Universidade Estadual de Londrina

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ASSOCIAÇÃO ENTRE FORÇA MUSCULAR E COMPOSIÇÃO CORPORAL, CAPACIDADE FUNCIONAL, QUALIDADE MUSCULAR E BIOMARCADORES SANGUÍNEOS EM MULHERES IDOSAS SUBMETIDAS AO TREINAMENTO RESISTIDO

Londrina
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Tese de Doutorado apresentada ao Programa de Pós-Graduação Associado em Educação Física - UEM/UEL, como requisito para a obtenção do título de Doutor em Educação Física.

Orientador: Prof. Dr. Edilson Serpeloni Cyrino
Co Orientador: Prof. Dr. Leandro Altimari

Londrina
2020

Ficha de identificação da obra elaborada pelo autor, através do Programa de Geração Automática do Sistema de Bibliotecas da UEL

M827 Moraes, Jean.

Associação entre força muscular e composição corporal, capacidade funcional, qualidade muscular e biomarcadores sanguíneos em mulheres idosas submetidas ao treinamento resistido / Jean Moraes. - Londrina, 2020.
96 f. : il.

Orientador: Edilson Cyrino.
Coorientador: Leandro Altimari.
Tese (Doutorado em Educação Física) - Universidade Estadual de Londrina, Centro de Educação Física e Esportes, Programa de Pós-Graduação em Educação Física, 2020.
Inclui bibliografia.

1. Força muscular, composição corporal, capacidade funcional, qualidade muscular, idosas, treinamento resistido - Tese. I. Cyrino, Edilson. II. Altimari, Leandro. III. Universidade Estadual de Londrina. Centro de Educação Física e Esportes. Programa de Pós-Graduação em Educação Física. IV. Título.

CDU 796

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Londrina, 23 de outubro de 2020.

Dedico este trabalho a minha família. Aos meus pais Waldenir e Rosemeire, pelo amor incondicional que sempre me dedicaram. Aos meus filhos Tharik e Nathan, razão maior de iniciar este caminho e de continuar sonhando.

AGRADECIMENTOS

Uma das principais virtudes do homem é a gratidão, por isso sou grato a várias pessoas que contribuíram para que fosse possível finalizar esta etapa de minha vida.

Á **Deus**, pela vida, pela saúde e por me dar força interior para superar as dificuldades e me suprir em todas as minhas necessidades.

À **minha família**, a qual amo muito, pelo carinho, paciência e incentivo.

Ao meu orientador, **Prof. Dr. Edilson Serpeloni Cyrino**, pelo exemplo de profissional e por ter acreditado no meu potencial. Obrigado pela confiança, amizade, paciência e por me permitir fazer parte do seu grupo.

À meu co-orientador, **Prof. Dr. Leandro Altimari**, pela amizade, incentivo nos momentos difíceis e contribuição marcante na construção desse trabalho.

Ao meu amigo **Prof. Dr. Alex Silva Ribeiro** por me auxiliar nos momentos de dificuldade, pelas palavras de apoio, conversas e conselhos.

Aos professores **Dr. Denilson de Castro Teixeira**, **Dr. Arli Ramos de Oliveira**, **Dr. Andreo Fernando Aguiar** e **Dr. Juliano Casonato**, por aceitarem o convite para a avaliação deste trabalho, pelas contribuições e pela disposição em ajudar, sempre.

À Ivone, **secretária** do programa, pelo excelente atendimento prestado sempre que precisei sanar dúvidas.

A todas as **idosas participantes** que aceitaram participar desse projeto, e não mediram esforços para estarem presentes durante todo período e, mesmo em dias de frio e com chuva, não desistiram. Muito obrigado pelo carinho e lição de vida.

Ao **Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq)**, à **Fundação Araucária** e ao **Ministério da Educação** pelo apoio financeiro ao projeto.

À **Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES)** pela concessão de bolsas de mestrado e doutorado para os participantes do meu projeto.

A todos os integrantes do **Grupo de Estudo e Pesquisa em Metabolismo, Nutrição e Exercício (GEPEMENE/UEL)**, amigos e companheiros, João Pedro, Leandro, Gabriel, Paolo, Melissa, Edilaine, Dani, Fabio, Helen, Letícia, Marcelo, Matheus, Nelson, Pamela e Witalo enfim, a todos aqueles que de uma maneira ou de outra contribuíram para que este percurso pudesse ser concluído. Obrigado pelo comprometimento com meu crescimento e aprendizado. Foi um prazer estar entre colegas e amigos tão competentes. Aprendi muito durante os momentos em que estivemos juntos.

Por fim, todos aqueles que acreditaram no meu potencial e me ajudaram com um sorriso, um abraço, uma palavra de incentivo, uma mão estendida!

Muito Obrigado!

MORAES, Jean Cléverson. **Associação entre força muscular e composição corporal, capacidade funcional, qualidade muscular e biomarcadores sanguíneos em mulheres idosas submetidas ao treinamento resistido.** 2020. 96 f. Tese (Doutorado em Educação Física) – Centro de Educação Física e Esporte. Universidade Estadual de Londrina, Londrina, 2020.

RESUMO

Introdução: A força muscular é um importante componente da aptidão física, exercendo papel fundamental para a saúde e qualidade de vida em idosos, sendo a prática de exercícios resistidos recomendados para o aumento da força muscular. Por outro lado, a redução da força muscular com o avanço da idade está relacionada com redução da capacidade funcional e maior risco de morte por todas as causas. **Objetivo:** Analisar o efeito do treinamento resistido sobre força muscular, composição corporal, capacidade funcional, qualidade muscular e biomarcadores sanguíneos em mulheres idosas não-treinadas com diferentes níveis de força muscular. **Métodos:** Noventa e nove mulheres (> 60 anos) fisicamente independentes foram submetidas a treinamento resistido (oito exercícios para membros inferiores, tronco e membros superiores), em três sessões semanais, durante 24 semanas. Medidas de força muscular (testes de 1-RM), capacidade funcional (bateria de testes motores), composição corporal (absortometria radiológica de dupla energia e impedância bioelétrica) e biomarcadores sanguíneos (glicose, triglicerídeos, colesterol total, LDL-c, HDL-c, proteína C-reativa) foram obtidas na linha de base e após 24 semanas de intervenção. A força muscular das participantes na linha de base foi categorizada em tercis (baixa, média e alta força) e os resultados encontrados foram comparados entre os três grupos. **Resultados:** Aumentos na força muscular ($P < 0,05$) foram encontrados nos três exercícios analisados (supino vertical = 32,8 - 41,8%; cadeira extensora = 22,1 - 33,3%; rosca scott = 13,6 – 17,6%), com diferenças entre os grupos somente para cadeira extensora (média > alta; $P < 0,05$). Ganhos estatisticamente significativos ($P < 0,05$) de massa muscular (3,4% a 5,6%), massa isenta de gordura e ossea de membros superiores (5,0% a 8,1%) e inferiores (2,3% a 4,3%) e melhoria da qualidade muscular (18,8% a 27,4%) foram encontrados em todos os grupos. Por outro lado, a massa isenta de gordura e osso de tronco só melhorou ($P < 0,05$) os grupos média e alta (2,2% e 2,3%; respectivamente). A velocidade de caminhada só melhorou no grupo alta (5,9%; $P < 0,05$), com diferenças entre os grupos (alta > média = baixa; $P < 0,05$). O desempenho no teste de levantar e sentar foi melhorado somente nos grupos baixa e média (15,3% e 11,4%; respectivamente), com diferenças estatisticamente significantes do grupo alta ($P < 0,001$). Aumentos significantes ($P < 0,05$) foram verificados para água corporal total (1,4% a 2,1%), água intracelular (1,9% a 2,3%) e ângulo de fase (2,6% a 3,7%) em todos os grupos. A concentração de triglicérides foi reduzida somente no grupo média (15,1%; $P < 0,05$) com diferenças estatisticamente significantes dos grupos baixa e alta ($P < 0,05$). Nenhuma alteração foi verificada nos demais parâmetros metabólicos, na pressão arterial e na relação cintura quadril ($P > 0,05$). Todos os grupos reduziram gordura relativa ($P < 0,05$) com o tamanho do efeito variando de 0,23 a 0,35. Por outro lado, somente o grupo média reduziu a gordura androide e de tronco ($P < 0,05$). Os resultados do presente estudo sugerem que o treinamento resistido pode melhorar a força muscular, capacidade funcional e composição corporal, independente dos níveis de força muscular, embora a magnitude das respostas adaptativas após 24 semanas de intervenção tenha sido menos pronunciada em mulheres idosas que apresentavam níveis iniciais de força mais reduzidos.

Palavras-chave: Idosas**.** Força muscular. Treinamento resistido. Massa muscular.

MORAES, Jean Cléverson. **Association between muscular strength and body composition, functional capacity, muscle quality, and blood biomarkers in older women submitted to resistance training.** 2020. 96 p. Thesis (Doctoral of Physical Education) - Physical Education and Sport Center. Londrina State University, Londrina, 2020.

ABSTRACT

Introduction: Muscle strength is an important component of physical fitness, playing a fundamental role for health and quality of life in the elderly, and the practice of resistance exercises is recommended to increase muscle strength. On the other hand, the reduction in muscle strength with advancing age is related to reduced functional capacity and increased risk of death from all causes. **Purpose:** To analyze the effect of resistance training on muscular strength, body composition, functional capacity, muscle quality, and blood biomarkers in untrained older women with different levels of muscle strength. **Methods:** Ninety-nine physically independent women (> 60 years old) were submitted to resistance training (eight exercises for lower limbs, trunk, and upper limbs) in three weekly sessions for 24 weeks. Muscular strength measurements (1-RM tests), functional capacity (battery of motor tests), body composition (dual-energy X-ray absorptiometry and bioelectric impedance), and blood biomarkers (glucose, triglycerides, total cholesterol, LDL-c, HDL-c, C-reactive protein) were obtained at baseline and after 24 weeks of intervention. The baseline muscular strength was categorized into tertiles (low, middle, and high strength) and the results found were compared between the three groups. **Results:** Increases in muscular strength ($P < 0.05$) were found in the three exercises analyzed (chest press = 32.8 - 41.8%; leg extension = 22.1 - 33.3%; preacher curl = 13.6 - 17.6%), with differences between groups only for leg extension (moderate > high; $P < 0.05$). Significant gains ($P < 0.05$) for muscle mass (3.4% to 5.6%), upper (5.0% to 8.1%) and lower limbs lean soft tissue (2.3% to 4.3%) and improvement of muscle quality (18.8% to 27.4%) were found in all groups. On the other hand, the trunk lean soft tissue only improved (P < 0.05), the middle and high groups (2.2% and 2.3%; respectively). Walking speed only improved in the high group (5.9%; P < 0.05), with differences between groups (high > middle = low; $P < 0.05$). Performance in the stand up from a chair for 30 s was improved only in the low and middle groups (15.3% and 11.4%, respectively), with statistically significant differences in the high group ($P < 0.001$). Significant increases (P < 0.05) were observed for total body water (1.4% to 2.1%), intracellular water (1.9% to 2.3%) and phase angle (2.6% to 3.7%) in all groups. The triglyceride concentration was reduced only in the middle group (15.1%; $P < 0.05$) with statistically significant differences of the low and high groups ($P < 0.05$). No changes were observed in the other metabolic parameters, blood pressure, and waist-to-hip ratio ($P > 0.05$). All groups reduced relative body fat ($P < 0.05$) with the effect size ranging from 0.23 to 0.35. On the other hand, only the middle group decreased android and trunk fat ($P < 0.05$). **Conclusion:** The results suggest that resistance training may promote the improvement of muscular strength, functional capacity, and body composition, regardless of muscular strength levels. However, the magnitude of adaptive responses after 24 weeks of the intervention was less pronounced in older women with lower initial strength levels.

Keywords: Elderly**.** Muscular strength. Resistance training. Muscle mass.

LISTA DE ABREVIATURAS E SIGLAS

ABNT	Associação Brasileira de Normas Técnicas
UEL	Universidade Estadual de Londrina
PAS	Pressão Sistólica
PAD	Pressão Diastólica
MIGO	Massa Isenta de Gordura e Osso
TR	Treinamento Resistido
IMC	Indice de Massa Corporal
MME	Massa Muscular Esquelética
RM	Repetição Máxima
DXA	Absortometria Radiológica de Dupla Enerfia

SUMÁRIO

1 INTRODUÇÃO

A força muscular é um dos principais componentes da aptidão física, tanto relacionada ao desempenho esportivo quanto à saúde, exercendo um papel importante para a prevenção e tratamento de doenças crônicas (JOCHEM *et al.*, 2019; WANG *et al.*, 2019; WU *et al.*, 2017). Em idosos, a redução dos níveis de força muscular associada ao processo de envelhecimento tem repercussão negativa sobre a capacidade funcional, autonomia e, consequentemente, sobre a qualidade de vida (CRUZ-JENTOFT, 2019). Nesse sentido, diversos estudos têm demonstrado uma relação inversa entre força muscular e mortalidade por todas as causas (GARCÍA-HERMOSO *et al.*, 2018; GUADALUPE-GRAU *et al.*, 2015; JOCHEM *et al.*, 2019; LEONG *et al.*, 2015; VERONESE *et al.*, 2017; WU *et al.*, 2017).

A prática de treinamento resistido (TR) é a principal estratégia não-farmacológica recomendada para aumentar a força muscular, sobretudo em idosos, uma vez que possibilita uma prescrição individualizada, de acordo com os objetivos e necessidades dos praticantes, considerando as características individuais (limitações ortopédicas, doenças preexistentes, fragilidades, entre outras) (FRAGALA *et al.*, 2019). Além disso, o TR permite a aplicação de uma sobrecarga progressiva necessária para se alcançar diferentes respostas adaptativas (AMERICAN COLLEGE OF SPORTS MEDICINE, 2009; KRAEMER; RATAMESS, 2004), sendo considerado um tipo de treinamento seguro e confortável para essa população (FRAGALA *et al.*, 2019).

Desse modo, inúmeros estudos têm comprovado a eficácia do TR para a população idosa, com benefícios morfológicos, neuromusculares, metabólicos, fisiológicos, cognitivos e comportamentais (CUNHA *et al.*, 2019; DIB *et al.*, 2020; NASCIMENTO *et al.*, 2019; OLSON *et al.*, 2007; PADILHA *et al.*, 2015; PINA *et al.*, 2020a, 2020b, SANTOS *et al.*, 2017). Entretanto, o impacto dos níveis iniciais de força muscular para as respostas adaptativas ao TR, ainda, precisa ser elucidado. Considerando que mulheres, em geral, apresentam níveis de força muscular inferiores aos dos homens, desde a juventude, é possível que com o avançar da idade essas diferenças tornem as mulheres mais susceptíveis à desfechos negativos para à saúde e qualidade de vida, em particular, devido as alterações metabólicas associadas à menopausa (MALTAIS; DESROCHES;

DIONNE, 2009). Nesse ciclo da vida, o TR pode atenuar ou até mesmo reverter diversas modificações induzidas pelo envelhecimento.

Com relação aos aspectos neuromusculares, a redução da força, potência, resistência muscular e, consequentemente, da capacidade funcional com o envelhecimento vem acompanhada de uma redução nas unidades motoras de alto limiar, com redução e inativação das fibras musculares do tipo II e de células satélites (CLARK; MANINI, 2008; CRUZ-JENTOFT, 2019; FOLLAND; WILLIAMS, 2007; LEXELL; TAYLOR; SJÖSTRÖM, 1988; WANG *et al.*, 1993). O TR tem se mostrado efetivo para a reversão desse quadro em períodos de intervenção relativamente curtos, ou seja, até 12 semanas em mulheres idosas (DIB *et al.*, 2020; NASCIMENTO *et al.*, 2019; PADILHA *et al.*, 2015). Muitas dessas modificações têm sido associadas com o aumento da massa muscular (NASCIMENTO *et al.*, 2019) e redução dos depósitos de gordura corporal (CUNHA *et al.*, 2019). Por outro lado, níveis reduzidos de atividade física guardam estreita relação com o desenvolvimento de um quadro clínico denominado de obesidade sarcopênica, um fenômeno caracterizado pelo aumento da gordura corporal, sobretudo, visceral concomitantemente com a redução da massa muscular e da capacidade funcional (DE OLIVEIRA SILVA *et al.*, 2018; VASCONCELOS *et al.*, 2016). Estudos recentes têm reportado que o TR pode exercer um papel importante sobre todos esses componentes reduzindo a taxa de prevalência em mulheres idosas (DE OLIVEIRA SILVA *et al.*, 2018).

As modificações na massa muscular e na gordura corporal em idosos, via de regra são acompanhadas pela redução da hidratação corporal, principalmente, na fração intracelular. Esses processos são agravados por mudanças no apetite, na sensação de sede, nos órgãos sensoriais o que favorecem a redução do consumo diário de alimentos, bem como de macro e micronutrientes, com destaque para a diminuição do aporte de proteínas e cálcio. Além disso, idosos desenvolvem um processo denominado de resistência anabólica, modificando o *turnover* proteico, com maior dificuldade para a síntese diária de proteínas (NILSSON *et al.*, 2013). Com isso, a estrutura músculo esquelética fica fragilizada e mais suscetível a desequilíbrios, quedas, lesões e fraturas. Embora a prática do TR possa auxiliar na melhoria da força muscular e na composição corporal de idosos, poucos são os estudos que tem procurado monitorar os hábitos alimentares dos praticantes. A importância dessas informações foi demonstrada recentemente, indicando que mulheres idosas com uma ingestão proteica mais elevada podem alcançar aumentos muito mais acentuados, tanto na força muscular quanto na massa muscular total e segmentar.

A melhoria da composição corporal e da força muscular acarretada pelo TR em mulheres idosas pode estar relacionada, também, com a saúde celular. Estudos recentes têm revelado aumento no ângulo de fase, um parâmetro derivado do método de impedância bioelétrica e aceito com indicador de saúde celular, conjuntamente com a melhoria da força e da composição corporal em protocolos de TR. A redução do ângulo de fase, bastante comum na população idosa, está associada com processo inflamatório (BEBERASHVILI *et al.*, 2016; TOMELERI *et al.*, 2018b), estresse oxidativo (TOMELERI *et al.*, 2018b), obesidade sarcopênica (MARINI *et al.*, 2012), redução da força muscular (NORMAN *et al.*, 2015), diminuição da qualidade muscular (NORMAN *et al.*, 2015), sarcopenia (BASILE *et al.*, 2014). Portanto, a reversão deste processo, em particular em idosos, pode significar melhoria da funcionalidade (MATIAS *et al.*, 2020) e saúde celular (RIBEIRO *et al.*, 2020). A melhoria do ângulo de fase a partir do TR tem sido associado com aumento de força, massa muscular e qualidade muscular (CUNHA *et al.*, 2018; NUNES *et al.*, 2019) e capacidade funcional TOMELERI *et al.*, 2019).

Assim, o TR pode favorecer a melhoria de fatores de risco cardiometabólicos como a pressão arterial (PA), a distribuição da gordura corporal, a redução na glicose e a melhoria de perfil lipídico e inflamatório (FAHLMAN *et al.*, 2002; LEMES *et al.*, 2016; MACDONALD *et al.*, 2016; MARTEL *et al.*, 1999; OLSON *et al.*, 2007; STEPHENS; SPARKS, 2015). Entretanto, muitas das respostas associadas ao TR podem ser tempo-dependentes, de modo que períodos de intervenção curtos (até 12 semanas) muitas vezes produzem respostas inconclusivas, fato que remete a necessidade de estudos longitudinais mais longos e com amostras representativas (BORDE; HORTOBAGYI; GRANACHER, 2015; PINA *et al.*, 2020a). Além disso, devido a possível influência isolada ou combinada de inúmeros fatores, tais como as características genéticas, os hábitos alimentares, a massa corporal total e a massa muscular, o nível de adiposidade e os níveis de força muscular sobre as respostas adaptativas induzidas pelo treinamento, não se pode desprezar o importante papel moderador ou mediador de cada um deles durante a intervenção (AHTIAINEN *et al.*, 2016; CHMELO *et al.*, 2015; DAVIDSEN *et al.*, 2011; HECKSTEDEN *et al.*, 2015; MANN; LAMBERTS; LAMBERT, 2014). Portanto, a análise do comportamento combinado dessas variáveis associada a protocolos de TR de longa duração pode contribuir acentuadamente para a tomada de decisão com relação as estratégias a serem adotadas para a melhoria da saúde e da qualidade de vida da população idosa.

