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ACUTE EFFECTS OF FOAM ROLLING ON THE MECHANICAL PROPERTIES OF MYOFASCIAL TISSUES AND MUSCLE STRENGTH: A SYSTEMATIC REVIEW AND META-ANALYSIS

Santa Maria, RS
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Dissertação de mestrado apresentado ao Programa de Pós-Graduação em Educação Física do Centro de Educação Física e Desportos da Universidade Federal de Santa Maria (UFSM), como um requisito final para obtenção do título de Mestre em Educação Física.

Orientador: Prof. Dr. Jeam Marcel Geremia

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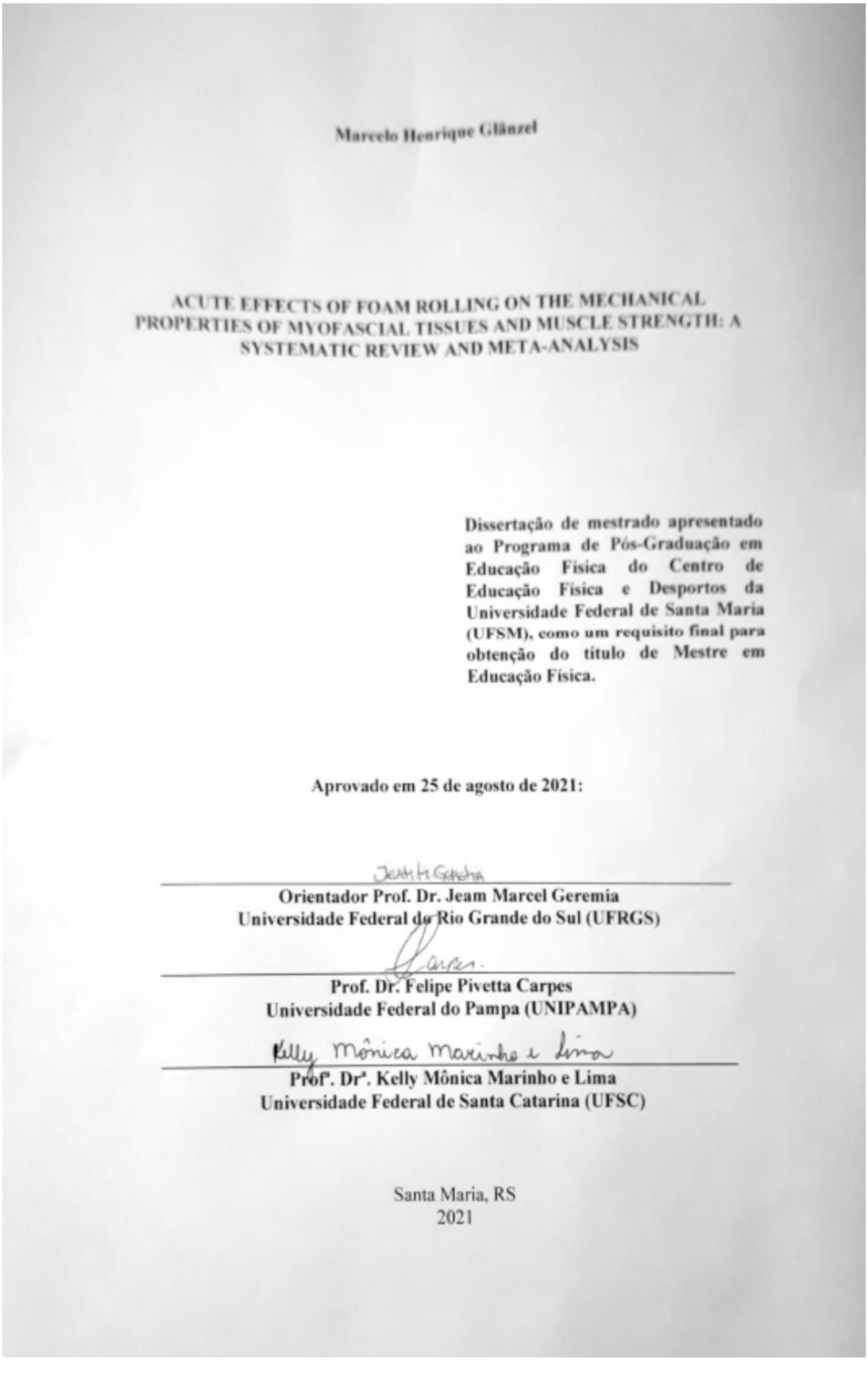

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“*I do not know what I may appear to the world, but to myself I seem to have been only like a boy playing on the seashore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me”*.

Isaac Newton

RESUMO

EFEITOS AGUDOS DO FOAM ROLLING SOBRE AS PROPRIEDADES MECÂNICAS DOS TECIDOS MIOFASCIAIS E NA FORÇA MUSCULAR: UMA REVISÃO SISTEMÁTICA E META-ANÁLISE

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A automassagem, utilizando rolo de espuma [i.e., *foam rolling* (FR)] é amplamente utilizada em programas de reabilitação e treinamento físico. Embora existam algumas evidências de que o FR possa alterar a rigidez dos tecidos miofasciais e a força muscular, não existe um consenso sobre os efeitos desta técnica nestes parâmetros. O objetivo deste estudo foi revisar e avaliar por meio de meta-análise, estudos que testaram os efeitos agudos do FR na rigidez dos tecidos miofasciais e na força muscular. Uma revisão sistemática foi realizada usando as recomendações da Cochrane para revisar estudos indexados nas bases de dados PubMed, Web of Science, Embase e PEDro. A pesquisa buscou ensaios clínicos randomizados que testaram os efeitos agudos do FR na rigidez dos tecidos miofasciais e na força muscular em adultos saudáveis e/ ou atletas. Os estudos incluídos foram avaliados metodologicamente pela escala PEDro. Os desfechos avaliados foram rigidez fascial e muscular, força muscular isométrica e isocinética e taxa de produção de força (TPF). Os dados disponíveis foram agrupados em meta-análise. A certeza das evidências foi avaliada pela abordagem GRADE. Dos 20 estudos incluídos [PEDro: média 5,0±1,3 (amplitude 4-8)], quatro avaliaram a rigidez de tecidos fasciais da região do tronco e da coxa, sete avaliaram a rigidez muscular de músculos da coxa e panturrilha, enquanto 12 avaliaram a força muscular de músculos extensores e flexores de joelho, e flexores plantares, durante contrações isométricas (n=9) e isocinéticas (n=3). A análise qualitativa mostrou diminuição na rigidez fascial e muscular após o FR. No entanto, as meta-análises mostraram que o FR não altera a rigidez dos tecidos miofasciais. As análises qualitativa e quantitativa não mostraram efeitos significativos sobre a força muscular isométrica, torque excêntrico e TPF. No entanto, o torque concêntrico apresentou resultados contraditórios. A meta-análise mostrou aumento no torque concêntrico nos extensores, mas não nos flexores do joelho após a aplicação do FR. Considerando que nossos resultados sugerem que o FR não altera a rigidez dos tecidos miofasciais, alterações em parâmetros funcionais parecem estar relacionadas com mecanismos neurais e não com a rigidez dos tecidos. Em relação à força muscular, parece haver um consenso de que o FR não afeta a força isométrica, enquanto as evidências sobre o torque excêntrico e TPF ainda são limitadas. Poucas evidências sugerem aumento no torque concêntrico dos extensores de joelho, no entanto, esses achados devem ser interpretados com cautela devido à baixa qualidade metodológica dos estudos e baixo nível de certeza das evidências. A análise da GRADE mostrou evidências insuficientes para a rigidez dos tecidos miofasciais e para a força muscular, indicando que os estudos possuem sérias limitações metodológicas e grande imprecisão dos resultados. Estudos de alta qualidade metodológica devem ser realizados para melhor determinar os efeitos do FR na rigidez dos tecidos miofasciais e na força muscular. Baseado nas evidências disponíveis, o FR parece, de modo agudo, aumentar o torque concêntrico dos extensores do joelho, mas não afeta a rigidez dos tecidos miofasciais do tronco, e a força muscular isométrica de membros inferiores.

Palavras-chave: aquecimento; automassagem; autoliberação miofascial; propriedades mecânicas; produção de força muscular.

ABSTRACT

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Foam rolling (FR) is widely used as part of rehabilitation and physical training programs. Although there is some evidence showing FR's effects on myofascial tissues' stiffness and muscle strength, there is no consensus on the FR's effect on these parameters. The purpose of this study was to systematically review and evaluated through meta-analysis, trials that tested the FR's acute effects on the myofascial tissues' stiffness and muscle strength. A systematic review was performed using the Cochrane's recommendations to reviewing papers indexed in PubMed, Web of Science, Embase, and PEDro databases. The search focused on randomized controlled trials that tested the FR's acute effects on the myofascial tissues' stiffness and muscle strength in healthy adults and/or athletes. Included studies were methodologically assessed by the PEDro scale. Assessed outcomes were fascial and muscle stiffness, isometric and isokinetic muscle strength, and rate of force development (RFD). Available data were pooled in a meta-analysis. Certainty of evidence was assessed using GRADE's approach. Of the 20 included studies [PEDro: mean 5.0±1.3 (range 4-8)], four evaluated the stiffness of fascial tissues in the trunk and thigh region, seven assessed the muscle stiffness of thigh and calf muscles, while 12 evaluated the muscle strength of knee extensors and flexors, and plantar flexors, during isometric (n=9) and isokinetic (n=3) contractions. Qualitative analysis showed decreases in fascial and muscle stiffness after FR. However, the meta-analysis showed that FR does not change myofascial tissues' stiffness. Qualitative and quantitative analysis showed no effects on isometric muscle strength, eccentric torque, and RFD. However, the concentric torque showed contradictory results. The meta-analysis showed increases in concentric torque of the knee extensors, but not of the knee flexors. Our findings suggest that FR induces no changes in the myofascial tissues' stiffness. Therefore, changes in functional parameters (e.g., joint range of motion) reported in the literature, seems to occur due to neural mechanisms and not due to tissues' stiffness. Regarding muscle strength, there seems to be a consensus that FR does not affect isometric muscle strength, while evidence for the FR's effects on eccentric torque and RFD is still limited. Small evidence suggests an increase in the knee extensors' concentric torque, however, these findings must be interpreted with caution due to the studies' poor methodological quality and the low level of evidence's certainty. The GRADE's analysis showed an insufficient evidence level of FR for myofascial tissues' stiffness and muscle strength, indicating that the studies have serious methodological limitations and large imprecision of the results. Future high methodological quality studies should be performed to better determine which exactly FR acute effects on the myofascial tissues' stiffness and muscle strength are. Based on the available evidence, FR may increase the knee extensors' concentric torque, but it does not seem to acutely change the myofascial tissues' stiffness of the trunk, and isometric muscle strength of the lower limbs.

Keywords: warm-up; self-massage; self-myofascial release; mechanical properties; muscle force production.

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LISTA DE ABREVIATURAS, ACRÔNIMOS E UNIDADES DE MEDIDAS

ADM	amplitude de movimento articular
CI	confidence interval
CMJ	countermovement jump
CON	control condition
CYC	cycling condition
DTR	deep tissue roller
DS	dynamic stretch condition
ECC	eccentric training condition
EJ	músculos extensors do joelho
ES	effect size
F	força/ force
FJ	músculos flexores do joelho
FL	fáscia lata
FP	músculos flexores plantares do tornozelo
FR	foam rolling
GRADE	Grading of Recommendations Assessment, Development, and Evaluation
h	horas/ hours
HAM	hamstring muscles
I^2	inconsistency test
IT	músculos isquiotibiais
ITB	iliotibial band
M	men
MG	medial gastrocnemius muscle
min	minutos/ minutes
n	tamanho da amostra/ sample size
ni	não informado
NPRS	numeric pain ratio scale
ns	estatisticamente não significativo/ statistically non-significant
p	level of statistical significance
PBO	placebo condition
PEDro	Physiotherapy Evidence Database
PF	plantar flexor muscles
PICOS	Population, Intervention, Comparison, Outcomes and Study design
PLE	plank exercise condition
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyzes
QUAD	músculo quadríceps/ quadriceps muscle
r	correlation coefficient
RCT	randomized controlled trial
reps	repetições/ repetitions
RF	rectus femoris muscle
RFD	rate of force development
rpm	repetições por minuto/ repetitions per minute
ROM	range of motion
s	segundos/seconds
SE	standard error
SJ	squat jump

SMD	standardized mean difference
SS	static stretch condition
ST	strength training condition
T	torque
TGF-b1	fator de crescimento transformante beta tipo 1
TLF	thoracolumbar fascia
TPF	taxa de produção de força
VAR	variance
VFR	vibration foam rolling
VL	vastus lateralis muscle
VM	vastus medialis muscle
W	women
Z	effect size (Z)

SUMÁRIO

1. PREFÁCIO

O *foam rolling* (FR) é uma técnica de automassagem realizada pelo próprio indivíduo, utilizando o peso corporal, sobre um rolo de espuma. Essa técnica tem sido popularmente utilizada em programas de reabilitação e treinamento físico, a fim de recuperar disfunções miofasciais e melhorar o desempenho em atividades funcionais e esportivas (HEALEY et al., 2014; MACDONALD et al., 2013). A literatura e a prática clínica frequentemente descrevem o FR como uma técnica de autoliberação miofascial, que pode melhorar a mobilidade entre o tecido fascial e o músculo esquelético (BEHM; WILKE, 2019; KRAUSE et al., 2019), embora este efeito ainda não esteja claro (MACGREGOR et al., 2018; MAYER et al., 2019; PEPPER et al., 2021).

Nos processos de reabilitação, o FR é utilizado para restaurar a extensibilidade dos tecidos moles (MACDONALD et al., 2014), uma vez que o tecido fascial pode fixar-se em torno de áreas traumatizadas, formando aderências fibrosas capazes de reduzir a extensibilidade destes tecidos (GIOVANELLI et al., 2018; MACDONALD et al., 2013). A diminuição da extensibilidade do tecido fascial pode causar prejuízos funcionais como redução da amplitude de movimento articular (ADM), do comprimento e força muscular, bem como levar ao desenvolvimento de dores miofasciais (MACDONALD et al., 2013). Em circunstâncias patológicas, várias síndromes de dores miofasciais podem ser influenciadas por alterações nas propriedades mecânicas dos tecidos (SCHLEIP et al., 2019), como a síndrome da banda iliotibial (WILKE et al., 2019), fascite plantar (WU et al., 2012) e dores na região lombar (MASAKI et al., 2017). Assim, o FR surge como uma alternativa para auxiliar no tratamento de disfunções miofasciais.

No ambiente esportivo, o FR é utilizado no aquecimento antes do treinamento ou competição, e para reduzir a dor muscular de início tardio (WIEWELHOVE et al., 2019). Quando usado durante o aquecimento, pode promover um aumento na ADM semelhante ao alongamento (ŠKARABOT et al., 2015), sem afetar negativamente o desempenho da força muscular (MACDONALD et al., 2013; MACGREGOR et al., 2018). Em ocasiões em que o FR é utilizado na recuperação muscular, parece contribuir na redução da sensibilidade e da dor muscular (DRINKWATER et al., 2019; MACDONALD et al., 2014).

Os mecanismos relacionados às alterações induzidas pelo FR ainda não são totalmente compreendidos, embora se considere a participação de componentes psicológicos, neurológicos, fisiológicos e biomecânicos (GIOVANELLI et al., 2018). De forma aguda, o FR parece reduzir a rigidez do tecido fascial (MAYER et al., 2019), bem como aumentar (GRIEFAHN et al., 2017) ou reduzir (KRAUSE et al., 2019) o deslizamento fascial. Em relação ao tecido muscular, enquanto alguns estudos observaram redução da rigidez (BAUMGART et al., 2019; MACGREGOR et al., 2018; MORALES-ARTACHO et al., 2017; WILKE et al., 2019), outros não encontram alterações após a aplicação do FR (BAUMGART et al., 2019; MARTÍNEZ-CABRERA; NÚÑEZ-SÁNCHEZ, 2016; MAYER et al., 2019). Além disso, poucos estudos (BAUMGART et al., 2019; NAKAMURA et al., 2021) investigaram os efeitos do FR sobre a rigidez de músculos flexores plantares. Em relação ao tecido tendíneo, nenhum estudo buscou investigar os efeitos do FR sobre as propriedades mecânicas do tendão de Aquiles.

Considerando que o FR pode causar alterações sobre as propriedades mecânicas dos tecidos fascial e muscular, alterações funcionais também podem ocorrer. O aumento da flexibilidade após a utilização do FR é frequentemente encontrado (AUNE et al., 2018; KRAUSE et al., 2019; LEE et al., 2018; MACDONALD et al., 2013; YOSHIMURA et al., 2021), e vem sendo considerado como um dos principais efeitos da aplicação da técnica (WIEWELHOVE et al., 2019). Apesar disso, os efeitos do FR sobre a ADM não parecem ser um consenso na literatura, uma vez que alguns estudos não observaram alterações nesta variável após a aplicação do FR (MACGREGOR et al., 2018; MORALES-ARTACHO et al., 2017; MORTON et al., 2016; PHILLIPS et al., 2018; WILKE et al., 2019; ŠKARABOT et al., 2015).

Além disso, eventuais alterações nos tecidos miofasciais e tendíneos poderiam afetar a produção e transferência da força muscular. Uma maior rigidez dos componentes elásticos pode aumentar a capacidade do tecido conjuntivo de transmitir a força muscular (BOJSEN-MØLLER et al., 2005), podendo contribuir para um aumento na produção de força e potência muscular (RODRÍGUEZ-ROSELL et al., 2018; WILSON et al., 1994). No entanto, uma unidade miotendíena mais complacente permite um encurtamento mais rápido dos componentes contráteis (WILSON et al., 1994), podendo favorecer o desempenho em tarefas que envolvam o ciclo alongamento-encurtamento (KUBO et al., 2005). Estudos têm mostrado que a aplicação do FR parece não alterar a produção de torque isométrico (AUNE et al., 2018; MACDONALD et al., 2013; MACGREGOR et al., 2018) e excêntrico (MADONI et al., 2018). Um fator que pode influenciar na produção de força excêntrica na articulação do tornozelo é a ADM. Maiores valores de ADM de flexão dorsal estão relacionados com maiores níveis de produção de torque de flexão plantar (GAO et al., 2011). Isso ocorre uma vez que a produção de força dos flexores plantares aumenta conforme este grupo muscular é alongado (HERMAN, 1967; SALE et al., 1982), indicando que tais músculos operam na porção ascendente da relação força-comprimento. Além disso, alguns estudos demonstram aumento (LEE et al., 2018; SU et al., 2017), bem como a manutenção (MADONI et al., 2018; SU et al., 2017) do torque concêntrico. A taxa de produção de força (TPF) parece não ser afetada pela aplicação do FR (MACDONALD et al., 2013; MORTON et al., 2016). Dessa forma, embora alguns estudos apresentem algumas informações sobre os efeitos do FR na ADM, capacidade de produção e transmissão da força muscular, os dados são escassos e, em alguns casos, contraditórios. Por fim, a maior parte dos estudos busca verificar os efeitos do FR nos músculos extensores do joelho (BEHARA; JACOBSON, 2017; FLECKENSTEIN et al., 2017; LEE et al., 2018; MACDONALD et al., 2013; MACGREGOR et al., 2018; MORTON et al., 2016; SU et al., 2017), enquanto que poucos estudos buscaram entender estes efeitos nos músculos flexores plantares do tornozelo (AUNE et al., 2018; BAUMGART et al., 2019).

Além da insuficiente compreensão dos mecanismos causados pelo FR, e suas consequências na produção e transmissão da força muscular, não existe um consenso em relação à forma ideal de aplicação do FR (HOTFIEL et al., 2017). O tempo de duração do FR parece ser um fator importante (GIOVANELLI et al., 2018; SCHROEDER; BEST, 2015). Os tempos de duração mais utilizados estão entre 30s (HEALEY et al., 2014; RICHMAN et al., 2019; SMITH et al., 2018) e 60s (BEHARA; JACOBSON, 2017; GIOVANELLI et al., 2018; MACDONALD et al., 2013; PHILLIPS et al., 2018). Para tarefas envolvendo desempenho esportivo, um tempo de duração menor que 30s parece ser insignificante (GIOVANELLI et al., 2018). Por outro lado, maiores tempos de duração (e.g., 120s e 300s) podem causar prejuízos no desempenho de tarefas que envolvam potência muscular (PHILLIPS et al., 2018). Assim, a magnitude dos efeitos do FR pode estar interligada a uma relação dose-resposta, que ainda não foi estabelecida para este tipo de intervenção.

Inicialmente, esta dissertação teve como objetivo verificar por meio de dois diferentes ensaios clínicos randomizados: 1) efeitos agudos de diferentes tempos de aplicação (30s e 60s) de FR na rigidez dos tecidos miofasciais dos músculos tríceps sural e tendão de Aquiles, bem como sua influência sobre parâmetros funcionais (ADM de dorsiflexão do tornozelo, força muscular e taxa de desenvolvimento de torque dos músculos flexores plantares de indivíduos saudáveis); 2) efeitos agudos de diferentes tempos de aplicação (30s e 60s) do FR nas propriedades morfológicas, mecânicas e materiais do tendão de Aquiles em indivíduos saudáveis. No entanto, devido à pandemia da Covid-19, não foi possível desenvolver os ensaios clínicos como havíamos planejado inicialmente.

Portanto, optamos por desenvolver uma revisão sistemática e meta-análise sobre os efeitos agudos do FR sobre as propriedades mecânicas dos tecidos miofasciais e na força muscular de indivíduos saudáveis e/ ou atletas. Este estudo difere da proposta inicial, mas, embora existam algumas evidências na literatura mostrando os efeitos do FR na rigidez dos tecidos miofasciais e na força muscular, ainda não existe uma revisão sistemática das evidências disponíveis e de sua qualidade metodológica. Portanto, este estudo apresenta uma síntese de informações sobre os efeitos da aplicação do FR nas propriedades mecânicas dos tecidos miofasciais e na força muscular, o que abre novos rumos para futuras investigações dos mecanismos e implicações práticas do uso do FR no ambiente clínico e esportivo.

2. REFERENCIAL TEÓRICO

2.1 Contextualização

O uso da automassagem sobre o rolo de espuma (i.e., FR) tem alcançado bastante popularidade nos últimos anos (SMITH et al., 2018). Esse modelo de tratamento é realizado com o peso corporal por meio de movimentos de rolamento sobre um rolo de espuma densa e rígida, em uma região ou músculo de interesse (MACDONALD et al., 2013). Apesar do FR ser muito utilizado na prática clínica e como parte de programas de treinamento físico, o conhecimento acerca dos efeitos desta técnica ainda é escasso. Além disso, embora a aplicação do FR possa ser realizada em diversos grupos musculares, grande parte dos estudos têm utilizado esta técnica nos músculos extensores e flexores do joelho (BEHARA; JACOBSON, 2017; KRAUSE et al., 2019; MACDONALD et al., 2013; MACGREGOR et al., 2018), abdutores e adutores do quadril (DRINKWATER et al., 2019; FLECKENSTEIN et al., 2017; RICHMAN et al., 2019) e flexores plantares (AUNE et al., 2018; PHILLIPS et al., 2018; YOSHIMURA et al., 2021).

