System 4; Biodex Medical Systems, Shirley, New York, USA) was used to collect the primary outcome, knee extension torque during MVICs. The mechanical axis of the dynamometer was visually aligned with the flexion-extension axis of the knee and hip angles were adjusted with a goniometer, and the lever arm of the dynamometer transducer was firmly attached 2-3 cm above the lateral malleolus with a strap. A warm-up of submaximal isometric contractions was performed for muscle and tendon pre-conditioning: 50%: 3 contractions; 75%: 2 contractions; and 90%: 1 contraction. 10seconds of rest was provided between submaximal contractions (Lanza et al., 2017). Following the warm-up, participants completed 12 MVICs and were encouraged verbally to perform maximum strength on ramping contractions during 6 – 10s and received visual feedback of the torque produced. 2-minutes rest was provided between MVICs.

2.5.2 EMG

EMG of the VL, VM, RF, and most lateral portion of biceps femoris was recorded bipolarly with a sampling frequency of 1000 Hz by the data acquisition device New Myotool (Miotec – Biomedical Equipment, Porto Alegre, Brazil®). The device was synchronized with the dynamometer, and electrical activity was recorded. Passive electrodes (circular silver-silver chloride electrodes with a 20 mm diameter) were positioned on the belly of the muscles (De Luca, 1997) with an inter-electrode distance (center to center) of 20 mm. A reference electrode was fixed on the patella of the ipsilateral limb (Babault et al., 2006). Impedance reduction between the two electrodes was achieved through trichotomy and skin cleaning with alcohol swabs. Raw EMG signal was band-pass filtered (20 – 500 Hz) to remove artifacts, and a notch filter of 60 Hz was applied, because of the noise in the EMG signals. The raw RMS values were calculated within a 500 ms period in the most stable part of the torque trace (the MVIC plateau).

2.5.3 Neuromuscular efficiency

Neuromuscular efficiency was calculated by dividing the peak knee extension torque by the RMS of the knee extensors (Shahrjerdi et al., 2020; Remaud et al., 2005) and then transformed into a percentage multiplied by 100.

2.5.4 Muscle architecture

A linear probe (40 mm, 7.5 MHz, depth 6.0 cm, sampling frequency of 30 Hz) was connected to an ultrasound system (M-turbo, Sonosite, Washington, USA). The ultrasound probe was covered with a water-soluble transmission gel and positioned longitudinally to the muscle fiber and perpendicular to the skin at 50% (RF), 60% (VL), 75% (VM), and 80% Vastus Intermedius (VI), from proximal to the distal, of the distance between the medial aspect of the anterior superior iliac spine and the patella base, as adapted from previous reports (Blazevich et al., 2006, Massey et al., 2015). These regions were preferred because an isotropic muscle architecture and minimal fascicle curvature were expected (Blazevich et al., 2006). The RF and VI were visualized on the anterior aspect of the thigh, while the VL and VM were visualized, respectively, on the lateral and medial aspects. For the VI, although it could be seen on the same window of the RF or VL (Blazevich et al., 2006), VI visualization could be partially lost during contraction. Thus, it was recorded more distally. A custom-made device (Figure 2) held the ultrasound probe preventing it from moving. The probe was aligned so that the superficial and deep aponeuroses were parallel, and several fascicles could be delineated across the image (Baroni et al., 2013b; Geremia et al., 2019). With cine-loop ultrasound imaging, two recordings (from rest to MVC plateau) were obtained for each quadriceps femoris constituent, and the best recording (better fascicle visualization) was used for analysis. The recordings' frames (at rest and MVIC plateau) were saved as image files and analyzed in ImageJ software (v. 1.46; National Institutes of Health, Bethesda, USA. The best fascicle (i.e., the fascicle that could be clearly delineated from its insertion on the deep aponeurosis to the probe field-of-view limits) was used for Lf and θp analysis (Geremia et al., 2019). The θp was calculated considering the angle between the deep aponeurosis and the fascicles. The Lf was considered as the length of the fascicular path between superficial and deep aponeuroses. Thus, according to previous studies, the remaining fascicle portion, from the field-of-view boundary to the superficial aponeurosis, was estimated by equation (Finni T, 2002). For all ultrasound imaging outcomes, three measurements were performed and averaged. All measurements were conducted by the same investigator with extensive experience in ultrasonography. Furthermore, to synchronize the MVIC and all ultrasonographic recordings, we used a data acquisition device, New Miotool (Miotec Biomedical Equipment Ltd., POA, Brazil®) collected with a sampling rate of 2000 Hz per channel, A/D converter of 14 bits, common rejection mode of 110 db (at 60 Hz). For this, the data acquisition device was connected to the computerized dynamometer, and a high-definition camera was positioned to capture the ultrasound display. When the assessor started recording cine-loop ultrasound images prior to the MVICs, a visual indicator appeared on the ultrasound screen, which enabled the synchronization of all data on a torque-time recording generated by the device (Bojsen-Moller et al., 2003).

Figure 2 – A custom-made device to held the ultrasound probe for preventing it from moving.

2.5.5 TAC Stiffness

The TAC displacement of each quadriceps femoris muscle constituent was assessed using the same video recordings obtained to extract muscle architecture variables. During data collection, a custom-made device held the probe, preventing it from moving. Moreover, the operator carefully maintained the instrument and probe to avoid any sliding further and maintain the best probe inclination concerning the skin surface along with contraction. If sliding occurred, it was corrected concerning a hypoechoic shadow provided by an adhesive tape. Moreover, ultrasonographic recordings were performed during passive motion (two for each quadriceps' constituent at 10º/s) of the knee from 60º to 0º in both seated and supine positions to correct displacement overestimation due to any knee joint angular rotation. Only the corrected values were used to calculate each constituent's stiffness (Kubo et al., 2006).

We used the Tracker 4.87 software to manually track the cross point between the fascicle and the deep aponeurosis and its displacement in millimeters from rest to MVIC. Due to the possibility of its deep insertion starting outside the probe's field-of-view, we commonly made linear extrapolation, which is a standardized method (Massey et al., 2015; Cavalcante et al., 2021). Quadriceps femoris muscle force was obtained by dividing the knee extensor torque values by the patellar moment arm, which was standardized for all participants according to the knee angle (60º: 0.056 m; 20º: 0.0475 m) (Krevolin et al., 2004). To obtain a quadriceps femoris TAC stiffness of all quadriceps femoris constituents, we used the delta from 50% to 100% of the MVIC and the delta displacement of each quadriceps femoris constituent at the respective levels of force (50% and 100%) (Massey et al., 2018).

2.5.6 Patellar tendon properties

For all analyses of patellar tendon properties, participants then performed six 5-second submaximal isometric knee extension for tendon pre-conditioning (Seynnes et al., 2015), which was mentioned above in the torque assessment section. Following the submaximal, the four MVICs were randomly performed to assess the patellar tendon with 120 s of rest between each.

2.5.6.1 Morphological properties

We used an M-turbo® (Sonosite, Bothwell, WA, USA) ultrasound system with a wide-band linear array probe with a central frequency of 7.5 MHz to evaluate patellar tendon morphology at rest while the participants were positioned in each condition. The resting length was obtained with the ultrasound probe positioned longitudinally along the tendon, from the patella's apex to the deep insertion to the tibial tuberosity (O'Brien et al., 2010). If the size of the transducer did not allow the complete visualization of the patellar tendon, and it was obtained using an overlapping images method adopted by (Urlando and Hawkins 2007), The length from the marker to each anatomical structure was measured with Tracker 4.87 software (www.physlets.org/tracker/) and summed to determine the patellar tendon length, accordingly to Cavalcante et al., 2021.