2 OBJETIVO

Considerando que a presente tese foi estruturada de acordo com o modelo escandinavo, no qual a contextualização do problema dá origem ao estabelecimento de diferentes objetivos, que por sua vez são analisados a partir da redação de artigos científicos, os objetivos desta investigação foram comparar os efeitos de 24 semanas de TR, de acordo com os níveis iniciais de força muscular de mulheres idosas, sobre:

- a força muscular isoinercial (membros inferiores, tronco e membros superiores), a massa isenta de gordura e osso segmentar (membros inferiores, tronco e membros superiores), a massa muscular, a qualidade muscular e a capacidade funcional;
- a hidratação corporal (água corporal total e suas frações intra e extracelular) e o ângulo de fase;
- a gordura corporal total e relativa, distribuição da gordura (andróide e ginóide) e fatores de risco cardiometabólicos (PA, glicose, triglicerídeos, colesterol total, HDL-C e LDL-C).

3 HIPÓTESES

Com base nas informações disponíveis na literatura até o presente momento sobre os benefícios do TR, particularmente, para mulheres idosas, as principais hipóteses desta investigação são que este tipo de treinamento promoverá:

- aumentos de força muscular isoinercial (membros inferiores, tronco e membros superiores), de massa isenta de gordura e osso segmentar (membros inferiores, tronco e membros superiores), de massa muscular, da água corporal intracelular, do ângulo de fase;
- manutenção da água corporal (total e extracelular) e das concentrações de triglicerídeos e HDL-C;
- redução da gordura corporal (total e relativa), PA e das concentrações de glicose, colesterol total e LDL-C;
- melhoria da relação entre a distribuição da gordura androide e ginóide;
- as adaptações ocorrerão de forma similar, independente dos níveis de força iniciais das participantes;
- as respostas de maior magnitude ocorrerão na força muscular e na capacidade funcional.

4 MÉTODOS

4.1 Delineamento Experimental

O presente estudo faz parte do projeto de pesquisa "*Active Aging Longitudinal Study*", iniciado em 2012, cujo objetivo é analisar os efeitos dos programas de TR supervisionados, estruturados e progressivos sobre desfechos neuromusculares, morfológicos, fisiológicos, metabólicos e cognitivos em idosas. Os dados atuais foram obtidos a partir de duas coortes (2015 e 2018) que seguiram um protocolo experimental semelhante ao longo de 30 semanas, com seis semanas destinadas para testes, medidas e avaliações e 24 semanas dedicadas ao programa de treinamento. Foram realizados testes de força muscular, medidas antropométricas e de composição corporal, testes motores e coletas de sangue nas semanas 1-3 e 28-30. A ingestão dietética foi avaliada nas duas primeiras e nas duas últimas semanas de intervenção (semanas 4-5 e 26-27). O programa de TR foi realizado durante as semanas 4-27. As participantes foram instruídos a manterem sua rotina habitual de atividade física e seus hábitos alimentares e para não se envolverem em nenhum outro programa de exercícios físicos sistematizados ao longo do período da investigação.

4.2 Participantes

O recrutamento das voluntárias foi realizado por meio de anúncios em veículos de comunicação (jornais, televisão e rádio) e entrega de panfletos nos bairros centrais da cidade e residenciais. Os interessados preencheram questionários detalhados de histórico de saúde e, posteriormente, foram admitidos no estudo se atendessem aos seguintes critérios de inclusão: (1) possuir idade ≥ 60 anos; (2) sexo feminino; (3) ser fisicamente independente; (4) não apresentar diagnóstico de disfunção cardíaca, ortopédica ou musculoesquelética que pudesse impedir a prática de exercícios físicos ou a realização de testes motores; (5) não ser portadora de diabetes mellitus ou hipertensão descontrolada; (6) não receber terapia de reposição hormonal; (7) não estar envolvida com a prática regular e sistematizada de atividade física por mais de uma vez por semana durante os três meses anteriores o início do estudo. Adicionalmente, as participantes que atenderam os critérios de inclusão preestabelecidos foram submetidas a uma avaliação cardiológica (teste de eletrocardiograma de 12 derivações, anamnese clínica e teste de esforço em esteira, quando necessário), sendo liberadas para a prática de TR sem restrição. A frequência às sessões de treinamento inferior a 85% foi adotada como critério de exclusão. Cento e trinta e quatro mulheres (coorte de 2015 = 61 e coorte de 2018 = 72) que atenderam aos critérios iniciais de inclusão e concluíram os testes, medidas e avaliações na linha de base iniciaram o programa de TR. Noventa e nove participantes finalizaram o estudo (coorte de 2015 = 45 e corte de 2018 = 54; idade = 69 ± 6 anos; massa corporal = 66 ± 12 kg; estatura = 155 ± 6 cm; índice de massa corporal = 27 ± 4 kg/m²) e foram incluídas nas análises. A exclusão de 34 participantes foi associada a desistência voluntária ou não atendimento ao número de sessões de TR estabelecido para a presente investigação em virtude de motivos pessoais, falta de tempo disponível para o treinamento, viagens, problemas de saúde ou cirurgias não relacionadas à prática de TR.

As 99 participantes que concluíram o estudo foram divididas em três grupos experimentais por meio tercis, de acordo com o desempenho alcançado individualmente em três testes de força isoinercial na linha de base. Os grupos tercil inferior, médio e superior de força muscular foram compostos por 33 participantes cada. O cálculo do tamanho da amostra foi estabelecido com base em um poder estatístico (probabilidade de erro de 1-β) de 0,80, um tamanho de efeito a partir dos valores de F (interação grupo vs. tempo) de 0,27 para a força muscular, e um nível geral de α de 0,05. O cálculo a priori indicou um tamanho amostral mínimo de grupo de 30 indivíduos por grupo experimental. Um termo de consentimento livre e esclarecido foi assinado por todas as participantes após uma descrição detalhada dos procedimentos aos quais seriam submetidas, bem como os riscos e benefícios da participação no estudo. Este estudo foi realizado de acordo com a Declaração de Helsinque e os projetos que deram origem a ambas as coortes investigadas foram aprovados pelo Comitê de Ética em Pesquisa com Seres Humanos da Universidade Estadual de Londrina.

4.3 ANTROPOMETRIA

A massa corporal foi mensurada em uma balança de leitura digital Balmak, modelo Classe III (Balmak Indústria e Comércio Ltda, Santa Bárbara d'Oeste, SP, Brasil), com escala de 0,1 kg, ao passo que a estatura foi determinada por meio de um estadiômetro acoplado à mesma, com escala de 0,1 cm, de acordo com os procedimentos descritos na literatura (GORDON; CHUMLEA; ROCHE, 1988). A partir dessas medidas, foi calculado o índice de massa corporal (IMC), por meio da razão entre a massa corporal e o quadrado da estatura, sendo a massa corporal expressa em quilogramas (kg) e a estatura em metros (m).

4.4 COMPOSIÇÃO CORPORAL

Exames de absortometria radiológica de dupla energia (DXA) foram usados para determinar a massa isenta de gordura e osso de tronco, membros superiores e inferiores; tecido mole e magro apendicular (somatória da massa isenta de gordura e osso de membros superiores e inferiores) (MIGO-AP); gordura corporal absoluta e relativa; distribuição da gordura (andróide e ginóide) em equipamento Lunar, modelo NRL 419900 (GE Lunar, Madison, WI, USA). A massa muscular esquelética (MME) foi estimada pela seguinte equação (KIM *et al.*, 2004): MME (kg) = [(MIGO-AP * 1,18) - (idade * 0,03) - 0,14], sendo a idade em anos. As participantes foram instruídas a remover todos os objetos contendo metal, anteriormente ao exame. Durante o exame as participantes foram posicionadas na mesa do equipamento em decúbito dorsal. Os pés foram fixados paralelamente para imobilizar as pernas por meio de uma fita de velcro, enquanto as mãos foram mantidas na posição pronada dentro da região de varredura. A calibração do equipamento seguiu as recomendações do fabricante. Um software específico gerou linhas padrão que separaram membros, tronco e cabeça, utilizando pontos anatômicos específicos determinados pelo fabricante. Um técnico de laboratório qualificado realizou calibrações do equipamento, ajustes das linhas e as análises. Exames anteriores do nosso laboratório com 13 participantes do projeto conferiram confiabilidade satisfatória todas as medidas realizadas (ICCs ≥ 0,98).

Um analisador de impedância bioelétrica espectral (Xitron Hydra, modelo 4200, Xitron Technologies, San Diego, CA, USA) foi usado para estimar água corporal total e suas frações intra e extracelular, resistência (R) e reactância (Xc). Posteriormente, o ângulo de fase (PhA) foi calculado a partir da seguinte equação: PhA = arco-tangente (Xc/R) × 180°/π (NORMAN *et al.*, 2012). Todas as medidas de impedância bioelétrica espectral foram realizadas das 6h00min às 9h00min. Antes da medida, as participantes removeram todos os objetos contendo metal de seus corpos. As medidas foram realizadas sob uma maca isolada de condutores elétricos. As participantes permaneceram deitadas ao longo do eixo longitudinal da maca, com as pernas abduzidas em um ângulo de 45° em relação à linha média do corpo e mãos pronadas. Após a limpeza da pele com álcool, dois eletrodos foram colocados na superfície da mão direita e dois no pé direito de acordo com procedimentos descritos anteriormente (SARDINHA *et al.*, 1998). As participantes ficaram deitadas em decúbito dorsal por 10 minutos antes das medidas. As participantes foram instruídas a urinar cerca de 30 min antes do exame, abster-se alimentos ou bebidas nas últimas quatro horas, evitar exercícios físicos extenuantes por pelo menos 24 h, abster-se do consumo de bebidas alcoólicas e com cafeína por pelo menos 48 h antes do exame. De analisador de impedância bioelétrica espectral foi calibrado de acordo com as recomendações do fabricante. Todas as medidas foram executadas por um único avaliador com experiência nesse tipo de exame.

4.5 FORÇA MUSCULAR

A força dinâmica máxima foi avaliada por meio de testes de 1RM avaliados nos exercícios supino vertical, cadeira extensora e rosca scott. Uma sessão de familiarização e três sessões de testes de 1RM foram realizadas pela manhã, separadas por 48-72 horas. Para a sessão de familiarização, as participantes realizaram 2-3 séries de 10-15 repetições em cada exercício com uma carga leve. Três pesquisadores experientes supervisionaram todas as sessões para a segurança e integridade das participantes. A técnica de execução de cada exercício foi padronizada e continuamente monitorada para garantir a confiabilidade das medidas. Para cada sessão de teste, as participantes realizaram um aquecimento específico (6-10 repetições), em cada exercício, com aproximadamente 50% da carga estimada para a primeira tentativa. No primeiro dia de testes, a carga selecionada foi baseada na experiência dos pesquisadores, na carga utilizada individualmente na familiarização e na percepção da dificuldade (esforço) em que os sujeitos realizaram o aquecimento. Durante os testes de 1RM, os sujeitos foram incentivados a tentar executar duas repetições com a carga selecionada. Incentivo verbal, acompanhado de palmas, foi fornecido as participantes pelos avaliadores em todas as tentativas, nos diferentes exercícios (NUNES *et al.*, 2020b). Nas situações cujas tentativas foram executadas com sucesso, a carga foi aumentada para a próxima tentativa (3-10% da tentativa anterior). Por outro lado, nas situações cujas tentativas não foram executadas com sucesso, a carga foi reduzida na mesma proporção. O período de descanso foi de três a cinco minutos entre cada tentativa e cinco minutos entre os exercícios. A carga para a primeira tentativa, na segunda e terceira sessão de testes foi a carga máxima obtida individualmente em cada exercício na sessão anterior. O valor de 1RM em cada exercício foi registrado como a carga mais alta levantada em uma única ação voluntária máxima concêntrica e excêntrica nas três sessões de testes (AMARANTE DO NASCIMENTO *et al.*, 2013). A maioria dos participantes (> 95%) atingiu a carga máxima (1RM) na segunda e terceira sessões. O coeficiente de correlação intraclasse foi satisfatório para supino vertical (0,98), cadeira extensora (0,98) e rosca scott (0,99). A força total foi determinada pela soma do desempenho (kg) nos três exercícios (NUNES *et al.*, 2018).

4.6 Capacidade Funcional

A capacidade funcional foi determinada por meio de dois testes: velocidade de caminhada habitual (W4.6m), e levantar e sentar em uma cadeira durante 30 s (RIKLI; JONES, 2013). Para o teste W4.6m, cada participante percorreu andando (o mais rápido possível, sem correr) uma distância de 8,6 m, sendo que apenas o tempo de cobertura medial de 4,6 m (marcado por fitas adesivas no chão) foi cronometrado, desconsiderando as seções adicionais de 2 m (também marcadas com fitas) antes e depois do percurso estabelecido de 4,6 m. Três tentativas foram realizadas, com o valor médio sendo registrado. Para o teste UPchair30s, cada participante foi inicialmente sentado em uma cadeira (50 cm). Em seguida, a avaliada executou o número máximo de repetições possíveis em 30 s na tarefa de levantar e sentar na cadeira, mantendo os pés totalmente apoiados no chão e braços cruzados sobre o tronco com as mãos apoiadas sob os ombros. Um escore z de aptidão funcional foi determinado pela média da somatória das pontuações alcançadas nos dois testes.

4.7 Pressão Arterial

A avaliação da pressão arterial em repouso foi realizada utilizando-se equipamento automático, oscilométrico Omron, modelo HEM-742INT (Omron Corporation, Kyoto, Kansai, Japão). As participantes compareceram ao laboratório em três dias diferentes e, durante cada visita, permaneceram sentadas por cinco minutos com o manguito posicionado no braço direito em um ambiente calmo e com temperatura entre 20 e 24ºC. Posteriormente, três medidas consecutivas de pressão arterial foram realizadas com intervalos de um minuto entre elas, em três dias não consecutivos, em horário semelhante do dia. A diferença nas leituras de PAS e pressão arterial diastólica (DBP) não diferiu mais do que 4 mmHg. Os procedimentos seguiram as recomendações da American Heart Association (PICKERING *et al.*, 2005). O valor médio entre as medidas obtidas nos diferentes dias foi registrado como valor de referência em cada momento do estudo. A pressão arterial média (PAM) foi calculada pela seguinte equação: PAM = PAD + 1/3 (PAS - PAD).

4.8 Bioquímica Sanguínea

Coletas de sangue foram realizadas por técnicos experientes, nos diferentes momentos do estudo, nas primeiras horas da manhã em uma sala adaptada para este fim, com as participantes respeitando um período de jejum de 12 h. Amostras de 14 ml de sangue venoso foram obtidas na veia antecubital. Para a coleta de sangue as participantes foram mantidas sentadas em uma cadeira, com o antebraço apoiado sobre um suporte localizado aproximadamente na altura dos ombros. Após o braço ser garroteado no ponto médio do úmero, foi realizada assepsia com algodão embebido em álcool 70%. A punção foi realizada com agulha descartável de 25 por 8 mm no referido local. O sangue venoso foi aspirado em um tubo de coleta a vácuo e as agulhas descartadas de forma segura, assim como todos os outros materiais descartáveis contaminados, tanto nos procedimentos de coleta, quanto nas análises sanguíneas, conforme procedimento padrão do laboratório. As amostras foram depositadas em tubos a vácuo, com gel separador sem anticoagulante, e centrifugadas por 10 min a 3000 rpm para separação do soro e plasma. Posteriormente foram determinadas as concentrações de proteína C-reativa ultra-sensível, glicose, colesterol total, lipoproteína de alta densidade (HDL-c) e triglicerídeos. Para a determinação das lipoproteínas de baixa densidade (LDL-c) foi utilizada a seguinte equação (FRIEDEWALD; LEVY; FREDRICKSON, 1972): (LDL-c = CT - HDL-c + triglicerídeos/5). As análises foram realizadas utilizando-se um auto-analisador bioquímico Dimension RXL (Simens Dade Behring Inc., Newark, DE, USA), de acordo com métodos estabelecidos na literatura especializada, seguindo os protocolos recomendados pelo fabricante.

4.9 HÁBITOS ALIMENTARES

O consumo alimentar foi avaliado pelo método recordatório alimentar de 24 h, aplicado em dois dias não consecutivos da semana. Durante a entrevista, foi utilizado um manual fotográfico com o tamanho da porção dos alimentos para melhorar as informações relatadas. As medidas de consumo de alimentos caseiros foram convertidas em gramas e mililitros pelo software online Virtual Nutri Plus (Keeple®, Rio de Janeiro, RJ, Brasil). Alguns alimentos não foram encontrados no banco de dados do programa e, portanto, tais itens foram adicionados de outras tabelas de composição dos alimentos. O programa estatístico métodos de fontes múltiplas (https://msm.dife.de/) foi utilizado para reduzir erros na estimativa do consumo habitual obtido por meio do recordatório alimentar de 24 h. Este programa gera informações sobre a ingestão regular estimada de um indivíduo, a partir da combinação de probabilidades, utilizando repetições de recordatórios alimentares de 24 h ou registros alimentares (HAUBROCK *et al.*, 2011). Todos os participantes foram solicitados a manter sua dieta regular durante todo o período de estudo.

4.10 Treinamento Resistido

Todos os participantes foram submetidos a um programa de TR supervisionado durante o período da manhã, às segundas, quartas e sextas-feiras, nas instalações da Universidade Estadual de Londrina. As participantes foram supervisionadas por profissionais de Educação Física (1-2 supervisores por exercício) com experiência substancial em TR para garantir um desempenho consistente e seguro. O programa de TR foi estruturado para a melhoria da resistência e força muscular da população idosa (AMERICAN COLLEGE OF SPORTS MEDICINE, 2009; GARBER *et al.*, 2011). Oito exercícios para os diferentes segmentos corporais foram executados, a saber: supino vertical, *leg press* horizontal, remada sentada, cadeira extensora, rosca scott (pesos livres), cadeira flexora, tríceps no *pulley* e panturrilha sentado. Todos os exercícios foram realizados em três séries de 10-15 repetições durante as primeiras 12 semanas e três séries de 8-12 repetições nas últimas 12 semanas de TR, com 1-2 min de intervalo de descanso entre as séries e 2-3 min entre os exercícios. As participantes foram instruídas a inspirar durante a ação muscular excêntrica e expirar durante a ação muscular concêntrica, mantendo uma velocidade de movimento em uma razão de 1:2 (ações musculares concêntricas e excêntricas, respectivamente). As cargas de cada exercício foram ajustadas ao longo do estudo, de acordo com a capacidade da participante e a melhoria no condicionamento físico, para a manutenção da intensidade do treinamento, mantendo a técnica adequada de execução de cada exercício. As cargas de treinamento foram ajustadas com base no desempenho individual em cada exercício. Assim, quando os limites superiores da zona de repetição estabelecida foram atingidos por duas sessões consecutivas em todas as séries, o peso foi aumentado de 2-5% para exercícios de membros superiores e 5-10% para exercícios de membros inferiores na próxima sessão de treinamento (AMERICAN COLLEGE OF SPORTS MEDICINE, 2009). Durante todas as sessões de treinamento, os instrutores registraram as cargas e as repetições executadas pelas participantes para cada um dos oito exercícios.