O entendimento dos possíveis efeitos do FR nos flexores plantares é de extrema importância, tendo em vista o papel fundamental deste grupo muscular para atividades de vida diária (LEE; PIAZZA, 2012; OLMOS et al., 2019), bem como para o desempenho esportivo (KAY; BLAZEVICH, 2009; UENO et al., 2018). No entanto, a maior parte dos estudos tem buscado entender os efeitos do FR nos músculos extensores do joelho (BAUMGART et al., 2019; BEHARA; JACOBSON, 2017; FLECKENSTEIN et al., 2017; KRAUSE et al., 2019; LEE et al., 2018; MACDONALD et al., 2013; MACGREGOR et al., 2018; MADONI et al., 2018; MARTÍNEZ-CABRERA; NÚÑEZ-SÁNCHEZ, 2016; MAYER et al., 2019; SU et al., 2017; WILKE et al., 2019), enquanto que poucos estudos verificaram os efeitos desta técnica nos músculos flexores plantares (AUNE et al., 2018; BAUMGART et al., 2019; de SOUZA et al., 2019; PHILLIPS et al., 2018; YOSHIMURA et al., 2021; ŠKARABOT et al., 2015). Além disso, estes poucos estudos apresentam uma grande variabilidade metodológica, principalmente no que se refere ao número (15-27), sexo (masculino e feminino) e atividade (indivíduos saudáveis – atletas) dos participantes, à pressão de rolamento, velocidade, e tempo de duração do FR, bem como no volume da intervenção. Essa grande variabilidade metodológica dificulta a comparação dos resultados obtidos, uma vez que os estímulos impostos pelo FR podem ser diferentes entre os estudos. A tabela 1 apresenta um resumo das características dos indivíduos, bem como dos métodos de aplicação do FR nos músculos flexores plantares utilizados nos principais estudos desta revisão.

Tabela 1 - Características dos estudos e intervenções envolvendo a utilização do FR sobre os músculos flexores plantares.

Autor (ano)	**Amostra n (homens/ mulheres)**	**Idade**	**Pressão do rolamento**	**Velocidade do rolamento**	**Duração total do rolamento**	**Volume**
Aune et al. (2018)	Jogadores de futebol 23 (12/11)	18 ± 1	Maior pressão possível	Autosselecionada	180s	3 x 60s
Baumgart et al. (2019)	Atletas amadores 20 (20/0)	27 ± 3	ni	ni	60reps	2 x 30reps
de Souza et al. (2019)	Indivíduos saudáveis/ fisicamente ativos 14 (14/0)	25 ± 3	Autosselecionada	Cadência de 4s	20reps	2 x 10reps
Nakamura et al. (2021)	Indivíduos saudáveis/ sedentários 45 (23/23)	21 ± 1	Escore de 7 em escala de 0-10 de desconforto	30rpm	30s 90s 300s	1 x 30s 3 x 30s 10 x 30s
Phillips et al. (2018)	Indivíduos saudáveis/ fisicamente ativos 24 (8/16)	24 ± 5	Maior pressão possível	Cadência de 6s	60s 300s	1 x 60s 1 x 300s
Škarabot et al. (2015)	Nadadores 11 (6/5)	15 ± 1	Maior pressão possível	ni	90s	3 x 30s
Yoshimura et al. (2021)	Estudantes universitários 22 (22/0)	22 ± 1	15-25% da massa corporal	25rpm	180s	3 x 60s

n: tamanho da amostra; idade: valores descritos em média ± desvio padrão; ni: não informado; reps: número de repetições; rpm: repetições por minuto; s: segundos. Pressão do rolamento: pressão exercida durante o FR; velocidade do rolamento: velocidade de aplicação do FR; duração total do rolamento: tempo de duração total do FR; volume: número de séries x tempo de duração/ número de repetições por série no local de aplicação.

2.2 Tecidos fascial, muscular e tendíneo: conceitos e definições

A fáscia é considerada uma variedade de tecidos conjuntivos que inclui: aponeurose, fáscia superficial e profunda, expansões miofasciais e todos os tecidos conjuntivos intra e extramusculares (ZÜGEL et al., 2018). Esta matriz de tecidos conjuntivos envolve os músculos (epimísio), fascículos (perimísio) e fibras musculares (endomísio) (FRONTERA; OCHALA, 2015; LIEBER et al., 2017). O sistema fascial consiste em uma rede global de tecido fibroso com estrutura poliédrica com característica mutável (ADSTRUM et al., 2017), composto por elastina e fibras de tecido conjuntivo de colágeno (MACDONALD et al., 2016). Esse tecido forma uma série de camadas de folhas ou faixas sob a pele, que fazem parte de um sistema de transmissão de força tensional em todo o corpo (MCDONALD et al., 2016; WILKE et al., 2017; YOUNG et al., 2018). Neste sistema, três grupos de mecanorreceptores podem ser encontrados: órgãos tendinosos de Golgi (tipo Ib), corpúsculos de Pacini (tipo II), terminações de Ruffini, e receptores de tecido miofascial intersticial (tipo III/ IV) (YOUNG et al., 2018). Este último considerado o mais abundante, é responsivo à alterações na tensão ou pressão mecânica (YOUNG et al., 2018). Os receptores intersticiais tipo III e IV também podem afetar a ativação simpática e parassimpática, apresentando capacidades sensoriais de limiares baixo e alto, e respondendo a estímulos mecânicos de pressão rápida e sustentada (BEHM; WILKE, 2019).

O sistema fascial abrange todos os órgãos, músculos, ossos e fibras nervosas, fornecendo estrutura capaz de permitir que todos os sistemas do corpo possam estar conectados (ADSTRUM et al., 2017; ZÜGEL et al., 2018). Essas conexões formam estruturas interligadas que se estendem do crânio até os dedos do pé (SKINNER et al., 2020), indicando que estes tecidos não separam, mas conectam os músculos esqueléticos (WILKE et al., 2020b). Deste modo, é amplamente aceito que esse sistema integrado possa cumprir várias funções importantes no corpo, incluindo funções estruturais, neurológicas, morfogênese, transmissão de sinal celular e transmissão de força (ADSTRUM et al., 2017).

Embora seja habitualmente considerado como um tecido relativamente inerte, assumindo um papel passivo (SCHLEIP et al., 2019), os tecidos fasciais intermusculares e extramusculares também contribuem na transmissão de força e aparentam ter a capacidade de se contraírem, embora a magnitude da força produzida por estes tecidos ainda seja contestada (ZÜGEL et al., 2018). Recentemente, foram descobertos indícios de existência de células contráteis (i.e., miofibroblastos) em diferentes tecidos fasciais (SCHLEIP et al., 2019), sugerindo que estes apresentam respostas contráteis quando expostos à diferentes substâncias estimulantes (e.g., TGF-b1). No entanto, a contribuição destes tecidos sobre a produção de força muscular pode ser dependente de suas propriedades mecânicas (i.e., rigidez) (ZÜGEL et al., 2018). Além disso, especula-se que essas potenciais forças contráteis poderiam produzir efeitos mecânicos mínimos, sendo pelo menos duas vezes menores à força produzida pelo musculo esquelético (SCHLEIP et al., 2019).

O tecido muscular é o principal responsável pela produção de força e movimento a partir da conversão de energia química em energia mecânica (FRONTERA; OCHALA, 2015). Sua estrutura é formada por um sistema hierárquico composto por um núcleo capaz de gerar força, em que os sarcômeros formam uma unidade contrátil a partir de uma organização em forma de pacote de fibras e miofibrilas que juntos formam um músculo completo (LIEBER et al., 2017). O músculo esquelético é um tecido anisotrópico, heterogêneo e viscoelástico (LIMA et al., 2019), o qual é constituído por componentes contráteis e elásticos (MURAMATSU et al., 2001). Os componentes contráteis correspondem às fibras musculares, enquanto os componentes elásticos se referem aos elementos passivos, como a titina (associada a funções mecânicas, estruturais relacionadas a organização dos sarcômeros, e de sinalização e sensoriamento mecânico) e filamentos de colágeno incorporados nas várias camadas dos tecidos conjuntivos do músculo (i.e., epimísio, perimísio e endomísio) (HERZOG, 2018; LIEBER et al., 2017).

A interação entre os componentes contráteis e elásticos possuem um papel significativo sobre o desempenho das atividades físicas, especialmente em músculos com tendões longos (e.g., flexores plantares do tornozelo) (MURAMATSU et al., 2001). Os tendões promovem a ligação entre músculos e ossos, e apresentam um comportamento viscoelástico (MAGANARIS et al., 2008), atuando como armazenadores de energia elástica (KUBO et al., 2005). O tecido tendíneo é constituído principalmente por colágeno do tipo I em uma matriz extracelular composta de mucopolissacarídeo, proteoglicanas e elastina (O'BRIEN, 2005). Interações entre elementos mecânicos e biológicos podem promover adaptações no tecido tendíneo (BOHM et al., 2014). No entanto, as adaptações tendinosas ocorrem de modo paralelo às adaptações musculares (WERKHAUSEN et al., 2018). Mesmo sendo altamente sensível quando exposto a cargas mecânicas (BOHM et al., 2014), em que a estimulação aguda e crônica provoca a remodelação de colágeno (ZÜGEL et al., 2018), o processo de adaptação tendínea é mais lento em comparação ao tecido muscular (KUBO et al., 2010). A deformação que ocorre nas células do tendão manifesta a presença de genes responsáveis por respostas anabólicas e catabólicas a níveis celular e molecular, como a síntese de colágeno, que por sua vez atinge as suas propriedades morfológicas, mecânicas e materiais (BOHM et al., 2014).

2.3 Influência das propriedades mecânicas dos tecidos fascial, muscular e tendíneo sobre a produção de força muscular

A influência da rigidez dos tecidos pode afetar a produção de força de modos distintos, considerando os diferentes tecidos de forma independente (i.e., fáscia, músculo e tendão) (ANDO; SUZUKI, 2019). O tecido fascial atua como transmissor de força muscular (ADSTRUM et al., 2017), a qual é influenciada pelo complexo aponeurose-tendão (DUCLAY et al., 2009). No entanto, parece haver um padrão diferente de deformação entre a fáscia e o tendão, os quais parecem apresentar diferentes propriedades mecânicas (MAGNUSSON et al., 2003; SUYDAM et al., 2015). Desta forma, sugere-se que estes tecidos devem ser avaliados de forma isolada (e.g., por meio de técnicas de elastografia) (SUYDAM et al., 2015). Estas diferenças podem indicar que ambos tecidos podem apresentar diferentes contribuições na transmissão de força (MAGNUSSON et al., 2003). Embora, ainda que o tecido fascial possua uma importante função na transmissão da força muscular, a influência de alterações na sua rigidez sobre a produção e transferência de força muscular foi pouco explorada. Ainda assim, sugere-se que componentes elásticos mais rígidos podem aumentar a capacidade do tecido conjuntivo (i.e., tendão e aponeuroses) de transmitir as forças contráteis de modo eficaz (BOJSEN-MØLLER et al., 2005), contribuindo para o aumento da força muscular (WILSON et al., 1994).

Sabe-se que a produção de força também está relacionada com parâmetros morfológicos musculares como área de secção transversa e arquitetura muscular (KAWAKAMI et al., 1993), bem como com as relações de força-comprimento e força-velocidade (HERZOG, 2017). Além disso, a rigidez do músculo esquelético pode indicar a condição deste tecido, pois músculos mais rígidos são relacionados a várias condições envolvendo câimbras, espasmos e danos teciduais (AKAGI; TAKAHASHI, 2013). A rigidez parece ser um aspecto importante para o tecido muscular, a qual uma menor rigidez permite o movimento e contribui para a integridade do tecido (LIM et al., 2019), e parece estar relacionada a uma menor produção de torque passivo (KAY; BLAZEVICH, 2009), sugerindo uma menor resistência dos tecidos quando tensionados. Além disso, a rigidez muscular também parece estar relacionada com a capacidade de produção de força, existindo uma relação linear entre a rigidez muscular e a força isométrica (ATEŞ et al., 2015). Portanto, músculos mais rígidos estão associados a uma maior capacidade de produção de força (MASSEY et al., 2017). No entanto, nenhuma correlação foi observada entre a rigidez muscular e tendínea em repouso e a produção de torque isométrico. A ausência de tal correlação sugere que a rigidez dos tecidos em repouso podem não predizer a capacidade de produção de força da unidade musculo-tendínea (LIMA et al., 2017). No entanto, essa ausência de correlação não parece ser um consenso na literatura, uma vez que uma forte correlação foi encontrada entre a rigidez de músculos com menor produção de torque (e.g., músculos abdutores dos dedos) e o torque isométrico (BOUILLARD et al., 2011).

A produção de força muscular também parece estar relacionada às propriedades tendíneas (WERKHAUSEN et al., 2018), em que o comportamento mecânico tendíneo pode ser avaliado por meio das propriedades morfológicas, mecânicas e materiais (MARTIN et al., 1998). As propriedades morfológicas correspondem à área e comprimento do tecido (GEREMIA et al., 2018; WIESINGER et al., 2015), enquanto as propriedades mecânicas correspondem à sua rigidez (WIESINGER et al., 2015; YOUK et al., 2014), e as propriedades materiais representam medidas de rigidez considerando as dimensões do tecido (WIESINGER et al., 2015). O tendão atua como o principal transmissor da força contrátil produzida pelo músculo (MAGANARIS et al., 2008; MURAMATSU et al., 2001). Assim, alterações nas propriedades tendíneas podem influenciar na magnitude da transmissão de força, podendo produzir um efeito significativo sobre a mecânica muscular (ZÜGEL et al., 2018). Neste contexto, estes tecidos agem como componentes passivos ou elásticos, os quais podem ser alongados passivamente durante a ação de forças externas, interagindo assim com os componentes contráteis (MURAMATSU et al., 2001).

A taxa de encurtamento dos componentes contráteis e a deformação da unidade musculo-tendínea são proporcionais à magnitude da contração muscular e à rigidez da unidade musculo-tendão (WILSON et al., 1994). Uma unidade musculo-tendínea mais rígida aumenta a capacidade de produção de força isométrica ou concêntrica (WILSON et al., 1994), a partir de uma transmissão de força mais eficaz dos elementos contráteis para o osso (RODRÍGUEZ-ROSELL et al., 2018). Essa transmissão de força com maior eficácia, pode resultar de aumentos na TPF (RODRÍGUEZ-ROSELL et al., 2018), pois o tempo de transmissão de força de tecidos mais rígidos é teoricamente menor (MASSEY et al., 2017). Assim, a rigidez dos tecidos conectivos (i.e., tendões e aponeuroses) parece ser responsável por ~30% da variação da TPF (BOJSEN-MØLLER et al., 2005).

Por outro lado, uma unidade músculo-tendínea mais complacente parece implicar em uma maior ADM (IKEDA et al., 2019). Em articulações como a do tornozelo, uma maior ADM de dorsiflexão do tornozelo poderia aumentar a produção de torque dos músculos flexores plantares. Isso poderia ocorrer devido ao deslocamento da relação torque-ângulo dos flexores plantares para maiores comprimentos musculares, no qual o torque de flexão plantar aumenta à medida em que a dorsiflexão do tornozelo aumenta (GAO et al., 2011). Ao mesmo tempo, uma unidade musculo-tendínea mais complacente também permite o encurtamento mais rápido dos componentes contráteis (WILSON et al., 1994). Assim, essa maior complacência pode contribuir para reduzir os níveis de força devido a relação força-velocidade (WILSON et al., 1994), deslocando a curva desta relação para a direita (BOJSEN-MØLLER et al., 2005).

Além disso, tendões mais complacentes podem afetar a TPF, provocando a sua redução (BOJSEN-MØLLER et al., 2005; RODRÍGUEZ-ROSELL et al., 2018). Atrasos na transmissão da força muscular podem diminuir a capacidade de produzir força rapidamente, bem como prejudicar o equilíbrio e a estabilidade corporal, aumentando o tempo de reação e causando movimentos mais lentos, o que pode prejudicar o desempenho atlético em esportes que envolvem potência muscular (AAGAARD et al., 2002; WAUGH et al., 2014), e aumentar o risco de queda em outras populações, como idosos (AAGAARD et al., 2002; MAFFIULETTI et al., 2016; RODRÍGUEZ-ROSELL et al., 2018).

Os tecidos fascial, muscular e tendíneo respondem a diferentes estímulos que lhes são impostos (BOHM et al., 2015; LIEBER et al., 2017; ZÜGEL et al., 2018). Assim, diferentes estímulos mecânicos causados por técnicas de massagem (CROMMERT et al., 2015; MINE et al., 2018) e automassagem (CAPOBIANCO et al., 2019; CAVANAUGH et al., 2017; MACGREGOR et al., 2018), podem promover eventuais mudanças nas propriedades mecânicas (e.g., rigidez) dos tecidos miofasciais e, consequentemente, em aspectos funcionais (e.g., flexibilidade, força e potência muscular).

2.4 *Foam rolling*

O FR é uma técnica de automassagem que ganhou considerável popularidade nos últimos anos (SMITH et al., 2018). Nesta técnica, o indivíduo utiliza o peso do próprio corpo para aplicar pressão sobre os tecidos miofasciais (KRAUSE et al., 2019), utilizando um rolo de espuma densa e rígida (MACDONALD et al., 2013). Assim, o uso do FR requer a capacidade do indivíduo de suportar sua massa corporal (total ou parcial), semelhante a exercícios de prancha, em que o corpo é sustentado de forma isométrica, utilizando principalmente os músculos do *core* (HEALEY et al., 2014).

Apesar do FR ser amplamente utilizado, o conhecimento sobre os seus efeitos ainda é insuficiente, embora algumas revisões sistemáticas tenham sido desenvolvidas recentemente (HENDRICKS et al., 2020; HUGHES; RAMER, 2019; SKINNER et al., 2020; WIEWELHOVE et al., 2019; WILKE et al., 2020a). Entre os principais efeitos, técnicas de automassagem parecem aumentar a ADM (WIEWELHOVE et al., 2019; WILKE et al., 2020a) e reduzir a sensação de dor muscular causada pelo dano muscular induzido por exercício (HUGHES; RAMER, 2019; WIEWELHOVE et al., 2019). Embora a automassagem possa promover um grande tamanho de efeito sobre a ADM (WILKE et al., 2020a), isso parece não ser um consenso na literatura (WIEWELHOVE et al., 2019). Em relação à parâmetros de performance atlética, a automassagem parece não afetar aspectos funcionais como o desempenho em *sprints* ou tarefas de salto, força e potência muscular (WIEWELHOVE et al., 2019). No entanto, em algumas revisões sistemáticas (HUGHES; RAMER, 2019; WIEWELHOVE et al., 2019; WILKE et al., 2020a), o FR não foi tratado como o foco principal, sendo incluídas outras modalidades de automassagem (e.g., bastão de massagem). Portanto, tais efeitos não podem ser considerados exclusivos do FR.

Enquanto alguns estudos (HUGHES; RAMER, 2019; WIEWELHOVE et al., 2019; WILKE et al., 2020a) investigaram os efeitos de diferentes técnicas de automassagem, outros investigaram exclusivamente os efeitos do FR na recuperação muscular e no desempenho atlético (e.g., flexibilidade, força e potência muscular) (HENDRICKS et al., 2020; SKINNER; et al., 2020). Portanto, embora existam algumas revisões sistemáticas, os estudos investigaram principalmente os efeitos do FR em aspectos funcionais (e.g., ADM e dor muscular) (HENDRICKS et al., 2020; SKINNER et al., 2020), e nenhuma revisão sistemática buscou compreender exclusivamente os efeitos agudos do FR sobre as propriedades mecânicas dos tecidos miofasciais e na força muscular.

2.5 Influência do FR sobre as propriedades mecânicas dos tecidos miofasciais

Dentro de diferentes perspectivas, o FR têm sido muito utilizado tanto no âmbito da reabilitação quanto do treinamento. Na reabilitação, o FR é usado para fins de reduzir a dor muscular pós exercício (WIEWELHOVE et al., 2019), e restaurar a extensibilidade dos tecidos moles (MACDONALD et al., 2014), uma vez que o tecido fascial pode fixar-se em torno de áreas traumatizadas, formando adesões fibrosas capazes de reduzir a extensibilidade dos tecidos miofasciais (MACDONALD et al., 2013; PHILLIPS et al., 2018). O comportamento contrátil dos miofibroblastos representa, em parte, uma explicação plausível para tais alterações (KRAUSE et al., 2016). Supõe-se que o encurtamento e enrijecimento do tecido fascial em circunstâncias patológicas sejam impulsionados por miofibroblastos, e a contratura formada no tecido seja resultante de uma combinação incremental de contração celular, reticulação de colágeno e remodelação da matriz (SCHLEIP et al., 2019). Neste contexto, várias síndromes de dores miofasciais podem ser influenciadas por mudanças nas propriedades do tecido fascial (SCHLEIP et al., 2019), como a síndrome da banda iliotibial (WILKE et al., 2019), fascite plantar (WU et al., 2012), e dores na região lombar (MASAKI et al., 2017). Assim, a utilização do FR poderia ser uma alternativa para o tratamento de disfunções miofasciais (MACDONALD et al., 2014). Na área do treinamento físico/desportivo, o FR é utilizado principalmente durante o aquecimento pré-evento (i.e., sessão de treinamento e/ ou competição) para melhora do desempenho (BAUMGART et al., 2019), a partir de um aumento no aporte sanguíneo na região de tratamento (HOTFIEL et al., 2017), e também para o aumento na extensibilidade dos tecidos miofasciais (MACDONALD et al., 2013).

Durante o uso do FR, uma pressão direta e abrangente é exercida sobre os tecidos moles (i.e., pele, fáscia, músculo e tendão), os quais são tensionados e friccionados durante o contato com o rolo de espuma (BEHM; WILKE, 2019; MACDONALD et al., 2013; WIEWELHOVE et al., 2019). Na literatura e na prática clínica, o FR é frequentemente descrito como uma técnica de autoliberação miofascial, embora, o uso do termo "liberação miofascial" pode ser considerado inapropriado, pois pode se referir a um mecanismo falso ou incorreto (BEHM; WILKE, 2019; YOSHIMURA et al., 2021), uma vez que o FR pode não afetar alguns aspectos miofasciais como o comprimento de fascículo muscular e o deslizamento do tecido fascial (YOSHIMURA et al., 2021). Entretanto, isso parece não ser um consenso na literatura, uma vez que alguns estudos indicam que o FR pode promover mudanças nas propriedades mecânicas dos tecidos miofasciais (BAUMGART et al., 2019; MACGREGOR et al., 2018; MAYER et al., 2019; MORALES-ARTACHO et al., 2017).