Patellar tendon CSA was obtained with the ultrasound probe positioned perpendicular to the long-axis of the tendon. The mean value from three images was obtained at each location (25%, 50%, and 75% of the tendon length) (Kongsgaard et al., 2007) and mean values of three locations was adopted to allow patellar tendon CSA to be measured from these axial images using Image J software (v. 1.46; National Institutes of Health, Bethesda, Maryland).

2.5.6.2 Mechanical properties

Patellar tendon force was defined by the torque obtained during MVIC divided by the patellar tendon moment arm, from previous literature as 0.056 m and 0.0475 m at 60º and 20º of knee flexion, respectively (Krevolin et al., 2004). Patellar tendon force was determined at 10% intervals of the MVIC (from 0 to 100%). The elongation was measured with cine-loop ultrasound imaging during MVIC using the same landmarks described above for the patellar tendon rest length. Patellar tendon elongation was defined as the length change between the patellar tendon proximal and distal insertions. The patella's apex and the tendon's deeper insertion to the tibial tuberosity were determined by manual tracking using Tracker 4.87 (www.physlets.org/tracker/). Patellar tendon strength and elongation were synchronized using the same technique mentioned above in the muscle architecture assessment section, as proposed by Bojsen-Moeller et al., (2003). Force-elongation plots were fitted with a second-order polynomial forced through zero. The slope of the force-elongation curve, obtained from 50 to 100% MVIC (Geremia et al., 2018), was considered the tendon stiffness.

2.5.6.3 Material properties

Stresses and strains were obtained at 10% torque steps throughout the MVIC to assess the patellar tendon stress-strain relationship and estimate patellar tendon material properties for each condition (Geremia et al., 2018). The patellar tendon stress was calculated by dividing tendon force by CSA, and tendon strain was calculated by dividing tendon elongation by patellar tendon resting length. Stress-strain plots were fitted with a second-order polynomial forced through zero. Using the associated quadratic equations Young's Modulus was determined as the stress-strain relationship using the same relative (50% - 100%) force levels as selected for determining tendon stiffness force.

2.6 Statistical analysis and sample size

All outcomes are reported as geometric mean and 95% confidence intervals (95% CI). To compare peak knee extension torque, RMS, neuromuscular efficiency, tendon-aponeurosis complex stiffness, and patellar tendon properties between the different positions, we used repeated-measures one-way analysis of variance (ANOVA. For θp and Lf, once we had valued at rest and during MVIC, a repeated measures two-way ANOVA [position by condition (rest and MVIC)] was used. When a significant difference was detected, a Tukey post-hoc test was applied to identify the differences. Effect sizes and statistical power were calculated. The effect size was determined using partial eta squared ($\eta\rho 2$), according to the following classification: small ($\eta\rho 2 = 0.01$), medium ($\eta\rho 2 = 0.06$), and large ($\eta\rho 2 = 0.14$) effects (Cohen, 1988).

For reliability assessment, the intra-class correlation (ICC) of torque (all eight MVIC performed during muscle ultrasound imaging for each position) was obtained using a mean of multiple measurements, absolute agreement, 2-way mixed-effects model. The purpose of this ICC was to guarantee that all of the muscle structure assessments were performed under stable conditions of contraction intensity. Moreover, a single-measurement, absolute-agreement, 2-way mixed-effects model was used for the interrater ICC of muscle architecture and the TAC displacement [two repeated analyses, seven to 14 between-days, of 25 recordings for each quadriceps femoris constituents). To determine the reliability of measuring tendon elongation, two repeated measurements of 25 random points (i.e., at any force level) were obtained for each condition from the force-elongation curve and used to calculate the ICC using a single-measurement, absolute-agreement, 2-way mixed-effects model. Reliability was classified as: poor (< 0.5), moderate (0.5 – 0.75), good (> 0.75 – 0.9), and excellent (> 0.9) (Koo and Li, 2016). All statistical analyses used a significance level at $p \leq 0.05$. All analyses were performed using STATISTICA 23.0 (STATSOFT Inc., Tulsa, Oklahoma, USA), and the software GraphPad PRISM 8.4.1 (San Diego, CA, USA) was used for graphic design.

The sample size for the primary outcome was determined a priori using G*Power (version 3.1.3; University of Trier, Trier, Germany) with the level of significance set at p =0.05 and power (1-β) = 0.80 to detect a large effect size (ηρ2 = 0.45). Based on Lanza et al. (Lanza et al. 2017) we expected means and standard deviations from knee extension torques to be approximately 125.93 ± 31.81 Nm, 249.3 ± 30.13 Nm, 267.1 ± 32.26, and 216.3 ± 36.25 Nm for knee flexion angles of 25º, 50º, 80º, and 106º, respectively. Based on these values, we found a combined standard deviation of 63.62 Nm with a sample size of 20 participants.

3. Results

3.1 Reliability of measurements

High test-retest reliability was observed from the ICC values for torque at SUP60 (0.92), SIT60 (0.94) SUP20 (0.92), and SIT20 (0.93). We obtained good reliability for the θ_p of RF (0.75), VL (0.78), VM (0.82), and VI (0.77), L_f of RF (0.81), VL (0.80), VM (0.77), VI (0.79) and an excellent reliability for tendon-aponeurosis complex displacement for RF (0.98), VL (0.95), VM (0.95), and for maximal elongation of the patellar tendon (0.98), only except good reliability for VI (0.86).

3.2 MVIC, raw RMS, and quadriceps femoris neuromuscular efficiency

A significant main effect of position was found for peak knee extension torque ($F_{3,57}$ = 87.57, p < 0.0001, ηρ2: 0.82, power: 1.0). The post-hoc analysis showed that knee flexed at 60° (SUP60 and SIT60) had higher MVIC (p < 0.001 for all analyses) than SUP20 and SIT20 (Fig.2). No main effect of position was observed for raw RMS ($F_{3,57}$ = 0.87, p = 0.46, ηρ2: 0.04, power: 0.22). (Fig.2.). A significant main effect of position was found for quadriceps femoris neuromuscular efficiency ($F_{3,57}$ = 22.32, p < 0.0001, ηρ2: 0.54, power: 1.0). The post-hoc analysis showed that knee flexed at 60° (SUP60 and SIT60) had higher values (p < 0.001 for all analyses) than SUP20 and SIT20 (Fig.3).