4.11 TRATAMENTO ESTATÍSTICO

A distribuição dos dados foi avaliada pelo teste de Shapiro-Wilk. As participantes foram categorizadas em tercis com base em um escore z composto, incluindo medidas de força em três segmentos (membros superiores, tronco e membros inferiores) e a massa isenta de gordura e osso da região envolvida, tomando como referência os valores obtidos na linha de base. Para tanto, o escore z composto foi obtido pela seguinte equação: [(1RM no supino vertical / MIGO de tronco) z-score + (1RM na cadeira extensora / MIGO de pernas) z-score + (1RM na rosca scott / MIGO de braços) z-score)] / 3. Equações de estimativa generalizadas (GEE) foram utilizadas para comparar os resultados em diferentes momentos do estudo (pré-treinamento vs. pós-treinamento) e entre grupos (tercil inferior vs. médio vs. superior). O teste *post-hoc* de Bonferroni foi utilizado para a localização das diferenças. O modelo adotado apresentou as seguintes características: distribuição normal com função de ligação linear e matriz de covariância não estruturada. O teste de Hotelling T2 pareado foi utilizado para avaliar se as alterações nos vetores médios de impedância bioelétrica do grupo (pré-treinamento e pós-treinamento) foram ou não diferentes de zero (vetor nulo). Uma elipse de confiança de 95%, excluindo o vetor nulo, foi adotada para representar o deslocamento vetorial. O tamanho do efeito (TE) foi calculado pela diferença entre as médias (pós-treinamento - pré-treinamento) dividida pelo desvio padrão agrupado (COHEN, 1988). Um TE < 0,20 foi considerado trivial, 0,20-0,49 foi considerado pequeno, 0,50-0,79 foi considerado moderado e ≥ 0,80 foi considerado grande (COHEN, 1988). O coeficiente de correlação linear de Pearson foi utilizado para determinar a relação entre as diferenças encontradas (pré-treinamento vs. pós-treinamento) entre conjuntos de duas variáveis. Uma correlação ≤ 0,20 foi considerada muito fraca, 0,21-0,40 fraca, 0,41-0,60 moderada, 0,61-0,80 forte e ≥ 0,80 muito forte. Para todas as análises foi aceito um nível de significância $P < 0,05$. Os dados foram processados no pacote IBM SPSS Statistics, v. 23.0 (IBM Corp., Armonk, NY, USA).

5 RESULTADOS

Os resultados do presente estudo foram organizados a partir da redação de três artigos originais. Para análise do efeito de 24 semanas de TR, de acordo com os diferentes níveis de força muscular, as participantes foram categorizadas em tercis, por meio de um escore de força muscular, baseado no desempenho em testes de 1-RM e na massa isenta de gordura e osso, de braços, pernas e tronco, na linha de base da presente investigação.

Os desfechos primários associados ao TR (força muscular, massa muscular e capacidade funcional) foram tratados no primeiro artigo, a partir do desempenho alcançado em testes de 1-RM, testes motores desenvolvidos para a população idosa e da estimativa da massa muscular, por meio de equação específica desenvolvida com base no tecido mole e magro apendicular determinado por DXA. No segundo artigo, componentes da composição corporal e da saúde celular foram analisados a partir das informações produzidas pelo método de impedância bioelétrica. Por fim, o terceiro artigo analisou fatores de risco cardiovascular e a sua associação com a força muscular, com base na gordura corporal total, na distribuição da gordura (androide e ginóide) e no comportamento de biomarcadores metabólicos.

5.1 ARTIGO ORIGINAL 1

Does initial muscle strength dictate the magnitude of morphological and functional adaptations in response to a resistance training program in older women?

Abstract

Muscular strength emerges as one of the main health indicators in the older population. In an attempt to understand how and what is the role of strength in other related-health factors, we compared the effects of initial muscular strength on the magnitude of morphological and functional adaptations and responsiveness in response to resistance training (RT) in older women. Ninety-nine physically independent women (> 60 years old) were submitted to RT (eight exercises for lower limbs, trunk, and upper limbs) in three weekly sessions for 24 weeks. Muscular strength (one-repetition maximum), skeletal muscle mass, muscle quality index, and functional fitness were measured at baseline and after 24 weeks of intervention. The participants were analyzed according to the tertiles for baseline muscular strength into three groups: LOW (lower), MED (medium), and UPP (upper). The magnitude of the improvements was similar for almost all outcomes independent of the strength tertile. The only difference in the magnitude of the changes was in the muscular endurance, which was more significant in the LOW (ES = 0.78) than the UPP (ES = 0.12). Besides, inter-individual variability of responses to RT was not explained by initial muscular strength scores ($R^2 \leq 18\%$). From a general overview, the improvements induced by RT in older women are not affected by the initial strength levels. Thus, our results suggest that gains in muscular strength and muscle mass, and improvements in the functional fitness occur similarly independently of initial muscular strength level in older women.

Keywords: strength training, responsiveness, muscle hypertrophy, aging.

Resumo

A força muscular surge como um dos principais indicadores de saúde da população idosa. Na tentativa de entender como e qual é o papel da força em outros fatores relacionados à saúde, comparamos os efeitos da força muscular inicial sobre a magnitude das adaptações morfológicas e funcionais e a responsividade ao treinamento resistido (TR) em idosas. Noventa e nove mulheres fisicamente independentes (> 60 anos) foram submetidas ao TR (oito exercícios para membros inferiores, tronco e membros superiores), em três sessões semanais, durante 24 semanas. A força muscular (uma repetição máxima), massa muscular esquelética, índice de qualidade muscular e capacidade funcional foram avaliados na linha de base e após 24 semanas de intervenção. Os participantes foram analisados de acordo com os tercis de força muscular na linha de base, em três grupos: BAIXO (inferior), MED (médio) e UPP (superior). A magnitude das melhorias foi semelhante para a maioria dos resultados, independente dos grupos. A única diferença na magnitude das alterações foi na resistência muscular, que foi mais significativa no LOW (ES = 0,78) do que na UPP (ES = 0,12). Além disso, a variabilidade interindividual das respostas ao TR não foi explicada pelos escores iniciais de força muscular ($R^2 \leq 18\%$). Do ponto de vista geral, as melhorias induzidas pelo TR em mulheres idosas não foram afetadas pelos níveis iniciais de força. Assim, nossos resultados sugerem que os ganhos de força muscular e massa muscular, e melhoria na capacidade funcional ocorrem de forma semelhante independente do nível inicial de força muscular em mulheres idosas.

Palavras-chave: treinamento de força, responsividade, hipertrofia muscular, envelhecimento.

Introduction

The body of literature has shown many studies relating to muscular strength to different health markers (BUCKNER *et al.*, 2017). For instance, high levels of strength are associated with a lower risk of death from all causes (BUCKNER *et al.*, 2017). In older adults, muscular strength has a positive relationship with physical independence, functional capacity, and daily living activities, resulting in a better quality of life (MANINI; CLARK, 2012). One of the main exercises suggested to optimize this capacity is resistance training (RT) (AMERICAN COLLEGE OF SPORTS MEDICINE, 2009). Although many researchers have been concerned with better understanding which RT strategies influence chronic responses on muscle mass and functional capacity (DIB *et al.*, 2020; SANTOS *et al.*, 2017), it is essential to note that the condition before training (level of training, the period of experience, and ability to generate strength) can play a fundamental role in these responses (BURLEY *et al.*, 2018).

It seems that weaker individuals have advantages in neuromuscular responses when they are submitted to an RT program. That is, the gains appear to be more pronounced when compared to stronger subjects (AMERICAN COLLEGE OF SPORTS MEDICINE, 2009; BUCKNER *et al.*, 2019). Furthermore, little is known whether muscle strength can also influence the magnitude of long-term gains (BURLEY *et al.*, 2018; MANGINE *et al.*, 2018). Burley *et al.* (2018) showed that individuals located in the lower quartile (25%) presented a more significant increase in maximum strength (one-repetition maximum) and localized muscular endurance (repetitions maximum) when compared to individuals in the upper quartile (75%). Notably, the study previously mentioned was carried out with trained young recruits of both sexes. Besides, the training program was composed of different modalities, given the military training regime. Thus, the extrapolation of results is restricted.

Concerning muscle mass, some authors claim a contributory relationship between exercise-induced hypertrophy and muscle strength (TABER *et al.*, 2019).

However, whether there is a relationship in the opposite direction or initial strength levels affect the magnitude of hypertrophy, still unknown. Furthermore, as well as muscular strength responses to RT, there is heterogeneity in the extent of muscle mass gains (NUNES *et al.*, 2020a). Thus, it is important to investigate possible factors that may influence hypertrophic responses, once skeletal muscle plays a fundamental role in some health parameters, such as the production of anti-inflammatory cytokines, reduction of resistance to insulin (TOMELERI *et al.*, 2016), besides affects the contractile function of a muscle group, reducing the force and ability of the muscle to contract (CLARK; MANINI, 2008).

Changes from aging occur in an integrated way. In other words, as well as quantity, muscle quality is also affected, and these events influence the functionality of older individuals (FRAGALA; KENNY; KUCHEL, 2015). Several phenomena occur within the muscle individually, such as the reduction in the number and size of muscle fibers (mainly type II fibers) (LEXELL; TAYLOR; SJÖSTRÖM, 1988), increased levels of pro-inflammatory cytokines that impair protein synthesis (LANG *et al.*, 2002), in addition to the increase in the number of lysosomes in the cell muscle that facilitates protein breakdown (SCELSI; MARCHETTI; POGGI, 1980). Together, these findings direct the older individual to reduce functional capacity (FRAGALA; KENNY; KUCHEL, 2015). Although various investigations have analyzed the influence of RT on these parameters, to the best of our knowledge, no study has tested whether initial strength levels can influence different aspects of health (strength, hypertrophy, and muscle quality, as well as functional fitness) over the long-term in older women.

Considering that the initial levels of muscle strength can affect the chronic responses of the strength itself (MANGINE *et al.*, 2018), as well as other aspects related to health, this study aimed to compare the magnitude of gains in muscle strength, muscle mass, muscle quality, functional capacity, and responsiveness of untrained older women, divided into tertiles (lower, medium, and upper) based on baseline strength levels. Our initial hypothesis was that the older women allocated to the lower tertile (weaker in the baseline) would experience more significant gains in all variables analyzed than their peers with higher muscle strength levels.

Methods

Experimental design

The present study is part of the research project "Active Aging Longitudinal Study", initiated in 2012, whose purpose is to analyze the effects of supervised, structured, and progressive RT programs on neuromuscular, morphological, physiological, metabolic, and cognitive outcomes in older women. The current data was obtained from two cohorts (2015 and 2018) that followed a similar experimental protocol over 30 weeks, with six weeks allocated for tests, measurements, and evaluations and 24 weeks dedicated to the training program. Muscular strength, anthropometric, body composition, and functional fitness tests were carried out in weeks 1-3 and 28-30. Dietary intake was assessed in two first and two last weeks of intervention (weeks 4-5 and 26-27). The RT program was performed over weeks 4-27. Participants were instructed to keep their physical activity and dietary habits and not engage in any other systematized physical exercise program.

Participants

Recruitment was carried out through newspapers, television, radio advertisements, and home delivery of flyers in the central city and residential neighborhoods. Interested subjects completed detailed health history questionnaires and were subsequently admitted to the study if they met the following inclusion criteria: ≥ 60 years old; female; physically independent; had no cardiac, orthopedic, or musculoskeletal dysfunction that could impede physical exercise; not having uncontrolled diabetes mellitus or hypertension; not receiving hormonal replacement therapy, and not be involved in the practice of regular physical activity performed more than once a week over the three months before the start of the study. Subsequently, subjects should present release from a cardiologist (resting 12-lead electrocardiogram test, personal interview, and treadmill stress test when deemed necessary) to practice RT without restriction. One-hundred thirty-four women (2015-cohort = 61, 2018-cohort = 72) that met initial inclusion criteria and completed pre-training tests started the RT program and 99 accomplished the whole study (2015-cohort = 45, 2018-cohort = 54; age = 69 ± 6 years; body mass = 66 ± 12 kg; stature = 155 ± 6 cm; body mass index = 27 ± 4 kg/m²). Drop-outs were related to personal reasons, traveling, health problems or surgeries not related to RT practice, and lack of time.

Participants were divided into tertiles according to their relative performance on strength tests pre-training period. Lower (LOW), medium (MED), and upper (UPP) tertile-groups comprised 33 participants each. Based on data from previous studies (BORDE; HORTOBAGYI; GRANACHER, 2015), we adopted a priori sample size for the F test (within-between interaction) was calculated using G*Power (version 3.1.9.7, Universität Kiel, Germany). Based on a statistical power (1–β error probability) of 0.80, an effect size F = 0.27, and an overall α level of 0.05, a group sample size of 30 individuals were required for this study. Written informed consent was obtained from all subjects after providing a detailed description of the study procedures. This study was conducted according to the Declaration of Helsinki, and University Ethics Committee approved the experimental procedures.

Procedures

Anthropometry

Body mass was measured to the nearest 0.1 kg using a calibrated electronic scale Balmak, model Class III (Balmak Indústria e Comércio Ltda, Santa Bárbara d'Oeste, SP, Brazil), and height was measured to the nearest 0.1 cm with a stadiometer attached to the scale, according to the procedures described in the literature (GORDON; CHUMLEA; ROCHE, 1988). All participants wore light workout clothing and no shoes during the measurements. Body mass index (BMI) was calculated as body mass in kilograms divided by the square of height in meters.

Muscular strength

The maximum dynamic strength was evaluated using 1RM tests assessed on the chest press, leg extension, and preacher curl exercises, in this order. One familiarization session and three 1RM test sessions were performed in the morning, separated by 48-72 hours. The participants performed 2-3 sets of 10-15 repetitions in each exercise with a light load for the familiarization session. Three experienced researchers supervised all sessions to ensure the safety and integrity of the participants. The execution technique of each exercise was standardized and continuously monitored to ensure the reliability of the measurements. For each test session, the participants performed a specific warm-up (6-10 repetitions) in each exercise, with approximately 50% of the first attempt's estimated load. On the first day of testing, the selected load was based on the researchers' experience and the perception of the difficulty (effort) in which the subjects underwent heating. During the 1RM tests, the participants were encouraged to perform two repetitions with the selected load. Verbal encouragement, accompanied by applause, the participants were provided by the evaluators in all attempts in the different exercises (NUNES *et al.*, 2020b). In situations whose attempts were successfully executed, the load was increased to the next attempt (3-10% of the previous attempt). On the other hand, in situations whose attempts were not successfully executed, the load was reduced in the same proportion. The rest period was three to five minutes between each attempt and five minutes between the exercises. The load for the first attempt in the second and third test session was the maximum load obtained individually in each exercise in the previous session. The value of 1RM for each exercise was recorded as the highest load lifting in a concentric and eccentric maximal voluntary action in the three test sessions (AMARANTE DO NASCIMENTO *et al.*, 2013). Most participants (> 95%) maximum load (1RM) in the second and third sessions. The intraclass correlation coefficient was satisfactory for chest press (0.98), leg extension (0.98), and preacher curl (0.99). The total strength was determined by the sum of performance (kg) in the three exercises (NUNES *et al.*, 2019).

Muscle mass and muscle quality index

Dual-energy X-ray absorptiometry exams were used to determining trunk (TRLST), upper (ULLST), and lower limbs lean soft tissue (LLLST) in Lunar Prodigy advice, model NRL 419900 (GE Lunar, Madison, WI, USA). The sum of ULLST and LLLST was used for determining the appendicular lean soft tissue (ALST). Skeletal muscle mass (SMM) was estimated by the following equation (KIM *et al.*, 2004): SMM = [(ALST*1.18) - (age*0.03) - 0.14]. Participants were instructed to remove all objects containing metal previously to scanning. Participants were asked to urinate about 30 min before testing, abstain from ingesting food or drink in the last four hours before testing, avoid strenuous physical exercise for at least 24 h before testing, refrain from the consumption of alcoholic and caffeinated beverages for at least 48 h before testing, and avoid the use of diuretics for at least seven days before testing. Scans were performed with the subjects lying supine along the table’s longitudinal centerline axis. Feet were taped together at the toes to immobilize the legs, and hands were maintained in a pronated position within the scanning region. Equipment calibration followed the manufacturer's recommendations. The software generated standard lines that segmented the limbs from trunk and head, arranged using specific anatomical points determined by the manufacturer. The same skilled laboratory technician carried out calibrations, line adjustments, and analyses. Previous test-retest scans in 13 subjects conferred satisfactory reliability for TRLST, ULLST, LLLST, and skeletal muscle mass (ICCs ≥ 0.98). The muscle quality index was determined by the ratio between total strength and total body skeletal muscle mass (NUNES *et al.*, 2019).

Functional fitness

The functional fitness was determined through the following two tests: habitual walking speed (W4.6m), and stand up from a chair for 30 s (UPchair30s) (RIKLI; JONES, 2013). For the W4.6m test, each subject should walk (as fast as possible, without running) a distance of 8.6 m, whereby only the time taken to cover the medial 4.6 m (marked by adhesive tapes on the floor) was timed, disregard the additional 2-m sections (also marked with tapes) before and after the 4.6-m measurement course. Three attempts were performed, and the mean was considered. For the UPchair30s test, each subject was initially seated on a chair (50 cm), with feet fully resting on the floor and arms crossed over the shoulders, then should perform maximum repetitions of standing wholly upright and sitting for 30 s. An evaluator timed the test and counted the number of repetitions performed. An overall functional fitness z-score was created by the average mean of the two z-scores of the tests' performance. The overall training effect on functional fitness was analyzed as the simple mean of the percentage pre-to-post training changes of the analyzed tests. The changes were multiplied by -1, because negative alterations represent better results. Thus, a positive overall change is observed with positive scores.

Dietary intake

Food consumption was assessed by the 24-h dietary recall method applied on two non-consecutive days of the week. During the interview, a photographic manual of food portion size was used to improve the information reported. The homemade food consumption measurements were converted into grams and milliliters by online software Virtual Nutri Plus (Keeple®, Rio de Janeiro, RJ, Brazil). Some foods were not found in the program database, and therefore several items were added from other food tables. The multiple source method (https://msm.dife.de/) statistical program was used to reduce errors in estimating habitual consumption obtained through the 24 h dietary recall, which is a new statistical method to estimate usual food consumption. This program generates information regarding the estimated regular intake of an individual, from the combination of probabilities, using repetitions of 24 h dietary recall or food records (HAUBROCK *et al.*, 2011). All participants were requested to maintain their regular diet throughout the study period.

Resistance training program

All participants were submitted to a supervised RT program during the morning hours, on Mondays, Wednesdays, and Fridays in the University facilities. Participants were personally supervised by Physical Education professionals (1-2 supervisors per exercise) with substantial RT experience to ensure consistent and safe exercise performance. A whole-body RT program to improve muscle endurance and muscular strength in older adults was used in this study (AMERICAN COLLEGE OF SPORTS MEDICINE, 2009; GARBER *et al.*, 2011). Eight exercises (chest press, horizontal leg press, seated row, leg extension, preacher curl, leg curl, triceps pushdown, and seated calf raise) were performed in three sets of 10–15 repetitions over the first 12-week RT and 8-12 repetitions in the last 12-week, with rest of 1-2 min between sets and 2-3 min between each exercise. Participants were instructed to inhale during the eccentric muscle action and exhale during the concentric muscle action while maintaining a movement velocity at a ratio of 1:2 (concentric and eccentric muscle actions, respectively). The training load for each exercise was adjusted according to the participant's ability and improvements throughout the study to ensure that they were exercising with as much resistance as possible while maintaining proper exercise execution techniques. Thus, when the repetitions zone's upper limit was reached for two consecutive sessions, weight was increased 2-5% for upper limb exercises and 5-10% for lower limb exercises in the next training session (AMERICAN COLLEGE OF SPORTS MEDICINE, 2009).