2.5.1 Efeitos do FR sobre as propriedades mecânicas dos tecidos miofasciais

Alguns estudos buscaram entender os efeitos do FR sobre a rigidez dos tecidos miofasciais. No tecido fascial, Pepper et al. (2021) encontrou a manutenção da rigidez após a aplicação do FR na banda iliotibial (volume = 300s; pressão de rolamento = autosselecionada) de indivíduos saudáveis. Neste estudo, a rigidez fascial da banda iliotibial foi avaliada por elastografia *shear-wave* em duas posições (porção média e porção distal da lateral da coxa) e duas condições (0º e 10º de abdução de quadril). Os autores especulam que a manutenção possa ter ocorrido pelo fato de que possíveis alterações teciduais ocorram lentamente ao longo do tempo e, portanto, podem exigir um tempo adicional para demonstrar alterações na rigidez da banda iliotibial.

A redução da rigidez fascial da banda iliotibial foi encontrada no estudo de Mayer et al. (2019), após aplicação do FR (volume = 225s; pressão de rolamento = maior possível; velocidade de rolamento = cadência de 2s) em dois grupos de atletas [com experiência prévia com FR (n = 20); sem experiência prévia com FR (n = 20)]. A rigidez da banda iliotibial foi avaliada por elastografia *shear-wave*. Após a intervenção, foram observadas reduções da rigidez da banda iliotibial no grupo de atletas experientes (-13,2% após 30min; -12,1% após 6h). No entanto, nenhuma alteração de rigidez foi observada nos atletas sem experiência com a técnica. Portanto, a familiaridade com o FR pode ser determinante para promover a redução da rigidez do tecido fascial. De acordo com os autores, essas alterações poderiam estar relacionadas à dois fatores: a) adaptações crônicas da função endotelial devido à prática frequente do FR; b) alterações no sistema nervoso simpático e mudanças na percepção da dor.

O aumento do deslizamento fascial também foi observado após a aplicação do FR na fáscia toracolombar. Griefahn et al. (2017) investigaram o efeito da aplicação do FR (volume = 90s; pressão de rolamento = autosselecionada; velocidade de rolamento = cadência de 2-3s) sobre o deslizamento da fáscia toracolombar de indivíduos saudáveis. Logo após o FR, foi observado o aumento do deslizamento fascial (56,5%), o que de acordo com os autores, uma fáscia mais móvel está relacionada com uma fáscia mais saudável. Portanto, tal achado sugere que o FR pode melhorar a mobilidade do tecido fascial, a partir de uma possível redução na rigidez deste tecido.

Um conjunto de mecanismos podem estar ligados às alterações das propriedades dos tecidos fasciais (BEHM; WILKE, 2019). Estes mecanismos podem ser divididos em fisiológicos, neurais e mecânicos (MACGREGOR et al., 2018). O mecanismo fisiológico está relacionado com o aumento do fluxo sanguíneo e da temperatura intramuscular, uma vez que imediatamente após a aplicação da automassagem pode ocorrer um aumento de ~75% no fluxo sanguíneo no local da aplicação, e após 30min é possível observar um aumento do fluxo sanguíneo de até 53% em relação aos seus valores basais (CAPOBIANCO et al., 2019). O aumento do fluxo sanguíneo poderia ser explicado pela liberação do óxido nítrico, o qual possui um papel importante na regulação da constrição e dilatação vascular (HOTFIEL et al., 2017). Okamoto et al. (2014) observaram um aumento na concentração plasmática de óxido nítrico após a aplicação do FR, sugerindo que a técnica leva a redução da rigidez arterial e alterações na função endotelial vascular. O aumento no fluxo sanguíneo também poderia estimular a atividade das células contráteis (i.e., miofibroblastos), podendo causar alterações em suas propriedades e assim provocar alterações na rigidez dos tecidos miofasciais (GIOVANELLI et al., 2018; HOTFIEL et al., 2017; WILKE et al., 2019).

O mecanismo neural está relacionado com possíveis alterações na atividade dos mecanorreceptores, proprioceptores e receptores de dor encapsulados na fáscia, os quais poderiam modificar a dinâmica autorreguladora do sistema nervoso autônomo e assim causar alterações na extensibilidade dos tecidos miofasciais (ABOODARDA et al., 2018; ŠKARABOT et al., 2015). Já o mecanismo mecânico pressupõe que o atrito causado pelo contato com o rolo de espuma possa provocar um aquecimento nos tecidos fasciais, afetando assim a sua hidratação (GIOVANELLI et al., 2018; MACDONALD et al., 2013), a qual parece causar alterações nas propriedades mecânicas dos tecidos (KRAUSE et al., 2019). Assim, quando o tecido fascial é perturbado por meio de calor e/ ou tensão mecânica, assume um estado semelhante a gel (i.e., propriedade tixotrópica). A tixotropia ocorre quando um tecido viscoso se torna mais fluido e com menor viscosidade quando agitados, cortados ou tensionados (BEHM; WILKE, 2019). Tal comportamento pode atingir seu pico aproximadamente entre três e quatro horas após a aplicação do estímulo mecânico (GIOVANELLI et al., 2018). A estimulação constante dos conteúdos líquidos dos tecidos também desencadeia a liberação da enzima MMP-1, a qual possui uma forte função de degradação de colágeno, e a mesma só é liberada em um intervalo entre quatro e oito horas após sua estimulação, contribuindo na redução da rigidez por meio de uma quebra tardia das fibras de colágeno (WILKE et al., 2019).

Embora alguns estudos tenham encontrado manutenção e redução da rigidez fascial, a redução do deslizamento fascial (associada com o aumento da rigidez fascial) também foi encontrada. Krause et al. (2019) investigaram os efeitos do FR sobre o deslizamento fascial da fáscia lata do músculo reto femoral. O FR foi aplicado sobre o quadríceps (volume = 120s; pressão de rolamento = 6-7 em escala de desconforto; velocidade de rolamento = 15rpm), e o deslizamento fascial foi avaliado por meio de imagens de ultrassonografia realizadas durante movimentos passivos dos extensores do joelho em dinamômetro isocinético. Diferente do estudo de Griefahn et al. (2017), em que o tecido fascial foi considerado como um único tecido (desconsiderando as camadas superficiais e profundas), os autores avaliaram as camadas superficial e profunda de forma independente, bem como também foi avaliado o deslizamento entre as duas camadas (i.e., tecidos intrafasciais). Após o FR, os autores encontraram redução de 9% do deslizamento da camada fascial profunda, bem como uma diminuição de quase 17% no deslizamento intrafascial entre a camada superficial e profunda da fáscia lata do músculo reto femoral. No entanto, a camada superficial permaneceu inalterada após o FR. De acordo com os autores, tais reduções no deslizamento fascial podem ter ocorrido por alterações na viscosidade dos tecidos conjuntivos entre a camada fascial profunda e o músculo, as quais podem ter alterado a carga eletromagnética de colágeno e proteoglicanas dentro da matriz extracelular, bem como ter causado mudanças nas propriedades tixotrópicas do tecido. Além disso, um suposto aumento no deslizamento entre a banda iliotibial e o músculo, poderia explicar a diminuição do movimento da camada fascial profunda.

Além do tecido fascial, o FR promove estimulo mecânico sobre o tecido muscular. Macgregor et al. (2018) investigaram o efeito do FR sobre a rigidez muscular do quadríceps em homens saudáveis. A rigidez dos músculos reto femoral e vasto lateral foi avaliada por meio de um sensor de tensiomiografia. Imediatamente após a aplicação do FR (volume = 120s; pressão de rolamento = autosselecionada; velocidade de rolamento = cadência de 2s), foi observada a redução da rigidez muscular do vasto lateral (-20,8%), permanecendo até 30min (-19,3%) após a intervenção. De acordo com os autores, a redução na rigidez do vasto lateral seria resultado de uma estimulação dos fusos musculares e órgãos tendinosos de Golgi, provocada pela aplicação do FR sobre os tecidos. Essa estimulação levaria ao aumento da atividade dos motoneurônios aferentes do tipo Ib, resultando em maior *feedback* proprioceptivo do músculo ao sistema nervoso central.

Os resultados de Wilke et al. (2019) vão ao encontro dos achados de Macgregor et al. (2018). Nesse estudo, indivíduos saudáveis foram submetidos à aplicação do FR em diferentes velocidades de rolamento (velocidade lenta = 6rpm; velocidade rápida = 60rpm) sobre os músculos extensores do joelho (volume = 180s; pressão de rolamento = entre 6-7 em escala de 0-10 de desconforto). A rigidez muscular do quadríceps foi avaliada por meio de um medidor semieletrônico de complacência de tecidos (Indentometer Pro, University of Technology Chemnitz, Germany), com avaliações realizadas em três momentos distintos: imediatamente, cinco e 10min após a aplicação do FR. Houve redução da rigidez muscular do quadríceps tanto na aplicação na velocidade lenta (após 10min: -15%), quanto na velocidade rápida (após 5min: -17%; após 10min: -24%). De acordo com os autores, a redução da rigidez muscular pode ser atribuída à alguns fatores como: 1) a maior perfusão sanguínea na região de intervenção; 2) a redução da excitabilidade corticoespinhal; 3) a reduções na viscoelasticidade dos tecidos conjuntivos extramusculares; e 4) a mudanças temporárias no conteúdo líquido dos tecidos comprimidos durante o FR. As diferenças observadas entre as velocidades podem ser atribuídas a quantidade total de rolamentos em cada condição, considerando que o mesmo volume de aplicação foi adotado entre elas (i.e., 4 séries de 45s).

Assim como nos estudos de Wilke et al. (2019) e Macgregor et al. (2018), a aplicação do FR também promoveu redução da rigidez muscular no estudo de Baumgart et al. (2019). Atletas recreativos foram submetidos a aplicação do FR sobre o quadríceps (volume = 60reps; pressão de rolamento = autosselecionada). A rigidez muscular foi avaliada por um dispositivo miomecanográfico (MyotonPRO, Myoton AS, Tallinn, Estonia). Após a intervenção foi observada redução imediata da rigidez muscular do reto femoral (-2,7%). Os autores justificam tais alterações baseados em duas suposições: 1) uma quebra de pontes cruzadas em condição de repouso; e 2) um aumento da temperatura intramuscular. No entanto, estes efeitos não se mantiveram por mais de 15min após a aplicação. Assim, tais alterações sugerem que os efeitos do FR sobre a rigidez muscular possam ser de curta duração.

A redução da rigidez muscular observada no quadríceps também foi observada em músculos isquiotibiais. Morales-Artacho et al. (2017) aplicaram o FR em homens saudáveis e fisicamente ativos. A rigidez muscular foi avaliada em músculos isquiotibiais por meio da elastografia *shear-wave* antes e após o FR por cinco séries de 60s (unilateralmente), com uma série extra de 60s aplicada em ambos os membros de forma simultânea (volume = 360s; velocidade de rolamento = 27rpm). Após o FR, uma redução de 5,4% da rigidez muscular dos isquiotibiais foi observada. Tal redução é atribuída a uma possível liberação de pontes cruzadas entre actina e miosina em condição de repouso, considerando que o número de pontes cruzadas poderia influenciar na rigidez muscular.

A redução da rigidez muscular provocada pelo uso do FR não é um consenso na literatura, uma vez que alguns estudos não encontraram alterações neste parâmetro. Mayer et al. (2019) aplicaram o FR sobre os extensores do joelho (volume = 225s; pressão de rolamento = maior possível; velocidade de rolamento = cadência de 2s) de atletas universitários com (n = 20) e sem experiência (n = 20). A rigidez dos músculos vasto lateral e vasto intermédio foram avaliadas por meio da elastografia *shear-wave* em diferentes momentos: imediatamente, 30min, seis e 24h após o FR. No entanto, não foram observadas alterações na rigidez muscular. De acordo com os autores, tal achado pode ter ocorrido devido ao atraso da formação de edema causado por lesões microarquitetônicas no músculo produzidas pelo tratamento, visto que a presença do edema poderia contribuir para alterações nas propriedades viscoelásticas. Apesar de não ter sido avaliado, esperava-se que um possível edema poderia atingir seu pico somente entre 48 e 72h após o estímulo, ocorrendo um efeito tardio.

A manutenção da rigidez muscular dos extensores de joelho também foi observada no estudo de Martínez-Cabrera e Núñez-Sánchez (2016), após aplicação do FR sobre a região anterior da coxa de jogadores de futebol (volume = 30s; pressão de rolamento = maior possível; velocidade de rolamento = 30rpm). A avaliação da rigidez muscular foi realizada no músculo reto femoral por meio de um sensor de tensiomiografia. Especula-se que a manutenção da rigidez do reto femoral possa ter ocorrido em função do protocolo de aplicação do FR, em que o volume de aplicação pode ter sido insuficiente para provocar alterações na rigidez muscular.

A ausência de alterações na rigidez muscular encontrada nos extensores do joelho, também foi encontrada nos flexores plantares. Após a aplicação do FR, Baumgart et al. (2019) não observaram alterações na rigidez do músculo gastrocnêmio medial. Como mencionado anteriormente, embora neste estudo tenha sido observada redução na rigidez do reto femoral, os autores acreditam que os diferentes efeitos sobre a rigidez dos tecidos podem ser atribuídos ao fato de serem abordados mais de um grupo muscular (i.e., quadríceps e tríceps sural), tratando-se de um possível efeito de curta duração. Em outras palavras, pressupõe-se que o tempo entre a aplicação da técnica e os procedimentos de avaliação dos diferentes grupos musculares possa ter atenuado os efeitos da técnica sobre os flexores plantares.

Assim como no estudo de Baumgart et al. (2019), a manutenção da rigidez dos flexores plantares também foi observada por Nakamura et al. (2021), após a aplicação de diferentes volumes de FR sobre os flexores plantares de adultos saudáveis e sedentários (volume = 1, 3 e 10 séries de 30s; i.e., 30-300s; pressão de rolamento = 7 em escala de 0-10 de desconforto; velocidade de rolamento = 30rpm). Os autores sugerem que a manutenção observada na rigidez dos flexores plantares possa ter ocorrido em função da pressão aplicada sobre o músculo durante o FR, a qual poderia variar entre diferentes grupos musculares, como observado no estudo de Baumgart et al. (2019), em que a descarga de peso durante o FR sobre o quadríceps foi 2% maior do que a aplicada sobre os flexores plantares.

Considerando que o FR possa causar alterações na rigidez fascial e muscular, pode-se esperar que o tecido tendíneo também possa responder a esse estímulo. No entanto, não foram encontrados estudos que buscassem entender os efeitos do FR sobre as propriedades mecânicas do tendão. Portanto, fica evidente que existe uma lacuna na literatura acerca dos possíveis efeitos do FR sobre as propriedades mecânicas do tecido tendíneo.

Em síntese, a literatura apresenta dados contraditórios em relação aos efeitos da aplicação do FR na rigidez dos tecidos miofasciais. Essas divergências podem ter ocorrido devido aos diferentes protocolos de aplicação do FR adotados entre os estudos (e.g., volume e pressão aplicada sobre os tecidos), o que poderia justificar em parte tais resultados conflitantes. Embora existam estudos que investigaram os efeitos do FR sobre os tecidos miofasciais (avaliados de forma isolada), nenhuma revisão sistemática buscou agrupar estas informações e tentar responder se de fato estes efeitos são significativos, e se o FR realmente pode provocar um efeito de "liberação miofascial" sobre os tecidos. A tabela 2 apresenta um resumo dos principais resultados encontrados pelos estudos sobre os efeitos do FR nas propriedades mecânicas dos tecidos miofasciais de indivíduos saudáveis.

Tabela 2 - Efeitos da aplicação do FR sobre as propriedades mecânicas dos tecidos miofasciais do tronco e dos membros inferiores.

Autor (ano)	**Rigidez fascial**	**Rigidez muscular**
Baumgart *et al.* (2019)	-	QUAD = ↓3% FP = ns
Griefahn et al. (2017)	Fáscia toracolombar = ↓57%	-
Krause et al. (2019)	Camada superficial da FL = ns Camada profunda da FL = ↑9% Tecidos intrafasciais = ↑17%	-
Macgregor et al. (2018)	-	QUAD = ↓21%
Martínez-Cabrera e Núñez-Sánchez (2016)	-	QUAD = ns
Mayer et al. (2019)	Banda iliotibial = ↓13,2%	QUAD = ns
Morales-Artacho et al. (2017)	-	IT = ↓5%
Nakamura et al., (2021)	-	FP = ns
Pepper et al. (2021)	Banda iliotibial = ns	-
Wilke et al. (2019)	-	QUAD = ↓15-24%

↓ redução estatisticamente significativa; ↑ aumento estatisticamente significativo; ns: não significativo. FL: fáscia lata; FP: músculos flexores plantares do tornozelo; IT: músculos isquiotibiais; QUAD: músculo quadríceps.

2.5.2 Efeitos do FR sobre a produção de força muscular

Considerando que alguns estudos (GRIEFAHN et al., 2017; MAYER et al., 2019; MORALES-ARTACHO et al., 2017; REINER et al., 2021) demonstram que o FR pode causar alterações sobre a rigidez dos tecidos miofasciais, alterações em parâmetros funcionais também poderiam ser esperadas. O aumento da flexibilidade após o FR é frequentemente encontrado na literatura (AUNE et al., 2018; KRAUSE et al., 2019; LEE et al., 2018; MACDONALD et al., 2013; YOSHIMURA et al., 2021), e vem sendo considerado como um dos principais efeitos da aplicação do FR (WIEWELHOVE et al., 2019). Além disso, embora existam evidências de que o alongamento pode aumentar a flexibilidade de modo imediato, seus efeitos podem comprometer a função muscular e prejudicar o desempenho atlético (BEHM et al., 2016; MINE et al., 2018; WILKE et al., 2020a). Por outro lado, o FR parece promover o aumento da ADM sem causar prejuízos na produção de força e potência muscular (BEHARA; JACOBSON, 2017; MACDONALD et al., 2013; WILKE et al., 2020a), além de existir indícios de aumento da ADM acompanhada de aumento na força muscular (LEE et al., 2018; SU et al., 2017).

MacDonald et al. (2013) aplicaram o FR nos extensores de joelho de indivíduos saudáveis (volume = 120s; pressão de rolamento = maior possível; velocidade de rolamento = cadência de 3-4rpm). A força isométrica foi avaliada por meio de uma célula de carga a 90º de flexão do joelho (0º = extensão completa). Três avaliações foram realizadas em momentos distintos da intervenção (pré-intervenção, e após 2 e 10min). Após a aplicação do FR não foram observadas alterações na produção de força isométrica dos extensores do joelho. Resultados semelhantes aos encontrados por MacDonald et al. (2013) foram observados também no estudo de Macgregor et al. (2018), os quais avaliaram o efeito do FR sobre a produção de torque isométrico dos extensores de joelho. No estudo de Macgregor et al. (2018), indivíduos saudáveis foram submetidos a aplicação do FR (volume = 120s; pressão de rolamento = autosselecionada; velocidade de rolamento = cadência de 2s). O torque isométrico dos extensores de joelho foi avaliado por meio de dinamometria isocinética a 60º de flexão do joelho (0º = extensão completa). Trinta minutos após o FR, nenhuma alteração foi observada neste parâmetro.

A manutenção observada na força/torque em músculos extensores do joelho (BEHARA; JACOBSON, 2017; MACDONALD et al., 2013; MACGREGOR et al., 2018) também foi observada em flexores do joelho (BEHARA; JACOBSON, 2017; MORTON et al., 2016; NEHRING et al., 2021) e em flexores plantares do tornozelo (AUNE et al., 2018;

NAKAMURA et al., 2021), parecendo haver um consenso na literatura em relação a manutenção da força muscular em contrações isométricas após o uso do FR. Esse consenso é observado também nos achados da meta-análise de Wiewelhove et al. (2019), em que a força muscular demonstrou não ser afetada por diferentes técnicas de automassagem. No entanto, tais resultados não correspondem exclusivamente aos efeitos do FR sobre este parâmetro.

Embora estudos não tenham observado alterações sobre a produção de força muscular isométrica, alguns estudos encontraram aumento do torque concêntrico após a aplicação do FR (LEE et al., 2018; SU et al., 2017). Lee et al. (2018) submeteram estudantes universitários a diferentes intervenções envolvendo FR sobre os músculos extensores e flexores do joelho: a) FR com dispositivo vibratório; e b) FR com dispositivo não-vibratório. As duas condições apresentaram o mesmo volume (90s), pressão de aplicação (maior possível) e velocidade de rolamento (40rpm). O torque concêntrico dos músculos extensores e flexores do joelho foi avaliado em dinamômetro isocinético, em velocidade angular de 60º/s. Os autores observaram aumento do torque concêntrico dos extensores de joelho após FR com ambos os dispositivos, enquanto que para os flexores de joelho, apenas o FR vibratório produziu tal aumento. De acordo com Capobianco et al. (2019), o estresse mecânico causado sobre as células endoteliais poderia resultar no aumento do fluxo sanguíneo e na liberação de óxido nítrico, aumentando a vasodilatação, que por sua vez, poderia aumentar a reposição de fosfocreatina, ou acelerar o retorno ao pH basal entre as contrações, aumentando o desempenho durante uma contração máxima. Este mecanismo pode ter ocorrido devido a combinação entre volume e pressão aplicada sobre os tecidos. Tais achados vão ao encontro dos resultados do estudo de Su et al. (2017), o qual a aplicação do FR com protocolo de aplicação semelhante ao utilizado por Lee et al. (2018), demonstrou um aumento de 7,8% no torque concêntrico de extensores de joelho, sem alterações nos flexores de joelho.

Ainda que o aumento do torque concêntrico dos extensores de joelho seja reportado na literatura, a manutenção deste parâmetro foi encontrada nos flexores de joelho após o FR (LEE et al., 2018; MADONI et al., 2018; SU et al., 2017). Su et al. (2017) investigaram os efeitos do FR também sobre o torque concêntrico dos flexores do joelho, os quais não observaram nenhuma alteração. Especula-se que as diferentes respostas entre os músculos extensores e flexores do joelho possam ter ocorrido devido às diferentes posições de rolamento durante o FR, que apresentam diferentes braços de alavanca, as quais poderiam aplicar diferentes níveis de pressão em cada músculo.