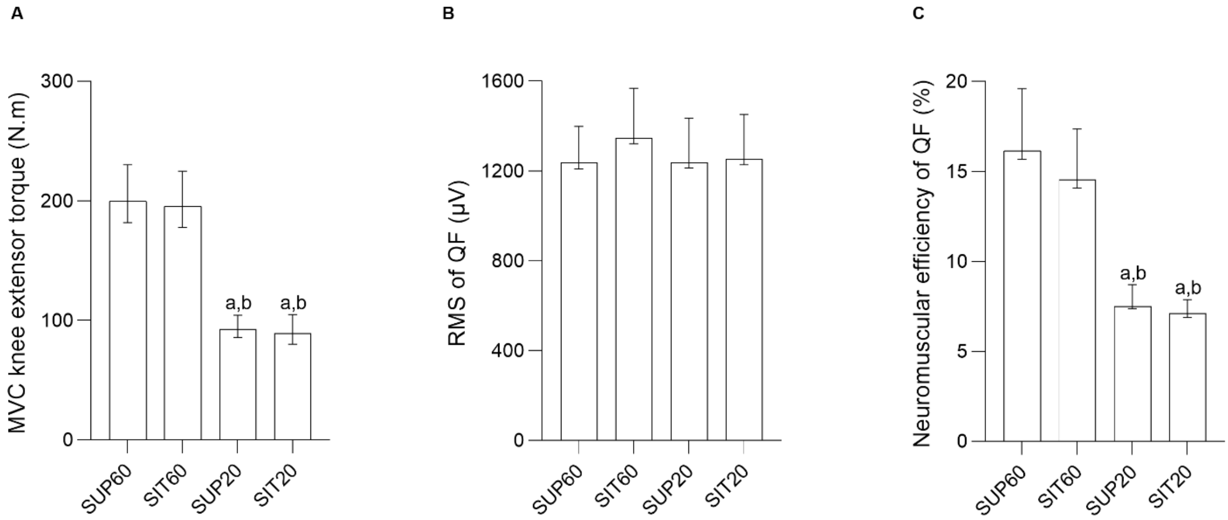


Figure 3 – MVIC knee extensor torque, Root Mean Square and neuromuscular efficiency of the quadriceps femoris constituents according to hip and knee angles during contraction. **(A)** MVIC knee extensor torque (N.m) (y-axis) and different conditions (x-axis). **(B)** Root Mean Square of quadriceps femoris (µV) (y-axis) and different conditions (x-axis). **(C)** Neuromuscular efficiency of the quadriceps femoris (%) (y-axis) and different conditions (x-axis). Data are presented as geometric mean and confidence interval (CI 95%). Legend: *MVIC:* Maximal Voluntary Isometric Contraction; *RMS:* Root Mean Square; *QF:* Quadriceps femoris; *SUP60:* supine with 60º of knee flexion; *SIT60:* seated with 60º of knee flexion; *SUP20:* supine with 20º of knee flexion; *SIT20:* seated with 20º of knee flexion. Significant differences: [a] different from SUP60 at ($p \leq 0.05$). [b] different from SIT60 at ($p \leq 0.05$).

3.2 Muscle architecture

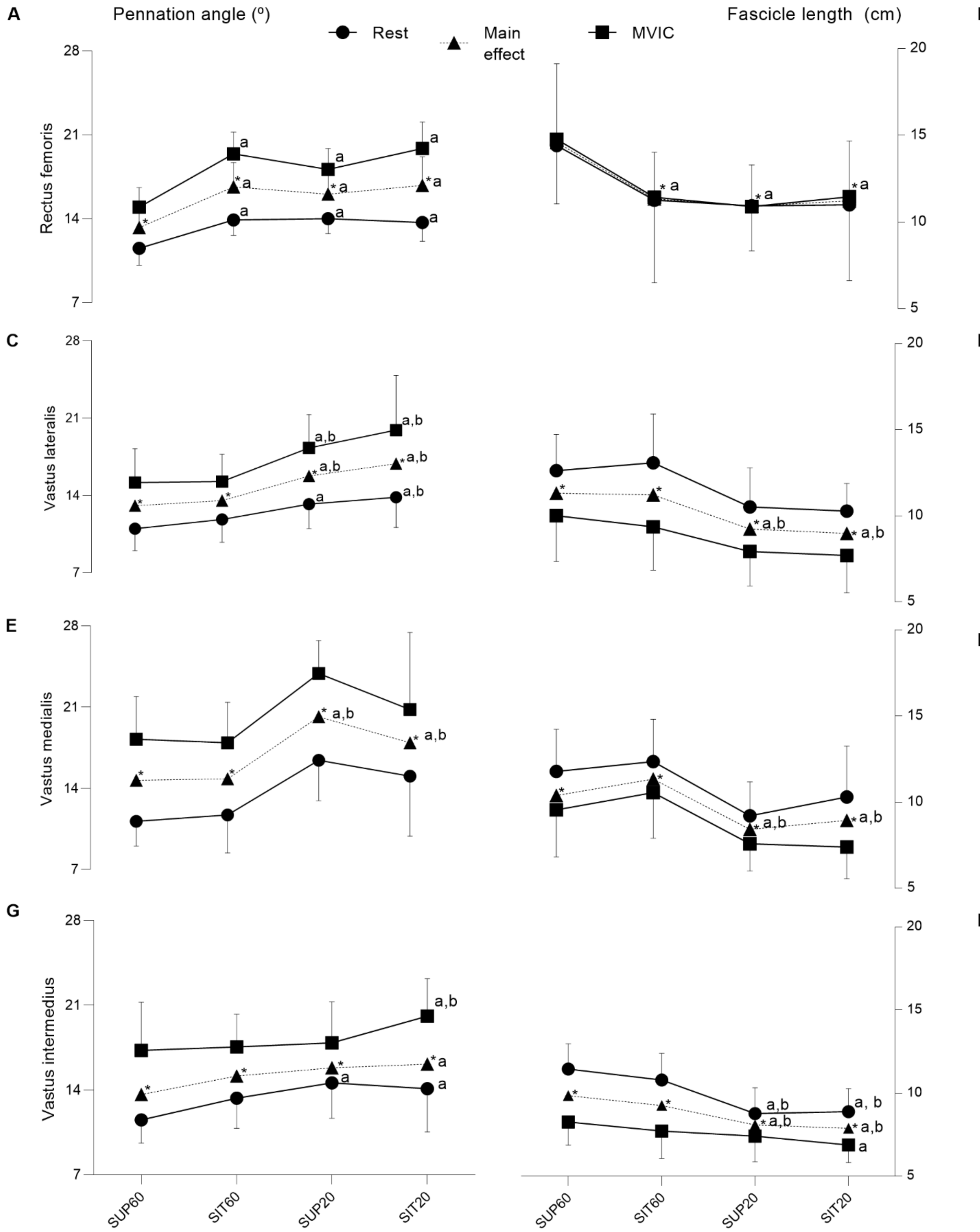


Figure 4 – The pennation angle and fascicle length of the quadriceps femoris constituents according to hip and knee angles during rest and contraction. Muscle (y-axis) and different conditions (x-axis). Rest (closed circle line), main effect (closed triangle line) and during MVIC (closed square line). The first column presented the pennation angle – θp (°) values and second column fascicle length - Lf (cm) values. Data are presented as mean and confidence interval (CI 95%). (A-B): Rectus femoris; (C-D): Vastus lateralis; (E-F): Vastus medialis; (G-H): Vastus intermedius. Legend: *SUP60:* supine with 60º of knee flexion; *SIT60:* seated with 60º of knee flexion; *SUP20:* supine with 20º of knee flexion; *SIT20:* seated with 20º of knee flexion; θp: pennation angle; Lf: fascicle length. Significant differences: [a] different from SUP60 at ($p \leq 0.05$); [b] different from SIT60 ($p \leq 0.05$); *indicate significant difference on intensity ($p \leq 0.05$) between rest and MVIC.

For RF (Fig. 4A-B), there was interaction between position and condition for the θp ($F_{3, 57} = 3.65$, $p = 0.017$, ηρ2: 0.16, power: 0.77). The post-hoc analysis showed that both at rest and during contraction, SUP60 had lower θp compared to SIT60, SUP20, and SIT20 ($p < 0.001$ – 0.036), with no difference between other comparisons ($p = 0.15$ – 0.99). There was no interaction of factors for Lf ($F_{3, 57} = 1.87$, $p = 0.14$, ηρ2: 0.089, power: 0.46), but the effect of position was significant ($F_{3, 57} = 24.89$, $p < 0.001$, ηρ2: 0.56, power: 1.00), where the post-hoc analysis showed greater Lf for SUP60 ($p < 0.001$; Fig 3B) than all positions, with no difference between other comparisons ($p = 0.46$ – 0.97).