Statistical analyses

The data distribution was check by the Shapiro-Wilk test. Missing values were imputed with intention-to-treat analyses. The scores were calculated from multiple linear regressions using the previous time-points, body mass index, and age as covariates. Subjects were categorized into tertiles based on a composite z-score created by the simple mean of the three relative 1RM-strength measures (strength score divided by the lean soft tissue of the body region involved) obtained at pre-training, as follows: [(chest press 1RM / TRLST) z-score + (leg extension 1RM / LLLST) z-score + (preacher curl 1RM / ULLST) z-score)] / 3. Generalized estimation equation (GEE) was performed to compare the outcomes within different time-points (pre-training vs. post-training) and between tertile-groups (LOW vs. MED vs. UPP), and to compare the absolute training change scores (pre-to-post) between groups tertile-groups (LOW vs. MED vs. UPP). Bonferroni posthoc was used to identify the differences when Wald X^2 reached significance. The model adopted had the following characteristics: normal distribution with linear link function and unstructured covariance matrix. Effect size (ES) was calculated as the current time-point mean minus previous time-point mean divided by the pooled previous time-point standard deviation (COHEN, 1988). An ES of 0.00-0.19 was considered trivial, 0.20-0.49 was considered small, 0.50-0.79 was considered moderate, and ≥ 0.80 was considered large (COHEN, 1988). Pearson's r was performed to determine the relationship between the pre-training strength z-score with the percentage change-scores of the outcomes. Correlations of 0.00-0.20 were considered very weak, 0.21-0.40 as weak, 0.41-0.60 as moderate, 0.61-0.80 as strong, and ≥ 0.80 as very strong. For all analyses, a $P < 0.05$ was accepted as statistically significant. The data were expressed as mean, standard deviation, and 95% confidence intervals (CI). The data were analyzed using IBM SPSS Statistics, v. 23.0 (IBM Corp., Armonk, NY, USA).

Results

The general characteristics of the sample at baseline, according to tertiles, are presented in Table 1. Significant differences ($P < 0.05$) were observed between groups for some variables. In general, the UPP group participants were younger, and LOW presented higher body mass, BMI, and muscle mass than their peers. There were observed differences between groups for strength due to tertile stratification into groups based on the baseline relative strength scores (LOW < MED < UPP). However, almost no difference ($P < 0.05$) was observed between groups for functional fitness measures.

Table 1. General characteristics of the participants at baseline.

Variables	**LOW (n = 33)**	**MED (n = 33)**	**UPP (n = 33)**	***P-value***
Age (years)	70.2 ± 6.0	70.4 ± 6.6	65.2 ± 4.5*†	< 0.001
Body mass (kg)	72.6 ± 11.9	62.9 ± 10.7*	61.7 ± 9.8*	< 0.001
Height (cm)	156.7 ± 5.7	155.2 ± 6.0	153.4 ± 5.9	0.08
BMI (kg/m²)	29.5 ± 4.3	26.1 ± 4.1*	26.2 ± 3.6*	< 0.01
SMM (%)	24.7 ± 2.2	25.6 ± 3.3	26.2 ± 3.4	0.09

LOW = lower tertile for muscular strength, MED = middle tertile for muscular strength, UPP = upper tertile for muscular strength, BMI = body mass index, SMM = skeletal muscle mass. *$P < 0.05$ vs. LOW. †$P < 0.05$ vs. MED. Data are presented as mean ± standard deviation.

Total energy and macronutrients intake data are presented in Table 2. No time vs. tertile effects was observed, whereas UPP had significantly higher energy, carbohydrate, and lipid intake compared to LOW ($P < 0.05$).

Table 2. Energy and macronutrients intake of the participants during the study period.

Variables	**LOW (n = 33)**	**MED (n = 33)**	**UPP (n = 33)**	***Effect***	***P-value***
Energy (kcal/kg/d)				Group	< 0.001
Pre	22.9 ± 4.3	25.4 ± 4.8	28.2 ± 5.1	Time	< 0.01
Post	23.6 ± 4.6	26.4 ± 5.3	29.9 ± 5.5	Interaction	0.86
Protein (g/kg/d)				Group	0.02
Pre	0.9 ± 0.2	1.0 ± 0.2	1.1 ± 0.2	Time	< 0.01
Post	1.0 ± 0.2	1.1 ± 0.2	1.1 ± 0.2	Interaction	0.93
Carbohydrate (g/kg/d)				Group	< 0.01
Pre	3.0 ± 0.7	3.3 ± 0.7	3.8 ± 0.7	Time	< 0.001
Post	3.1 ± 0.7	3.4 ± 0.7	3.9 ± 0.7	Interaction	0.79
Lipid (g/kg/d)				Group	0.30
Pre	0.7 ± 0.1	0.8 ± 0.2	0.9 ± 0.2	Time	< 0.001
Post	0.7 ± 0.1	0.9 ± 0.2	0.9 ± 0.2	Interaction	0.28

LOW = lower tertile for muscular strength, MED = middle tertile for muscular strength, UPP = upper tertile for muscular strength. *$P<0.05$ vs. LOW. Data are presented as mean ± standard deviation.

Results concerning muscular strength and mass are presented in Table 3, while functional fitness scores are shown in Table 4. In Table 3 and 4, there are presented the raw data which were interpreted from GEE time vs. tertile effects. Moreover, the change-score data were shown in Table 5, analyzed from GEE comparing tertile effects. This latter analysis is essential in the current experiment because groups were intentionally different at baseline for some variables. Thus, besides the use of time vs. tertile-GEE to identify whether the groups' scores continued different in each time-point (e.g., whether LOW improved in strength to the point to not be different to MED and UPP in the post), tertile-GEE was used to identify whether or not the magnitude of changes from training (pre-to-post) were different between groups. The 24-week training effects were of large magnitude for muscular strength tests, small for muscle mass, and trivial-to-small for functional fitness tests. Figure 1 pictured the main results and the correlations between the pre-training relative strength z-score with the outcomes' change-scores.

Table 3. Muscular strength and muscle mass of the older women during the study period.

	LOW (n = 33)	**MED (n = 33)**	**UPP (n = 33)**	***Effect***	***P-value***
Chest press 1RM (kg)				Group	< 0.001
Pre	40.2 ± 7.4	41.9 ± 6.0	47.8 ± 7.5	Time	< 0.001
Post	53.4 ± 11.8*	59.4 ± 12.5*	64.4 ± 13.3*	Interaction	0.27
Leg extension 1RM (kg)				Group	< 0.001
Pre	47.0 ± 11.1	51.7 ± 11.4	62.4 ± 11.3	Time	< 0.001
Post	60.7 ± 13.9*	68.9 ± 13.1*	76.2 ± 12.0*	Interaction	< 0.001
Preacher curl 1RM (kg)				Group	< 0.01
Pre	21.4 ± 4.9	22.7 ± 4.8	24.5 ± 4.0	Time	< 0.01
Post	24.3 ± 4.6*	26.7 ± 4.8*	28.0 ± 4.5*	Interaction	0.36
Upper limbs LST (kg)				Group	0.11
Pre	4.0 ± 0.7	3.7 ± 0.6	3.7 ± 0.6	Time	< 0.001
Post	4.2 ± 0.8*	4.0 ± 0.7*	3.9 ± 0.5*	Interaction	0.12
Lower limbs LST (kg)				Group	< 0.01
Pre	13.0 ± 1.8	11.7 ± 1.4	11.6 ± 1.6	Time	< 0.001
Post	13.3 ± 1.9*	12.1 ± 1.6*	12.1 ± 1.7*	Interaction	0.16
Trunk LST (kg)				Group	< 0.001
Pre	19.9 ± 2.5	17.8 ± 2.1	17.3 ± 1.8	Time	< 0.001
Post	20.0 ± 2.6	18.2 ± 2.2*	17.7 ± 2.0*	Interaction	0.08
SMM (kg)				Group	< 0.01
Pre	17.8 ± 2.8	15.9 ± 2.4	16.0 ± 2.5	Time	< 0.001
Post	18.4 ± 3.0*	16.7 ± 2.6*	16.9 ± 2.6*	Interaction	0.07
MQI (kg/kg)				Group	< 0.001
Pre	6.1 ± 0.6	7.3 ± 0.6	8.5 ± 0.8	Time	< 0.001
Post	7.6 ± 1.1*	9.3 ± 1.3*	10.1 ± 1.3*	Interaction	< 0.001

LOW = lower tertile for muscular strength, MED = middle tertile for muscular strength, UPP = upper tertile for muscular strength, SMM = skeletal muscle mass, MQI = muscle quality index. *$P < 0.05$ vs. pre. Data are presented as mean ± standard deviation.

Table 4. Functional fitness of the older women during the study period.

Variables	**LOW (n = 33)**	**MED (n = 33)**	**UPP (n = 33)**	***Effect***	***P-value***
W4.6m (s)				Group	0.06
Pre	3.6 ± 0.5	3.3 ± 0.4	3.4 ± 0.5	Time	0.36
Post	3.6 ± 0.5	3.3 ± 0.4	3.2 ± 0.4	Interaction	< 0.05
UPchair30s (reps)				Group	< 0.001
Pre	11.1 ± 2.2	13.2 ± 1.7	14.1 ± 1.8	Time	< 0.001
Post	12.8 ± 1.8*	14.7 ± 1.3*	14.4 ± 1.1	Interaction	< 0.001

LOW = lower tertile for muscular strength, MED = middle tertile for muscular strength, UPP = upper tertile for muscular strength, W4.6m = habitual walking speed, UPchair30s = stand up from a chair for 30 s. **P* < 0.05 vs. pre. Data are presented as mean ± standard deviation.

Table 5. Relative change scores of muscular strength, muscle mass, and functional fitness between baseline and post-training in older women.

Variables	**LOW (n = 33)**	**MED (n = 33)**	**UPP (n = 33)**	***P-value***
Chest press 1RM	34.6 (25.8/43.3)	42.0 (33.9/50.1)	35.1 (28.7/41.6)	0.35
Leg extension 1RM	30.4 (24.1/36.8)	36.5 (27.1/45.9)	23.1 (19.0/27.2)†	< 0.05
Preacher curl 1RM	14.9 (11.3/18.6)	18.9 (14.6/23.2)	15.0 (11.9/18.2)	0.29
Upper limbs LST	4.1 (2.1/6.1)	6.5 (5.1/8.0)	6.5 (5.2/7.9)	0.11
Lower limbs LST	2.5 (1.0/4.0)	3.8 (2.6/5.1)	4.4 (3.1/5.6)	0.16
Trunk LST	0.5 (-0.9/1.9)	2.3 (1.1/3.5)	2.2 (1.2/3.3)	0.09
Skeletal muscle mass	0.6 (0.3/0.8)	0.8 (0.6/1.0)	0.9 (0.7/1.1)	0.21
Muscle quality index	24.1 (20.2/28.2)	27.3 (23.4/31.2)	18.9 (15.9/21.9)†	< 0.01
W4.6m	2.8 (-3.4/9.1)	0.3 (-2.5/3.2)	-4.8 (-8.5/-1.0)	< 0.05
UPchair30s	19.1 (10.5/27.7)	12.6 (6.1/19.2)	3.2 (-2.3/8.7)*	< 0.01
Overall functiona fitness	3.6 (1.7/5.5)	2.3 (0.7/3.9)	0.8 (-1.1/2.6)	0.12

LOW = lower tertile for muscular strength, MED = middle tertile for muscular strength, UPP = upper tertile for muscular strength, 1RM = one-repetition maximum, LST = lean soft tissue, W4.6m = habitual walking speed, UPchair30s = stand up from a chair for 30 s. **P* < 0.05 vs. LOW and †*P* < 0.05 vs. MED. Data are presented as mean (lower/upper limits of the 95% Wald confidence intervals).

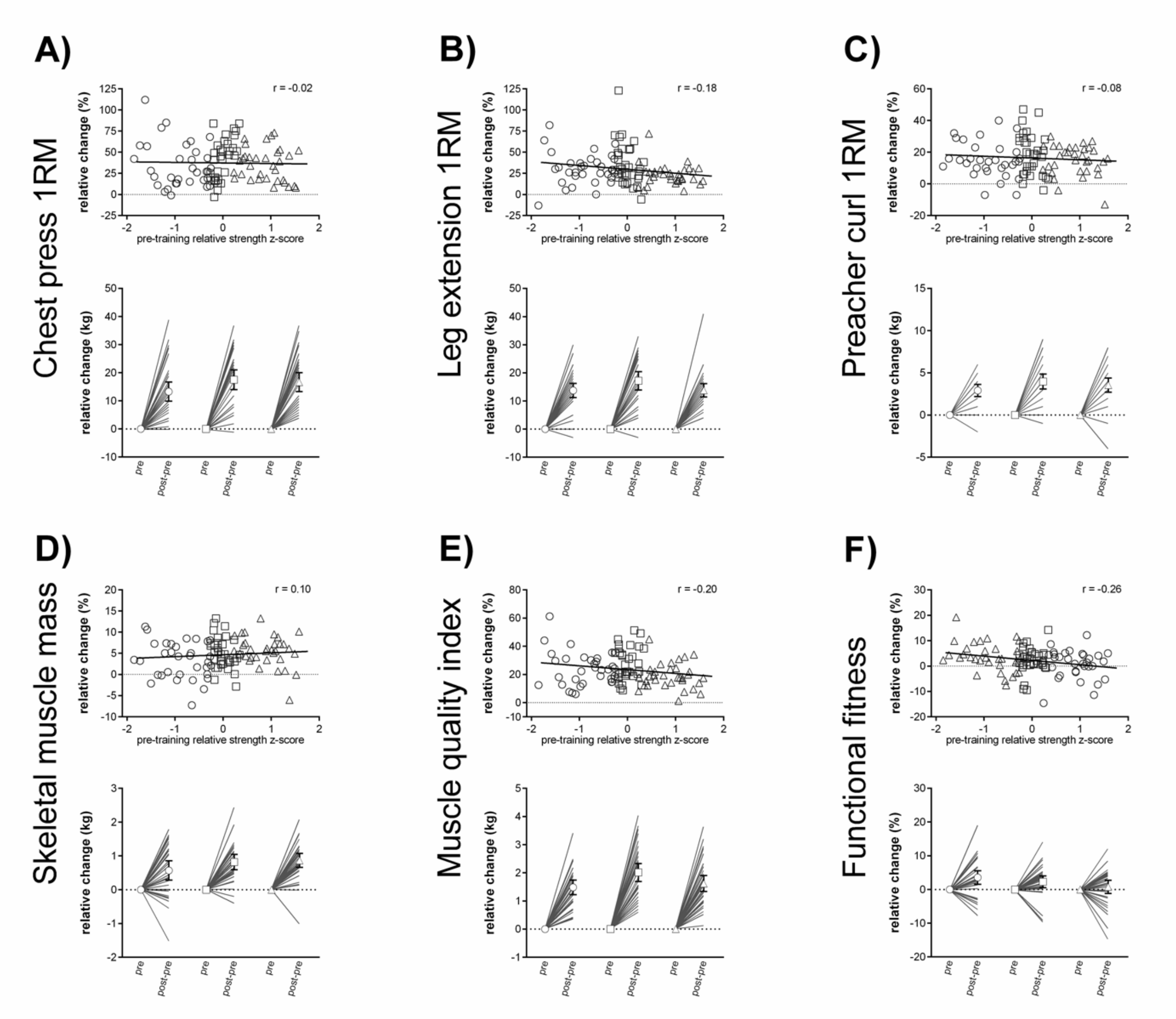

Figure 1. Correlations between the pre-training relative strength z-score with the percentage change-scores of the outcomes and individual training effects on muscular strength, muscle mass, and functional fitness in older women (n = 99). LOW = lower tertile for muscular strength, MED = middle tertile for muscular strength, UPP = upper tertile for muscular strength. Data of the lower graphs of each panel are mean and 95% confidence intervals. ◯ = LOW; □ = MED; Δ = UPP.

For chest press 1RM, UPP had greater scores compared to LOW and MED at baseline; at the post, UPP was different only compared to LOW, but not to MED, indicating that subjects from MED had improvements which were in magnitude so that the strength level became similar to the UPP group. LOW and MED was not different at post ($P > 0.05$). All groups significantly improved ($P < 0.05$) chest press 1RM from pre-to-post, and changes were of large magnitude (ES: LOW = 1.73; MED = 2.29; UPP = 2.18). For leg extension 1RM, UPP had greater scores compared to LOW and MED at baseline; at the post, UPP was different only compared to LOW, but not to MED, indicating that subjects from MED had improvements which were in magnitude so that the strength level became similar to the UPP group. LOW and MED was not different at post ($P > 0.05$). All groups significantly improved ($P < 0.05$)

leg extension 1RM from pre-to-post, and changes were of large magnitude (ES: LOW = 1.07; MED = 1.33; UPP = 1.07). For preacher curl 1RM, groups were not different at baseline; at the post, UPP had greater scores compared to LOW, but not to MED, indicating that UPP improvements were in magnitude so that the strength level became different to LOW. All groups significantly improved ($P < 0.05$) preacher curl 1RM from pre-to-post, and changes were of moderate magnitude (ES: LOW = 0.62; MED = 0.85; UPP = 0.75).

No significant difference was observed between groups ($P > 0.05$) for the change-scores following the training period for all 1RM-strength variables (Table 5). In line with this, Pearson's *r* indicated non-significant weak correlations between the pre-training overall relative strength z-score and the changes in 1RM on chest press ($r = -0.02$; $P = 0.833$), leg extension ($r = -0.18$; $P = 0.079$), and preacher curl ($r = -0.08$; $P = 0.420$) exercises (Figure 1).

For upper limb LST, groups were not different at baseline, nor the post. LOW, MED, and UPP significantly improved ($P < 0.05$) upper limbs LST from pre-to-post, and changes were of small magnitude (ES: LOW = 0.26; MED = 0.38; UPP = 0.37). For lower limbs LST, at baseline, UPP and MED had less mass compared to LOW ($P < 0.05$). However, such differences were not present at the post. LOW, MED, and UPP significantly improved ($P < 0.05$) lower limbs LST from pre-to-post, and changes were of small magnitude (ES: LOW = 0.19; MED = 0.26; UPP = 0.29). For trunk LST, at baseline and post, UPP and MED had less mass compared to LOW ($P < 0.05$). MED, and UPP significantly improved ($P < 0.05$) trunk LST from pre-to-post, while LOW showed no change on it (ES: LOW = 0.04; MED = 0.17; UPP = 0.16). For skeletal muscle mass, at baseline MED was different from LOW. However, such a difference was not present at the post. LOW, MED, and UPP significantly improved ($P < 0.05$) skeletal muscle mass, and changes were of small magnitude (ES: LOW = 0.21; MED = 0.30; UPP = 0.32). At baseline, UPP had greater scores for muscle quality index compare to LOW and MED, and MED had greater scores compare to LOW. At the post, MED and UPP continued to have greater scores compared to LOW, indicating similar training effects on muscle quality index between LOW, MED, and UPP. All groups significantly improved ($P < 0.05$) muscle quality index from pre-to-post, and changes were of large magnitude (ES: LOW = 1.25; MED = 1.70; UPP = 1.37).

No significant difference was observed between groups ($P > 0.05$) for the change-scores following the training period for all muscle mass variables (Table 5). In line with this, Pearson's *r* indicated non-significant weak correlations between the pre-training overall relative strength z-score and the changes in upper limbs LST ($r = 0.16$; $P = 0.124$), lower limbs LST ($r = 0.05$; $P = 0.594$), trunk LST ($r = 0.09$; $P = 0.375$), skeletal muscle mass ($r = 0.10$; $P = 0.342$), and muscle quality index ($r = -0.20$; $P = 0.053$).