A manutenção do torque concêntrico também foi observada por Madoni et al. (2018), em mulheres fisicamente ativas. A aplicação do FR foi realizada sobre os músculos isquiotibiais (volume = 30s; pressão de rolamento = maior possível). As avaliações do torque concêntrico foram realizadas a partir de contrações máximas de flexão do joelho, em um dinamômetro isocinético, em diferentes velocidades angulares (60º/s, 180º/s e 300º/s). Após a intervenção, a manutenção do torque concêntrico dos flexores de joelho foi observada em todas as velocidades. No entanto, os autores reportaram que diferenças entre protocolos de avaliação, intervenção, e diferentes populações levam a maiores dificuldades em comparar tais achados.

Embora alguns estudos tenham verificado os efeitos do FR na produção de força em contrações isométricas e concêntricas, são escassos os estudos que buscaram avaliar o efeito desta técnica em contrações excêntricas. O estudo de Madoni et al. (2018) foi o único estudo encontrado que investigou tais efeitos sobre o torque excêntrico, avaliado nos flexores do joelho a velocidades angulares de 60º/s e 180º/s. Após a intervenção, nenhuma alteração no torque excêntrico dos flexores de joelho foi observada em ambas as velocidades de contração. Tais achados demonstram não haver efeitos adversos sobre o torque excêntrico após o FR, embora as evidências em relação a estes parâmetros ainda são insuficientes.

Ainda que a capacidade de produção de força máxima seja um parâmetro importante, o quão rápido esta força se desenvolve possui grandes implicações funcionais (AAGAARD et al., 2002; MAFFIULETTI et al., 2016; RODRÍGUEZ-ROSELL et al., 2018). Desta forma, alguns estudos investigaram os efeitos do FR sobre a TPF. No estudo de MacDonald et al. (2013), os indivíduos foram submetidos a aplicação do FR no quadríceps (volume = 120s; pressão de rolamento = maior possível; velocidade de rolamento = cadência de 3-4rpm). Os efeitos agudos do FR foram avaliados após dois e 10min da intervenção. A TPF foi avaliada nos primeiros 200ms de contrações isométricas máximas de extensão do joelho. Após o FR, não foram observadas alterações na TPF dos extensores do joelho.

Outras técnicas de automassagem também não causaram alterações sobre a TPF (HALPERIN et al., 2014). No estudo de Halperin et al. (2014) os autores aplicaram a automassagem com bastão (volume = 90s; pressão de aplicação = 7 em escala de 0-10 de desconforto; velocidade de aplicação = cadência de 2s). A avaliação da TPF foi feita nos primeiros 100ms de contrações isométricas máximas de flexão plantar, realizadas em dinamômetro isocinético, e momentos distintos antes e após a intervenção (pré 1 e 2, pós 1min, e pós 10min). Após a automassagem, nenhuma alteração foi observada na TPF dos flexores plantares.

A manutenção da TPF também foi observada em condições dinâmicas [i.e., saltos verticais; *squat jump* (SJ) e *countermovement jump* (CMJ)] (GIOVANELLI et al., 2018). A TPF foi avaliada por meio de uma plataforma de força, imediatamente após 60s de FR (pressão de aplicação = autosselecionada; velocidade de aplicação = cadência de 2s) em cada um dos oito locais de aplicação do FR nos membros inferiores (i.e., fáscia lata, glúteos, isquiotibiais, quadríceps com e sem o joelho flexionado, tibial anterior, flexores plantares e fáscia plantar)

Entre os estudos que encontraram tal manutenção, o volume aplicado sobre o mesmo grupo muscular pode ter sido insuficiente (60-120s), uma vez que a redução da TPF foi observada após um volume de 300s de FR aplicado no membro contralateral sobre os músculos isquiotibiais (efeito *cross-over*) (YE et al., 2019), e após 5min de alongamento passivo (TRAJANO et al., 2019). Por outro lado, um efeito tardio também foi observado 3h após a aplicação do FR, demonstrando aumento da TPF durante o CMJ mas não no SJ (GIOVANELLI et al., 2018). O CMJ possui maior contribuição dos tecidos passivos no armazenamento e aproveitamento da energia elástica durante a transição entre a fase excêntrica e concêntrica, em relação ao SJ (GIOVANELLI et al., 2018; KUBO et al., 2005). Assim, especula-se que uma maior utilização de energia elástica pode ocorrer mais tarde, devido a mudanças na hidratação dos tecidos após o FR.

Em síntese, a literatura se mostra contraditória no que se refere aos efeitos do FR em parâmetros relacionados com a produção de força muscular. Apesar de a maioria dos estudos observarem manutenção da força muscular isométrica após o FR (AUNE et al., 2018; BEHARA; JACOBSON, 2017; MACDONALD et al., 2013; MACGREGOR et al., 2018), o aumento (LEE et al., 2018; SU et al., 2017) e a manutenção (LEE et al., 2018; MADONI et al., 2018; SU et al., 2017) no torque concêntrico também foram observados. No entanto, um único estudo investigou os efeitos do FR sobre o torque excêntrico, o qual não observou alterações (MADONI et al., 2018). No entanto, nenhuma revisão sistemática buscou entender os efeitos exclusivos do FR sobre a força muscular, além disso, os diferentes tipos de contração muscular também não foram considerados.

Em relação a TPF, embora existam poucos estudos com FR, resultados conflitantes podem ser observados com diferentes técnicas e formas de aplicação da automassagem, uma vez que estudos encontraram manutenção (GIOVANELLI et al., 2018; HALPERIN et al., 2014; MACDONALD et al., 2013), redução (YE et al., 2019) e até o aumento da TPF (GIOVANELLI et al., 2018). Além disso, o número de evidências acerca dos efeitos exclusivos do FR sobre a TPF é limitado (GIOVANELLI et al., 2018; MACDONALD et al., 2013; MORTON et al., 2016; YE et al., 2019). Além disso, assim como para os efeitos do FR sobre a capacidade de produção de força máxima, nenhuma revisão se propôs a investigar os efeitos desta técnica sobre a TPF.

Tabela 3 - Efeitos agudos da aplicação do FR sobre propriedades funcionais de membros inferiores.

Autor (ano)	**Força/Torque isométrica(o)**	**Torque concêntrico**	**Torque excêntrico**	**TPF**
Aune et al. (2018)	T_{FP} = ns	-	-	-
Behara e Jacobson (2017)	T_{EJ} = ns T_{FJ} = ns	-	-	-
Giovanelli et al. (2018)	-	-	-	CMJ = ns SJ = ns
Lee et al. (2018)	-	T_{EJ} = ↑4% T_{FJ} = ns	-	-
MacDonald et al. (2013)	F_{EJ} = ns	-	-	EJ = ns
Macgregor et al. (2018)	T_{EJ} = ns	-	-	-
Madoni et al. (2018)		$T_{FJ\ 60^{\circ}/s}$ = ns $T_{FJ\ 180^{\circ}/s}$ = ns $T_{FJ\ 300^{\circ}/s}$ = ns	$T_{FJ\ 60^{\circ}/s}$ = ns $T_{FJ\ 180^{\circ}/s}$ = ns	-
Su et al. (2017)		T_{EJ} = ↑8% T_{FJ} = ns		

↑ aumento estatisticamente significativo; ns: não significativo. CMJ: *countermovement jump*; EJ: extensores do joelho; F: pico de força; FJ: flexores do joelho; FP: flexores plantares do tornozelo; SJ: *squat jump*; T: pico de torque; TPF: taxa de produção de força.

2.6 Revisão crítica da literatura

De acordo com o observado na literatura, existem indícios de que o FR pode provocar alterações sobre as propriedades mecânicas dos tecidos miofasciais, as quais podem estar relacionadas com o comportamento elástico destes tecidos. No entanto, não há consenso na literatura acerca destas alterações, uma vez que alguns estudos não encontraram mudanças na rigidez dos tecidos miofasciais após o FR. Além disso, não foram encontrados estudos que buscassem entender os efeitos do FR sobre o tecido tendíneo (desconsiderando o tecido como unidade musculo-tendínea). Portanto, existe uma lacuna na literatura acerca das alterações causadas pelo FR sobre o tecido tendíneo.

Resultados conflitantes também podem ser observados em relação aos efeitos do FR sobre a capacidade de produção de força muscular. Evidências demonstram que o FR não afeta a capacidade de produzir força muscular em contrações isométricas e excêntricas, enquanto pequenos indícios sugerem que possa ocorrer o aumento do torque muscular em contrações concêntricas. Além disso, embora o número de evidências seja limitado, estudos demonstram que o FR não altera a TPF de forma imediata, enquanto a redução foi observada com o FR aplicado no membro contralateral, e o aumento também foi reportado após 3h, demonstrando indícios de que possa existir um efeito tardio.

Uma série de limitações são evidenciadas após a revisão da literatura acerca dos efeitos do FR sobre as propriedades mecânicas dos tecidos miofasciais e na produção de força muscular. A literatura apresenta uma variedade de estudos, os quais apresentam diferentes protocolos de intervenção com o FR, as quais vão desde diferentes dispositivos de tratamento (tipo de *foam roller*), volume, pressão e velocidade de aplicação, até a forma em que os desfechos são avaliados.

Em relação aos efeitos gerais do FR, recentemente algumas revisões sistemáticas foram desenvolvidas. No entanto, poucos estudos investigaram a utilização do FR de forma exclusiva, desconsiderando outras técnicas de automassagem. Além disso, nenhuma revisão sistemática investigou os efeitos do FR sobre as propriedades mecânicas dos tecidos miofasciais e na produção de força muscular, em especial, considerando os diferentes tipos de tecidos e tipos de contrações musculares. Portanto, existe uma lacuna na literatura acerca das informações que poderiam sustentar a hipótese de que o FR pode alterar a rigidez dos tecidos miofasciais, induzindo a um efeito de “liberação miofascial”, e se o FR pode afetar a produção de força muscular em diferentes tipos de contrações.

3. OBJETIVOS

3.1 Objetivo geral

Revisar sistematicamente e avaliar quantitativamente, por meio de meta-análise, ensaios clínicos randomizados que testaram os efeitos agudos do FR sobre as propriedades mecânicas dos tecidos miofasciais e na força muscular.

3.2 Objetivos específicos

- Verificar qualitativamente e quantitativamente os efeitos agudos do FR na rigidez dos tecidos fascial, muscular e tendíneo;
- Verificar qualitativamente e quantitativamente os efeitos agudos do FR na força muscular isométrica e isocinética e na TPF.

3.3 Hipóteses

- O uso do FR provocará a redução da rigidez dos tecidos fascial, muscular e tendíneo;
- O uso do FR provocará a manutenção da força muscular isométrica, do torque excêntrico e da TPF, e o aumento do torque concêntrico.

4. ARTIGO: *FOAM ROLLING ACUTE EFFECTS ON MYOFASCIAL TISSUES' MECHANICAL PROPERTIES AND MUSCLE STRENGTH: A SYSTEMATIC REVIEW AND META-ANALYSIS*

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FOAM ROLLING ACUTE EFFECTS ON MYOFASCIAL TISSUES’ MECHANICAL PROPERTIES AND MUSCLE STRENGTH: A SYSTEMATIC REVIEW AND META-ANALYSIS

ABSTRACT

Introduction: Foam rolling (FR) is widely used in rehabilitation and physical training. However, the FR’s effects on myofascial tissues and muscle strength remain unclear. **Aim:** To perform a systematic review with meta-analysis of trials that tested the FR acute effects on the myofascial tissues’ stiffness and muscle strength in healthy adults and/or athletes. **Methods:** This systematic review (CRD42021227048) was performed according to Cochrane’s recommendations, with searches performed in PubMed, Web of Science, Embase, and PEDro databases. Syntheses of included studies’ data were performed, and the PEDro scale was used to assess the studies’ methodological quality. Certainty of evidence was assessed using the GRADE’s approach. **Results:** Twenty included studies assessed trunk and thigh fascial tissues’ stiffness, and thigh and calf muscles’ stiffness, while muscle strength was assessed in the knee extensors and flexors, and plantar flexors muscles. Qualitative analysis showed decreases in fascial (n=2) and muscle (n=5) stiffness after FR. However, the meta-analysis showed no FR’s effects on myofascial tissues’ stiffness. Both qualitative and quantitative analysis showed no FR’s effects on isometric muscle strength, eccentric torque, and rate of force development. However, the knee extensors’ concentric torque increased after FR. **Conclusion:** FR increases the knee extensors’ concentric torque, but it does not acutely change the myofascial tissues’ stiffness and isometric muscle strength. However, these studies’ evidences provide low certainty to state that FR does not change these parameters. Therefore, high methodological quality studies should be performed to better ascertain the FR effects on the myofascial tissues’ stiffness and on muscle strength.

Keywords: warm-up; self-massage; self-myofascial release; stiffness; muscle force production.

1 Introduction

Foam rolling (FR) has achieved a large popularity in recent years [1]. This treatment model is performed through rolling movements of the body mass on a dense and rigid foam roller, over a muscle or region of interest [2]. Literature and clinical practice often describe FR as a self-myofascial release technique, but these effects are still questionable [3]. Despite being widely used in rehabilitation and physical training programs, knowledge about FR’s effects on myofascial mechanical properties is still scarce.

In rehabilitation, FR is used to restore soft tissues’ extensibility [4] in regions where the fascial tissue is assumed to be fixed around traumatized areas, forming fibrous adhesions that reduce these tissues’ extensibility [2, 5]. Several myofascial pain syndromes are influenced by changes in the soft tissues’ properties [6], such as the iliotibial band syndrome [7], and low back pain [8]. Thus, FR is an alternative for the treatment of myofascial and musculoskeletal disorders [4]. In sports, FR is used to increase training efficiency and/or to prepare for competition [9-11], as well as to reduce muscle soreness [4]. When used before training or competition, it can increase flexibility similar to static [12] and dynamic stretching [1, 12, 13], without causing muscle strength losses [2].

The mechanisms explaining the effects induced by FR are not yet fully understood. Although psychological (well-being and/or placebo effect due to the increase in plasma endorphins), physiological (increased blood flow and parasympathetic circulation, and inflammatory responses), neurological (changes in the activity of mechanoreceptors, proprioceptors, and pain receptors), and biomechanical (reduction in tissue adhesion, altered tissue stiffness, and thixotropic responses) mechanisms have been considered [9, 14, 15], changes in the tissues' mechanical properties are not yet clear. Acutely, FR appears to decrease [16-18], increase [17], and to induce no changes [19] on the fascial tissues' stiffness. On the muscle, while some studies have found reduced stiffness [7, 11, 15, 20], others found no changes after FR [11, 16, 21]. Assuming that FR can promote changes in the myofascial tissues' mechanical properties (i.e., stiffness), changes in functional parameters (e.g., muscle strength) could also be expected [9].

Changes in myofascial tissues' mechanical properties may affect the production and transfer of muscle strength to bones. The increased stiffness of elastic components, for example, can improve the connective tissue's ability to transmit muscle force [22], contributing to an increase in muscle strength [23, 24]. However, a more compliant myotendinous unit allows for faster shortening of contractile components [23], favoring the performance in stretching-shortening cycle tasks [25]. Studies have shown that FR does not seem to change the isometric [2, 15, 26], and eccentric torques [27], although increase [28, 29], and maintenance [27-29] of concentric torque have been reported. In addition, the rate of force development (RFD) (i.e., how fast the force is produced from a resting condition) [2, 30] seems to be unaffected by FR [2, 31].

Among five recent systematic reviews [9, 32-35], only two investigated the FR effects on flexibility [joint range of motion (ROM)], recovery (muscle soreness), and athletic performance (functional outcomes) [32, 34], and none investigated the FR effects on the myofascial tissues' stiffness and on muscle strength from the different muscle contraction types. Given the conflicting results and the lack of information about the FR's effects (especially related to the myofascial tissues' mechanical properties), this systematic review with meta-analysis aimed to investigate randomized controlled trials that tested the FR acute effects on the myofascial tissues' mechanical properties, and on muscle strength in healthy adults and/or athletes.

2 Methods

A systematic review with meta-analysis was performed following the recommendations from the Cochrane Collaboration [36], and the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyzes) reporting guidelines [37]. This study was registered in the PROSPERO database (CRD42021227048). The study selection, data extraction, methodological quality assessment of the included studies, and the certainty of evidence were conducted by two independent investigators (M.H.G. and D.R.R.). When there was between-reviewers disagreement, a third reviewer (G.N.P.) was consulted to reach a consensus.

2.1 Search Strategy

The literature search on the electronic library was conducted in the following databases until July 2021: ISI Web of Knowledge (Web of Science), MEDLINE (PubMed), Embase, and PEDro database. No temporal delimitation was considered in the search strategy. Similar keywords were used in all electronic databases, although combinations of terms were adapted for each platform using the Boolean operators "AND" and "OR".

The combinations of terms used were: Web of Science and PubMed: (adult OR athlete) AND ("self-massage" OR "self-myofascial release" OR "foam rolling" OR "foam roller"); Embase: ('adult' OR 'athlete') AND 'self-massage' OR 'self-myofascial release' OR 'foam rolling' OR 'foam roller'); and PEDro database: (*self-massage* *self-myofascial release* *foam rolling* *foam roller*). In addition, the reference lists of all included studies and previous systematic reviews with self-massage techniques including FR [9, 32-35] were checked to identify other potentially eligible studies.

2.2 Inclusion Criteria

Randomized controlled trials (crossovers or parallel-group studies) with the full and accessible text were included in this review. Only studies published and written in English language were considered. The inclusion criteria were related to the PICOS question: a) healthy adults and/or athletes; b) self-massage intervention with foam roller device; c) at least data of the pre-post treatment for the FR condition (crossover studies), or comparison of post-treatment measurements between intervention and control group (parallel groups) had to be presented; d) assessments of the FR acute effects on mechanical properties of myofascial tissues, and/or muscle strength. In studies measuring acute and chronic effects, only acute effects were considered [35]. Studies' exclusion criteria were: a) not FR intervention; b) FR combined with other techniques (e.g., stretch or cycling); c) remote effects (contralateral limb or non-target rolling); d) effects on exercise recovery or chronic effect measurements.

2.3 Data Extraction

Searches on databases were completed by July 15, 2021. Data (mean and standard deviation values) related to study design, sample size, participant characteristics, FR intervention (volume, pressure, and rolling speed), measured outcomes (test and targeted muscle group), and results (post-intervention changes of FR, or comparison effects between FR and control condition on fascial, muscular, and tendon stiffness, and muscle strength) were extracted individually and exported to a spreadsheet.

2.4 Data Synthesis and Statistics

Data from both crossover and parallel-group studies were included. When studies did not provide enough data (incomplete reporting), the corresponding author of the study was contacted by email and asked to provide the information or access to the study database. When the database was provided, raw data were used for quantitative analysis [11, 15, 26, 27, 38, 39]. When authors did not respond or could not provide the required data, the mean and standard deviation values were obtained manually from the plots using the ImageJ tool (version 1.48v, National Institutes of Health, Bethesda, MA, USA). When access to the data was not possible, or in case of incompatible data (non-groupable tissue/muscle group), the study was not included in the quantitative analysis [7, 17, 19, 20, 40, 41].

Common outcomes between two or more studies were considered for the meta-analyses using the standardized mean difference (SMD), standard error (SE), and confidence interval (CI) as measures of effect and dispersion, respectively. Thus, five meta-analyses were performed based on the FR effects on fascial and muscle stiffness and muscle strength. In the meta-analyses conducted including muscle stiffness, isometric muscle strength, and isokinetic torque, subgroup analyses were performed considering the different muscle groups:

stiffness of gastrocnemius medialis and quadriceps muscles; isometric force and torque of knee extensor muscles, isometric torque of knee flexor muscles; and concentric torque of knee extensor and flexor muscles. In studies presenting data from both limbs (left and right), the right limb data was selected because of the between-sides muscle strength similarity [42], and because most people have the right limb as the preferred limb for tasks such as jumping and kicking a ball [42, 43].

In the crossover trials, when a study did not present the correlation coefficient (r) values between the pre and post-intervention measures, a sensitivity analysis using different values (r=0.5; r=0.7; and r=0.8) was performed. As none of the values directly affected the results of the meta-analyses, we adopted a conservative estimate of r=0.7, as recommended by Rosenthal [44] and previously used by Kishita et al. [45]. The random-effects model was used in all meta-analyses, due to the heterogeneity in the types of intervention and measures of the results, and confirmed by the I^2 test interpreted according to Higgins et al. [46], where values above 25% and 50% were classified as moderate and high heterogeneity, respectively. When moderate or high heterogeneity was found (values >25%), sensitivity analysis was performed and the heterogeneity was explored. All statistical analyses were performed using the Comprehensive Meta-Analysis (version 2; Biostat, Englewood, NJ, USA). The level of statistical significance was determined as $\alpha \leq 0.05$.

2.5 Methodological Quality

The methodological quality of the included studies was assessed by the PEDro scale, which has high reliability and validity [35, 47]. This scale consists of 11 items in which, each item that is considered satisfied (except item 11 on the form), contributes one point to the total score. Studies' total scores equal to or greater than six on the PEDro scale were considered to have high methodological quality [47].

2.6 Risk of Bias and Confidence in Evidence

Publication bias was verified using the Egger, Begg and Mazumdar, and Duval and Tweedie's trim-and-fill regression tests, adjusting asymmetric values. Visual analysis of the funnel plots (effect size against SE) was performed by independent analyses among studies that investigated the FR effects on myofascial tissues' stiffness, and muscle strength.

The grading strength of recommendations was assessed using the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) approach [48]. The GRADE assumes high quality that can be downgraded according to five factors: study limitations (methodological quality), inconsistency of results (heterogeneity), indirectness of evidence, imprecision of results (95% confidence intervals), and publication bias. The criteria used to determine the meta-analyses' level of recommendation were: methodological quality (PEDro mean score of the meta-analyses included studies divided into three classifications: scores ≥6 "no serious", 4-5 "serious", and 0-3 "very serious"); inconsistency (I^2 values below 25%, between 25-50%, and above 50% were classified as "no serious", "serious" and "very serious", respectively); indirectness (the evidence was considered to be direct when it answered the PICOS question, so the criterion "not serious" was adopted for all meta-analyses); imprecision (CI amplitude less than the SMD value as "no serious", CI amplitude between half SMD and SMD values as "serious", and CI amplitude greater than the SMD value as "very serious"), and publication bias (detectable if there was a tendency to publish studies only with positive results).

3 Results

3.1 Search Results

A flow diagram of the literature search and screening is displayed in **Fig. 1**. The initial search identified 574 studies in the four databases. After study selection, 19 studies [2, 7, 11, 15, 17-20, 26-29, 38-40, 49-52] met all the eligibility criteria and were included in the review. One additional study [41] was found in the references from a previous systematic review. Thus, 20 eligible studies were included in this review.