VL (Fig. 4C-D) presented a significant interaction between positioning and condition for θp ($F_{3, 57} = 3.48$, $p = 0.021$, ηρ2: 0.15, power: 0.75). The post-hoc analysis showed that, at rest, there was lower θp for SUP60 compared to SUP20 ($p = 0.012$; Fig. 3C) and SIT20 ($P < 0.001$), and at SIT60 compared to SIT20 ($p = 0.033$), with no difference between other comparisons ($p = 0.31$ – 0.97). Furthermore, during MVIC, θp was lower ($p <0.001$) at SUP60 and SIT60 compared to SUP20 and SIT20. No difference was observed between SUP60 and SIT60 ($p = 1.0$), as well as between SUP20 and SIT20 ($p = 0.16$). Position factor was significant for the θp ($F_{3, 57} = 13.66$, $p < 0.001$, ηρ2: 0.41, power: 0.99). The post-hoc analysis indicated lower θp ($p < 0.0001$-0.001) for SUP60 and SIT60 compared to SUP20 and SIT20. No difference was observed between SUP60 and SIT60 ($p = 0.90$), as well as between SUP20 and SIT20 ($p = 0.37$). There was no interaction for Lf ($F_{3, 57} = 0.56$, $p = 0.064$, ηρ2: 0.02, power: 0.15), but there was a significant main effect of positioning ($F_{3, 57} = 14.10$, $p < 0.001$, ηρ2: 0.42, power: 0.99), with post-hoc analyses showing higher Lf at SUP60 compared to SUP20 and SIT20 ($p = 0.0006$; $p = 0.0002$), respectively. The same was true at SIT60 when compared to SUP20 and SIT20 ($p = 0.000368$; $p < 0.0001$), respectively.

Only for VM (Fig. 4E-F), there was no significant interaction between position and condition for θp (F 3, 57 = 0.31, p = 0.812, ηρ2: 0.01, power: 0.10) and for Lf (F 3, 57 = 0.85, p = 0.46, ηρ2: 0.043, power: 0.22). However, position factor was significant for both θp (F 3, 57 = 37,40, p < 0.001, ηρ2: 0.66, power: 1.00) and Lf (F3, 57 = 13.06, p < 0.001, ηρ2: 0.40, power: 0.99), with post-hoc analysis indicated lower θp (p <0.0001) and greater Lf (p < 0.0023 - 0.037) for SUP60 and SIT60 compared to SUP20 and SIT20.

Regarding VI (Fig. 4G-H), there was significant effect of interaction between position and condition for both θp (F 3, 57 = 2.82, p = 0.046, ηρ2: 0.12, power: 0.64) and Lf (F 3, 57 = 6.24, p < 0.001, ηρ2: 0.24, power: 0.95). The post-hoc analysis showed that, at rest, there was a lower θp for SUP60 compared to SUP20 (p = 0.003) and SIT20 (p = 0.02). During MVIC a lower θp was found for SUP 60 and SIT60 when compared to SIT20 (p = 0.008; p = 0.027), respectively. Other pairwise comparisons at rest and during MVIC were not significant (p = 0.26 – 0.99). A greater Lf was found at rest only for SUP60 and SIT60 (p < 0.0001 for all analyses) when compared to SUP20 and SIT20. For Lf other pairwise comparisons during rest were not significant (p = 0.56 – 0.99). However, during MVIC only at SUP60 was greater Lf compared to SIT20 (p = 0.005). The main effect of position was also significant for both θp (F 3,57 = 4.40, p = 0.007, ηρ2: 0.18, power: 0.85) and Lf (F 3, 57 = 16.16, p < 0.001, ηρ2: 0.45, power: 0.99). The θp was lower at SUP60 compared to SIT20 (p < 0.005) and, Lf was greater for SUP60 and SIT60 compared to SUP20 and SIT20 (p < 0,001 for all analyses).

3.3 TAC stiffness

TAC stiffness of quadriceps femoris is presented in Table. 1. A significant main effect of position was found for TAC ($F_{3,57} = 7.84$, $p = 0.001$, η_{ρ}^{2}: 0.29, power: 0.98) and the post-hoc analysis showed that TAC stiffness was greater in SUP60 (p = 0.001), SIT60 (p = 0.0004) and SUP20 (p = 0.01) compared to SIT20.

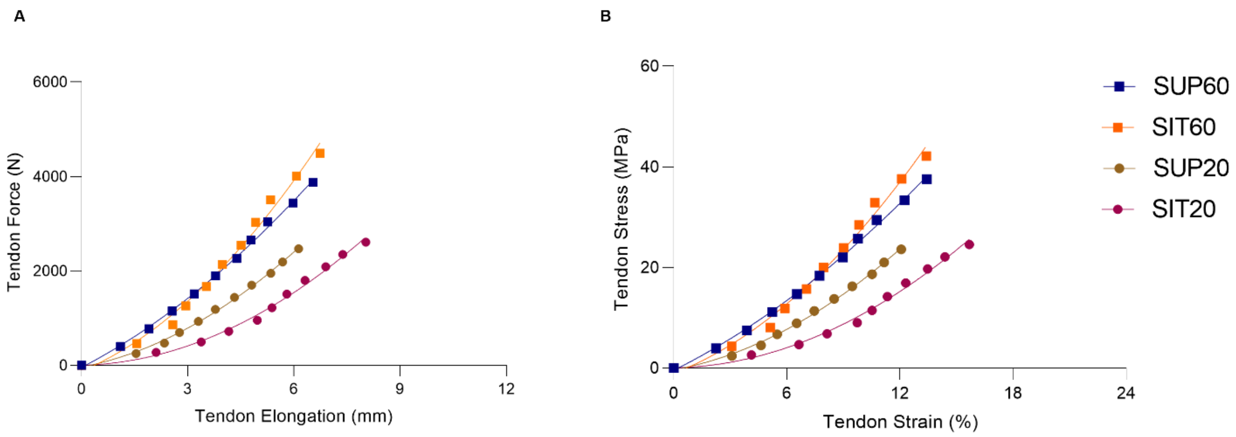
Table 1. Patellar tendon properties and Tendon Aponeurosis Complex Stiffness of quadriceps femoris at different hip and knee angles measured during maximal voluntary isometric contraction. Geometric Mean (95% CI)

	SUP60	SIT60	SUP20	SIT20
Morphological properties				
Resting length (mm)	48.95 (46.79 – 51.53)	50.45 (47.92 – 53.64)	50,62 (48.40 – 53.29)	50,55 (47.94 – 53.86)
CSA (mm²)	103.33 (97.63 – 110.45)	107.18 (102.23 – 113.16)	104.03 (98.20 – 111.14)	107.12 (103.98 – 110.68)
Mechanical properties				
Force (N)	3768.9 (3391.6 – 4353.1)	4341.37 (3913.85 – 5070.55)	2379.82 (2134.06 – 2807.60) [a, b]	2497.16 (2193.69 – 3025.21) [a, b]
Elongation (mm)	6.19 (5.44 – 7.64)	6.25 (5.49 – 7.98)	5.72 (5.07 – 7.20)	7.51 (6.53 – 9.54) [c]
Stiffness (N/mm)	771.75 (636.78 – 1112.95)	1008.33 (822.89 – 1674.57)	600.05 (511.31 – 816.29) [b]	579.92 (492.24 – 790.34) [b]
TAC Stiffness QF (N/mm)	174.17 (169.18 – 189.15)	176.22 (171.19 – 195.83)	158.77 (154.35 – 179.66)	114.00 (111.28 – 130.51) [a, b, c]
Material properties				
Stress (MPa)	36.48 (32.61 – 42.42)	40.51 (36.32 – 47.92)	22.88 (20.65 – 26.62) [a, b]	23.43 (20.61 – 28.53) [a, b]
Strain (%)	12.68 (11.15 – 15.69)	12.40 (10.83 – 15.97)	11.29 (9.97 – 14.14)	14.85 (13.02 – 18.34)
Young's Modulus (MPa)	393.65 (320.31 - 589.37)	512.28 (434.07 – 845.60)	313.63 (271.71 – 426.35) [b]	303.84 (256.47 – 416.28) [b]

Legend: *CI:* confidence interval; *SUP60*: supine with 60º of knee flexion; *SIT60:* seated with 60º of knee flexion; *SUP20:* supine with 20º knee flexion; *SIT20:* seated with 20º of knee flexion; *CSA*: Cross-Sectional Area, *Stiffnes* slope of the force-elongation curve from 50 to 100 % of maximal voluntary contraction force; *TAC:* Tendon aponeurosis complex; *QF:* Quadriceps femoris; *Young's Modulus* slope of the stress-strain curve obtained from 50 to 100% of maximal voluntary stress. [a] Significantly different from SUP60 at $p < 0.05$. [b] Significantly different from SIT60 at $p < 0.05$. [c] Significantly different from SUP20 at $p < 0.05$.