No difference between tertiles was observed at pre and post for W10m ($P > 0.05$). For UPchair30s a main effect of time was observed ($P < 0.05$) with effects of moderate magnitude for LOW and MED (ES: LOW = 0.78; MED = 0.65) and trivial for UPP (ES = 0.12). In Figure 1, Pearson's *r* indicated non-significant correlations between the pre-training overall relative strength z-score and the changes in W4.6m ($r = -0.33$; $P = 0.016$) and UPchair30s ($r = -0.43$; $P = 0.001$), and the functional fitness overall z-score ($r = -0.05$; $P = 0.654$; Figure 1).

Discussion

The main findings of the present investigation were: (a) the magnitude of the changes in muscular strength after 24 weeks of RT were similar for all exercises evaluated among the older women who composed the three tertiles; (b) the same happened for the LST of lower, upper limbs, trunk, and total muscle mass, after 24 weeks of RT the tertiles did not differ for any of the LST and muscle mass measurements; (c) the improvements in the muscle quality index and functional capacity—except for the local muscular endurance—among older women with different initial strength levels were similar after 24 weeks of RT; (d) finally, there was non-significant to weak relationships between the strength scores in the initial condition and the magnitude of the responses of all outcomes assessed in the present study. These findings differ from our hypotheses, as the older women improved similarly regardless of the initial muscular strength level.

Although the practice of RT is well established as an effective strategy to promote improvements, the inter-individual responses appear to be heterogeneous, with some subjects presenting responses of lower magnitude (CHMELO *et al.*, 2015; CHURCHWARD-VENNE *et al.*, 2015). The explanations for this variability in adaptations remain elusive (PICKERING; KIELY, 2019), and muscular strength appears as a candidate for mediators. In this context, we sought to better understand the possible role of initial muscular strength levels in responses to RT. We observed that increases in muscular strength occurred in a similar magnitude among tertiles. These findings are reinforced by an absence or weak relationship ($r \leq$ -0.43) between initial strength levels and adaptive responses; together their indicate that initial strength levels do not influence muscular strength gains after 24 weeks of RT. These findings are in contrast to earlier studies with young participants that found more significant strength gains in subjects from the lower quartile (weaker) when compared to the upper quartile (stronger) (BURLEY *et al.*, 2018; MANGINE *et al.*, 2018). In this sense, even previously strong elderly women continue to increase strength substantially and similarly to their weak counterparts, which does not occur in young subjects (BURLEY *et al.*, 2018; MANGINE *et al.*, 2018).

Concerning muscle mass, the older women belonging to the three strength tertiles benefited similarly. The strength in the baseline did not present a relationship with the magnitude of muscle hypertrophy. A possible explanation for these findings may be the similar strength gains observed in the three tertiles. This increase in strength allows a continuous progression of the stress imposed on the muscles in each RT session (KRAEMER; RATAMESS, 2004), culminating in similar increases in muscle mass among the tertiles. In fact, training progression (e.g., increased overload, volume) appears to play an essential role in muscle hypertrophy (SCARPELLI *et al.*, 2020). Therefore, similarly to strength, muscle mass gains were not explained by the initial strength score, suggesting that other factors may be prevalent in determining the magnitude of responses to RT in older women (NUNES *et al.*, 2020a). From a general perspective, the benefits of strength and muscle mass granted to older women do not seem to differ due to strength in the baseline.

Another crucial aspect for the older population is the maintenance/improvement of functional fitness, which involves performing tasks such as sitting and standing and walking. In the present study, we did not observe any differences between the strength tertiles in two of the present study's four tests. More precisely, the LOW group improved the performance on UPchair30s more when compared to UPP (ES: LOW = 0.78, UPP = 0.12). In this sense, our findings suggest that the older women who composed, the lower tertile had a more significant adaptation window for localized muscular endurance. The improvements found in our study were trivial to small, corroborating with previous studies also carried out with older women (DIB *et al.*, 2020; SANTOS *et al.*, 2017). Therefore, suggesting that RT not only maintains but improves functional fitness for over six months. Although we have observed small effects, it is essential to note that even maintaining these components is an objective to be achieved, since the reduction of functional capacity is a process imbricated with aging (MANINI; CLARK, 2012). Our results can be explained, at least in part, because the sample of the present study comprises physically independent older women without musculoskeletal limitations and that already had satisfactory levels of physical function (DIB *et al.*, 2020; SANTOS *et al.*, 2017).

To our best knowledge, this was the first investigation with older women that verified if the magnitude of the changes occurs similarly between strong and weak older women after 24-weeks of RT. Besides, monitoring of eating habits and supervised training sessions strengthen the internal consistency. However, our study is not free of limitations. Some points should be considered in the interpretation and extrapolation of our findings, such as not quantifying the level of physical activity and sedentary behavior. Therefore, we could not accurately verify the possible role of these factors in our findings. Finally, participants were without training for a few months. However, we are not aware of how much experience they may have had before entering this study.

From a general overview, the RT-induced improvements in older women are not affected by the initial strength levels. Precisely, the magnitude of muscular strength changes will occur similarly among older women with different levels of muscular strength. On the other hand, older women who are initially weaker show greater localized muscular endurance improvements than their strong counterparts. It is important to note that the older women's upper tertiles' occupants will remain stronger when compared to their weak counterparts after 24-weeks of RT. Another inference from our findings is on responsiveness; the variability of inter-individual responses does not seem to explain the initial condition in older women. Together, these findings have important clinical implications. It is possible to infer that it is more important to pay attention to the changes over time of the same older woman regardless of previous muscular strength, to the detriment of reference values for muscular strength that might confer a protective effect against comorbidities and premature death.

Conclusion

Our results suggest that gains in muscular strength and muscle mass and, consequently, improvements in the functional fitness occur similarly independently of initial muscular strength level in older women.

5.2 ARTIGO ORIGINAL 2

Effects of different muscular strength levels on hydration and cellular integrity after 24-week resistance training in older women: Active Aging Longitudinal Study

Abstract

This study aimed to compare the effects of resistance training on hydration and phase angle (PhA) in older women with different muscular strength levels. Ninety-nine physically independent women (> 60 years old) were submitted to resistance training (eight exercises for lower limbs, trunk, and upper limbs) in three weekly sessions for 24 weeks. Muscular strength (1-RM tests) and body composition (bioelectric impedance) were obtained at baseline and after 24 weeks of intervention. The baseline muscular strength was categorized into tertiles (low, middle, and high strength) and the results found were compared between the three groups. A significant ($P < 0.05$) increase in PhA was observed in all groups. There were improvements in body composition (skeletal muscle mass and intracellular water) following 24 weeks of RT. Our results suggest that RT-induced increase in phase angle seems to occur independently of initial strength level in older women.

Keywords: strength training, bioelectrical impedance analysis, aging.

Resumo

Este estudo teve como objetivo comparar os efeitos do treinamento resistido sobre a hidratação e o ângulo de fase (PhA) em idosas com diferentes níveis de força muscular. Noventa e nove mulheres fisicamente independentes (> 60 anos) foram submetidas ao treinamento resistido (oito exercícios para membros inferiores, tronco e membros superiores), em três sessões semanais, durante 24 semanas. A força muscular (testes de 1-RM) e a composição corporal (impedância bioelétrica) foram obtidas na linha de base e após 24 semanas de intervenção. A força muscular da linha de base foi categorizada em tercis (baixa, média e alta força) e os resultados encontrados foram comparados entre os três grupos. Observou-se aumento significante ($P < 0,05$) no PhA em todos os grupos. Houve melhorias na composição corporal (massa muscular esquelética e água intracelular) após 24 semanas de TR ($P < 0,05$). Nossos resultados sugerem que o aumento induzido pelo TR no ângulo de fase parece ocorrer independentemente do nível inicial de força em mulheres idosas.

Palavras-chave: treinamento de força, análise de impedância bioelétrica, envelhecimento.

Introduction

Phase angle (PhA) is considered a cellular health parameter, with higher values indicating better cellular integrity and cell function (NORMAN *et al.*, 2012; SARDINHA, 2018). Higher PhA suggests a larger quantity of intact cell membranes, whereas lower PhA suggests cell death or decreased cell integrity (SELBERG; SELBERG, 2002). PhA has been used to predict functionality (MATIAS *et al.*, 2020), nutritional status (LUKASKI; KYLE; KONDRUP, 2017), disease prognosis (STOBAUS *et al.*, 2012), oxidative stress (TOMELERI *et al.*, 2018b), sarcopenia (BASILE *et al.*, 2014), and mortality risk (NORMAN *et al.*, 2015; WILHELM-LEEN *et al.*, 2014). The PhA is obtained from the bioimpedance parameters reactance (Xc) of tissues representing cell size and integrity of the cell membranes and resistance (R) of tissues, which is affected by hydration (XU *et al.*, 2016), thus providing a simple, non-invasive and inexpensive approach to estimate cellular health.

PhA has been widely used to monitor health cellular integrity in the older population, since older individuals present lower scores of PhA compared to young adults, with older women showing the lowest values (BOSY-WESTPHAL *et al.*, 2006; SARAGAT *et al.*, 2014). Moreover, the age-related body composition changes, such as reduced skeletal muscle mass and increased body fat, may influence parameters resulting in PhA decreases (BASILE *et al.*, 2014; MARINI *et al.*, 2012). On the other hand, resistance training (RT) is a modality of physical exercise that induces benefit changes in skeletal muscle tissue, which is one of the potential strategies to reverse and improve the adverse effects of aging on cellular integrity and function (CUNHA *et al.*, 2018).

Further than the well-established positive effects of RT in muscle mass and muscular strength, several investigations have shown improvements in PhA following RT (RIBEIRO *et al.*, 2020; TOMELERI *et al.*, 2018a). However, more recently, the analysis of individual variation in response to exercise has attracted the attention of the scientific community, since some researchers have reported a high heterogeneity in inter-individual responses in longitudinal experiments (CHMELO *et al.*, 2015). The average response of 4.8 ± 6.1% in muscle mass gain due to participation in resistance exercise programs was found in a recent meta-analysis (AHTIAINEN *et al.*, 2016). Therefore, there is the possibility of individuals who present adaptations due to the RT and individuals who do not have any change resulting from the intervention (BOUCHARD *et al.*, 2012; HECKSTEDEN *et al.*, 2015). Although the reasons why some individuals are non-responsive to RT are still not well established in the literature, it is believed that several factors such as genetic aspects, age, diet, comorbidities, and other lifestyle factors may be involved with this phenomenon (BUFORD; ROBERTS; CHURCH, 2013; STEPHENS; SPARKS, 2015). Nevertheless, there is a relationship between baseline scores of PhA and the percentage change from pre-training to post-training in PhA (RIBEIRO *et al.*, 2018), and considering a good association between PhA and muscular parameters (NORMAN *et al.*, 2015; NUNES *et al.*, 2019), the responsiveness of PhA due to RT may be affected by initial levels of muscular strength.

Therefore, the main purpose of this investigation was to compare the effects of RT on hydration and PhA in older women with different muscular strength levels. We hypothesized that the increases in hydration and PhA would be affected by muscular strength levels. The rationale for this hypothesis was based on the correlation between muscular-fitness parameters and PhA that is a viable indicator of muscular strength, muscle quality, and physical functionality (NORMAN *et al.*, 2015; NUNES *et al.*, 2019).

Methods

Experimental design

The present study is part of the research project “Active Aging Longitudinal Study”, initiated in 2012, whose purpose is to analyze the effects of supervised, structured, and progressive RT programs on neuromuscular, morphological, physiological, metabolic, and cognitive outcomes in older women. The current data was obtained from two cohorts (2015 and 2018) that followed a similar experimental protocol over 30 weeks, with six weeks allocated for tests, measurements, and evaluations and 24 weeks dedicated to the training program. Measures of anthropometry, muscular strength and body composition were carried out in weeks 1-3 and 28-30. Dietary intake was assessed in two first and two last weeks of intervention (weeks 4-5 and 26-27). The RT program was performed over weeks 4-27, and training volume was monitored over time. Participants were instructed to keep their physical activity and dietary habits and not engage in any other systematized physical exercise program. This study was conducted according to the Declaration of Helsinki, and University Ethics Committee approved the experimental procedures.

Participants

Recruitment was carried out through newspapers, television, radio advertisements, and home delivery of flyers in the central city and residential neighborhoods. Interested subjects completed detailed health history questionnaires and were subsequently admitted to the study if they met the following inclusion criteria: ≥ 60 years old; female; physically independent; had no cardiac, orthopedic, or musculoskeletal dysfunction that could impede physical exercise; not having uncontrolled diabetes mellitus or hypertension; not receiving hormonal replacement therapy, and not be involved in the practice of regular physical activity performed more than once a week over the three months before the start of the study. Subsequently, subjects should present release from a cardiologist (resting 12-lead electrocardiogram test, personal interview, and treadmill stress test when deemed necessary) to practice RT without restriction. One-hundred thirty-four women (2015-cohort = 61, 2018-cohort = 72) that met initial inclusion criteria and completed pre-training tests started the RT program and 99 accomplished the whole study (2015-cohort = 45, 2018-cohort = 54; age = 69 ± 6 years; body mass = 66 ± 12 kg; height = 155 ± 6 cm; body mass index = 27 ± 4 kg/m²). Drop-outs were related to personal reasons, traveling, health problems or surgeries not related to RT practice, and lack of time.

Participants were divided into tertiles according to their relative performance on muscular strength tests in the baseline. Lower (LOW), medium (MED), and upper (UPP) tertile-groups comprised 33 subjects each. We adopted a priori sample size for the F test (within-between interaction), calculated using G*Power (version 3.1.9.7, Universität Kiel, Germany). Based on a statistical power (1–β error probability) of 0.80, an effect size F = 0.27, and an overall α level of 0.05, a group sample size of 30 individuals were required for this study. Written informed consent was obtained from all subjects after providing a detailed description of the study procedures. No adverse event occurred during the intervention period.

Procedures

Anthropometry

Body mass was measured to the nearest 0.1 kg using a calibrated electronic scale Balmak, model Class III (Balmak Indústria e Comércio Ltda, Santa Bárbara d'Oeste, SP, Brazil), and height was measured to the nearest 0.1 cm with a stadiometer attached to the scale, according to the procedures described in the literature (GORDON; CHUMLEA; ROCHE, 1988). All participants wore light workout clothing and no shoes during the measurements. Body mass index (BMI) was calculated as body mass in kilograms divided by the square of height in meters.

Body composition

Spectral bioelectrical impedance analyzer (Xitron Hydra, model 4200, Xitron Technologies, San Diego, CA, USA) was used to estimate total body water (TBW), intracellular water (ICW), extracellular water, resistance (R), and reactance (Xc). Subsequently, the phase angle (PhA) was calculated as arctangent (Xc/R) × 180°/π (NORMAN *et al.*, 2012). All spectral bioelectrical impedance measurements were conducted from 6:00 a.m. to 9:00 a.m. Before measurement, participants removed all objects containing metal from their bodies. Measurements were performed on a table isolated from electrical conductors. Participants were lying supine along the table's longitudinal centerline axis, legs abducted at an angle of 45° relative to the body midline, and hands pronated. After cleaning the skin with alcohol, two electrodes were placed on the right hand's surface and two on the right foot following procedures previously described (SARDINHA *et al.*, 1998). Participants were in the lying supine position for 10 min before obtaining the bioelectrical impedance measurements. Participants were instructed to urinate about 30 min before testing, abstain from ingesting food or drink in the last four hours before testing, avoid strenuous physical exercise for at least 24 h before testing, refrain from the consumption of alcoholic and caffeinated beverages for at least 48 h before testing, and avoid the use of diuretics for at least seven days before testing. According to the manufacturer's recommendations, the spectral bioelectrical impedance equipment was calibrated before testing the first participant, each day. The same professional performed all the measures of the sample.

Dietary intake

Food consumption was assessed by the 24-h dietary recall method applied on two non-consecutive days of the week. During the interview, a photographic manual of food portion size was used to improve the information reported. The homemade food consumption measurements were converted into grams and milliliters by online software Virtual Nutri Plus (Keeple®, Rio de Janeiro, RJ, Brazil). Some foods were not found in the program database, and therefore several items were added from other food tables. The multiple source method (https://msm.dife.de/) statistical program was used to reduce errors in estimating habitual consumption obtained through the 24 h dietary recall, which is a new statistical method to estimate usual food consumption. This program generates information regarding the estimated regular intake of an individual, from the combination of probabilities, using repetitions of 24 h dietary recall or food records (HAUBROCK *et al.*, 2011). All participants were requested to maintain their regular diet throughout the study period.

Muscular strength

The maximum dynamic strength was evaluated using 1RM tests assessed on the chest press, leg extension, and preacher curl exercises, in this order. One familiarization session and three 1RM test sessions were performed in the morning, separated by 48-72 hours. The participants performed 2-3 sets of 10-15 repetitions in each exercise with a light load for the familiarization session. Three experienced researchers supervised all sessions to ensure the safety and integrity of the participants. The execution technique of each exercise was standardized and continuously monitored to ensure the reliability of the measurements. For each test session, the participants performed a specific warm-up (6-10 repetitions) in each exercise, with approximately 50% of the first attempt's estimated load. On the first day of testing, the selected load was based on the researchers' experience and the perception of the difficulty (effort) in which the subjects underwent heating. During the 1RM tests, the participants were encouraged to perform two repetitions with the selected load. Verbal encouragement, accompanied by applause, the participants were provided by the evaluators in all attempts in the different exercises (NUNES *et al.*, 2020b). In situations whose attempts were successfully executed, the load was increased to the next attempt (3-10% of the previous attempt). On the other hand, in situations whose attempts were not successfully executed, the load was reduced in the same proportion. The rest period was three to five minutes between each attempt and five minutes between the exercises. The load for the first attempt in the second and third test session was the maximum load obtained individually in each exercise in the previous session. The value of 1RM for each exercise was recorded as the highest load lifting in a concentric and eccentric maximal voluntary action in the three test sessions (AMARANTE DO NASCIMENTO *et al.*, 2013). Most participants (> 95%) maximum load (1RM) in the second and third sessions. The intraclass correlation coefficient was satisfactory for chest press (0.98), leg extension (0.98), and preacher curl (0.99).

Resistance training program

All participants were submitted to a supervised RT program during the morning hours, on Mondays, Wednesdays, and Fridays in the University facilities. Participants were personally supervised by Physical Education professionals (1-2 supervisors per exercise) with substantial RT experience to ensure consistent and safe exercise performance. A whole-body RT program to improve muscle endurance and muscular strength in older adults was used in this study (AMERICAN COLLEGE OF SPORTS MEDICINE, 2009; GARBER *et al.*, 2011). Eight exercises (chest press, horizontal leg press, seated row, leg extension, preacher curl, leg curl, triceps pushdown, and seated calf raise) were performed in three sets of 10–15 repetitions over the first 12-week RT and 8-12 repetitions in the last 12-week, with rest of 1-2 min between sets and 2-3 min between each exercise. Participants were instructed to inhale during the eccentric muscle action and exhale during the concentric muscle action while maintaining a movement velocity at a ratio of 1:2 (concentric and eccentric muscle actions, respectively). The training load for each exercise was adjusted according to the participant's ability and improvements throughout the study to ensure that they were exercising with as much resistance as possible while maintaining proper exercise execution techniques. Thus, when the repetitions zone's upper limit was reached for two consecutive sessions, weight was increased 2-5% for upper limb exercises and 5-10% for lower limb exercises in the next training session (AMERICAN COLLEGE OF SPORTS MEDICINE, 2009).