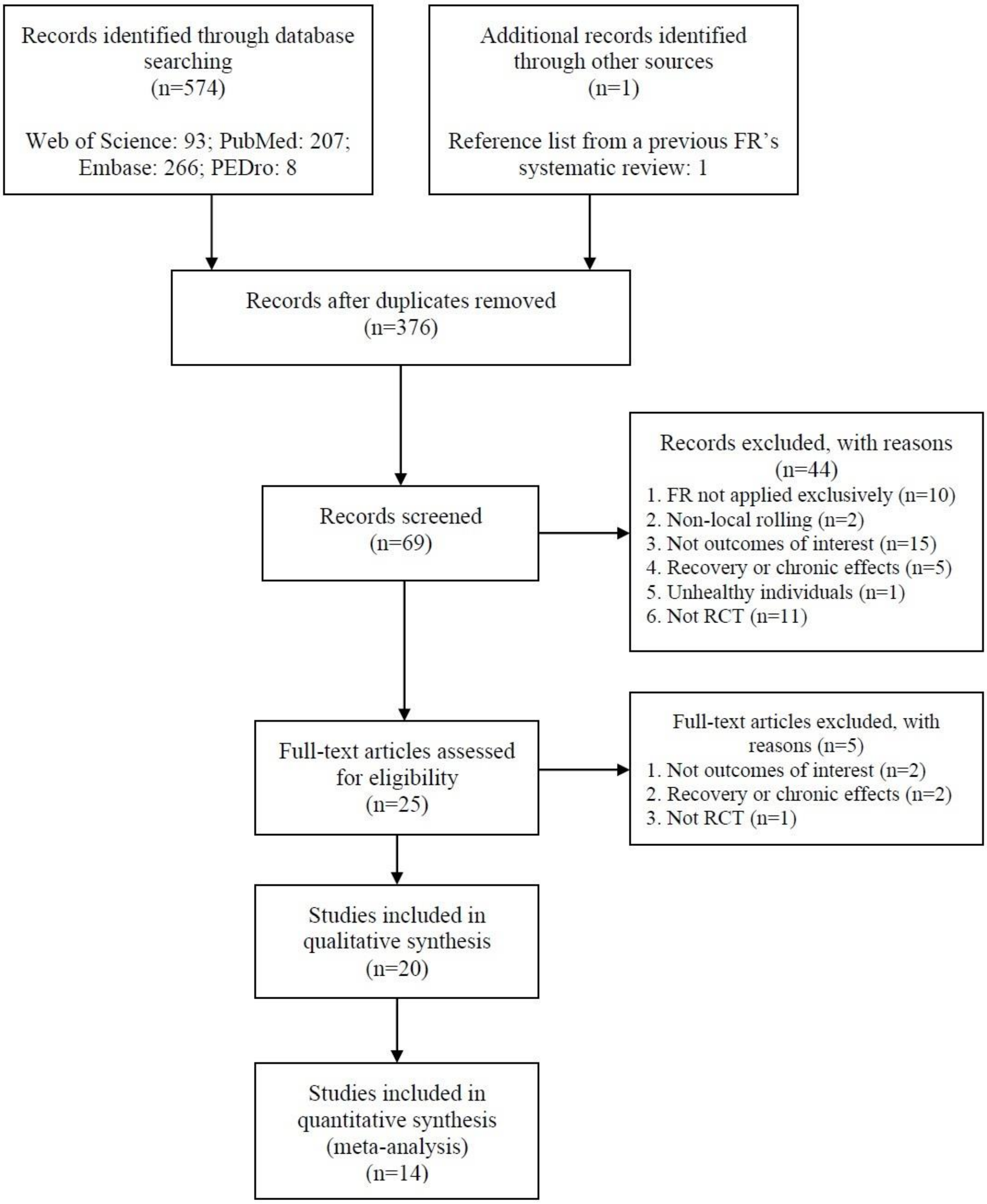


Fig. 1 PRISMA chart of the study flow. FR = foam rolling; RCT = randomized controlled trial.

3.2 Characteristics of the Included Studies

Tables 1.1 and 1.2 summarize the main information of the included studies. The crossover design was adopted by fourteen studies [2, 7, 11, 15, 17, 20, 27-29, 38, 40, 41, 49, 52] while six adopted parallel-groups [18, 19, 26, 39, 50, 51]. Twelve studies compared the FR acute effects with no treatment (control group) [2, 7, 11, 15, 17-20, 27, 38, 49, 50], while eight compared the pre-post changes after FR [26, 28, 29, 39-41, 51, 52]. In addition, only one study presented the placebo condition [18].

The samples were composed mostly by healthy adults [17, 19, 39], healthy and physically active adults [2, 7, 15, 18, 20, 27-29, 38, 40, 41, 50, 52], but also by healthy and sedentary adults [51], soccer [26] and football players [49], and athletes without specification [11]. The sample size varied from 11 [2] to 30 [28, 29] participants per group/condition, but only twelve studies determined the sample size based on sample calculation [7, 15, 17, 19, 20, 26, 27, 29, 40, 50-52]. A total of 490 participants (288 men and 202 women), with the mean age ranging between 18-32 years, were evaluated across all studies.

Seven studies mentioned the participants' level of experience with FR [11, 18, 19, 38, 40, 41, 50], and eleven studies [2, 7, 11, 17, 19, 26-29, 39, 52] performed familiarization procedures. While fifteen studies used a smooth foam roller [2, 7, 11, 17, 19, 26-28, 38-41, 50-52], three used a roller with raised nodules with sharp [49] or tubular shapes [15, 20], and two did not described the roller device [18, 29]. The volume of FR application ranged from a single [15, 39, 51] to 11 [20] sets, with duration per set ranging between 10s [27] and 120s [15, 39].

The FR effects on myofascial tissues' mechanical properties were assessed by 11 studies [7, 11, 15, 17-20, 41, 50-52]. Four of these trials [17-19, 50] tested the FR effects on fascial tissue, while seven [7, 11, 15, 20, 41, 51, 52] tested on muscle stiffness. No study investigated the FR effects exclusively on tendon stiffness. The FR effects on muscle strength were investigated by 12 trials [2, 15, 26-29, 38-40, 49, 51, 52]. Nine of these studies [2, 15, 26, 38-40, 49, 51, 52] performed isometric tests, while three used concentric tests [27-29], and only one trial [27] performed eccentric tests. Regarding explosive strength, only one study [2] investigated the FR effects on RFD.

Table 1.1 Summary of studies on the effects of FR on myofascial tissues' stiffness.

Study	Design	Participants	FR Protocol	Outcomes: Assessment Tools	Results
Baumgart et al. [11]	Crossover 1: FR 2: CYC 3: CON	Athletes (not specified) (n = 20; M = 20/W = 0) 27 ± 3 years	2 x 30reps – QUAD, and PF (two sets per muscle group)	-Muscle stiffness Mechanomyography	-Muscle stiffness QUAD: ↓2.7% PF: ns
Griefahn et al. [18]	Parallel groups 1: FR 2: CON 3: PBO	Healthy and physically active individuals (n = 38; M = 13/W = 25) 23 ± 3 years 1: (n = 13; M = 5/W = 8) 2: (n = 13; M = 5/W = 8) 3: (n = 12; M = 5/W = 7)	9 x 30s – Gluteus, spine erectors, and latissimus dorsi (3 sets per muscle group; self-selected pressure; cadence 2-3s)	-Fascial stiffness B-mode ultrasound	-Fascial stiffness TLF: ↓56.5%
Griefahn et al. [50]	Parallel groups 1: FR 2: VFR 3: CON	Healthy and physically active individuals (n= 45; M = 22; W = 23) 26 ± 4 years 1: (n = 14; M = 8/W = 6) 27 ± 5 years 2: (n = 16; M = 7/W = 9) 25 ± 3 years 3: (n = 15; M = 7/W = 8) 27 ± 4 years	12 x 30s – Gluteus, lateral trunk, upper and lower back (3 sets per muscle group; 30s rest between sets; self-selected pressure; 30rpm)	-Fascial stiffness B-mode ultrasound	-Fascial stiffness TLF: ↓21.0% Superficial layer of TLF: ns Deepest layer of TLF: ns

Krause et al. [17]	Crossover 1: FR 2: SS 3: CON	Healthy individuals (n = 16; M = 10/W = 6) 32 ± 5 years	2 x 60s – QUAD (30s rest between sets; pressure 6-7 of 10 scores in NPRS; 15rpm)	-Fascial stiffness B-mode ultrasound	-Fascial stiffness Superficial layer of the fascia lata: ns Deepest layer of the fascia lata: ↑9.2% Intrafascial tissues: ↑16.8%
Macgregor et al. [15]	Crossover 1: FR 2: CON	Healthy and physically active individuals (n = 16; M = 16/W = 0) 25 ± 4 years	1 x 120s – QUAD (self-selected pressure; cadence 2s)	-Muscle stiffness Tensiomyography	-Muscle stiffness RF: ns VL: ↓20.8%
Morales-Artacho et al. [20]	Crossover 1: FR 2: CYC 3: FR + CYC 4: CON	Healthy and physically active individuals (n = 14; M = 14/W = 0) 27 ± 5 years	11 x 60s – HAM (one set for both legs simultaneously, and five sets unilaterally for each limb; 30s rest between sets; 27rpm)	-Muscle stiffness Shear-wave elastography	-Muscle stiffness 1: FR HAM: ↓5.4% Semimembranous: ns Semitendinosus: ns Biceps femoris: ns
Nakamura et al. [51]	Parallel groups 1: FR 2: FR 3: FR	Healthy sedentary individuals (n = 45; M = 23/W = 22) 1: (n = 15; M = 8/W = 7) 21 ± 1 years 2: (n = 15; M = 7/W = 8) 21 ± 1 years 3: (n = 15; M = 8/W = 7) 21 ± 2 years	1: 1 x 30s – PF (dominant limb; 30s rest between sets; pressure of 6-7 of 10 scores in NPRS; 30rpm) 2: 3 x 30s - PF (dominant limb; 30s rest between sets; pressure of 6-7 of 10 scores in NPRS; 30rpm) 3: 10 x 30s - PF (dominant limb; 30s rest between sets; pressure of 6-7 of 10 scores in NPRS; 30rpm)	-Muscle stiffness Shear-wave elastography	-Muscle stiffness 1: MG: ns 2: MG: ns 3: MG: ns

Pepper et al. [19]	Parallel groups 1: FR 2: SS 3: CON	Healthy individuals (n = 30; M = 11; W = 19) 25-27 years 1: (n = 10; M = 3; W = 7) 27 ± 7 years 2: (n = 10; M = 4; W = 6) 27 ± 9 years 3: (n = 10; M = 4; W = 6) 25 ± 7 years	5 x 60s – ITB (rest 30s between sets; self-selected pressure)	-Fascial stiffness Shear-wave elastography	-Fascial stiffness ITB lateral mid-thigh: ns ITB lateral distal-thigh: ns
Reiner et al. [52]	Crossover 1: FR 2: VFR	Healthy and physically active individuals (n = 21; M = 21/W = 0) 25 ± 4 years	3 x 60s – RF, VM, and VL (right limb; one set for each muscle; 30s rest between sets; greater pressure as possible; cadence 2s/ 30rpm)	-Muscle stiffness Shear-wave elastography	-Muscle stiffness 1: FR RF: ↓16.4% VM: ns VL: ns
Schroeder et al. [41]	Crossover 1: FR 2: Stretch 3: ST	Healthy and physically active individuals (n = 12; M = 6/W = 6) 27 ± 6 years	3 x 60s – HAM, gluteus, and lower back (one set per muscle group; 60s rest between sets; pressure of 40-75% body weight; cadence 2s)	-Muscle stiffness Tensiomyography	-Muscle stiffness HAM: ns
Wilke et al. [7]	Crossover 1: FR (fast) 2: FR (slow) 3: CON	Healthy and physically active individuals (n = 17; M = 7/W = 10) 25 ± 2 years	1: 4 x 45s – QUAD (30s rest between sets; pressure of 6-7 of 10 scores in NPRS; 60rpm) 2: 4 x 45s – QUAD (30s rest between sets; pressure of 6-7 of 10 scores in NPRS; 6rpm)	-Muscle stiffness: Tensiomyography	-Muscle stiffness 1: FR QUAD: ↓17.0-24.0% 2: FR QUAD: ↓15.0%

n: sample size; M: men; W: women; age data are mean ± standard deviation; ns: statistically non-significant; ↓ statistically significant decrease; ↑ statistically significant increase; reps: number of repetitions; rpm: repetitions per minute; s: seconds. CON: control condition; CYC: cycling condition; FR: foam rolling condition; HAM: hamstring muscles; ITB: iliotibial band; MG: medial gastrocnemius muscle; NPRS: numeric pain rating scale; PBO: placebo condition; PF: plantar flexor muscles; QUAD: quadriceps muscle; RF: rectus femoris muscle; SS: static stretch condition; ST: strength training condition; TLF: thoracolumbar fascia; VFR: vibration foam rolling condition; VL: vastus lateralis muscle; VM: vastus medialis muscle.

Table 1.2 Summary of studies on the effects of FR on muscle strength.

Study	Design	Participants	FR Protocol	Outcomes: Assessment Tools	Results
Aune et al. [26]	Parallel groups 1: FR 2: ECC	Athletes (soccer players) (n = 23; M = 12/W = 11) 18 ± 1 years 1: (n = 12; M = 6/W = 6) 18 ± 1 years 2: (n = 11; M = 6/W = 5) 18 ± 1 years	3 x 30s – PF (dominant limb; 30s rest between sets; greater pressure as possible; self-selected speed)	-Muscle strength Force plate	-Isometric torque (joint angle not specified) PF: ns
Behara & Jacobson [49]	Crossover 1: DTR 2: DS 3: CON	Athletes (football players) (n = 14; M = 14/W = 0) 20 ± 1 years	8 x 60s - QUAD, PF, HAM, and gluteus maximus (1 set per muscle group bilaterally; self-selected pressure)	-Muscle strength Isokinetic dynamometer	-Isometric torque at 60º of knee flexion QUAD: ns HAM: ns
Cornell & Ebersole [38]	Crossover 1: FR 2: CON	Healthy and physically active individuals (n = 20; M = 10; W = 10) 24 ± 3 years	3 x 60s – VL (only dominant limb; rest 60s between sets; greater pressure as possible; self-selected speed)	-Muscle strength Handheld dynamometer	-Isometric force at 60º of knee flexion QUAD: ↑5.1-9.9%
Healey et al. [40]	Crossover 1: FR 2: PLE	Healthy and physically active individuals (n = 26; M = 13/W = 13) 22 ± 2 years	6 x 30s – QUAD, PF, HAM, ITB, latissimus dorsi, and rhomboids (self-selected pressure)	-Muscle strength Force plate	-Isometric force at quarter squat (~45-80º of knee flexion) Isometric squat force: ns
Lee et al. [28]	Crossover 1: FR 2: VFR 3: SS	Healthy and physically active individuals (n = 30; M = 30/W = 0) 20 ± 1 years	6 x 30s – QUAD, and HAM (three sets per muscle group bilaterally; greater pressure as possible; 40rpm)	-Muscle strength Isokinetic dynamometer	-Concentric torque at 60º/s 1: FR QUAD: ↑3.7% HAM: ns

MacDonald et al. [2]	Crossover 1: FR 2: CON	Healthy and physically active individuals (n = 11; M = 11/W = 0) 22 ± 4 years	2 x 60s – QUAD (right limb; 30s rest between sets; greater pressure as possible; 3-4rpm)	-Muscle strength and power output Strain gauge	-Isometric force at 90º of knee flexion QUAD: ns -RFD at 90º of knee flexion (0-200ms): QUAD: ns
Macgregor et al. [15]	Crossover 1: FR 2: CON	Healthy and physically active individuals (n = 16; M = 16/W = 0) 25 ± 4 years	1 x 120s – QUAD (self-selected pressure; cadence 2s)	-Muscle strength: Isokinetic dynamometer	-Isometric torque at 60º of knee flexion QUAD: ns
Madoni et al. [27]	Crossover 1: FR 2: CON	Healthy and physically active individuals (n = 22; M = 0/W = 22) 22 ± 2 years	3 x 10s – HAM (only dominant limb; 10s rest between sets; greater pressure as possible)	-Muscle strength Isokinetic dynamometer	-Concentric torque at 60º/s HAM: ns -Concentric torque at 180º/s HAM: ns -Concentric torque at 300º/s HAM: ns -Eccentric torque at 60º/s HAM: ns -Eccentric torque at 180º/s HAM: ns
Nakamura et al. [51]	Parallel groups 1: FR 2: FR 3: FR	Healthy sedentary individuals (n = 45; M = 23/W = 22) 1: (n = 15; M = 8/W = 7) 21 ± 1 years 2: (n = 15; M = 7/W = 8) 21 ± 1 years 3: (n = 15; M = 8/W = 7) 21 ± 2 years	1: 1 x 30s – PF (dominant limb; 30s rest between sets; pressure of 6-7 of 10 scores in NPRS; 30rpm) 2: 3 x 30s - PF (dominant limb; 30s rest between sets; pressure of 6-7 of 10 scores in NPRS; 30rpm) 3: 10 x 30s - PF (dominant limb; 30s rest between sets; pressure of 6-7 of 10 scores in NPRS; 30rpm)	-Muscle strength: Isokinetic dynamometer	-Isometric torque at ankle neutral position (at 0° of plantarflexion) 1: PF: ns 2: PF: ns 3: PF: ns

Nehring et al. [39]	Parallel groups 1: FR (30s) 2: FR (120s)	Healthy individuals (n = 40; M = 20/W = 20) 1: (n = 20; M = 10/W = 10) 22 ± 3 years 2: (n = 20; M = 10/W = 10) 22 ± 2 years	1: 1 x 30s – HAM (cadence 2s) 2: 1 x 120s – HAM (cadence 2s)	-Muscle strength Handheld dynamometer	-Isometric torque at 90° of knee flexion 1: HAM: ns 2: HAM: ns
Reiner et al. [52]	Crossover 1: FR 2: VFR	Healthy and physically active individuals (n = 21; M = 21/W = 0) 25 ± 4 years	3 x 60s – RF, VM, and VL (right limb; one set for each muscle; 30s rest between sets; greater pressure as possible; cadence 2s/ 30rpm)	-Muscle strength: Isokinetic dynamometer	-Isometric torque at 70º of knee flexion 1: FR QUAD: ↑2.8%
Su et al. [29]	Crossover 1: FR 2: SS 3: DS	Healthy and physically active individuals (n = 30; M = 15/W = 15) 21 ± 1 years	6 x 30s – QUAD, and HAM (three sets per muscle group bilaterally; greater pressure as possible; cadence 2s)	-Muscle strength: Isokinetic dynamometer	-Concentric torque at 60º/s QUAD: ↑7.8% HAM: ns

n: sample size; M: men; W: women; age data are mean ± standard deviation; ns: statistically non-significant; ↓ statistically significant decrease; ↑ statistically significant increase; rpm: repetitions per minute; s: seconds. CON: control condition; DTR: deep tissue roller condition; DS: dynamic stretch condition; ECC: eccentric training condition; FR: foam rolling condition; HAM: hamstring muscles; ITB: iliotibial band; NPRS: numeric pain rating scale; PF: plantar flexor muscles; PLE: plank exercise condition; QUAD: quadriceps muscle; RF: rectus femoris muscle; RFD: rate of force development; SS: static stretch condition; VFR: vibration foam rolling condition; VL: vastus lateralis muscle; VM: vastus medialis muscle.

3.3 Methodological Quality

The results of the studies' methodological quality assessment showed an agreement of 201 (91.4%) of the 220 criteria of the PEDro scale between the two reviewers. All cases of disagreement were resolved after consulting the third reviewer. The included studies' scores varied between 4 and 8 points out of 10 (mean 5.0±1.3), indicating a low methodological quality for most studies (**Table 2**) [47]. The main methodological problems found were lack of concealed allocation (5.0% attended), blinding of participants (0.0% attended), therapists (10.0% attended) and assessors (20.0% attended), and measurements of at least one key outcome being obtained in >85% of subjects (20.0% attended). Although the blinding of the subjects was not possible due to the nature of the FR's technique [9], four studies blinded the assessors [18, 19, 39, 50].

Table 2 Methodological quality of the included studies (ratings on the PEDro scale).