3.4 Tendon properties

The patellar tendon (morphological, mechanical, and material) properties for each position are presented in Table 1. The tendon force–elongation (A) and stress-strain relationships (B) are shown in Fig.5. For patellar tendon variables, two volunteers were excluded due to technical problems in the data collection.



3.4.1 Morphological properties

No changes were found in the patellar tendon resting length ($p = 0.186$) and CSA ($p = 0.563$) for all conditions.

3.4.2 Mechanical properties

The mechanical properties of the patellar tendon are shown in Table 1 and Fig. 5A. A significant main effect of position was found for patellar tendon force ($F_{3,51} = 33.90$; $p < 0.01$; $\eta\rho^2$: 0.66; power: 1.00). In the post-hoc analysis both SUP60 and SIT60 showed a greater force ($p < 0.001$) than SUP20 and SIT20, with no differences between positions with the same knee angle: SUP60 vs. SIT60: $p = 0.057$; SUP20 vs. SIT20: $p = 0.93$. Maximal tendon elongation presented main effect of position ($F_{3,51} = 3.29$; $p = 0.027$; $\eta\rho^2$: 0.16; power: 0.71) and the post-hoc analyses showed SIT20 significantly higher than SUP20 ($p = 0.022$), but there was no significant difference in comparison to SUP60 and SIT60 ($p = 0.10$, $p = 0.19$), respectively. Significantly greater Stiffness at SIT60 was found compared to SUP20 and SIT20 ($F_{3,51} = 6.88$; $p < 0.01$; $\eta\rho^2$: 0.28; power: 0.96) with post-hoc analysis $p < 0.001$.

3.4.3 Material properties

The material properties of the patellar tendon are shown in table 1 and Fig. 5B. The stress at SUP60 and SIT60 was significantly higher than SUP20 and SIT20 ($F_{3,51} = 30.10$; $p < 0.01$; $\eta\rho^2$: 0.63; power: 1.00). However, no differences were found in tendon stress at the same knee angle (SUP60 vs. SIT60 and SUP20 vs. SIT20). The tendon strain was not changed ($p = 0.057$). We found a significant main effect of position for Young's Modulus ($F_{3,51} = 7.01$; $p < 0.01$; $\eta\rho^2$: 0.29; power: 0.97). In the post-hoc analysis SIT60 was higher than SUP20 ($p = 0.0017$) and SIT20 ($p = 0.0010$).

4. Discussion

To the best of our knowledge, this is the first study to assess different hip and knee joint angles on torque generation, RMS activity, neuromuscular efficiency, muscle architecture, and tendon-aponeurosis complex stiffness of the quadriceps muscle constituents and patellar tendon properties in healthy adults. In general, we found (1) higher torque and neuromuscular efficiency at 60º of knee flexion compared to 20º, regardless of hip position; (2) no differences were found for RMS between positions; (3) RF showed a lower pennation angle and greater fascicle length at SUP60 compared to all other position, while VL, VM, and VI showed lower pennation angle, and greater fascicle length at 60º of knee flexion when compared to 20º; (4) the TAC stiffness was greater at the more elongated position; (5) tendon force, stiffness, stress and 'Young's Modulus were greater with the knee flexed at 60º, compared to 20º.

4.1 MVIC, RMS, and quadriceps neuromuscular efficiency

We found greater MVIC at 60º of knee flexion compared to 20º. According to Lanza et al., 2017, the differences in torque production are due to the force-length relationship of the muscle, in which changes in the joint's angle and the muscle's length affect the extent of force generation (Lanza et al., 2017). Thus, the knee extensor torque reduction on positions closer to the full extension could be partly attributed to mechanical factors, such as the reduced number of cross-bridges attached subsequent to sarcomere beyond the optimal actin-myosin overlap (Babault et al., 2003; Herzog et al., 1990).

Our results demonstrated no differences in MVIC torque between supine and seated positions and corroborated Bampouras et al., (2017). In contrast, Maffiuletti et al., (2003) and Ema et al., (2017) found higher torque values in the seated position, and this may be due to the difference in the operated region of the force-length relationship of RF between the two hip positions (Ema et al.2017). However, the choice of knee angle for Maffiuletti et al. 2003 and Ema et al. 2017 were 90º and 70º, respectively. It is possible that we did not find any differences in our study since 60º of knee flexion may not have been enough to lengthen the RF and generate a considerable effect on torque output, showing a disadvantage from one position to the other.

We demonstrated no differences in RMS activity between positions. Babault et al. (2003) found higher activation values at short (i.e., 35° knee flexion) compared with long (i.e., 75° knee flexion) quadriceps muscle length. With a shortened position, lesser muscle activation was expected (Newman et al. 2003, Kooistra et al. 2007); higher activation was observed that would compensate for the weaker torque observed at higher degrees of knee flexion (Babault et al. 2003). Maffiuletti et al., (2003) demonstrated greater activation in the seated position in comparison with the supine position for VM, VL, and RF muscles (Maffiuletti et al., 2003). However, it is noteworthy that Maffiuletti found the greatest neural activation of the knee extensors with the knee positioned at 90º, which may reflect a neurophysiological mechanism as compensation for the neuromuscular transmission-propagation deficiency and/or mechanical disadvantage of RF in shortened position (Maffiuletti et al., 2003). These results still fluctuate widely between these two positions because the lack of significant effect of the hip joint angle on agonist and antagonist muscle activations found by Ema et al., (2017) suggests that neural factors may not have a substantial effect on the difference in knee extension torque and need to be further investigated.

Neuromuscular efficiency could be shown in several *in vivo* human studies, indicating optimized muscle function (Seiberl et al., 2016). Aragão et al. (2015) consider those individuals as efficient capable of producing greater strength with a lower magnitude of muscle activation (Aragão et al., 2015). We found greater efficiency for the quadriceps femoris muscle in positions with the knee flexed at 60º. Although the RMS did not present differences between the positions, 60º positions indicate an economic and efficient mechanism since it was not necessary to increase muscle activation to generate greater torque, demonstrating the mechanical advantage of this joint angle.

4.2 Muscle architecture

The observable adaptations in the muscular architecture during a contraction are the increase of the muscle thickness and the pennation angle and the decrease of the fascicle length, which are determinants in the generation of strength, range of motion and velocity of muscular shortening (Fukunaga et al., 1997; Aagaard et al., 2001; Blazevitch et al., 2003; Reeves & Narici, 2003; Oliveira et al., 2018a). We found an increase in pennation angle of quadriceps femoris constituents from rest to contraction, and they are consistent with previous studies (Massey et al., 2015; Manal et al., 2006). Therefore, fascicle length and pennation angle change depending on the shortening or lengthening of the sarcomeres and the response to variations in tendon slack and the total muscle length. As a result, these changes have important functional relevance concerning the production of force that is modified by the sarcomere and changes in whole muscle length (Stevens et al., 2014).