Statistical analyses

The normality of the data was check by the Shapiro-Wilk test. Subjects were categorized into tertiles based on a composite z-score created by the simple mean of the three relative 1RM-strength measures (i.e., strength value divided by the LST of the body region involved) obtained at pre-training, as follows: [(chest press 1RM / TRLST) z-score + (leg extension 1RM / LLLST) z-score + (preacher curl 1RM / ULLST) z-score)] / 3. Generalized estimation equation (GEE) was performed to compare the outcomes within different time-points (pre-training vs. post-training) and between tertile-groups (LOW vs. MED vs. UPP). Bonferroni post hoc test was adopted when significant effects on group, time, or interaction were confirmed. The paired one-sample Hotelling T2-test was used to evaluate if the changes in the mean group vectors (pre-training vs. post-training) were significantly different from zero (null vector); a 95% confidence ellipse excluding the null vector indicated a significant vector displacement. Effect size (ES) was calculated as the current time-point mean minus previous time-point mean divided by the pooled previous time-point standard deviation (COHEN, 1988). An ES of 0.00-0.19 was considered trivial, 0.20-0.49 was considered small, 0.50-0.79 was considered moderate, and ≥ 0.80 was considered large (COHEN, 1988). For all statistical analyses, statistical significance was established at $P < 0.05$. The data were expressed as mean, standard deviation, and 95% confidence intervals (CI). The data were analyzed using IBM SPSS Statistics, v. 23.0 (IBM Corp., Armonk, NY, USA).

Results

The total energy and macronutrient intake are presented in Table 6, according to tertiles groups. There was a significant ($P < 0.05$) group by time interaction for protein and energy intake, where LOW and MED presented an increase from pre- to post-training. There is a time effect for carbohydrates and lipids.

Table 6. Energy and macronutrients intake of the participants during the study period.

Variables	**LOW (n = 33)**	**MED (n = 33)**	**UPP (n = 33)**	***Effect***	***P-value***
Energy (kcal/kg/d)				Group	< 0.001
Pre	22.9 ± 4.3	25.4 ± 4.8	28.2 ± 5.1	Time	< 0.01
Post	23.6 ± 4.6	26.4 ± 5.3	29.9 ± 5.5	Interaction	0.86
Protein (g/kg/d)				Group	0.02
Pre	0.9 ± 0.2	1.0 ± 0.2	1.1 ± 0.2	Time	< 0.01
Post	1.0 ± 0.2	1.1 ± 0.2	1.1 ± 0.2	Interaction	0.93
Carbohydrate (g/kg/d)				Group	< 0.01
Pre	3.0 ± 0.7	3.3 ± 0.7	3.8 ± 0.7	Time	< 0.001

Variables	LOW (n = 33)	MED (n = 33)	UPP (n = 33)	*Effect*	*P-value*
Post	3.1 ± 0.7	3.4 ± 0.7	3.9 ± 0.7	Interaction	0.79
Lipid (g/kg/d)				Group	0.30
Pre	0.7 ± 0.1	0.8 ± 0.2	0.9 ± 0.2	Time	< 0.001
Post	0.7 ± 0.1	0.9 ± 0.2	0.9 ± 0.2	Interaction	0.28

LOW = lower tertile for muscular strength, MED = middle tertile for muscular strength, UPP = upper tertile for muscular strength. *P<0.05 vs. LOW. Data are presented as mean ± standard deviation.

The values for the analyzed outcomes according to groups at pre- and post-training intervention are shown in Table 7. There was no group by time interaction for any variable investigated ($P > 0.05$). There was a main effect ($P < 0.05$) of time for TBW, ICW, R, and PhA, with all these variables presenting changed values at post-training compared to pre-training. For body mass, ECW, and Xc, no effect of time was observed ($P > 0.05$).

Table 7. Impedance bioelectrical measures to groups at pre- and post-training.

Variables		LOW (n = 33)	MED (n = 33)	UPP (n = 33)	*Effect*	*P-value*
Body Mass (kg)	Pre	72.6 ± 11.9	62.9 ± 10.7	61.7 ± 9.8	Group	< 0.001
	Post	72.7 ± 12.6	63.0 ± 11.1	62.3 ± 10.1	Time	0.17
	ES	0.01	0.01	0.06	Interaction	0.41
TBW (L)	Pre	32.0 ± 3.1	29.2 ± 3.5	29.5 ± 2.9	Group	< 0.001
	Post	32.6 ± 3.9*	29.8 ± 3.7*	29.9 ± 3.2*	Time	< 0.01
	ES	0.19	0.17	0.14	Interaction	0.93
ICW (L)	Pre	23.3 ± 2.4	21.3 ± 2.9	21.6 ± 2.4	Group	< 0.01
	Post	23.8 ± 2.9*	21.8 ± 3.0*	22.0 ± 2.7*	Time	< 0.01
	ES	0.21	0.17	0.17	Interaction	0.93
ECW (L)	Pre	8.7 ± 0.9	7.9 ± 0.7	7.9 ± 0.7	Group	< 0.001
	Post	8.8 ± 1.0	8.0 ± 0.8	7.9 ± 0.6	Time	0.34
	ES	0.11	0.14	0.01	Interaction	0.96
R (Ohm)	Pre	550.3 ± 56.8	591.0 ± 55.2	564.6 ± 59.4	Group	< 0.01
	Post	534.5 ± 61.0	572.0 ± 55.9	550.5 ± 59.9	Time	< 0.001
	ES	-0.28	-0.34	-0.24	Interaction	0.88
R/H (Ohm/m)	Pre	351.4 ± 36.9	381.6 ± 42.2	368.2 ± 38.5	Group	< 0.01
	Post	342.3 ± 41.0	370.4 ± 41.5	360.7 ± 39.3	Time	< 0.001
	ES	-0.25	-0.27	-0.19	Interaction	0.82
Xc (Ohm)	Pre	49.0 ± 9.1	56.3 ± 6.0	56.3 ± 7.0	Group	<

Variables		LOW (n = 33)	MED (n = 33)	UPP (n = 33)	*Effect*	*P-value*
						0.001
	Post	48.7 ± 8.2	56.0 ± 6.7	56.9 ± 5.7	Time	0.95
	ES	-0.03	-0.05	0.09	Interaction	0.39
Xc/H (Ohm/m)	Pre	31.3 ± 5.9	36.4 ± 4.5	36.7 ± 4.8	Group	< 0.001
	Post	31.2 ± 5.3	36.3 ± 5.0	37.3 ± 4.3	Time	0.79
	ES	-0.02	-0.02	0.13	Interaction	0.66
PhA (degrees)	Pre	5.08 ± 0.7	5.45 ± 0.5	5.70 ± 0.5	Group	< 0.001
	Post	5.22 ± 0.7*	5.59 ± 0.5*	5.91 ± 0.4*	Time	< 0.001
	ES	0.20	0.28	0.42	Interaction	0.72

LOW = lower tertile for muscular strength, MED = middle tertile for muscular strength, UPP = upper tertile for muscular strength, ECW = extracellular body water, ICW = intracellular body water, PhA = phase angle, R = resistance, R/H = resistance/height, TBW = total body water, Xc = reactance, Xc/H = reactance/height. *$P < 0.05$ vs. pre. Data are presented as mean ± standard deviation.

The mean differences in R/H and Xc/H vectors with 95% confidence ellipses by groups are presented in Figure 2. Significant differences were observed in the MED and UPP groups ($P < 0.05$).

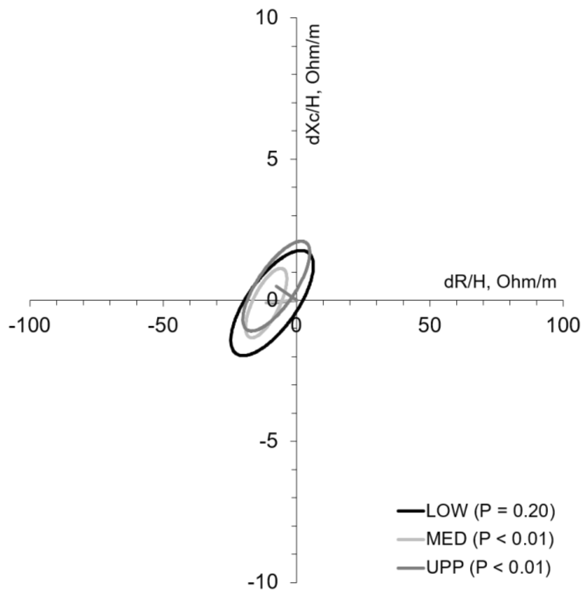

Figure 2. Mean difference vector displacement with the 95% confidence ellipses of the differences for LOW, MED, and UPP groups. LOW = lower tertile for muscular strength, MED = middle tertile for muscular strength, UPP = upper tertile for muscular strength.

Discussion

The main finding of this experiment is that the responsiveness of PhA to RT seems not dependent on older women's strength levels. We hypothesized that the increases in PhA would be affected by baseline strength level. The rationale for this hypothesis was based on a correlation between muscular-fitness parameters and PhA. A growing body of evidence shows that PhA is an indicator of muscular strength, muscle quality, and physical functionality (CUNHA *et al.*, 2018; MATIAS *et al.*, 2020; NORMAN *et al.*, 2015; NUNES *et al.*, 2019; TOMELERI *et al.*, 2019). PhA may represent cell integrity, represented by Xc, that would hypothetically translate into a higher capacity to produce muscular strength. Moreover, the changes observed in PhA following RT are negatively associated with baseline scores, which is the greatest responsiveness in PhA being in those with a lower PhA at baseline (RIBEIRO *et al.*, 2018). Based on this supposition, it is convincible that the different muscular strength levels may elicit distinct improvements in PhA following RT. However, contrary to our hypothesis, all groups presented similar increases in PhA following 24 weeks of RT. This result suggests that a possible ceiling effect was not reached even in the stronger groups. A period longer than 24 may be necessary to achieve a plateau of adaptation for PhA.

To the best of our knowledge, this is the first study investigating the responsiveness of PhA following RT according to strength levels. Thus, no direct comparison can be made with the current literature. Nevertheless, De Oliveira Silva *et al.* (2018) compared the effects of RT on the muscular strength of older women with and without sarcopenic obesity. Results suggest that adaptations induced by 16 weeks of RT are attenuated in older women with sarcopenic obesity. Vasconcelos *et al.* (2016) also reported that older women with sarcopenic obesity showed no improvements in knee extensor strength after 15 weeks of RT. Moreover, Ribeiro *et al.* (2018) observed a correlation between baseline scores of PhA and the percentage change from pre-training to post-training in PhA, so it would be expected that the women in the weakest groups achieved more significant improvements. Still, contrary to this supposition, these groups did not present a higher increase. The lack of difference among groups is not readily apparent but may be related to some factors. Aging is characterized by several impairments in neuromuscular systems, particularly low force generation, heightened inflammation pathways, abnormal protein turnover, and attenuated anabolic signaling. Thus, all these abnormalities may impair exercise adaptations mitigating gains in muscle function (NILSSON *et al.*, 2013; RIVAS *et al.*, 2012). For example, aging is also associated with low-grade inflammation, characterized by increased concentrations of inflammatory mediators such as interleukin-6, tumor necrosis factor-alpha (TILG; MOSCHEN, 2006). These inflammatory biomarkers may affect contractile properties impairing the neuromuscular junction function (GONZALEZ-FREIRE *et al.*, 2014; REID; LI, 2001), and considering that there is a good body of evidence showing that the overproduction of inflammatory biomarkers is associated with reducing muscular strength at older ages (CESARI *et al.*, 2004; SOUSA *et al.*, 2016) and that the changes in PhA due RT seem to be related to changes in inflammatory markers (BEBERASHVILI *et al.*, 2016; TOMELERI *et al.*, 2018a) is feasible to argue that participants could have higher levels of inflammation biomarkers thereby presenting more difficult to increase PhA. Furthermore, aging is also related to other factors that also affect the PhA and reduces the anabolic environment, such as metabolic diseases (NORMAN *et al.*, 2012; STOBAUS *et al.*, 2012), malnutrition (DE FRANÇA *et al.*, 2016; ZHANG *et al.*, 2014), and oxidative stress (TOMELERI *et al.*, 2018a, 2018b; ZOURIDAKIS *et al.*, 2016).

Despite the absence of group by time interaction, there was an effect of time where all groups presented an increase in PhA. Several experiments have already shown that PhA can be improved by RT (FUKUDA *et al.*, 2016; SOUZA *et al.*, 2017; TOMELERI *et al.*, 2018a). The physiological mechanisms by which RT improves PhA are not entirely understood but may be attributed to some known factors.

Because Xc and R determine PhA, any alteration in cellular membrane integrity (Xc) or body fluid (R) or a combination of both results in PhA changes; therefore, the found differences may be related to body composition changes. For example, SMM is a highly hydrated tissue having higher conductivity; thus, an increase in SMM would reflect on increased conductivity, which may at least in part explain the reduction observed in bioimpedance R after the intervention period. Moreover, results revealed an increase in ICW, enhancing conductivity, and reducing R, contributing to a higher PhA. It can be speculated that the rise in ICW was due, at least in part, to an increase in muscle tissue, which is a well-hydrated tissue. An increase in ICW in older women after a period of RT has been reported previously (RIBEIRO *et al.*, 2017, 2018, 2020). However, our results did not indicate any significant changes in

Xc. This lack of changes from a statistical probability standpoint in these variables is not readily apparent.

The present study showed that RT resulted in a significant increase in ICW. This result agrees with previous investigations (RIBEIRO *et al.*, 2017, 2020). The rise in ICW may be related to several factors, although a definitive mechanism explaining the ICW increase is still unclear. However, we can speculate on some possibilities. Cellular hydration is maximized by exercise that relies heavily on anaerobic glycolysis, due to the resulting lactate accumulation acting as a primary contributor to osmotic changes in skeletal muscle (ADAMS; SALTIN; SJOGAARD, 1985; FRIGERI *et al.*, 1998). RT can elicit cellular hydration by increasing glycogen storage (MACDOUGALL *et al.*, 1977) since each gram of glycogen is stored with 3.2 g of water (CHAN *et al.*, 1982). Furthermore, muscle mass is a well-hydrated tissue; thus, an increase in muscle mass will increase total intramuscular fluid (HUBBARD *et al.*, 1975; WANG *et al.*, 1993).

This investigation had some limitations. First, our findings should not be extrapolated to populations other than obese older women and are limited to the training length, intensity, and volume investigated. We could not monitor physical activity levels outside of the investigation environment, which may have confounded results. Finally, dietary intake was not controlled during the experiment, hindering our ability to determine whether nutritional changes occurred across the study period.

Conclusion

Our results suggest that RT-induced increase in phase angle seems to occur independently of initial strength level in older women.

5.3 ARTIGO ORIGINAL 3

The role of muscular strength on cardiovascular risk factors in older women

Abstract

Strength muscular is an essential component for functional capacity enhanced by resistance training in older adults. However, the role of strength muscular on cardiovascular risk factors is not yet well established. Therefore, the purpose of this study was to investigate whether muscular strength level influences changes in cardiovascular risk factors after 24-week resistance training. Ninety-nine physically independent women (> 60 years old) were submitted to resistance training (eight exercises for lower limbs, trunk, and upper limbs) in three weekly sessions for 24 weeks. Total and regional body fat (android and gynoid), blood biomarkers (glucose, triglycerides, total cholesterol, HDL-c, LDL-c, C-reactive protein), blood pressure, and waist-hip ratio were measured at baseline and after 24 weeks of intervention. The baseline muscular strength was categorized into tertiles (low, middle, and high strength) and the results found were compared between the three groups. An interaction group vs. time ($P < 0.05$) revealed a higher muscular strength increase in the group with high muscular strength levels. After 24 weeks of RT, the magnitude of the responses found was similar for total- and regional body fat, glucose, total cholesterol, HDL-c, LDL-c, C reactive-protein, and blood pressure independently muscular strength levels. Our results suggest that muscular strength levels in the baseline do not seem to influence chronic adaptations to resistance training regarding cardiovascular risk factors in older women.

Keywords: force; strength training; elderly; heath´s woman.

Resumo

A força muscular é um componente essencial para a capacidade funcional que pode ser melhorada pelo treinamento resistido em idosos. No entanto, o papel da força muscular nos fatores de risco cardiovasculares ainda não está bem estabelecido. Assim, o objetivo deste estudo foi investigar se o nível de força muscular influencia ou não as mudanças nos fatores de risco cardiovasculares após 24 semanas de treinamento resistido. Noventa e nove mulheres fisicamente independentes (> 60 anos) foram submetidas ao treinamento resistido (oito exercícios para membros inferiores, tronco e membros superiores), em três sessões semanais, durante 24 semanas. Gordura corporal total e regional (androide e ginoide), biomarcadores sanguíneos (glicose, triglicérides, colesterol total, HDL-c, LDL-c, proteína C-reativa), pressão arterial e relação cintura-quadril foram obtidas na linha de base e após 24 semanas de intervenção. A força muscular da linha de base foi categorizada em tercis (baixa, média e alta força) e os resultados encontrados foram comparados entre os três grupos. Uma interação grupo vs. tempo ($P < 0,05$) revelou um aumento de força muscular maior no grupo com altos níveis de força muscular. Após 24 semanas de TR, a magnitude das respostas encontradas foi semelhante para gordura corporal total e regional, glicose, colesterol total, HDL-c, LDL-c, C reativa-proteína, pressão arterial e relação cintura-quadril independentemente dos níveis de força muscular. Nossos resultados sugerem que os níveis de força muscular na linha de base não parecem influenciar as adaptações crônicas ao treinamento resistido com relação aos fatores de risco cardiovasculares em mulheres idosas.

Palavras-chave: força, treinamento de força, idosos, saúde da mulher.

Introduction

Muscular strength is an essential component of physical fitness that contributes to sports and physical activity and the performance of several activities of daily life (HAFF; TRIPLETT, 2015). Lower muscular strength levels explain the accelerated decline in functional capacity (i.e., walking, chair stand, and balance) (BAHAT *et al.*, 2019), and is associated with a higher risk of mortality (ALEGRE *et al.*, 2015). In contrast, higher muscular strength levels are also related to reduced C-reactive protein (VOLAKLIS *et al.*, 2015), total cholesterol (BOAREDLY *et al.*, 2002), and systolic blood pressure (SBP) (HURLBUT *et al.*, 1999). Indeed, stronger older adults may have protective factors for several disorders, such as hypertension, dyslipidemia, among other metabolic diseases (FERREIRA *et al.*, 2016). In this regard, higher muscular strength seems to be particularly more important for older women because they generally have lower muscular strength levels than older men (BRADY; EVANS; STRAIGHT, 2015).

Besides, the link between women aging and body fat excess is key to developing metabolic risk factors, such as dyslipidemia, insulin resistance, and elevated blood pressure (PFEILSCHIFTER *et al.*, 2002; ZHANG *et al.*, 2008). Moreover, abdominal body fat excess (i.e., visceral adiposity) and high C-reactive protein are associated with cardiovascular diseases (FRANCESCHI *et al.*, 2000), which are the major cause of death globally (BURINI *et al.*, 2020). Although excess body fat is negatively associated with muscular strength (MOORE *et al.*, 2020), it is not certain whether different muscular strength levels might affect body fat deposits and distribution changes in older women. Regarding this, two well-accepted types of body fat distribution include android and gynoid regions (MATSUZAWA et al., 1992). A cohort study recently reported that body fat excess in the gynoid region is associated with a greater incidence of falls than total body fat in older women (NERI et al., 2020). Noteworthy, it has been reported that higher concentrations of trunk body fat, waist circumference, and the higher ratio between android and gynoid regions are associated with the risk of mortality in older women (TANNE et al., 2005; TOSS et al., 2012). Thus, preventing higher concentrations of body fat distribution and metabolic biomarkers and elevated blood pressure with advancing age may blunt chronic diseases in older women.

Resistance training (RT) has been recommended as an efficient and safe strategy to increase muscular strength and improve body fat, metabolic biomarkers, and blood pressure in older women (CUNHA et al., 2019; FRAGALA et al., 2019; SARDELI et al., 2018). However, some adaptative responses to RT seem to be time-dependent (MARTINS *et al.*, 2010). For instance, a recent meta-analysis revealed improving in some metabolic biomarkers only in longer interventions than 12 weeks (SARDELI *et al.*, 2018). Nevertheless, other studies have reported changes after 12-

week RT or only after 24-week RT on muscular strength, muscle mass, body fat, and metabolic biomarkers, especially in the elderly (LEITE *et al.*, 2015, 2019; PINA *et al.*, 2020a, 2020b).