Study	**Inclusion criteria**	**Random allocation**	**Concealed allocation**	**Similarity at baseline**	**Subject blinding**	**Therapist blinding**	**Assessor blinding**	**>85% follow-up**	**Intention to treat analysis**	**Between-group comparisons**	**Point estimates and variability**	**Total (points)**
Aune et al. [26]	+	+	-	+	-	-	-	+	+	+	+	6
Baumgart et al. [11]	-	+	-	+	-	-	-	-	+	+	+	4
Behara & Jacobson [49]	+	+	-	+	-	-	-	+	+	+	+	6
Cornell & Ebersole [38]	-	+	-	+	-	-	-	-	+	+	-	4
Griefahn et al. [18]	+	+	-	+	-	-	+	-	+	+	+	6
Griefahn et al. [50]	+	+	-	+	-	+	+	-	+	+	+	7
Healey et al. [40]	+	+	-	+	-	-	-	-	+	+	+	5
Krause et al. [17]	-	+	-	+	-	-	-	-	+	+	+	4
Lee et al. [28]	-	+	-	+	-	-	-	-	+	+	+	4
MacDonald et al. [2]	-	+	-	+	-	-	-	-	+	+	+	4
Macgregor et al. [15]	-	+	-	+	-	-	-	-	+	+	+	4
Madoni et al. [27]	-	+	-	+	-	-	-	-	+	+	+	4
Morales-Artacho et al. [20]	-	+	-	+	-	-	-	-	+	+	+	4
Nakamura et al. [51]	-	+	-	+	-	-	-	-	+	+	+	4
Nehring et al. [39]	-	+	+	+	-	-	+	+	+	+	+	7

Pepper et al. [19]	+	+	-	+	-	+	+	+	+	+	+	8
Reiner et al. [52]	-	+	-	+	-	-	-	-	+	+	+	4
Schroeder et al. [41]	+	+	-	+	-	-	-	-	+	+	+	5
Su et al. [29]	+	+	-	+	-	-	-	-	+	+	+	5
Wilke et al. [7]	+	+	-	+	-	-	-	-	+	+	+	5

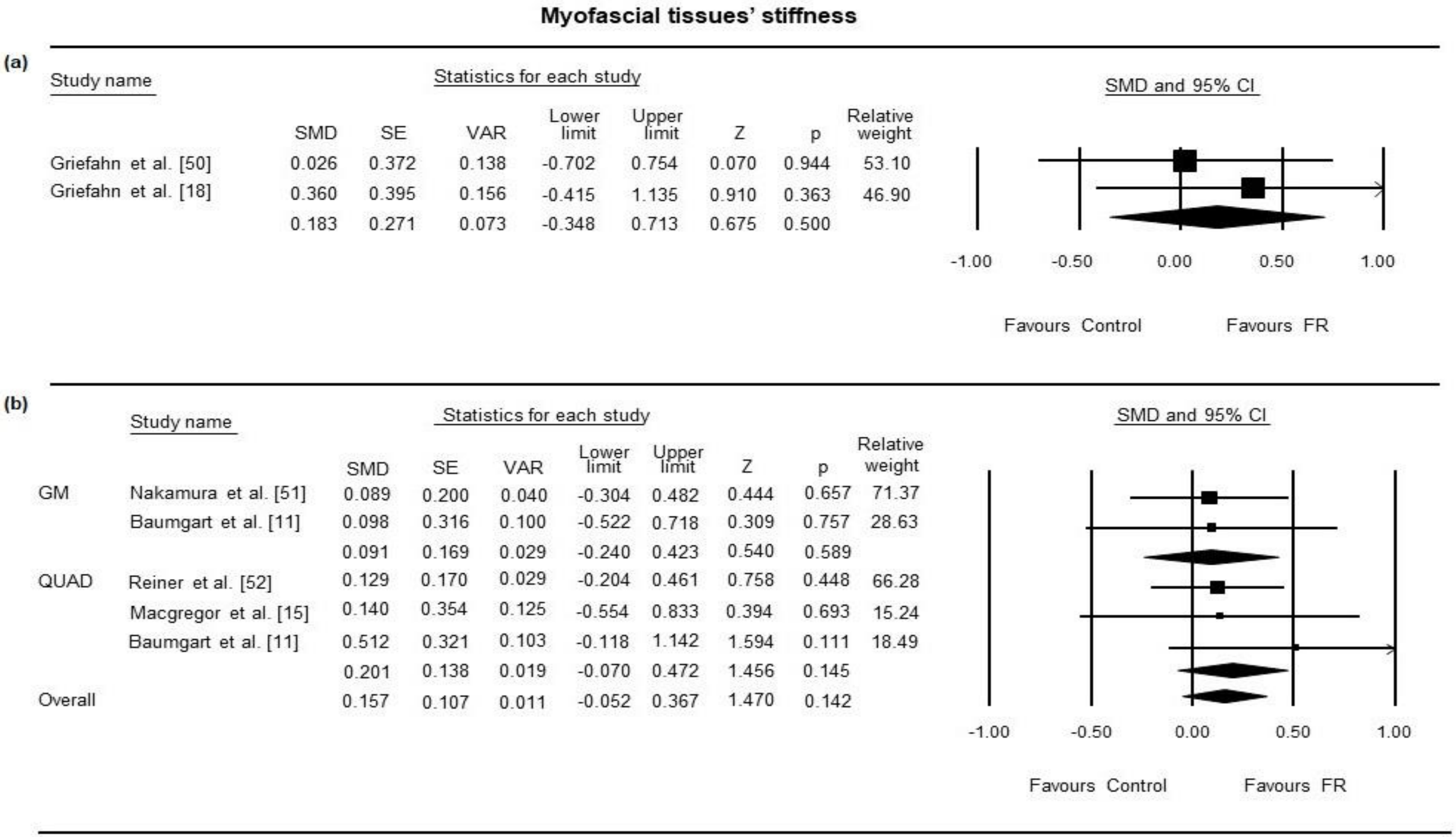
+ point awarded; - no point awarded

3.4 Foam Rolling and Myofascial Tissues' Stiffness

Four trials [17-19, 50] tested the FR effects on the fascial tissue's stiffness. Griefahn et al. [18, 50] applied FR on low back muscles and measured the thoracolumbar fascia's stiffness. Pepper et al. [19] applied FR on the iliotibial band, and measured fascial stiffness in two sites (the middle and distal portion of the lateral thigh), and two conditions (0º and 10º of hip abduction). Krause et al. [17] applied FR on the anterior thigh and assessed sliding of the fascia lata. Fascial stiffness was measured through fascial shear strain mobility, assessed by ultrasound video analysis using the Cross-Correlation Program Motion Analysis during passive movements [17, 18, 50], which describes the interconnected sliding of the two fascial layers and the subcutaneous tissue [50, 53], and using shear wave imaging elastography [19]. Griefahn et al. [18, 50] reported increases (21-57%) in thoracolumbar fascia shear strain mobility, which apparently is related to reduced fascial stiffness [17, 18]. However, while Griefahn et al. [18] presented the fascial sliding values for the entire thoracolumbar fascia and did not mention the behavior of each fascial layer (superficial or deep) independently, Griefahn et al. [50] assessed both superficial and deep layers' shear strain mobility separately and together (representing the sliding of the entire thoracolumbar fascia). However, they found no changes after the FR application. Maintenance of fascial stiffness was observed by Pepper et al. [19], who found no changes in the iliotibial band's stiffness at the middle and distal portion of the lateral thigh, and at 0º and 10º of hip abduction. Krause et al. [17] found no change in the superficial layer of the thigh's anterior fascia lata mobility. However, the authors also reported decreases in the deep fascial layer mobility (-9.2%) and on intrafascial sliding (-16.8%) between the fascia lata's deep and superficial layers. Considering the different regions (low back, and lateral and anterior thigh) and fascial layers (superficial or deep), only two studies [18, 50] were pooled in the meta-analysis (**Fig. 2a**), which revealed no FR acute effects on fascial stiffness (SMD: 0.183, 95% CI -0.348 to 0.713, p=0.500, I^2=0%). In addition, GRADE's assessment showed a low level of certainty for these evidences.

Seven studies [7, 11, 15, 20, 41, 51, 52] investigated the FR effects on muscle stiffness, which was assessed in the knee extensors [7, 11, 15, 52], and flexors [20, 41], and ankle plantar flexors [11, 51]. Different means of assessing stiffness were observed, as studies used shear-wave elastography [20, 51, 52], tensiomyography [15, 41], digital algometer [7], and tissue compliance meter [11]. While five of these studies demonstrated decreases (3-24%) in muscle stiffness [7, 11, 15, 20, 52], three studies reported no changes [11, 41, 51]. Three studies [7, 15, 52] that reported a decrease in muscle stiffness applied the FR on the anterior thigh, with FR application volume ranging between 1-4 sets of 30-120s [7, 15, 52]. In view of the studies' heterogeneity on the target muscle group, we performed a subgroup analysis according to the analyzed muscle groups. Therefore, of the five studies pooled in the meta-analysis, two assessed plantar flexor muscles [11, 51], while the other three assessed the quadriceps muscle [11, 15, 52] (**Fig. 2b**). For the plantar flexor muscles, one study [51] showed three different FR conditions (i.e., application times of 30, 90, and 300s, divided among 1, 3, and 10 sets, respectively). Thus, for the meta-analysis, the condition in which the FR was applied to the plantar flexors through three sets of 30s, with a rolling speed of 30rpm, was adopted as the total volume of rolls per set, which was closer to that used by Baumgart et al. [11] on the same muscle group. The meta-analysis revealed no FR acute effects on plantar flexor (SMD: 0.091, 95% CI -0.240 to 0.423, p=0.589, I^2=0%) and quadriceps (SMD: 0.201, 95% CI -0.070 to 0.472, p=0.145, I^2=0%) muscles' stiffness. No overall effect on muscle stiffness was observed (SMD: 0.157, 95%

CI -0.052 to 0.367, $p=0.142$, $I^2=0\%$). In addition, GRADE's assessment showed a very low level of certainty for all analyses.



Myofascial tissues' stiffness

(a)

Study name	SMD	SE	VAR	Lower limit	Upper limit	Z	p	Relative weight
Griefahn et al. [50]	0.026	0.372	0.138	-0.702	0.754	0.070	0.944	53.10
Griefahn et al. [18]	0.360	0.395	0.156	-0.415	1.135	0.910	0.363	46.90
	0.183	0.271	0.073	-0.348	0.713	0.675	0.500	

(b)

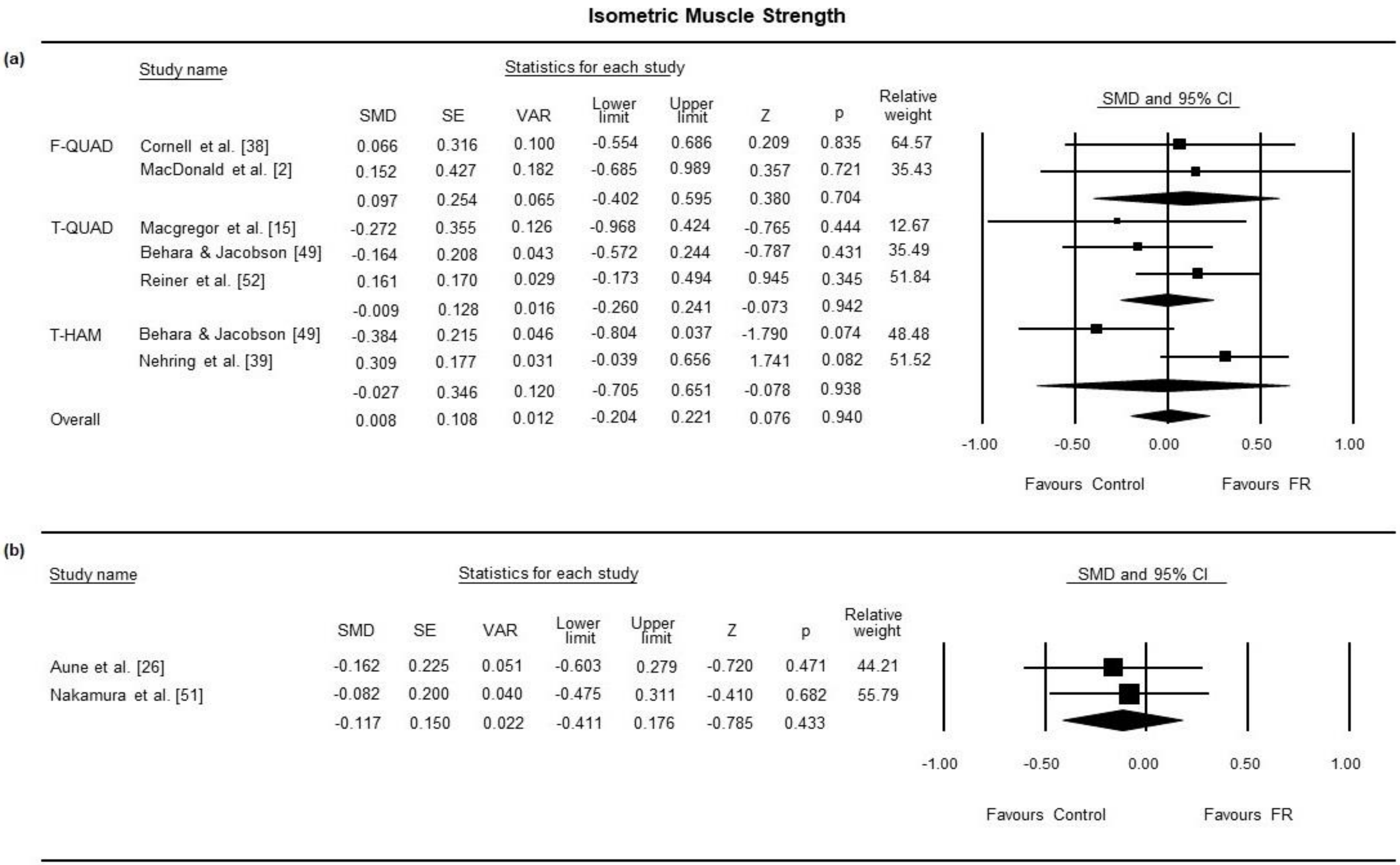
	Study name	SMD	SE	VAR	Lower limit	Upper limit	Z	p	Relative weight
GM	Nakamura et al. [51]	0.089	0.200	0.040	-0.304	0.482	0.444	0.657	71.37
	Baumgart et al. [11]	0.098	0.316	0.100	-0.522	0.718	0.309	0.757	28.63
		0.091	0.169	0.029	-0.240	0.423	0.540	0.589	
QUAD	Reiner et al. [52]	0.129	0.170	0.029	-0.204	0.461	0.758	0.448	66.28
	Macgregor et al. [15]	0.140	0.354	0.125	-0.554	0.833	0.394	0.693	15.24
	Baumgart et al. [11]	0.512	0.321	0.103	-0.118	1.142	1.594	0.111	18.49
		0.201	0.138	0.019	-0.070	0.472	1.456	0.145	
Overall		0.157	0.107	0.011	-0.052	0.367	1.470	0.142	

Fig. 2 Effects of no-exercise control vs. foam rolling (FR) on myofascial tissues' stiffness. Forest plots with pooled standardized mean differences (SMD), standard errors (SE), variance (VAR), and 95% confidence intervals (CI) are displayed: (**a**) analysis of acute effects on fascial tissue; (**b**) subgroup analysis of acute effects on muscle tissue separated by muscle group (GM: gastrocnemius medialis; QUAD: quadriceps muscles).

3.5 Foam Rolling and Isometric Muscle Strength

Isometric muscle strength was tested by nine trials [2, 15, 26, 38-40, 49, 51, 52], which assessed knee extensors [2, 15, 38, 49, 52] and flexors [39, 49], ankle plantar flexors [26, 51], and isometric squat force [40]. In general, most studies reported that FR did not affect isometric muscle strength. However, two studies [38, 52] observed increases in knee extensors' isometric strength. A meta-analysis with subgroup analyses was performed for isometric muscle strength (**Fig. 3a**), with two trials [2, 38] for knee extensors' force at joint angles of 60º [38] and 90º [2] (0º = full extension), three trials [15, 49, 52] for knee extensors' torque at joint angles of 60º [15, 49] and 70º [52] (0º = full extension), and two trials [39, 49] for knee flexors at joint angles of 60º [49] and 90º [39] (0º = full extension). For the knee flexors, one trial [39] applied the FR for different time periods (i.e., 30s and 120s). Thus, for the meta-analysis, a time of 120s was used, as the application volume for this muscle group was compatible between the studies [39, 49]. Another meta-analysis was performed for the plantar flexors' isometric torque [26, 51], with its effects evaluated 30min after FR. This post-intervention time was adopted because it was common in both studies (**Fig. 3b**).

No effect was detected by FR on the knee extensors' isometric force (SMD: 0.097, 95% CI -0.402 to 0.595, p=0.704, I^2=0%), and knee extensors' (SMD: -0.009, 95% CI -0.260 to 0.241, p=0.942, I^2=5%), and flexors' (SMD: -0.027, 95% CI -0.705 to 0.651, p=0.938, I^2=84%) isometric torque. The knee flexors' isometric muscle strength showed high values of I^2, and therefore, this heterogeneity was explored. Between-studies differences were observed regarding the participants' characteristics, foam roller's device and the protocol used, and the sample size. Behara & Jacobson [49] used a deep tissue roll, containing sharp, asymmetrical and semi-flexible "high profile" nodules, which were projected alternately about 10cm from the surface of the roll (The Rumble Roller, STI, Baton Rouge, LA), to apply the FR by 60s over the hamstrings of 14 athletes (NCAA Division 1 football offensive linemen). Nehring et al. [39] used a smooth foam roller composed of polypropylene (Foam Roller Brasil, Porto Alegre, Brazil) for 30-120s on the hamstrings of 20 healthy individuals, in a mixed sample (men and women). Theoretically, due to the sharp nodules, the deep tissue roller could exert more pressure on the tissues, because it does not contact a large surface area like the smooth roller does [49]. In addition, the results' imprecision, from the CIs' wide ranges, may also be the source of the high heterogeneity. No overall effect on isometric muscle strength was also observed (SMD: 0.008, 95% CI -0.204 to 0.221, p=0.940, I^2=29%). Moreover, no effect was observed on the plantar flexors' isometric torque 30min after FR (SMD: -0.117, 95% CI -0.411 to 0.176, p=0.433, I^2=0%). GRADE's assessment showed a very low certainty for all analyses, and these findings suggest that FR does not seem to affect the isometric muscle strength.



(a)

	Study name	SMD	SE	VAR	Lower limit	Upper limit	Z	p	Relative weight
F-QUAD	Cornell et al. [38]	0.066	0.316	0.100	-0.554	0.686	0.209	0.835	64.57
	MacDonald et al. [2]	0.152	0.427	0.182	-0.685	0.989	0.357	0.721	35.43
		0.097	0.254	0.065	-0.402	0.595	0.380	0.704	
T-QUAD	Macgregor et al. [15]	-0.272	0.355	0.126	-0.968	0.424	-0.765	0.444	12.67
	Behara & Jacobson [49]	-0.164	0.208	0.043	-0.572	0.244	-0.787	0.431	35.49
	Reiner et al. [52]	0.161	0.170	0.029	-0.173	0.494	0.945	0.345	51.84
		-0.009	0.128	0.016	-0.260	0.241	-0.073	0.942	
T-HAM	Behara & Jacobson [49]	-0.384	0.215	0.046	-0.804	0.037	-1.790	0.074	48.48
	Nehring et al. [39]	0.309	0.177	0.031	-0.039	0.656	1.741	0.082	51.52
		-0.027	0.346	0.120	-0.705	0.651	-0.078	0.938	
Overall		0.008	0.108	0.012	-0.204	0.221	0.076	0.940	

(b)

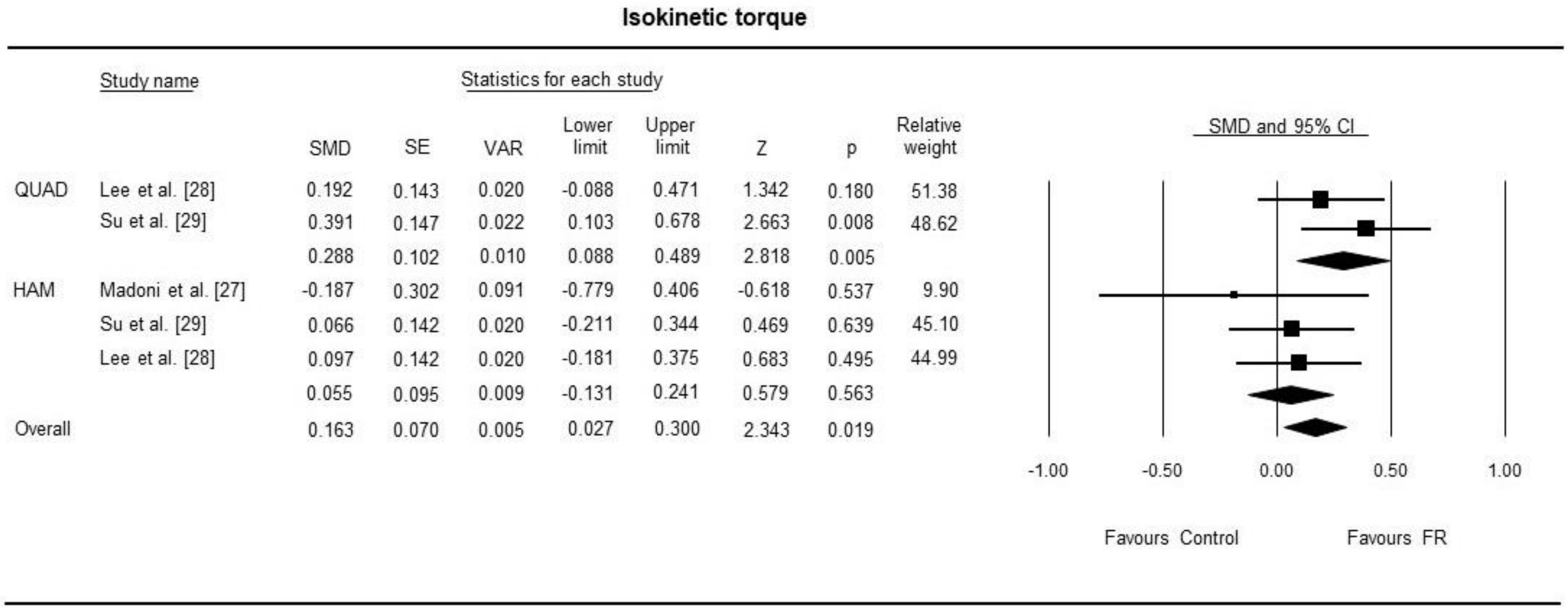
Study name	SMD	SE	VAR	Lower limit	Upper limit	Z	p	Relative weight
Aune et al. [26]	-0.162	0.225	0.051	-0.603	0.279	-0.720	0.471	44.21
Nakamura et al. [51]	-0.082	0.200	0.040	-0.475	0.311	-0.410	0.682	55.79
	-0.117	0.150	0.022	-0.411	0.176	-0.785	0.433	

Fig. 3 Effects of no-exercise control vs. foam rolling (FR) on isometric muscle strength. Forest plots with pooled standardized mean differences (SMD), standard errors (SE), variance (VAR), and 95% confidence intervals (CI) are displayed: (**a**) subgroup analysis of acute effects separated by muscle group (QUAD: quadriceps muscle; HAM: hamstring muscles) and muscle strength magnitude (F: force; T: torque); (**b**) effects of 30min post-FR on plantar flexors muscles' torque.

3.6 Foam Rolling and Isokinetic Torque

Three trials [27-29] tested the FR effects on the knee extensors' and flexors' isokinetic torque during concentric contractions at angular velocities of 60º/s. Furthermore, Madoni et al. [27] also assessed the isokinetic torque in other velocities (180º/s and 300º/s), and during eccentric contractions. While Lee et al. [28] and Su et al. [29] applied FR (3 sets of 30s per muscle group) on the anterior and posterior thigh, Madoni et al. [27] applied the technique (3 sets of 10s) only at the posterior thigh. After FR, increases (4-8%) of concentric torque during concentric contractions at 60º/s were reported for the knee extensors [28, 29], but not for the knee flexors [27-29]. Maintenance of knee flexors' torque was also observed during contractions at 180º/s and 300º/s [27], as well as during eccentric contractions at 60º/s and 180º/s [27].

A meta-analysis with subgroups analyses was performed by the muscle group (**Fig. 4**). Two trials [28, 29] were pooled for the knee extensors' concentric torque at the angular velocity of 60º/s, while three trials [27-29] were pooled for knee flexors' concentric torque at the angular velocity of 60º/s. An overall effect was also analyzed with all studies pooled, excluding the muscle group factor. Favorable effect was detected by FR on the knee extensors' concentric torque (SMD: 0.288, 95% CI -0.088 to 0.489, p=0.005, I^2=0%), but not on the concentric torque of the knee flexors (SMD: 0.055, 95% CI -0.131 to 0.241, p=0.563, I^2=0%). A favorable overall effect was also observed for the isokinetic torque (SMD: 0.163, 95% CI 0.027 to 0.300, p=0.019, I^2=11%). These findings suggest that FR may increase isokinetic torque, especially the knee extensors' concentric torque at the 60º/s angular velocity. However, GRADE's analysis showed a very low certainty for these effects.