We demonstrated an apparent effect of the hip angle on RF architecture, as expected for the quadriceps femoris's biarticular constituent. The pennation angle was lower, and fascicle length was higher at SUP60 than in all other positions. The VL, VM, and VI operated with lower pennation angle when the knee was flexed at 60º compared to 20º. Since placing the quadriceps femoris in a better physiological architectural configuration for generating torque favors a better transmission of muscle strength to the tendon and the ideal length of the sarcomere/fiber (Gordon et al., 1966, Fukunaga et al., 1997a, Lieber and Fridén, 2000). Furthermore, our findings demonstrate that fascicle length was shorter during VI contractions at SIT20, and the larger shortening would have been caused by taking up the elongated series elastic component (Fukunaga et al. 1997a). Therefore, positions at 60º set the quadriceps femoris in a better architectural configuration, leading to a neuromuscular economy. It can be considered in the proposals for strength rehabilitation programs, because of an improvement in the neuromuscular transmission of muscle strength to the tendon.

4.3 TAC stiffness

The TAC stiffness index of quadriceps femoris on SUP60 was higher than all other positions, similar to other studies (Cavalcante et al., 2021), indicating an increased passive tension that limited tendinous elongation during contraction (Fukutani et al., 2017). Shortened positions limit the mechanical stress and consequently lead the muscle to bear less force and generate less stress on the tendon. The increased tension of the TAC in stretched conditions is known to allow stronger contraction with less effort due to better force transmission (Abellaneda et al., 2009; Raiteri, 2018).

4.4 Patellar tendon properties

4.4.1 Morphological properties

Patellar tendon resting length and CSA were not different among conditions. Similar results were previously observed considering the changes in knee angle (Defrate et al., 2007, Edama et al., 2019, Cavalcante et al., 2021). We showed that the hip angle, from 85º of flexion to 0º, also did not provide any lengthening of the patellar tendon. This probably occurred because tendons designed to withstand high forces should not suffer significant length change between relatively close knee angles (60º and 20º), even with the additional stretch promoted by the hip extension (Cavalcante et al., 2021). The lack of changes in patellar tendon length may reflect biomechanical implications since it is not likely to attribute differences in stiffness to appreciable changes in the resting length, but possibly to collagen molecule coiling/uncoiling (Depalle et al., 2015), associated with crimp pattern, which may imply in tendon transmission of force and load (Zuskov et al., 2020).

4.4.2 Mechanical and material properties

Stiffness presented higher values at SIT60 in comparison with SUP20 and SIT20 positions. It is probably due to higher levels of force being applied to the tendon and, consequently, the higher level of tendon stiffness presented. It is possible to notice that a longer position generates greater tendon stiffness, in agreement with Kubo et al. 2006 during an isometric training protocol. According to these results, it seems preferable to load the patellar tendon at voluntary contractions using the knee at 60º. Simultaneously, the hip angle variation may affect how tensile loads are transmitted through the tendon. The increase of the stiffness in positions at 60° can provide an advantage in rehabilitation since it promotes more significant tension generation in the muscle-tendon unit. As tendon stiffness increases with high-intensity training (Bohm et al., 2015; Lazarckzuk et al., 2022), the high load achieved by muscle contractions in this angle can lead higher tendon adaptations than training programs with lower loads. A remarkable finding was that patellar tendon stress supports the force results (i.e., significant stress with the knee at 60º without the hip's influence). Therefore, we cannot attribute these results to differences in the CSA mean but rather to the different strength levels higher in positions at 60º of knee flexion. Stress and Young's Modulus were greater with the knee flexed at 60º compared with 20º.

A potential limitation of this study was the lack of estimated contribution of each muscle for the total quadriceps muscle force. Therefore, tendon-aponeurosis complex stiffness of each quadriceps muscle constituent was calculated considering the total force. These calculations may lead to errors due to changes in contribution according to both force and muscle length levels. However, once we did not perform comparisons between the constituents, our values may be useful as a snapshot. Another limitation was restricted to the healthy young male population used in this study. More broadly, research is also needed to determine these properties in women populations and other muscles and tendons.

Conclusion

Torque generation, neuromuscular efficiency, a greater fascicle length and lower pennation angle, the patellar tendon force, stiffness, stress and 'Young's Modulus were higher with the knee flexed at 60º compared to 20º. All quadriceps femoris constituents presented higher tendon-aponeurosis complex stiffness in more elongated positions, indicating a higher capacity to support tension and expose the tendon to greater stress. Our results suggest the superiority of the knee angle at 60º for isometric contractions compared to 20º, which may be important factors guiding the adaptations to regular training/rehabilitation on the muscle-tendon unit. It is possible to suggest that clinicians should preferably use SUP60 or SIT60 conditions for strengthening and remodeling purposes since these positions seem to provide a mechanical advantage for generating greater strength. Gaining a better understanding of the possible physiological mechanisms that underlie muscle and tendon efficiency can provide a framework to develop strengthened protocols to produce more effective contractions and improve the outcomes of rehabilitation programs.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author Contributions

AMMS, JGTC, DCLV, NB, JMG, PC, KGS, JLQD and RCM conceived and designed research; AMMS and JGTC performed experiments; AMMS, JGTC, DCLV, NB, JMG, JLQD and RCM analyzed data; AMMS, JGTC,DCLV, NB, JMG, PC, KGS, JLQD and RCM interpreted results of experiments; AMMS, JGTC and RCM prepared figures; AMMS, JGTC, JMG, PC, RCM drafted manuscript; AMMS, JGTC, DCLV, NB, JMG, PC, KGS, JLQD and RCM edited and revised manuscript; AMMS, JGTC, DCLV, NB, JMG, PC, KGS, JLQD and RCM approved final version of manuscript.

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CONSIDERAÇÕES FINAIS

A geração de torque, a eficiência neuromuscular, o maior comprimento do fascículo e o menor ângulo de penação, bem como a força do tendão patelar, a rigidez, o estresse e o módulo de Young foram maiores com o joelho flexionado a 60º comparado a 20º. Além disso, o alongamento foi maior na posição SIT20 em comparação com a posição SUP20. Todos os constituintes do músculo quadríceps femoral apresentaram maior rigidez do complexo tendão-aponeurose em posições mais encurtadas, indicando maior capacidade de absorver mais energia, o que consequentemente pode levar a suportar maior tensão e expor o tendão a maior estresse. Baseado nessas informações, nossos resultados sugerem a superioridade do ângulo do joelho a 60º para contrações isométricas em comparação com 20º, haja visto as características fisiológicas e estruturais significativas, que podem ser fatores importantes na orientação e adaptação ao treinamento/reabilitação da unidade músculo-tendínea. Além disso, o ângulo do quadril esteve envolvido em alterações no músculo quadríceps (não apenas no reto femoral) que pode ser explorado em estudos posteriores. Esses achados são essenciais para a compreensão da unidade musculotendínea do quadríceps femoral e necessitam de atenção, pois as modificações nos ângulos do quadril e joelho estão relacionados à transmissão de força, bem como as propriedades funcionais do tendão. Deste modo, é possível sugerir que os clínicos devem usar preferencialmente as posições SUP60 ou SIT60 para fins de fortalecimento muscular e remodelamento tecidual, uma vez que essas posições parecem proporcionar uma vantagem mecânica por gerar maior resistência. Ganhando uma melhor compreensão dos possíveis mecanismos fisiológicos subjacentes aos músculos e tendões, nossos achados podem fornecer um embasamento científico para a construção e desenvolvimento de melhores protocolos que visam a reabilitação de pacientes com dores no joelho.

IMPACTOS PRÁTICOS DOS ACHADOS PARA A SOCIEDADE

A partir do presente estudo, destaco a aplicabilidade prática dos nossos resultados, bem como a contribuição para a ciência e para a sociedade em questão:

- Durante a reabilitação de pacientes com dores no joelho, como exemplo os indivíduos com osteoartrite, tendinopatia patelar ou aqueles que possuem dor femoropatelar, sugere-se que clínicos, fisioterapeutas e educadores físicos devem preferivelmente posicionar os seus pacientes em posições mais encurtadas, ou seja, deitados ou sentados com o joelho flexionado a 60º, a despeito de 20º, quando visam maior promoção de força muscular e altas cargas no tendão patelar.