Considering that muscular strength gain is the primary adaptation to RT, the magnitude of this increase may depend on initial strength levels. Two studies reported more significant muscular strength increases in participants occupying the lower muscular strength level (weaker) than, the stronger (BURLEY *et al.*, 2018; MANGINE *et al.*, 2018). Indeed, these findings allow us to believe that different muscular strength levels may influence, at least in part, the magnitude of the RT-induced adaptations.

No previous studies have tested whether different muscular strength levels affect the morphological, neuromuscular, metabolic, and physiologic adaptations in older women to the best of our knowledge. Understanding these relationships may be an effective way to advance knowledge in RT prescription for health promotion, prevention, and treatment of diseases in older women. Therefore, the purpose of this study was to investigate whether weaker (LOW), medium (MED), and stronger (UPP) muscular strength levels influence changes in body fat, metabolic biomarkers, and blood pressure after 24-week of RT in older women. We hypothesized that older women with weaker muscular strength levels would present enhanced adaptations for body fat, metabolic biomarkers, and blood pressure than stronger.

Methods

Experimental design

The present study is part of the research project “Active Aging Longitudinal Study”, initiated in 2012, whose purpose is to analyze the effects of supervised, structured, and progressive RT programs on neuromuscular, morphological, physiological, metabolic, and cognitive outcomes in older women. The current data was obtained from two cohorts (2015 and 2018) that followed a similar experimental protocol over 30 weeks, with six weeks allocated for tests, measurements, and evaluations and 24 weeks dedicated to the training program. Muscular strength, anthropometric, body composition, and biochemical analysis were carried out in weeks 1-3 and 28-30. Dietary intake was assessed in two first and two last weeks of intervention (weeks 4-5 and 26-27). The RT program was performed over weeks 4-

27. Participants were instructed to keep their physical activity and dietary habits and not engage in any other systematized physical exercise program. This study was conducted according to the Declaration of Helsinki, and University Ethics Committee approved the experimental procedures.

Participants

Recruitment was carried out through newspapers, television, radio advertisements, and home delivery of flyers in the central city and residential neighborhoods. Interested subjects completed detailed health history questionnaires and were subsequently admitted to the study if they met the following inclusion criteria: ≥ 60 years old; female; physically independent; had no cardiac, orthopedic, or musculoskeletal dysfunction that could impede physical exercise; not having uncontrolled diabetes mellitus or hypertension; not receiving hormonal replacement therapy, and not be involved in the practice of regular physical activity performed more than once a week over the three months before the start of the study. Subsequently, subjects should present release from a cardiologist (resting 12-lead electrocardiogram test, personal interview, and treadmill stress test when deemed necessary) to practice RT without restriction. One-hundred thirty-four women (2015-cohort = 61, 2018-cohort = 72) that met initial inclusion criteria and completed pre-training tests started the RT program and 99 accomplished the whole study (2015-cohort = 45, 2018-cohort = 54; age = 69 ± 6 years; body mass = 66 ± 12 kg; height = 155 ± 6 cm; body mass index = 27 ± 4 kg/m^2). Drop-outs were related to personal reasons, traveling, health problems or surgeries not related to RT practice, and lack of time.

Participants were divided into tertiles according to their relative performance on muscular strength tests in the baseline. Lower (LOW), medium (MED), and upper (UPP) tertile-groups comprised 33 subjects each. We adopted a priori sample size for the F test (within-between interaction), calculated using G*Power (version 3.1.9.7, Universität Kiel, Germany). Based on a statistical power (1–β error probability) of 0.80, an effect size F = 0.27, and an overall α level of 0.05, a group sample size of 30 individuals were required for this study. Written informed consent was obtained from all subjects after providing a detailed description of the study procedures. No adverse event occurred during the intervention period. Figure 3 displays the schematic representation of participant recruitment and allocation.

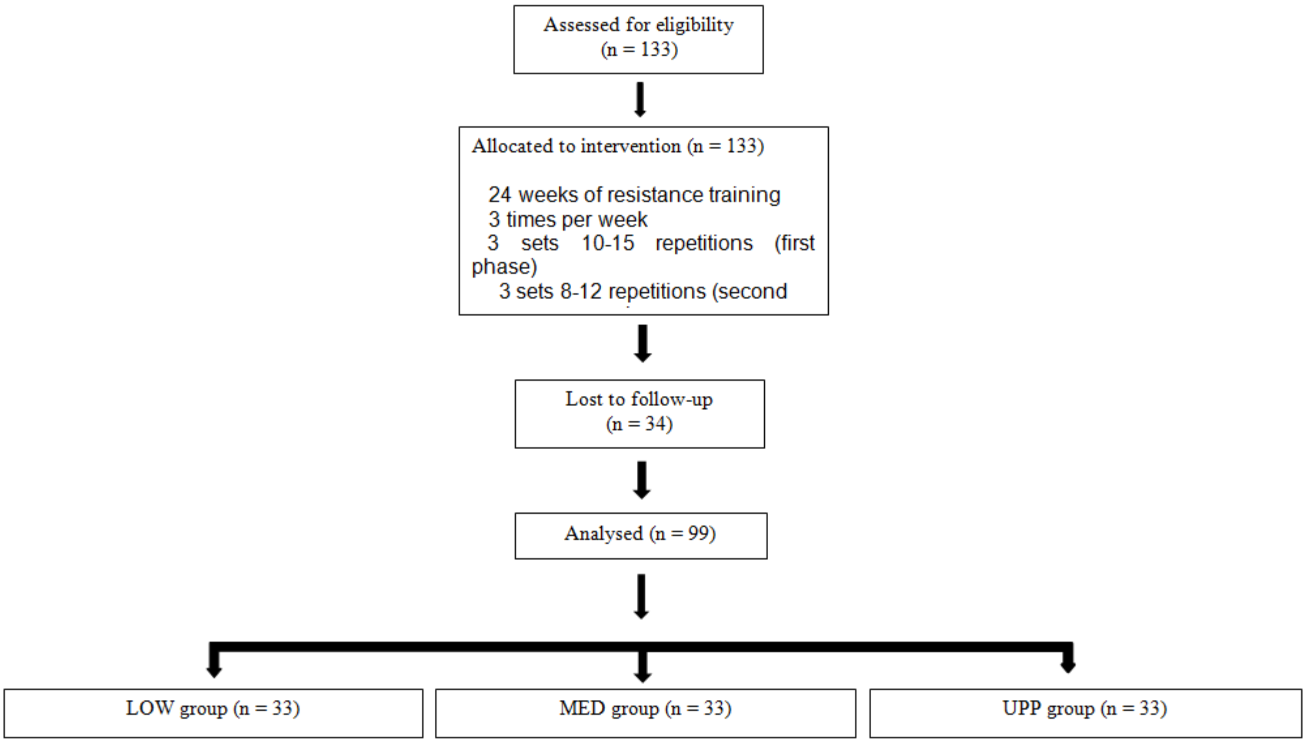

Figura 3 Flowchart of the study. Low = lower tertile for muscular strength, med = middle tertile for muscular strength, upp = upper tertile for muscular strength.

Procedures

Anthropometry

Body mass was measured to the nearest 0.1 kg using a calibrated electronic scale Balmak, model Class III (Balmak Indústria e Comércio Ltda, Santa Bárbara d'Oeste, SP, Brazil), and height was measured to the nearest 0.1 cm with a stadiometer attached to the scale, according to the procedures described in the literature (GORDON; CHUMLEA; ROCHE, 1988). All participants wore light workout clothing and no shoes during the measurements. Body mass index (BMI) was calculated as body mass in kilograms divided by the square of height in meters.

Body composition

Whole-body body fat and trunk body fat measurements were carried out using a dual-energy X-ray absorptiometry scan Lunar Prodigy, model NRL 419900 (GE Lunar, Madison, WI, USA). Calibration of the equipment followed the manufacturer's recommendations, and both calibration and analysis were performed by a laboratory technician with experience in this type of evaluation. Subjects were submitted to the examinations wearing light clothes, barefoot, and without any metallic object or any other accessory items on their body. Those surveyed lay flat on the scanning table until the finalization of the measure. Individual scans were evaluated for lean and soft tissues for the whole body and specific regions (trunk and upper and lower limbs). The limbs were separated from the trunk and head by standard lines generated by the software of the equipment. Demarcation lines were adjusted by the technician through specific anatomical points, as denoted in the equipment manual. Previous test-retest scans of 12 older women measured 24-48 h apart resulted in a technical error of measurement of 0.23 kg for body fat and intraclass correlation coefficients 0.99. The measurements were performed during the afternoon period (1:00 p.m. to 4:00 p.m.).

Blood pressure

Resting blood pressure assessment was performed using automatic oscillometric device Omron, HEM-742INT model (Omron Corporation, Kyoto, Kansai, Japan). Participants attended the laboratory on three different days and, during each visit, remained seated at rest for 5min with the cuff of the equipment in place on the right arm. Subsequently, several blood pressure measurements were performed at one-minute intervals to obtain three consecutive measurements. The difference in SBP and diastolic blood pressure (DBP) readings differed by no more than 4 mmHg. The procedures followed the recommendations of the American Heart Association (PICKERING *et al.*, 2005). The median of the three measurements for each day was averaged across the three visits. During all measures, the participants remained at rest and quiet in a temperature-controlled environment between 20 and 24ºC. Mean blood pressure (MBP) was calculated using the formula MBP = DBP + 1/3 (SBP-DBP).

Biochemical analyses

A sample of venous blood was collected in a tube containing a dipotassium ethylenediaminetetraacetic acid (12 ml, vacuum-sealed system; Vacutainer, England) between 7:00 a.m. and 9:00 a.m. by a trained laboratory technician, after an overnight fast of least 12 h. Participants rested in a seated position for at least five minutes before the withdrawal of 5 ml of blood from a prominent superficial vein in the antecubital space. All samples were centrifuged at 3,000 rpm for 15 min, and plasma or serum aliquots were stored at -80° C until assayed. Inter- and intra-assay coefficients of variation were < 10% as determined in human plasma. Measurements of serum levels of high-sensitivity C-reactive protein, glucose, total cholesterol (TC), high-density lipoprotein cholesterol (HDL-c), and triglycerides (TG) were determined by standard methods in a specialized hospital laboratory. The low-density lipoprotein cholesterol (LDL-c) was calculated using the following equation (FRIEDEWALD; LEVY; FREDRICKSON, 1972): LDL-c = TC – (HDL-c + TG/5). The analyses were performed using a biochemical auto-analyzer system, Dimension RxL Max (Siemens Dade Behring, Erlangen, Germany), according to established literature methods consistent with the manufacturer's protocol.

Dietary intake

Food consumption was assessed by the 24-h dietary recall method applied on two non-consecutive days of the week. During the interview, a photographic manual of food portion size was used to improve the information reported. The homemade food consumption measurements were converted into grams and milliliters by online software Virtual Nutri Plus (Keeple®, Rio de Janeiro, RJ, Brazil). Some foods were not found in the program database, and therefore several items were added from other food tables. The multiple source method (https://msm.dife.de/) statistical program was used to reduce errors in estimating habitual consumption obtained through the 24 h dietary recall, which is a new statistical method to estimate usual food consumption. This program generates information regarding the estimated regular intake of an individual, from the combination of probabilities, using repetitions of 24 h dietary recall or food records (HAUBROCK *et al.*, 2011). All participants were requested to maintain their regular diet throughout the study period.

Muscular strength

The maximum dynamic strength was evaluated using 1RM tests assessed on the chest press, leg extension, and preacher curl exercises, in this order. One familiarization session and three 1RM test sessions were performed in the morning, separated by 48-72 hours. The participants performed 2-3 sets of 10-15 repetitions in each exercise with a light load for the familiarization session. Three experienced researchers supervised all sessions to ensure the safety and integrity of the participants. The execution technique of each exercise was standardized and continuously monitored to ensure the reliability of the measurements. For each test session, the participants performed a specific warm-up (6-10 repetitions) in each exercise, with approximately 50% of the first attempt's estimated load. On the first day of testing, the selected load was based on the researchers' experience and the perception of the difficulty (effort) in which the subjects underwent heating. During the 1RM tests, the participants were encouraged to perform two repetitions with the selected load. Verbal encouragement, accompanied by applause, the participants were provided by the evaluators in all attempts in the different exercises (NUNES *et al.*, 2020b). In situations whose attempts were successfully executed, the load was increased to the next attempt (3-10% of the previous attempt). On the other hand, in situations whose attempts were not successfully executed, the load was reduced in the same proportion. The rest period was three to five minutes between each attempt and five minutes between the exercises. The load for the first attempt in the second and third test session was the maximum load obtained individually in each exercise in the previous session. The value of 1RM for each exercise was recorded as the highest load lifting in a concentric and eccentric maximal voluntary action in the three test sessions (AMARANTE DO NASCIMENTO *et al.*, 2013). Most participants (> 95%) maximum load (1RM) in the second and third sessions. The intraclass correlation coefficient was satisfactory for chest press (0.98), leg extension (0.98), and preacher curl (0.99). Total strength was determined by the sum of the performance (kg) in the three exercises (NUNES *et al.*, 2019).

Resistance training program

All participants were submitted to a supervised RT program during the morning hours, on Mondays, Wednesdays, and Fridays in the University facilities. Participants were personally supervised by Physical Education professionals (1-2 supervisors per exercise) with substantial RT experience to ensure consistent and safe exercise performance. A whole-body RT program to improve muscle endurance and muscular strength in older adults was used in this study (AMERICAN COLLEGE OF SPORTS MEDICINE, 2009; GARBER *et al.*, 2011). Eight exercises (chest press, horizontal leg press, seated row, leg extension, preacher curl, leg curl, triceps pushdown, and seated calf raise) were performed in three sets of 10–15 repetitions over the first 12-week RT and 8-12 repetitions in the last 12-week, with rest of 1-2 min between sets and 2-3 min between each exercise. Participants were instructed to inhale during the eccentric muscle action and exhale during the concentric muscle action while maintaining a movement velocity at a ratio of 1:2 (concentric and eccentric muscle actions, respectively). The training load for each exercise was adjusted according to the participant's ability and improvements throughout the study to ensure that they were exercising with as much resistance as possible while maintaining proper exercise execution techniques. Thus, when the repetitions zone's upper limit was reached for two consecutive sessions, weight was increased 2-5% for upper limb exercises and 5-10% for lower limb exercises in the next training session (AMERICAN COLLEGE OF SPORTS MEDICINE, 2009).

Statistical analyses

The data distribution was check by the Shapiro-Wilk test. Missing values were imputed with intention-to-treat analyses; the scores were calculated from multiple linear regressions using the score from the previous time-points, body mass index, and age as covariates. Subjects were categorized into tertiles based on a composite z-score created by the simple mean of the three relative 1RM-strength measures (i.e., strength score divided by the lean soft tissue of the body region involved) (35) obtained at pre-training, as follows: [(chest press 1RM / TRLST) z-score + (leg extension 1RM / LLLST) z-score + (preacher curl 1RM / ULLST) z-score)] / 3. Generalized estimation equation (GEE) was performed to compare the outcomes within different time-points (pre-training vs. post-training) and between tertile-groups (LOW vs. MED vs. UPP). Bonferroni posthoc was used to identify the differences when Wald X^2 reached significance. The model adopted had the following characteristics: normal distribution with linear link function and an unstructured covariance matrix. Effect size (ES) was calculated as the current time-point mean minus previous time-point mean divided by the pooled previous time-point standard deviation (COHEN, 1988). An ES of 0.00-0.19 was considered trivial, 0.20-0.49 was considered small, 0.50-0.79 was considered moderate, and ≥ 0.80 was considered large (COHEN, 1992). For all analyses, a $P < 0.05$ was accepted as statistically significant. The data were expressed as mean and standard deviation. The data were analyzed using IBM SPSS Statistics, v. 23.0 (IBM Corp., Armonk, NY, USA).

Results

General characteristics and medical history of the subjects are described in Table 8. There were differences in age, body mass, and BMI between groups, where LOW had higher age values and body mass and BMI values than the MED and LOW groups ($P < 0.05$). There were significant interaction group vs. time ($P < 0.05$) for total energy and macronutrient daily intake, indicating differences between UPP and

LOW groups. However, these differences were so small that they do not have an essential clinical effect (Table 9).

Table 8. General characteristics of the sample ate baseline.

Variables	**LOW (n = 33)**	**MED (n = 33)**	**UPP (n = 33)**	***P-value***
Age (years)	70.2 ± 6.0	70.4 ± 6.6	65.2 ± 4.5*†	< 0.001
Body mass (kg)	72.6 ± 11.9	62.9 ± 10.7*	61.7 ± 9.8*	< 0.001
Height (cm)	156.7 ± 5.7	155.2 ± 6.0	153.4 ± 5.9	0.08
BMI (kg/m²)	29.5 ± 4.3	26.1 ± 4.1*	26.2 ± 3.6*	< 0.01
Medical history[a]				
Smoking (%)	9.1	9.1	6.1	0.87
Type 2 diabetes (%)	21.2	3.0	3.0	0.01
Hypertension (%)	63.6	60.6	34.4	0.05
Dyslipidemia (%)	30.8	35.9	33.3	0.88
Other diseases (%)[b]	36.7	26.7	36.7	0.65
Statins (%)	21.2	27.3	33.3	0.54
Antihypertensive (%)	57.6	51.5	33.3	0.12
Hypoglycaemic (%)	21.2	3.0	6.1	0.03

LOW = lower tertile for muscular strength, MED = middle tertile for muscular strength, UPP = upper tertile for muscular strength, BMI = body mass index. *P < 0.05 vs. LOW. †P < 0.05 vs. MED. Data are presented in means and standard deviation or percentages (%). One-way ANOVA. [a]$\chi 2$ were used to compare the groups. [b]Hypothyroidism, depression, and anxiety.

Table 9. Energy and macronutrients intake of the participants during the study period.

Variables	**LOW (n = 33)**	**MED (n = 33)**	**UPP (n = 33)**	***Effect***	***P-value***
Energy (kcal/kg/d)				Group	< 0.001
Pre	22.9 ± 4.3	25.4 ± 4.8	28.2 ± 5.1	Time	< 0.01
Post	23.6 ± 4.6	26.4 ± 5.3	29.9 ± 5.5	Interaction	0.86
Protein (g/kg/d)				Group	0.02
Pre	0.9 ± 0.2	1.0 ± 0.2	1.1 ± 0.2	Time	< 0.01
Post	1.0 ± 0.2	1.1 ± 0.2	1.1 ± 0.2	Interaction	0.93
Carbohydrate (g/kg/d)				Group	< 0.01
Pre	3.0 ± 0.7	3.3 ± 0.7	3.8 ± 0.7	Time	< 0.001
Post	3.1 ± 0.7	3.4 ± 0.7	3.9 ± 0.7	Interaction	0.79
Lipid (g/kg/d)				Group	0.30
Pre	0.7 ± 0.1	0.8 ± 0.2	0.9 ± 0.2	Time	< 0.001
Post	0.7 ± 0.1	0.9 ± 0.2	0.9 ± 0.2	Interaction	0.28

LOW = lower tertile for muscular strength, MED = middle tertile for muscular strength, UPP = upper tertile for muscular strength. *P<0.05 vs. LOW. Data are presented as mean ± standard deviation.

For total strength, an interaction group vs. time (*P* < 0.05) revealed the difference between UPP compared to the LOW group for the total strength, indicating superiority for the UPP group (Figure 4).