Isokinetic torque

	Study name	SMD	SE	VAR	Lower limit	Upper limit	Z	p	Relative weight
QUAD	Lee et al. [28]	0.192	0.143	0.020	-0.088	0.471	1.342	0.180	51.38
	Su et al. [29]	0.391	0.147	0.022	0.103	0.678	2.663	0.008	48.62
		0.288	0.102	0.010	0.088	0.489	2.818	0.005	
HAM	Madoni et al. [27]	-0.187	0.302	0.091	-0.779	0.406	-0.618	0.537	9.90
	Su et al. [29]	0.066	0.142	0.020	-0.211	0.344	0.469	0.639	45.10
	Lee et al. [28]	0.097	0.142	0.020	-0.181	0.375	0.683	0.495	44.99
		0.055	0.095	0.009	-0.131	0.241	0.579	0.563	
Overall		0.163	0.070	0.005	0.027	0.300	2.343	0.019	

Fig. 4 Effects of no-exercise control vs. foam rolling (FR) on isokinetic torque during concentric contractions at angular velocities of 60º/s. Forest plots with pooled standardized mean differences (SMD), standard errors (SE), variance (VAR), and 95% confidence intervals (CI) are displayed: (**a**) subgroup analysis of acute effects separated by muscle group (QUAD: quadriceps muscle; HAM: hamstring muscles).

3.7 Foam Rolling and Rate of Force Development

The FR effects on RFD were investigated by a single study [2]. The knee extensors’ RFD was assessed in the early phase of the maximal voluntary isometric contraction (0-200ms). No differences were found after FR on RFD (p>0.05), but the existing evidence from this single study is insufficient to reject the hypothesis that FR can affect RFD.

3.8 Risk of Bias

Visual analyses of the funnel plots separately by outcome (myofascial tissues’ stiffness and muscle strength) is represented below (**Fig. 5**). The funnel plots suggested no potential reporting for publication bias, observed by a symmetric funnel plot. Both studies that found a significant effect and those that found no significant effect were included in the analyses. The outer diagonal lines indicate the triangular region within which 95% of studies are expected to lie in the absence of both biases and heterogeneity [54].

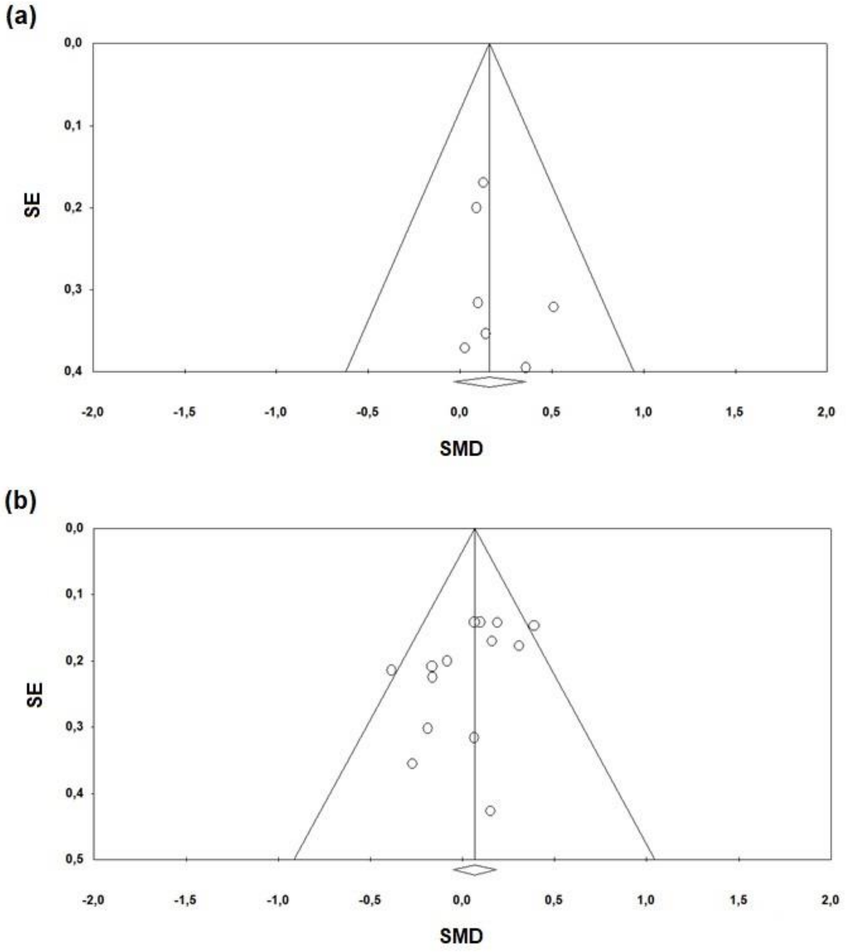


Fig. 5 Funnel plots of the overall effect of FR on: **(a)** myofascial tissues’ stiffness; and **(b)** muscle strength (effect sizes against SE). SE: standard error; SMD: standardized mean difference.

3.9 Confidence in Evidence

GRADE’s assessments are presented below (**Table 3**). In general, we found low (fascial stiffness) and very low (muscle stiffness, isometric muscle strength, and isokinetic torque) certainty, indicating that the included randomized controlled trials have important limitations and that any effect estimate is very uncertain [55].

Table 3 GRADE assessment for the certainty of evidence.

Outcomes	Study design (n)	Risk of bias in individual studies	Publication bias	Inconsistency	Indirectness	Imprecision	Confidence in evidence	Recommendation
Fascial stiffness TLF	RCTs (n = 2)	No serious	Undetected	No serious	No serious	Very serious[b]	⊕⊕○○ Low	No recommendation can be provided
Muscle stiffness GM	RCTs (n = 2)	Serious[a]	Undetected	No serious	No serious	Very serious[b]	⊕○○○ Very Low	No recommendation can be provided
Muscle stiffness QUAD	RCTs (n = 3)	Serious[a]	Undetected	No serious	No serious	Very serious[b]	⊕○○○ Very Low	No recommendation can be provided
Muscle stiffness overall	RCTs (n = 5)	Serious[a]	Undetected	No serious	No serious	Very serious[b]	⊕○○○ Very Low	No recommendation can be provided
Isometric force QUAD	RCTs (n = 2)	Serious[a]	Undetected	No serious	No serious	Very serious[b]	⊕○○○ Very Low	No recommendation can be provided
Isometric torque QUAD	RCTs (n = 3)	Serious[a]	Undetected	No serious	No serious	Very serious[b]	⊕○○○ Very Low	No recommendation can be provided
Isometric torque HAM	RCTs (n = 2)	No serious	Undetected	Very Serious[c]	No serious	Very serious[b]	⊕○○○ Very Low	No recommendation can be provided
Isometric muscle strength overall	RCTs (n = 5)	Serious[a]	Undetected	Serious[d]	No serious	Very serious[b]	⊕○○○ Very Low	No recommendation can be provided

Isometric torque PF post-30min	RCTs (n = 2)	Serious[a]	Undetected	No serious	No serious	Very serious[b]	⊕○○○ Very Low	No recommendation can be provided
Isokinetic torque at 60º/s QUAD	RCTs (n = 2)	Serious[a]	Undetected	No serious	No serious	Very serious[b]	⊕○○○ Very Low	No recommendation can be provided
Isokinetic torque at 60º/s HAM	RCTs (n = 3)	Serious[a]	Undetected	No serious	No serious	Very serious[b]	⊕○○○ Very Low	No recommendation can be provided
Isokinetic torque at 60º/s overall	RCTs (n = 5)	Serious[a]	Undetected	No serious	No serious	Very serious[b]	⊕○○○ Very Low	No recommendation can be provided

TLF: thoracolumbar fascia; GM: gastrocnemius medialis; QUAD: quadriceps; HAM: hamstrings; PF: plantar flexors; RCT: randomized controlled trial. a. The mean of the PEDro scores was between 4-5 (poor quality); b. Confidence interval is greater than mean values; c. Heterogeneity values are classified as high (I^2 values >50%); d. Heterogeneity values are classified as moderate (I^2 values between 25-50%).

4 Discussion

To the best of our knowledge, this study presents the first synthesis of available evidence on the FR acute effects on myofascial tissues' stiffness and muscle strength, stratified by tissue and muscle contraction type. The qualitative analysis suggests that FR decreases the thoracolumbar's fascial and the quadriceps' muscle stiffnesses. However, our meta-analyses demonstrated no significant FR effect on myofascial tissues' stiffness. In addition, FR does not seem to affect the knee extensors' and flexors', and ankle plantar flexors' isometric muscle strength, the knee flexors' concentric and eccentric torque, and the knee extensors' RFD. Nevertheless, our meta-analyses showed that FR promotes an increase in the knee extensors' concentric torque.

Literature shows evidence for a decrease in the fascial [16, 18, 50] and muscle [7, 11, 15, 20, 52] tissues' stiffness after FR. Physiological, mechanical and neurophysiological mechanisms might explain these decreases in myofascial tissues' stiffness [15]. The FR mechanical stress on the endothelial cells causes an immediate increase of ~75% in blood flow and in intramuscular temperature, and induce the release of nitric oxide (which plays an important role in regulating vascular dilation) [56, 57]. These physiological changes may induce tissue relaxation due to a break in the resting cross-bridges [58]. The FR mechanical stress may also change tissue hydration [59]. The fascia plays an important role in maintaining water throughout the body [59], and water content is directly related to the connective tissues' stiffness [3]. When the fascial tissue is disturbed by heat or mechanical stress, it can assume a gel-like state (i.e., thixotropic property), making the tissue more fluid and less viscous [3], thereby reducing its stiffness. Although the literature mentions this mechanical mechanism as the most important, evidence suggests that the main benefits of FR is related to the neural mechanisms [60, 61].

The neurophysiological mechanism is related to changes in the activity of mechanoreceptors, proprioceptors, and pain receptors encapsulated in fascial and muscle tissues [15]. In myofascial tissues, three groups of mechanoreceptors can be found: type Ib Golgi tendon organs and muscle spindle afferents (respond to changes in muscle length); type II Pacini bodies (respond to pressure changes and vibration) and Ruffini terminations (respond to sustained pressure), and type III/IV interstitial receptors (respond to pain and mechanical stimuli of rapid and sustained pressure) [61, 62]. The FR exerts mechanical pressure on skin, muscle, and fascia, primarily influencing nociceptors and mechanoreceptors [62, 63]. The mechanoreceptors' activation may modify the self-regulating dynamics of the autonomic nervous system through the activation of afferent feedback receptors [3, 60], by a possible negative disturbance on the Ia afferent pathway efficiency to excite alpha-motoneurons [64], thereby changing the myofascial tissues' extensibility [60]. Thus, the neural modulation of spinal excitability might explain the observed increases, for example, in joint ROM and pain tolerance. However, its inhibitory effects may be transient and pressure-dependent [61].

The pressure volume (i.e., number of sets x pressure time x pressure magnitude) applied to the myofascial tissues during FR seems to change the tissues' stiffness. Decreases were observed in the thoracolumbar [18, 50] and iliotibial band [16] fascial stiffness after three sets of 30s of FR, with self-selected pressure for the trunk region [18, 50], as well as after five sets of 45s with the greatest possible pressure for the iliotibial band [16]. The rolling speed ranged between 20-30rpm for both tissues [16, 18, 50]. For the thoracolumbar fascia, FR was performed in a supine position, with approximately 75% of the body weight supported by the roller [41], keeping both feet in contact with the ground. Therefore, the large pressure exerted by the body mass during the FR application on the posterior region of the trunk may explain this fascial tissue's stiffness reduction [18, 50]. However, divergent results were found for the iliotibial band. While Mayer et al. [16] found decreases in fascial stiffness after five sets of 45s (225s) with the largest tolerable pressure, Pepper et al. [19] observed a similar stiffness after five sets of 60s (300s) of FR were applied with self-selected pressure. Although the applied volume seems to be sufficient to induce changes in the iliotibial band stiffness, the applied pressure might have been insufficient.

In the hamstring muscles, six FR sets of 60s (360s) were sufficient to induce decreases in the hamstrings' stiffness in one study [20], while the other study [41] did not observe changes after 60s of FR on the posterior thigh. Further studies will be needed to determine the exact intervention volume that is able to decrease the hamstring muscles' stiffness.

The FR's applied volume also seems to explain the decreases in quadriceps muscle stiffness after acute intervention. All studies that investigated the FR effects on the quadriceps muscle [7, 11, 15, 52] observed decreases in muscle stiffness post FR application with volumes ranging between 90-180s, using the largest tolerable pressure [52], a self-selected pressure [15], and 6-7 discomfort levels [0-10 numeric pain rating scale (NPRS)] [7]. However, studies that applied higher-pressure volume showed greater decreases on quadriceps muscle stiffness. Baumgart et al. [11] found decreases in quadriceps muscle stiffness of smaller magnitude (3%) compared to other studies (15-24%) [7, 15, 52] after two sets of 30 repetitions on the anterior thigh. Although Baumgart et al. [11] used a sufficient volume (60reps), similar to that used by the other studies (90-180s; 18-180reps) [7, 15, 52], they did not provide information regarding the FR application time, pressure, and rolling speed. Furthermore, different from the other studies that evaluated healthy individuals [7, 15, 52], Baumgart et al. [11] evaluated athletes, without specifying the sport modality and training level. Therefore, the between-studies differences might be related to the magnitude of changes in muscle stiffness induced by FR.

FR with similar pressure volume levels as those of the quadriceps muscle, however, did not induce a muscle stiffness decrease in the plantar flexors [11], suggesting that these leg muscles require greater pressure volumes and/or pressure levels. In addition, increasing the FR volumes (30s, 90s and 300s) apparently did not decrease the plantar flexors' stiffness, suggesting that the pressure levels applied to this muscle group are the key factor. However, the pressure levels (as measured by the discomfort levels between 6-7 on a 0-10 NPRS) applied to this muscle group apparently were also insufficient to change the plantar flexors' muscle stiffness [51]. Although several studies [7, 51, 65-67] have used measured pain perception (such as NPRS) to control the pressure applied during FR and other self-massage techniques, perhaps this may not be the most adequate tool to assess FR pressure levels, as this tool does not assess pressure but the pain/discomfort levels.

Baumgart et al. [11] measured the vertical ground reaction forces during FR and observed 2% greater mean force values applied on the quadriceps muscle (34% of body weight) compared to the plantar flexors (32% of body weight). However, for each rolling movement, an increase in the soft tissues' deformation probably occurs with each rolling cycle, and this 2% difference does not reveal the total pressure applied to the tissues during the intervention. In addition, because participants supported the contralateral leg on the ground during the quadriceps rolling, the pressure applied to the quadriceps was not as high as when both limbs are over the roll. Therefore, this difference in weight bearing between quadriceps and plantar flexors rolling may be even greater, as during the simultaneous FR of both anterior thighs the load can be twice greater than when rolling with the contralateral leg on the ground [11, 15]. Furthermore, the authors showed that the FR's applied load can decrease as the roll is moved distally in the lower limb. The same behavior was observed in hamstrings, where the load also decreased when the roller was moved from the hip's proximal region of to the knee's posterior region [68]. Therefore, this indicates that the more distal the roller is moved, the shorter the lever arm's length, and consequently, less pressure levels are applied to the tissues.

In addition to the FR's pressure application, the subcutaneous adipose tissue thickness and the participants' previous experience seem to influence the FR's effects. A thick subcutaneous adipose tissue can dissipate part of the FR's applied pressure to the myofascial tissues, and the between-subjects variability in the amount of adipose tissue may promote different FR responses [1]. Curran et al. [69] showed no correlation between the FR's applied pressure and body weight and/or the leg circumference, suggesting that the applied pressure to the tissues was more related to the rolling technique. Greater pain tolerance can occur with the FR's frequent use, thereby allowing the application of greater pressure levels [16]. Decreases on the iliotibial band's stiffness were observed after FR (five sets of 45s with the largest tolerable pressure), but these changes only occurred in individuals who had previous experience with this technique (more than 6 months of FR experience; with a minimum regular practice of 15min/week) [16]. Pepper et al. [19] used a similar FR's application volume (five sets of 60s), but the applied pressure may have been insufficient (self-selected) compared to that used by Mayer et al. [16]. Furthermore, the non-regular FR's use may explain the maintenance of the iliotibial band's stiffness observed by Pepper et al. [19], since this region is more sensitive and can be quite uncomfortable for those who do not frequently perform FR on the iliotibial band surface. However, although the authors defined the regular FR use at iliotibial band as an exclusion criterion for the participants, they do not clarify the meaning of FR regular use. A similar response was seen for the plantar flexor muscles, in which FR induced no stiffness changes in sedentary healthy adults [51], and no familiarization procedures were mentioned by the authors.

Although two studies found fascial tissues' stiffness decreases [18, 50], our meta-analysis demonstrated no FR effects on the thoracolumbar fascial stiffness. Even though the studies [18, 50] included in our meta-analysis had high methodological quality (PEDro's rating of 6-7 points), their level of certainty for these effects was low due to the large CI amplitude. In addition, the low number of studies (n=2) is still insufficient to assume that, in fact, the FR does not change the fascial tissues' stiffness, once our qualitative and quantitative analysis showed contradictory results. Therefore, our findings must be looked with caution, and more studies with high methodological quality must be developed to determine if FR indeed does not induce changes in the fascial tissues' stiffness.

Disagreements were also observed for muscle stiffness. While our qualitative analysis showed that studies have shown decreases in quadriceps [7, 11, 15, 52], and hamstrings' stiffness [20] after FR, our meta-analysis demonstrated no effects of FR on the quadriceps and plantar flexor muscles' stiffness. However, these findings require careful interpretation. Studies included in our meta-analysis demonstrated low methodological quality, and the level of certainty about the effects of FR on muscle stiffness was very low. Therefore, considering the available evidence, it appears that the use of FR does not reduce muscle stiffness.

Although our meta-analysis has shown that the FR does not change the myofascial tissues' stiffness, studies have found decreases in fascial [16, 18, 50] and muscle [7, 11, 15, 20, 52] stiffness, and it would be expected that such reductions could affect muscle strength due to a reduced ability to produce and transmit muscle strength [22]. However, our qualitative analysis showed that most studies [2, 15, 26, 39, 40, 49, 51] observed no FR effects on isometric muscle strength, suggesting that there is no change in isometric muscle strength after FR. Nevertheless, increases in knee extensors' isometric strength were also observed [38, 52]. Reiner et al. [52] found increases in knee extensors' isometric torque after applying FR with a volume of three sets of 60s, with the largest tolerable pressure, and rolling speed of 30rpm. A similar effect was observed by Cornell & Ebersole [38] after the same volume and pressure were applied on the vastus lateralis muscle. In contrast, the three studies [2, 15, 49] that observed no changes in knee extensors' isometric muscle strength applied the FR on the anterior thigh with smaller volume (60-120s) [2, 15, 49], pressure (self-selected) [15, 49], and/or speed (3-4rpm) [2], compared to the studies that observed the isometric force increase [38, 52]. Our meta-analysis is in agreement with our qualitative analysis and with these studies, as well as with a previous systematic review [9] in which no effect of self-massage with different techniques was reported on isometric muscle strength. However, the meta-analysis showed high heterogeneity for the knee flexors' isometric torque, which may be related to participants' characteristics, different FR devices (smooth or with raised nodes), the protocol used, the different sample sizes, and large CIs. Furthermore, a very low certainty about the FR effects on isometric muscle strength was observed for knee extensors' force, knee extensors and flexors' torque, and ankle plantar flexors' torque 30min after FR. In summary, considering the available evidence, it appears that FR induces no changes in isometric muscle strength. However, studies with higher methodological quality, controlling some of the abovementioned FR parameters, should evaluate the effects of different volumes, pressure levels, and rolling speeds to determine how these parameters affect the knee extensors' isometric muscle strength.

Our review is the first to synthesize information about the FR effects on isokinetic torque. According to the qualitative analysis, FR appears to increase the concentric torque, especially of the knee extensors, but not the knee flexors. Lee et al. [28] and Su et al. [29] reported increases (4-8%) in the knee extensors' torque after FR, but they did not observe the same effects on the knee flexors. All the studies [28, 29, 38, 52] that observed increases in knee extensors' muscle strength used a FR volume of at least 90s (3 sets of 30s), combined to a 30-40rpm speed, and the largest tolerable pressure. However, these FR settings were probably not adequate to change the knee flexors' concentric torque [27-29].

Different FR positions during intervention may also account for the different responses in concentric torque observed between knee extensor and flexor muscles. For the knee extensors, FR was executed on a prone position, with the forearms placed on the floor, supporting the body load (similar to a plank exercise), with the roller under the anterior thigh. The roller was moved distally and proximally from the hip to the knee. For the hamstrings, FR was performed in a seated position, with the thighs supported on the foam roller, and the hands placed on the floor. The roller was moved proximally and distally from the lower part of the greater trochanter to the proximal region of the knee [40]. These different rolling positions may have determined different FR pressures being applied between the hamstrings and the quadriceps. More specifically, a shorter lever arm in the rolling position over the hamstrings suggest that a larger volume with higher pressure levels during FR may be necessary to induce changes in the knee flexors' concentric torque.

Our quantitative analysis, demonstrated by a subgroup analysis separated by muscle group, corroborates what was found in the qualitative analysis, supporting the hypothesis that FR may increase the knee extensors' concentric torque, but not the knee flexors'. Increases in muscle strength may be explained by the increase in local blood flow, similar to the warm-up effects, which may induce an increase in intramuscular temperature and nitric oxide release [56, 57], promoting vasodilation, and phosphocreatine replacement, or accelerating the pH return to baseline levels between contractions, thereby improving maximum contraction performance [56]. This mechanism might have occurred due to the total volume (90s) associated with the greatest tolerated pressure, and a high rolling speed (30-40rpm, which may be related to the total number of rolling cycles during a set) applied to the target muscle [28, 29]. In summary, FR can increase the knee extensors' concentric torque, but not the knee flexors' torque. However, these increases must be interpreted with caution, as the GRADE's analysis showed a very low certainty for these effects, and, in our meta-analysis, only one study [29] showed a significant increase in the knee extensors' concentric torque. Furthermore, the authors attributed this increase to a possible measurement error, and hence, the occurrence of a type I error cannot be rejected.

Similar to the isometric torque, eccentric torque also does not appear to be affected by FR [27]. However, as a single study [27] investigated the FR effects on eccentric torque, with a low volume of application (3 sets of 10s), the available evidence is limited and does not allow us to conclude about the FR effects on eccentric torque. Higher FR volume pressure, other muscle groups, as well as different contraction speeds still need to be explored.