- A partir de tais informações, podemos também citar como impacto prático para os clínicos, o embasamento e respaldo científico para construção de exercícios que considerem a biomecânica humana para favorecer a geração de força e a eficiência neuromuscular do quadríceps femoral. Associado a isso considerar que um adequado estímulo mecânico por meio da mecanotransdução, um processo importante de transmissão de sinais entre o meio extra e intra celular favorecerão o remodelamento tecidual tendíneo.

- Embora, as posições a 20º proporcionem menor estresse articular, as posições a 60º de flexão de joelho parecem ser mais favoráveis para a reabilitação de dores no joelho, principalmente pensando nos casos de osteaortrite severa, tendinopatia patelar em exacerbação, bem como para os pacientes que estão internados e necessitam realizar exercícios de extensão de joelho deitado e em isometria.

APÊNDICES E ANEXOS

Anexo I – Aprovação do Comitê de Ética e Pesquisa

UNB - FACULDADE DE CEILÂNDIA DA UNIVERSIDADE DE BRASÍLIA

Plataforma Brasil

PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: Efeitos agudos da estimulação elétrica neuromuscular em diferentes ângulos do quadril e do joelho nas adaptações neuromiotendíneas e no torque extensor do joelho em adultos jovens saudáveis

Pesquisador: Jonathan Galvão Tenório Cavalcante

Área Temática:

Versão: 1

CAAE: 94388718.8.0000.8093

Instituição Proponente: Universidade de Brasília Faculdade de Ceilândia

Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 2.799.049

Apresentação do Projeto:

Trata-se de um projeto mestrado do Programa de Pós Graduação em Ciências da Reabilitação, da Faculdade de Ceilândia – Universidade de Brasília, do mestrando Jonathan Galvão Tenório Cavalcante, e demais pesquisadores envolvidos: Karenina Arrais Guida Modesto, Rita de Cássia Marqueti Durigan, Nicolas Babault e João Luiz Quagliotti Durigan (orientador). Tem como Área de Estudo (Grandes Áreas do Conhecimento (CNPq): Grande Área 4. Ciências da Saúde e o Propósito Principal do Estudo (OMS): Clínico. O pesquisador deixa claro quais são os problemas ou Condições de saúde (Plasticidade musculotendínea, Força muscular, Relação comprimento-tensão, Atividade elétrica muscular) vinculando ao CID: M62.9 - Transtorno muscular não especificado e, M62 - Outros transtornos musculares.
Os pesquisadores informam que:
"Trata-se de um estudo observacional de delineamento transversal. As variáveis independentes são: 1) o posicionamento do membro inferior: angulação da articulação do joelho em 20° ou 60° com o quadril em 0° ou 80° (respectivamente, indivíduos deitados ou sentados com leve reclinação); 2) a estimulação elétrica neuromuscular para obtenção do torque evocado. As variáveis dependentes serão a contração voluntária máxima (CVM), o torque evocado eletricamente (TEE), a atividade elétrica de superfície, a arquitetura muscular (espessura muscular, ângulo de penação e comprimento fascicular) e o alongamento do complexo tendão-aponeurose do quadríceps e a

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UF: DF **Município:** BRASILIA
Telefone: (61)3107-8434 **E-mail:** cep.fce@gmail.com

Brasília, e os menores gastos serão arcados pelos pesquisadores.

Considerações sobre os Termos de apresentação obrigatória:

Todos os documentos foram adequadamente apresentados.

Conclusões ou Pendências e Lista de Inadequações:

Não há pendências.

Considerações Finais a critério do CEP:

Protocolo de pesquisa em consonância com a Resolução 466/12 do Conselho Nacional de Saúde. Cabe ressaltar que compete ao pesquisador responsável: desenvolver o projeto conforme delineado; elaborar e apresentar os relatórios parciais e final; apresentar dados solicitados pelo CEP ou pela CONEP a qualquer momento; manter os dados da pesquisa em arquivo, físico ou digital, sob sua guarda e responsabilidade, por um período de 5 anos após o término da pesquisa; encaminhar os resultados da pesquisa para publicação, com os devidos créditos aos pesquisadores associados e ao pessoal técnico integrante do projeto; e justificar fundamentadamente, perante o CEP ou a CONEP, interrupção do projeto ou a não publicação dos resultados.

Este parecer foi elaborado baseado nos documentos abaixo relacionados:

Tipo Documento	Arquivo	Postagem	Autor	Situação
Informações Básicas do Projeto	PB_INFORMAÇÕES_BÁSICAS_DO_PROJETO_1109531.pdf	23/07/2018 13:21:53		Aceito
Outros	Curriculo_Nicolas_Babault_ingles.pdf	23/07/2018 13:21:18	Jonathan Galvão Tenório Cavalcante	Aceito
Outros	Carta_resposta_membro_estrangeiro.pdf	23/07/2018 13:19:48	Jonathan Galvão Tenório Cavalcante	Aceito
Projeto Detalhado / Brochura Investigador	Projeto_Detalhado.docx	16/07/2018 18:24:30	Jonathan Galvão Tenório Cavalcante	Aceito
Outros	Curriculo_Lattes_Karenina_Arrais.pdf	16/07/2018 18:22:28	Jonathan Galvão Tenório Cavalcante	Aceito
Outros	Curriculo_Lattes_Rita_de_Cassia.pdf	16/07/2018 18:21:41	Jonathan Galvão Tenório Cavalcante	Aceito
Outros	Curriculo_Lattes_Joao_Luiz.pdf	16/07/2018 18:21:17	Jonathan Galvão Tenório Cavalcante	Aceito
Outros	Curriculo_Lattes_Jonathan_Galvao.pdf	16/07/2018 18:20:36	Jonathan Galvão Tenório Cavalcante	Aceito

Outros	termo_de_concordancia_de_instituicao_participante.pdf	16/07/2018 18:19:25	Jonathan Galvão Tenório Cavalcante	Aceito
Declaração de Pesquisadores	termo_de_responsabilidade_e_compromisso_do_pesquisador.pdf	16/07/2018 18:18:23	Jonathan Galvão Tenório Cavalcante	Aceito
Folha de Rosto	folhaDeRosto.pdf	16/07/2018 18:16:25	Jonathan Galvão Tenório Cavalcante	Aceito
Outros	cartaencaminhprojeto_ao_cepfce.docx	28/06/2018 11:08:53	Jonathan Galvão Tenório Cavalcante	Aceito
Orçamento	Planilha_de_orcamento.doc	28/06/2018 02:24:55	Jonathan Galvão Tenório Cavalcante	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TCLE_Jonathan_Galvao.doc	28/06/2018 02:22:51	Jonathan Galvão Tenório Cavalcante	Aceito
Cronograma	Cronograma.docx	28/06/2018 02:21:44	Jonathan Galvão Tenório Cavalcante	Aceito
Outros	termo_instituicao_proponente.jpg	28/06/2018 02:19:23	Jonathan Galvão Tenório Cavalcante	Aceito

Situação do Parecer:
Aprovado

Necessita Apreciação da CONEP:
Não

BRASILIA, 03 de Agosto de 2018

Assinado por:
Dayani Galato
(Coordenador)

ANEXO II – Email comprovando a submissão do manuscrito *"The influence of hip and knee joint angles on quadriceps muscle-tendon unit properties during maximal voluntary isometric contraction"* na revista *Frontiers in Physiology*.

Frontiers in Physiology <physiology.editorial.office@frontiersin.org> qui., 4 de ago. 12:06 (há 6 dias)
para mim

inglês > português Traduzir mensagem Desativar para: inglês

Dear Dr De Sousa

We are pleased to inform you that we have received the manuscript "THE INFLUENCE OF HIP AND KNEE JOINT ANGLES ON QUADRICEPS MUSCLE-TENDON UNIT PROPERTIES DURING MAXIMAL VOLUNTARY ISOMETRIC CONTRACTION" to be considered for publication in Frontiers in Physiology, section Striated Muscle Physiology.

You can access the review forum and track the progress of your manuscript using the following link:
https://www.frontiersin.org//Journal/MySubmission.aspx?stage=100

Your manuscript is now in the initial validation stage to determine its suitability for peer review. Should your manuscript be sent out for peer review, you will receive a notification once we receive the reports from reviewers and the interactive review forum is activated. You will then be able to read the review reports and exchange directly with the reviewers in the interactive review forum as well as submit a revised manuscript, if appropriate. If the required number of reviewers endorse your manuscript in the Independent Review stage, their tabs will be closed and the manuscript will be forwarded to the Review Finalized stage, where you will be able to interact with the handling editor via the Editor tab.

Best regards,

Your Frontiers in Physiology Team

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ANEXO III – Registro na plataforma Clinical.trials.gov.

NIH U.S. National Library of Medicine
ClinicalTrials.gov

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Home > Search Results > Study Record Detail Save this study

Angles of Knee and Hip Joints for Optimization of Neuromuscular Electrical Stimulation of the Quadriceps Femoris Muscle

The safety and scientific validity of this study is the responsibility of the study sponsor and investigators. Listing a study does not mean it has been evaluated by the U.S. Federal Government. Know the risks and potential benefits of clinical studies and talk to your health care provider before participating. Read our disclaimer for details.

ClinicalTrials.gov Identifier: NCT03822221

Recruitment Status : Not yet recruiting
First Posted : January 30, 2019
Last Update Posted : April 16, 2019

See **Contacts and Locations**

Sponsor:
University of Brasilia

Collaborator:
University of Burgundy

Information provided by (Responsible Party):
João Luiz Q. Durigan, University of Brasilia

PRODUTOS EDUCACIONAIS, CIENTÍFICOS, SOCIOCULTURAIS E TECNOLÓGICOS/ECONÔMICOS DESENVOLVIDOS NO PERÍODO DO MESTRADO

Durante os dois anos e meio como aluna do mestrado no Programa de Pós-Graduação em Ciências da Reabilitação da Universidade de Brasília/Faculdade de Ceilândia (UnB/FCE) produzi:

PRODUTOS COM IMPACTO CIENTÍFICO:

1. Manuscrito *"Hip and knee joint angles determine fatigue onset during quadriceps neuromuscular electrical stimulation"*
Jonathan Galvão Tenório Cavalcante, Álvaro de Almeida Ventura, Leandro Gomes de Jesus Ferreira, **Alessandra Martins Melo de Sousa**, Ivo Vieira de Sousa Neto, Rita de Cássia Marqueti, Nicolas Babault, João Luiz Quagliotti Durigan, "Hip and Knee Joint Angles Determine Fatigue Onset during Quadriceps Neuromuscular Electrical Stimulation", Applied Bionics and Biomechanics, vol. 2022, Article ID 4612867, 11 pages, 2022. https://doi.org/10.1155/2022/4612867

2. Manuscrito *"The Effect of Mat Pilates Training Combined With Aerobic Exercise Versus Mat Pilates Training Alone on Blood Pressure in Women With Hypertension: A Randomized Controlled Trial".*
Isabella da Silva Almeida, PT, Letícia de Souza Andrade, PT, **Alessandra Martins Melo de Sousa, PT**, Gerson Cipriano Junior, PT, PhD, Natália Turri-Silva, PT, Dahan da Cunha Nascimento, PhD, Yomara Lima Mota, PT, PhD, João Luiz Quagliotti Durigan, PT, PhD, The Effect of Mat Pilates Training Combined With Aerobic Exercise Versus Mat Pilates Training Alone on Blood Pressure in Women With Hypertension: A Randomized Controlled Trial, Physical Therapy, Volume 102, Issue 2, February 2022, pzab258, https://doi.org/10.1093/ptj/pzab258

3. Manuscrito *"The effects of knee and hip joint angles on patellar tendon loading during quadriceps neuromuscular electrical stimulation".*
Jonathan Galvão Tenório Cavalcante, Rita de Cássia Marqueti, Patrick Corrigan, **Alessandra Martins Melo de Sousa** , Martim Bottaro , Nicolas Babault , Jeam Marcel

Geremia , Karin Grävare Silbernagel , João Luiz Quaglioti Durigan. The effects of knee and hip joint angles on patellar tendon loading during quadriceps neuromuscular electrical stimulation. Translational Sports Medicine, v. 4, p. 587-596, 2021. https://doi.org/10.1002/tsm2.260

4. Manuscrito *"Is the combination of aerobic exercise with mat Pilates better than mat Pilates training alone on autonomic modulation related to functional outcomes in hypertensive women? Secondary analysis of a randomized controlled trial.*

   Authors: Isabella da Silva Almeida *, Letícia de Souza Andrade, **Alessandra Martins Melo de Sousa,** Gerson Cipriano Junior, Aparecida Maria Catai, Yomara Lima Mota, João Luiz Quagliotti Durigan *

   Fase: *Final proofreading before publication* na Revista *International Journal of Environmental Research and Public Health* (ISSN 1660-4601).

5. Integrante da comissão organizadora discente do I Simpósio Interdisciplinar em Ciências da Reabilitação (ISimReab), realizado no dia 20 de novembro de 2021 em modo síncrono, promovido pelo Programa de Pós-Graduação em Ciências da Reabilitação da Universidade de Brasília/Faculdade de Ceilândia (UnB/FCE).

6. Participação de discentes e docentes internacionais na discussão dos dados e na escrita dos manuscritos, como Dra. Karin Silbernagel da University of Delaware (USA); Dr. Patrick Corrigan da Univeristy of Saint Louis (USA) e Dr. Nicolas Babault da Universidade de Dijon (FRA), respectivamente. Além da parceria nacional com o pesquisador Dr. Jeam Marcel Geremia da Universidade Federal do Rio Grande do Sul.

PRODUTOS COM IMPACTO TECNOLÓGICO/ECONÔMICO

1. Apoio financeiro a Publicação em Revistas Científicas (Edital FAP/DF -11/2022, nº do processo 00193-00001219/2022-93);
2. Apoio à execução de projetos de pesquisas científicas, tecnológicas e de inovação de discentes de Pós-Graduação (Edital DPG n. 0004/2021);
3. Auxílio financeiro a estudantes de Pós-Graduação para aquisição de material de consumo para o adequado desenvolvimento do projeto de pesquisa relacionado com a dissertação de mestrado (Edital n. 03/2021);

4. Provimento de cotas de auxílio financeiro a estudantes de Pós-Graduação em situação de vulnerabilidade (Edital n. 02/2021, vinculado ao Edital DPG n. 0006/2021, nº do processo 23106.104941/2021-71).

PRODUTOS COM IMPACTO EDUCACIONAL

- Estágio em Práticas de capacitação docente, sob orientação da Professora Dra. Rita de Cássia Marqueti Durigan, vinculada a disciplina Suporte e Movimento - graduação (Carga horária: 30h).

- Participação como ouvinte no I Simpósio Interdisciplinar em Ciências da Reabilitação (ISimReab), realizado no dia 20 de novembro de 2021 em modo síncrono, promovido pelo Programa de Pós-Graduação em Ciências da Reabilitação da Universidade de Brasília/Faculdade de Ceilândia (UnB/FCE).

PRODUTOS COM IMPACTO SOCIOCULTURAL

- Criação dos *posts* informativos em redes sociais: "Qual é o melhor exercício para diminuir a pressão arterial em mulheres hipertensas?" e "Ciência não é só para pesquisador. Ciência é para o clínico e Ciência também é para a população" em linguagem não científica para comunicar aos clínicos e pacientes os resultados e a importância dos estudos do grupo de pesquisa.