The ankle plantar flexors, for example, may exhibit a different behavior after FR on the isokinetic torque. Although FR does not seem to change the plantar flexors' stiffness, changes in the ankle ROM have been previously reported [26, 70]. The increase in ankle dorsiflexion ROM might lead to an increase in the plantar flexors' isokinetic torque, as the plantar flexors' force production increases with increasing length, as these muscles operate on the ascending limb of the force-length relationship [71, 72]. In addition, the plantar flexors strength production has an important role in the lower limbs' locomotor function [73]. Thus, studies with other muscle groups should be developed to better determine the real effects of FR on isokinetic torque.

A neural mechanism has also been suggested to explain the FR main effects [60]. More specifically, FR may act over the neural drive (i.e., the sum of the neural activity of all recruited motor neurons), which can influence the ability to produce force quickly [30], also known as the RFD. Changes in RFD appear to be related to acute and chronic changes in neuromuscular function. A greater RFD is related to a greater neuromuscular activity at the onset of the contraction [74]. RFD seems to be influenced by neural factors at the onset of rapid contractions (<75ms), and becomes more strongly influenced by the mechanical factors at later contraction stages (>75ms) [74]. Considering that FR reduces spinal excitability [61], it would be expected to reduce RFD [64]. However, our qualitative analysis showed no change at the knee extensor muscles' RFD after two 60s sets of FR, similar to previous literature results [2]. Giovanelli et al. [14] also observed a RFD maintenance during vertical jump after 60s of FR applied in each of the eight treated muscle groups. Similar results were also observed after the application of self-massage with a stick on the plantar flexors (3 sets of 30s) [67]. The low FR volume in these studies (60-120s) [2, 14] might explain the absence of changes in RFD.

In contrast, decreases in RFD were reported on the contralateral limb (crossover effect) after ten sets of 30s (300s) of FR on the hamstring muscles [63], and after 5min of passive stretching [75]. These results suggest that larger FR volumes can decrease RFD. A corticospinal excitability decrease was suggested as the mechanism [63]. On other hand, increases were reported on RFD 3h after FR application during the countermovement jump, but not the squat jump [14]. Countermovement jump has a greater contribution of the passive tissues in the storage and use of elastic energy during the transition between eccentric and concentric phases, compared to the squat jump [14, 25]. The greater use of elastic energy may occur due to changes in tissue hydration after FR. Thixotropy (when a viscous tissue becomes more fluid) occurs when tissues are agitated, sheared or stressed [3], and can reach its peak approximately 3-4 hours after the mechanical stimulus [14]. Therefore, FR could induce a late increase in RFD, especially in functional tasks involving the stretch-shortening cycle. However, considering the small evidence about the FR effects on RFD, these findings are still limited, and more studies with high methodological quality are needed to better determine the acute and late effects of FR on the early and late phases of RFD.

In summary, the external validity of our findings demonstrates that FR does not change the myofascial tissues' stiffness, isometric muscle strength, eccentric torque, and RFD, although there is small and questionable evidence of increases in the knee extensors' concentric torque. As our meta-analysis demonstrated that FR does not change the myofascial tissues' stiffness, the assumptions that functional changes (e.g., ROM) could occur through lower tissue stiffness after FR appear to be false. The hypothesis that these changes may be mainly related to neural aspects, such as modulation of the corticospinal pathway of musculoskeletal sensory receptors, is very plausible. However, the literature and clinical practice often describe FR as a myofascial self-release technique. Despite the methodological limitations and uncertainties, our findings agree with the idea proposed by Behm & Wilke [3] that the use of the term "myofascial release" seems to be inappropriate as it refers to a false or incorrect mechanism [3], and our meta-analyses' results agree with their idea, as we found no FR effects on tissues' stiffness.

Finally, our review has some limitations. We only considered studies written in the English language. However, studies with the highest methodological quality are written in English and published in high-impact journals. Nevertheless, no study written in another language was found during study selection, and our funnel plots demonstrate no publication bias. The interpretation of our findings requires care. The small number of studies and their poor methodological quality (observed from PEDro's scores and GRADE's recommendations), in addition to the heterogeneity of the intervention protocols (e.g., pressure volume) limit further conclusions. Furthermore, not all studies had a control condition. In addition, some studies did not perform sample size calculation, and the sample size may have been insufficient, with the possibility of both type I and II errors occurrence. Future studies should also consider the level of the participants' previous experience with FR, as the lack of familiarity may have mitigated the FR effects [16, 76]. It has been shown that the experience level can be one of the factors responsible for the FR effects on aspects such as fascial tissues' stiffness. Greater experience may be related with a greater pain tolerance, thereby allowing higher pressure levels to be applied on the soft tissues during FR. FR's chronic use may also produce adaptations in the endothelial tissue [16], as the extracellular matrix, present in the fascial tissues, works as the molecular store, catching and releasing biologically active molecules to regulate tissue and organ function, growth and regeneration. The FR mechanical stress apparently induces the release and activation of the molecules stored in the extracellular matrix, which can modulate vascular growth and function [77]. Aspects related to the intervention protocol should also be considered, such as the pressure volume during FR, which may vary between region/target muscle group due to different rolling positions and body weightbearing [51]. In addition, most of the studies investigated the FR effects on isometric contractions, and considering the practical implications, effects of FR on muscle strength and RFD during dynamic contractions (e.g., vertical and horizontal jumps, and sprints performance) should be better explored. Finally, the FR effects may not be explained only by its application, but also by the methodological differences involving this technique's application, such as the volume pressure, roller device, different muscle groups, and participants' experience level.

5 Conclusion

Based on the available evidence, the use of FR appears to increase the knee extensor muscles' concentric torque, but it does not seem to acutely change the myofascial tissues' stiffness and isometric muscle strength. However, this evidence has an insufficient level of certainty to state that this technique does not provide changes in the myofascial tissues' mechanical properties, isometric muscle strength, isokinetic eccentric torque, and RFD, while increases in concentric torque must be interpreted carefully. The small number, and the low methodological quality of the studies, in addition to the heterogeneity of the intervention protocols limits further conclusions, especially considering the little evidence for eccentric torque and RFD. Therefore, future high methodological quality studies should be performed to better determine which exactly the FR acute effects on the myofascial tissues' mechanical properties and muscle strength are.

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ANEXOS

Check-list da PRISMA

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	Page 43
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	Page 43
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	Pages 43-44
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	Page 44
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	Page 44
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	Page 45

Section/topic	#	Checklist item	Reported on page #
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	Pages 44-45
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	Pages 44-45
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	Pages 45-46 and Figure 1
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	Pages 45-46
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	Page 45
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	Page 46
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	Pages 45-46
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	Pages 45-46
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	Page 46
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	Pages 45-46
RESULTS			

Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	Page 47 and Figure 1
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	Pages 48 and Tables 1.1-2
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	Page 55 and Table 2
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	Pages 47-64, Tables 1.1-2, and Figures 2-4
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	Pages 58-65 and Figures 2-4
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	Page 65
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	Pages 58-65 and Figures 2-4
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	Pages 69-75 and Table 3

Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	Pages 74-75
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	Page 75
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	Not applicable

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

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Registro do protocolo da revisão sistemática

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Acute effects of foam rolling application on the mechanical properties of myofascial tissues and on muscle force production

Marcelo Henrique Glanzel, Deivid Rodrigues, Gustavo Nascimento Petter, Daniel Pozzobon, Jeam Marcel Geremia

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Review question

What are the effects of foam rolling application on the mechanical properties of myofascial tissues and on muscle force production of healthy individuals?

Searches

A systematic search will be performed by two independent researchers in December 2020/ February 2021 using MEDLINE, EMBASE, Web of Science, and PEDro database to identify potentially relevant published studies in English language. Further studies will be identified by searching reference lists from included articles. The full search strategy employed will be documented and made available via the authors of the paper.

Types of study to be included

We will include randomised controlled trials (RCT) to assess the beneficial effects of the treatments.

Study designs eligible for inclusion: RCT

Study design not eligible for inclusion: abstracts, case reports, protocols, oral presentations, systematic reviews.

Condition or domain being studied

Self-massage by foam rolling application on the fascial and muscular mechanical properties, and on muscle force production.

Participants/population

Inclusion: randomized controlled trials, enrollment of healthy adults of athletes; intervention: self-myofascial release by foam rolling application; measurement of acute effects on the fascial and muscle mechanical properties, and on muscle force production.

Exclusion: other trial designs, impaired or unhealthy adults, measurement of chronic effects.

Intervention(s), exposure(s)

Studies investigating the acute effects of foam rolling on the fascial and muscle mechanical properties, and on force production will be eligible.

Comparator(s)/control

Compare to foam rolling intervention or no intervention.

Main outcome(s)

Fascial and muscle stiffness, and muscle force production changes from pre-intervention to postintervention.

Measures of effect

Where applicable, outcome measure will be pooled within a meta-analysis for quantitative analysis using standard mean differences as effect measures.

Additional outcome(s)

A moderator analysis will identify parameters affecting the treatment outcome (e.g. foam rolling duration time, pressure application, velocity).

Measures of effect

Where applicable, outcome measure will be pooled within a meta-analysis for quantitative analysis using standard mean differences as effect measures.

Data extraction (selection and coding)

Once the reviewers seem the paper suitable for inclusion based upon title/abstract, two reviewers will determine the study's eligibility. Any conflict of opinion will be resolved by a third reviewer. All suitable studies will then be fully reviewed by at least two reviewers independently and again, any conflict of findings will be resolved by a third reviewer. Both quantitative and qualitative data will be extracted using a data extraction form which includes details about the population, interventions, outcomes, time points of assessment, statistics, results as well as a section for comments.

Risk of bias (quality) assessment

The risk of bias (quality) of the included trials will be assessed by two investigators using the PEDro scale.

Strategy for data synthesis

If included studies have used the same type of intervention and comparator with the same outcome measure, we will pool the results using a fixed- and random effects meta-analysis, with standardised mean differences for continuous outcomes, and calculate 95% confidence intervals and two sided p-values for each outcome. Heterogeneity between the studies in effect measures will be assessed using I^2 statistic. We will consider an I^2 value greater than 50% indicative of substantial heterogeneity. We will also assess a potential publication bias. To account for dependency of effect sizes in crossover trials and to identify potential moderators, a multilevel analysis is performed.

Analysis of subgroups or subsets

Separate analyses will be performed for foam rolling vs. no-treatment control.

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Type and method of review

Meta-analysis, Systematic review

Anticipated or actual start date

02 November 2020

Anticipated completion date

15 February 2021

Funding sources/sponsors

Not applicable

Conflicts of interest

Language

English

Country

Brazil

Stage of review

Review Ongoing

Subject index terms status

Subject indexing assigned by CRD

Subject index terms

MeSH headings have not been applied to this record

Date of registration in PROSPERO

18 January 2021

Instruções para os autores – *Sports Medicine*

Types of Papers

Please note:

The word counts given below do not include the abstract, references, figure legends or table captions.

Review Article. Word count up to 6000. Provides an authoritative, balanced, comprehensive, fully referenced and critical review of the literature.

Current Opinion. Word count 1500 to 3000. Places an area in perspective given that it is of current international interest and a consensus has not yet been reached; therefore, the arguments presented may be controversial, but at the same time must be balanced and rational.

Leading Article. Word count up to 3000. Provides a short, balanced overview of the current state of development of an emerging area.

Systematic Review. Word count up to 10,000. Collates all empirical evidence that fits pre-specified eligibility criteria to answer a specific research question. It uses explicit, systematic methods that are selected with a view to minimizing bias, thus providing reliable findings from which conclusions can be drawn and decisions made. Please follow the reporting guidelines of PRISMA.

Original Research Article. Sports Medicine will consider high-quality original research with a strong link to clinical practice in the field of sport and exercise medicine.

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Organism: Filip1$^{tm1a(KOMP)Wtsi}$ **RRID:MMRRC_055641-UCD**

Cell Line: RST307 cell line **RRID:CVCL_C321**

Antibody: Luciferase antibody DSHB Cat# LUC-3, **RRID:AB_2722109**

Plasmid: mRuby3 plasmid **RRID:Addgene_104005**

Software: ImageJ Version 1.2.4 **RRID:SCR_003070**

RRIDs are provided by the Resource Identification Portal. Many commonly used research resources already have designated RRIDs. The portal also provides authors links so that they can quickly register a new resource and obtain an RRID.

Clinical Trial Registration

The World Health Organization (WHO) definition of a clinical trial is "any research study that prospectively assigns human participants or groups of humans to one or more health-related interventions to evaluate the effects on health outcomes". The WHO defines health interventions as “A health intervention is an act performed for, with or on behalf of a person or population whose purpose is to assess, improve, maintain, promote or modify health, functioning or health conditions” and a health-related outcome is generally defined as a change in the health of a person or population as a result of an intervention.

To ensure the integrity of the reporting of patient-centered trials, authors must register prospective clinical trials (phase II to IV trials) in suitable publicly available repositories. For example www.clinicaltrials.gov or any of the primary registries that participate in the WHO International Clinical Trials Registry Platform.

The trial registration number (TRN) and date of registration should be included as the last line of the manuscript abstract.

For clinical trials that have not been registered prospectively, authors are encouraged to register retrospectively to ensure the complete publication of all results. The trial registration number (TRN), date of registration and the words 'retrospectively registered’ should be included as the last line of the manuscript abstract.

Standards of reporting

Springer Nature advocates complete and transparent reporting of biomedical and biological research and research with biological applications. Authors are recommended to adhere to the minimum reporting guidelines hosted by the EQUATOR Network when preparing their manuscript.

Exact requirements may vary depending on the journal; please refer to the journal's Instructions for Authors.

Checklists are available for a number of study designs, including:

Randomised trials (CONSORT) and Study protocols (SPIRIT)
Observational studies (STROBE)
Systematic reviews and meta-analyses (PRISMA) and protocols (Prisma-P)
Diagnostic/prognostic studies (STARD) and (TRIPOD)
Case reports (CARE)
Clinical practice guidelines (AGREE) and (RIGHT)
Qualitative research (SRQR) and (COREQ)
Animal pre-clinical studies (ARRIVE)
Quality improvement studies (SQUIRE)
Economic evaluations (CHEERS)

Summary of requirements

The above should be summarized in a statement and placed in a 'Declarations' section before the reference list under a heading of 'Ethics approval'.

Examples of statements to be used when ethics approval has been obtained:

- All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study was approved by the Bioethics Committee of the Medical University of A (No. ...).
- This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of University B (Date.../No. ...).
- Approval was obtained from the ethics committee of University C. The procedures used in this study adhere to the tenets of the Declaration of Helsinki.
- The questionnaire and methodology for this study was approved by the Human Research Ethics committee of the University of D (Ethics approval number: ...).

Examples of statements to be used for a retrospective study:

- Ethical approval was waived by the local Ethics Committee of University A in view of the retrospective nature of the study and all the procedures being performed were part of the routine care.
- This research study was conducted retrospectively from data obtained for clinical purposes. We consulted extensively with the IRB of XYZ who determined that our study did not need ethical approval. An IRB official waiver of ethical approval was granted from the IRB of XYZ.
- This retrospective chart review study involving human participants was in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The Human Investigation Committee (IRB) of University B approved this study.

Examples of statements to be used when no ethical approval is required/exemption granted:

- This is an observational study. The XYZ Research Ethics Committee has confirmed that no ethical approval is required.
- The data reproduced from Article X utilized human tissue that was procured via our Biobank AB, which provides de-identified samples. This study was reviewed and deemed exempt by our XYZ Institutional Review Board. The BioBank protocols are in accordance with the ethical

standards of our institution and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Authors are responsible for correctness of the statements provided in the manuscript. See also Authorship Principles. The Editor-in-Chief reserves the right to reject submissions that do not meet the guidelines described in this section.

Informed consent

All individuals have individual rights that are not to be infringed. Individual participants in studies have, for example, the right to decide what happens to the (identifiable) personal data gathered, to what they have said during a study or an interview, as well as to any photograph that was taken. This is especially true concerning images of vulnerable people (e.g. minors, patients, refugees, etc) or the use of images in sensitive contexts. In many instances authors will need to secure written consent before including images.

Identifying details (names, dates of birth, identity numbers, biometrical characteristics (such as facial features, fingerprint, writing style, voice pattern, DNA or other distinguishing characteristic) and other information) of the participants that were studied should not be published in written descriptions, photographs, and genetic profiles unless the information is essential for scholarly purposes and the participant (or parent/guardian if the participant is a minor or incapable or legal representative) gave written informed consent for publication. Complete anonymity is difficult to achieve in some cases. Detailed descriptions of individual participants, whether of their whole bodies or of body sections, may lead to disclosure of their identity. Under certain circumstances consent is not required as long as information is anonymized and the submission does not include images that may identify the person.

Informed consent for publication should be obtained if there is any doubt. For example, masking the eye region in photographs of participants is inadequate protection of anonymity. If identifying characteristics are altered to protect anonymity, such as in genetic profiles, authors should provide assurance that alterations do not distort meaning.

Exceptions where it is not necessary to obtain consent:

- Images such as x rays, laparoscopic images, ultrasound images, brain scans, pathology slides unless there is a concern about identifying information in which case, authors should ensure that consent is obtained.
- Reuse of images: If images are being reused from prior publications, the Publisher will assume that the prior publication obtained the relevant information regarding consent. Authors should provide the appropriate attribution for republished images.

Consent and already available data and/or biologic material

Regardless of whether material is collected from living or dead patients, they (family or guardian if the deceased has not made a pre-mortem decision) must have given prior written consent. The aspect of confidentiality as well as any wishes from the deceased should be respected.

Data protection, confidentiality and privacy

When biological material is donated for or data is generated as part of a research project authors should ensure, as part of the informed consent procedure, that the participants are made aware what kind of (personal) data will be processed, how it will be used and for what purpose. In case of data acquired via a biobank/biorepository, it is possible they apply a broad consent which allows research participants to consent to a broad range of uses of their data and samples which is regarded by research ethics committees as specific enough to be considered “informed”. However, authors should always check the specific biobank/biorepository policies or any other type of data provider policies (in case of non-bio research) to be sure that this is the case.

Consent to Participate

For all research involving human subjects, freely-given, informed consent to participate in the study must be obtained from participants (or their parent or legal guardian in the case of children under 16) and a statement to this effect should appear in the manuscript. In the case of articles describing human transplantation studies, authors must include a statement declaring that no organs/tissues were obtained from prisoners and must also name the institution(s)/clinic(s)/department(s) via which organs/tissues were obtained. For manuscripts reporting studies involving vulnerable groups where there is the potential for coercion or where consent may not have been fully informed, extra care will be taken by the editor and may be referred to the Springer Nature Research Integrity Group.

Consent to Publish

Individuals may consent to participate in a study, but object to having their data published in a journal article. Authors should make sure to also seek consent from individuals to publish their data prior to submitting their paper to a journal. This is in particular applicable to case studies. A consent to publish form can be found

here. (Download docx, 36 kB)

Summary of requirements

The above should be summarized in a statement and placed in a ‘Declarations’ section before the reference list under a heading of ‘Consent to participate’ and/or ‘Consent to publish’. Other declarations include Funding, Conflicts of interest/competing interests, Ethics approval, Consent, Data and/or Code availability and Authors’ contribution statements.

Please see the various examples of wording below and revise/customize the sample statements according to your own needs.

Sample statements for **"Consent to participate"**:

Informed consent was obtained from all individual participants included in the study.

Informed consent was obtained from legal guardians.

Written informed consent was obtained from the parents.

Verbal informed consent was obtained prior to the interview.

Sample statements for **“Consent to publish”**:

The authors affirm that human research participants provided informed consent for publication of the images in Figure(s) 1a, 1b and 1c.

The participant has consented to the submission of the case report to the journal.

Patients signed informed consent regarding publishing their data and photographs.

Sample statements if identifying information about participants is available in the article:

Additional informed consent was obtained from all individual participants for whom identifying information is included in this article.

Authors are responsible for correctness of the statements provided in the manuscript. See also Authorship Principles. The Editor-in-Chief reserves the right to reject submissions that do not meet the guidelines described in this section.

Images will be removed from publication if authors have not obtained informed consent or the paper may be removed and replaced with a notice explaining the reason for removal.

Research Data Policy and Data Availability Statements

This journal operates a type 2 research data policy (life sciences). A submission to the journal implies that materials described in the manuscript, including all relevant raw data, will be freely available to any researcher wishing to use them for non-commercial purposes, without breaching participant confidentiality.

The journal strongly encourages that all datasets on which the conclusions of the paper rely should be available to readers. We encourage authors to ensure that their datasets are either deposited in publicly available repositories (where available and appropriate) or presented in the main manuscript or additional supporting files whenever possible. Please see Springer Nature’s information on recommended repositories.

List of Repositories

Research Data Policy

General repositories - for all types of research data - such as figshare and Dryad may be used where appropriate.

Datasets that are assigned digital object identifiers (DOIs) by a data repository may be cited in the reference list. Data citations should include the minimum information recommended by DataCite: authors, title, publisher (repository name), identifier.

DataCite

Where a widely established research community expectation for data archiving in public repositories exists, submission to a community-endorsed, public repository is mandatory. Persistent identifiers (such as DOIs and accession numbers) for relevant datasets must be provided in the paper

For the following types of data set, submission to a community-endorsed, public repository is mandatory:

Mandatory deposition	Suitable repositories
Protein sequences	Uniprot
DNA and RNA sequences	Genbank DNA DataBank of Japan (DDBJ) EMBL Nucleotide Sequence Database (ENA)
DNA and RNA sequencing data	NCBI Trace Archive NCBI Sequence Read Archive (SRA)
Genetic polymorphisms	dbSNP dbVar European Variation Archive (EVA)
Linked genotype and phenotype data	dbGAP

	The European Genome-phenome Archive (EGA)
Macromolecular structure	Worldwide Protein Data Bank (wwPDB) Biological Magnetic Resonance Data Bank (BMRB) Electron Microscopy Data Bank (EMDB)
Microarray data (must be MIAME compliant)	Gene Expression Omnibus (GEO) ArrayExpress
Crystallographic data for small molecules	Cambridge Structural Database

For more information:
Research Data Policy Frequently Asked Questions
Data availability

The journal encourages authors to provide a statement of Data availability in their article. Data availability statements should include information on where data supporting the results reported in the article can be found, including, where applicable, hyperlinks to publicly archived datasets analysed or generated during the study. Data availability statements can also indicate whether data are available on request from the authors and where no data are available, if appropriate.

Data Availability statements can take one of the following forms (or a combination of more than one if required for multiple datasets):

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2. The datasets generated during and/or analysed during the current study are not publicly available due [REASON WHY DATA ARE NOT PUBLIC] but are available from the corresponding author on reasonable request.
3. The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.
4. Data sharing not applicable to this article as no datasets were generated or analysed during the current study.
5. All data generated or analysed during this study are included in this published article [and its supplementary information files].

More examples of template data availability statements, which include examples of openly available and restricted access datasets, are available:
Data availability statements

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