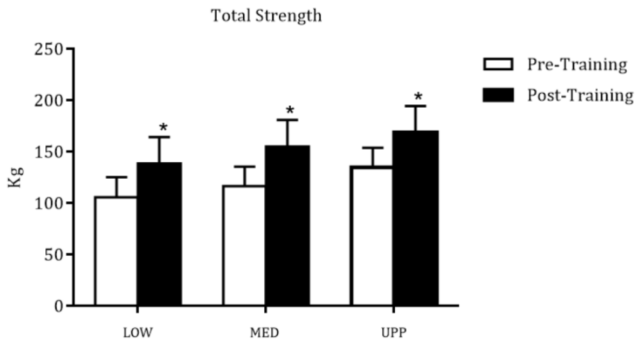

Figure 4. Total strength scores at pre-and post- intervention into the three groups (n = 99). LOW = lower tertile for muscular strength, MED = middle tertile for muscular strength, UPP = upper tertile for muscular strength. **P* < 0.05 vs pre-training.

Table 10 shows pre- post-training values for blood biomarkers. The UPP group showed lower glucose concentrations at post-training when compared to the LOW group (*P* < 0.05). For triglycerides, only the MED group was different compared to the LOW group. Also, more significant triglycerides changes were observed to post-training when compared to pre-training in this same group.

Table 10. Metabolic biomarkers at pre-and post-training into the three groups.

Variables	**LOW (n = 33)**		**MED (n = 33)**		**UPP (n = 33)**		***Interaction P*-value**
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	
Glucose (mg/dL)	110 ± 22	106 ± 15	98 ± 18	98 ± 12	97 ± 16	96 ± 10	0.61
Triglycerides (mg/dL)	132 ± 53	130 ± 47	99 ± 39	84 ± 33*	110 ± 46	104 ± 40	0.03
TC (mg/dL)	190 ± 30	191 ± 28	204 ± 34	202 ± 37	203 ± 30	202 ± 34	0.85
HDL-c (mg/dL)	54 ± 14	53 ± 14	63 ± 18	62 ± 19	62 ± 13	59 ± 13	0.47
LDL-c (mg/dL)	110 ± 27	111 ± 26	121 ± 27	123 ± 29	120 ± 27	122 ± 30	0.99
CRP (mg/dL)	3.6 ± 2.3	3.4 ± 2.3	2.8 ± 1.7	3.0 ± 2.0	2.7 ± 1 .3	2.5 ± 1.7	0.53

LOW = lower tertile for muscular strength, MED = middle tertile for muscular strength, UPP = upper tertile for muscular strength, CRP = C-reactive protein, HDL-c = high-density lipoprotein cholesterol, LDL-c = low-density lipoprotein cholesterol, TC = total cholesterol. **P* < 0.05 vs pre. Data are presented as mean ± standard deviation.

Figure 5 shows pre- and post-training values for the body fat (absolute and percentage), android fat and gynoid fat. All groups reduce relative body fat after 24-week of RT ($P < 0.05$). Otherwise, only MED and UPP groups reduce absolute body fat after the intervention ($P < 0.05$). Besides, the LOW group no change android fat and gynoid fat. Regarding the android fat, only the MED group reduces after the intervention ($P < 0.05$), and both groups (MED and UPP) had lower android fat pre- and post-training. And the gynoid fat reduces only in the UPP group post-training ($P < 0.05$). Finally, no changes were observed in the PAS, PAD, and PAM (Figure 6) after the intervention ($P > 0.05$).

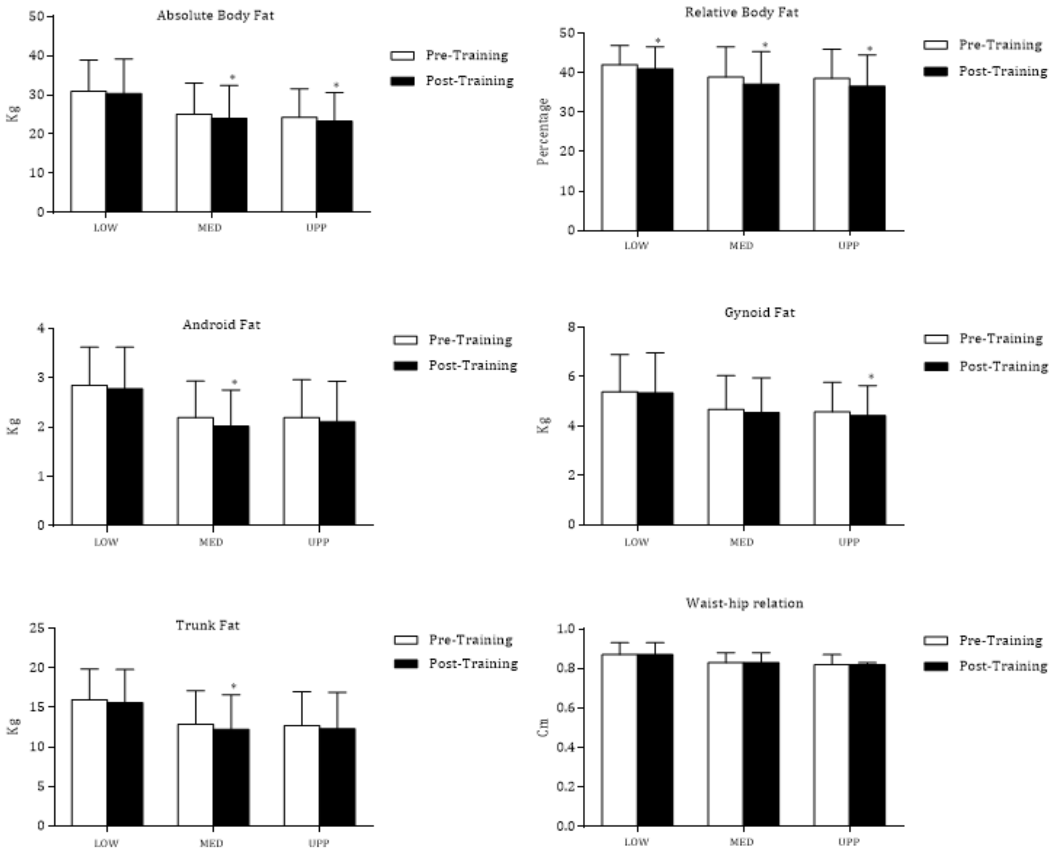

Figure 5. Body fat measurements and waist-hip ratio at pre-and post- intervention into the three groups. LOW = lower tertile for muscular strength, MED = middle tertile for muscular strength, UPP = upper tertile for muscular strength. *$P < 0.05$ vs pre-training.

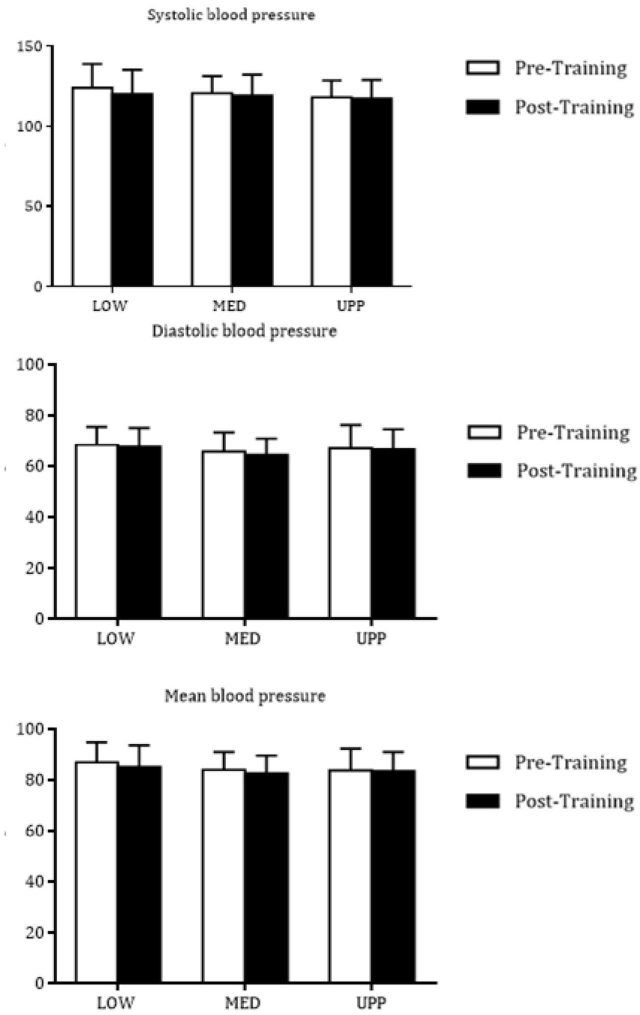

Figure 6. Participants' scores at pre-and post- intervention into the three groups for blood pressure. LOW = lower tertile for muscular strength, MED = middle tertile for muscular strength, UPP = upper tertile for muscular strength.

Also, the main time effect (*P* < 0.05) was found for some variables (TG, absolute body fat and relative, trunk fat, android fat, and gynoid fat. Interestingly, we did not observe any pattern in the behavior of the alterations in each of the groups. But in general, both groups stronger in baseline (MED and UPP) had better adaptations throughout the intervention period. Table 11 presents the effect-size values for the variables analyzed.

Table 11. Effect size values of the pre-to post-intervention changes for analyzed variables.

Variables	**LOW (n = 33)**	**MED (n = 33)**	**UPP (n = 33)**
Total strength (kg)	2.55	3.38	2.96
Glucose (mg/d/L)	-0.33	-0.08	-0.15
Triglycerides (mg/d/L)	-0.08	-0.08	-0.24
TC (mg/d/L)	0.04	-0.09	-0.10
HDL-c (mg/d/L)	-0.08	-0.12	-0.30
LDL-c (mg/d/L)	0.12	0.16	0.14
CRP (mg/d/L)	-0.08	0.06	-0.08
SBP (mmHg)	-0.42	-0.20	-0.10
DBP (mmHg)	-0.23	-0.24	-0.05
Body fat (kg)	-0.10	-0.17	-0.18
Body fat (%)	-0.23	-0.31	-0.35
Trunk fat (kg)	-0.09	-0.16	-0.09
Android fat (kg)	-0.03	-0.06	-0.03
Gynoid fat (kg)	-0.02	-0.05	-0.06
WHR (cm)	0.00	0.00	0.00

LOW = lower tertile for muscular strength, MED = middle tertile for muscular strength, UPP = upper tertile for muscular strength, CRP = C-reactive protein, DBP = diastolic blood pressure, HDL-c = high-density lipoprotein cholesterol, LDL-c = low-density lipoprotein cholesterol, MBP = mean blood pressure, SBP = systolic blood pressure, TC = total cholesterol, WHR = waist-hip ratio.

Discussion

The main findings of this study were: (1) the total strength increases in LOW, MED, and UPP groups when compared to pre- to 24-week of RT in older women (ES = 2.55, 3.38, and 2.96, respectively). Although LOW, MED, and UPP groups demonstrated large ES on total strength gains, the UPP group shows more significant progress on total strength when compared to the LOW group; (2) triglycerides concentrations reduce only in the MED group when compared to pre-training and are different when compared to the LOW group after 24-week of RT. The MED group improved body fat (absolute and percentage) and android fat after 24-week of RT. However, the MED group shows superior improvements to android fat when compared to the LOW group. Finally, the UPP group improved whole-body fat (absolute and percentage) and android fat compared to the LOW group after 24-week of RT. Moreover, the UPP group shows superior improvement in whole-body fat when compared to the LOW group. Collectively, the hypothesis that a LOW muscular strength level (weaker) would generate better adaptations compared to UPP muscular strength level (stronger) in older women was refuted.

Our results indicated that LOW, MED, and UPP groups increase muscular strength after 24-week of RT. However, the UPP group demonstrated a superior improvement in muscular strength than the LOW group. This response corroborates the hypothesis that it has suggested a more significant advantage to stronger individuals after RT programs (BUCKNER *et al.*, 2017). The baseline value of muscular strength before RT may be a more appropriate indicator regarding long-term health outcomes than the act of training itself (BUCKNER *et al.*, 2017). Indeed, stronger individuals would generally maintain superior drive neural, muscle size, and greater intermuscular control (HAFF; TRIPLETT, 2015). Although two studies had shown more significant increases in muscular strength in trained weaker individuals compared to trained stronger individuals following a short-duration RT program (LEITE *et al.*, 2015; MARTINS *et al.*, 2010), our results suggest that in untrained weaker older women submitted a long-duration RT program occurs a lower increase in muscular strength than untrained stronger older women. Thus, older women with superior muscular strength levels have higher muscular strength responses after a long-duration RT program.

In our study, only the MED group reduces triglycerides concentrations after 24-week of RT compared to the LOW group in older women. Simultaneously, the MED group reduces the android fat when compared to the LOW group in older women. On the other hand, increases in the android fat and gynoid fat accumulation has been significantly associated with triglycerides in adults (MIN; MIN, 2015). Besides, android fat, rather than gynoid fat, is fundamental for determining cardiovascular risk (MIN; MIN, 2015). Modifications in the lipid profile can be associated with body fat changes, suggesting that reductions in one will affect the other (CUNHA *et al.*, 2019; ECKEL; WANG, 2009). Indeed, the MED group reduces body fat (absolute) compared to the pre-training and LOW group after 24-week of RT. According to this approach, a recent study revealed a reduction in body fat and blood biomarkers and a correlation between their changes (CUNHA *et al.*, 2019). The association between changes in lipid profile and body fat may be related to increased free fatty acids, a condition leading to the formation of large triglycerides-rich VLDL particles, which alters the expression of key enzymes in the plasma such as decreased lipoprotein (ECKEL; WANG, 2009). Thus, an RT program with a long duration is sufficient to improve the body fat, android fat, and triglycerides in older women with medium muscular strength level.

Muscular strength is an indicator of predicting health-problems provoked by body fat disorders (PASDAR *et al.*, 2019). Our results indicated decreasing body fat relative to all experimental groups, although more significant changes were observed in the UPP and MED groups compared to the LOW group. Also, only MED and UPP reduce total body fat after 24-week RT. Moreover, the MED group reduces android fat than the LOW group, and the UPP group reduces gynoid fat when compared to pre-training. Although excess body fat is negatively associated with muscular strength (MOORE *et al.*, 2020), it is unsure whether different muscular strength levels might affect body fat distribution changes in older women. Recently, a cohort study reported that body fat excess in the gynoid region is associated with a greater incidence of falls than total body fat in older women (NERI *et al.*, 2020). Our results provide substantial evidence on the role of higher muscular strength level in reducing total and regional body fat in older women. Therefore, our results suggest that higher muscular strength levels associated with total and regional body fat reduction may have a protective effect on older women's health.

On the other hand, our study did not find changes for CRP and glucose concentrations, SBP, DBP, and MBP levels after 24-week RT in older women, independently of muscular strength levels. However, a recent meta-analysis has demonstrated that RT-induced improvement in CRP only occurs in longer durations than 12 weeks (SARDELI *et al.*, 2018). In this regard, Olson *et al.* (2007) showed that a 1-year RT promotes improvement in CRP concentrations in overweight women compared to the control group, whereas blood pressure levels did not change (OLSON *et al.*, 2007). Indeed, some adaptative responses RT-related, especially at blood biomarkers, seem to be time-dependent (PINA *et al.*, 2020a). A regarding the blood pressure, a study previous to our research group also did not found differences after a 12-week RT program in normotensive older women (GERAGE *et al.*, 2015). Although blood pressure levels did not significantly change after both intervention periods, the LOW group reduces 3.88 mmHg after 24-week of RT. This result is clinically relevant because blood pressure-lowering substantially reduces the risk of major cardiovascular disease events and all-cause mortality (ETTEHAD *et al.*, 2016). Indeed, RT can promote antihypertensive benefits (MACDONALD *et al.*, 2016).

This study has some limitations that are important to highlight. The results are specific to older women and should not be extrapolated to other populations. Moreover, we were not able to monitor physical activity levels outside of the study environment, which potentially may have confounded results. However, the participants were asked to maintain their regular daily living activities throughout this period to minimize lifestyle interferences. Finally, although computed tomography is the gold standard for abdominal body fat assessments, the dual-energy X-ray absorptiometry has been considered a precise method for measuring regional fat (MICKLESFIELD *et al.*, 2012).

On the other hand, the present study presents numerous strengths. The final sample size and the intervention duration allow a consistent analysis of the impact of RT in older women. The participant inclusion criteria provided a homogenous sample, reducing bias risks. The RT intensity (loads), volume (repetitions x load), and frequency (≥ 85% in RT sessions in both groups), and proficiency of exercise (technique) were controlled over intervention. All participants in the present study were followed closely by skilled fitness professionals, and they completed the intervention with high compliance. Indeed, it has been shown that supervised RT by professional results in more significant muscular strength gains, and body fat decreases when compared to unsupervised RT (LACROIX *et al.*, 2017). Finally, dietary intake was monitored at the beginning and the end of the experiment.

Conclusion

Our results suggest that higher initial muscular strength levels influence greater muscular strength gains after a long-duration RT program in older women. However, the changes in total and regional body fat, glucose, and triglycerides concentrations can occur independently of the initial muscular strength level.

6 CONSIDERAÇÕES FINAIS

O momento atual aponta a necessidade da busca por estratégias não-farmacológicas que favoreçam um envelhecimento saudável e com boa qualidade de vida, uma vez que os avanços científicos e tecnológicos, principalmente na área médica, têm proporcionado o aumento na expectativa de vida na grande maioria dos países do mundo. A inclusão de programas de atividade física ou de exercícios físicos no cotidiano da população idosa pode contribuir acentuadamente para um cenário positivo, caracterizado pela melhoria da capacidade funcional, autonomia, autoestima e redução de gastos com medicamentos, consultas médicas, internações e cirurgias.

Com base nessas informações, a presente investigação analisou o impacto de 24 semanas de TR sobre desfechos morfológicos, neuromusculares e metabólicos em mulheres idosas, tomando como base de análise os níveis de força muscular das participantes previamente ao início da intervenção. Essa tomada de decisão se pautou em um conjunto de informações disponíveis na literatura sobre a importância da força muscular para a redução da morbidade e mortalidade, particularmente, na população idosa.

Assim, inicialmente, procuramos resolver algumas questões metodológicas que poderiam colocar em risco as informações a serem produzidas por este estudo. A estratégia de separar as participantes por tercis, de acordo com os níveis iniciais de força muscular, apesar de ser interessante poderia dificultar sobremaneira a análise dos resultados, uma vez que a força e a massa muscular nos diferentes segmentos corporais apresentam comportamentos bastante distintos. Assim, na tentativa de estabelecer um critério mais consistente para a composição dos grupos experimentais desenvolvemos um escore z considerando a força muscular e a massa isenta de gordura e osso dos diferentes segmentos corporais (membros inferiores, tronco e membros superiores).

Com base na estratégia adotada, a estruturação do programa de TR deveria contemplar exercícios para o corpo inteiro. Assim, oito exercícios foram escolhidos, sendo um exercício para peitoral (supino vertical), um para as costas (remada sentada), um para o bíceps (rosca scott), um para o tríceps (tríceps no *pulley*), um para o quadríceps (cadeira extensora), um para o bíceps femoral (cadeira flexora), um para a panturrilha (panturrilha sentado) e um mais geral (*leg press* horizontal) envolvendo membros inferiores e glúteos.

Considerando que a adoção de modelos de progressão tem sido amplamente defendida pela literatura especializada como um estratégia importante e necessária para evitar um possível efeito platô das respostas adaptativas induzidas pelo TR ao longo do tempo (estabilização dos resultados alcançados), estabelecemos um critério único para os ajustes das cargas de treinamento. Esse critério foi aplicado em todos os exercícios que compuseram o programa de treinamento, de modo que a intensidade pudesse ser adequada a evolução individual de cada participante ao longo das 24 semanas de intervenção. Adicionalmente, adotamos uma modificação no número de repetições por série (10-15 vs. 8-12 repetições, na primeiras e nas últimas 12 semanas, respectivamente), em todos os exercícios, visando intensificar mais o treinamento, uma vez que nesse momento o nível de condicionamento muscular já estava mais elevado e as respostas adaptativas se tornariam mais limitadas.

A utilização de profissionais de Educação Física para a supervisão de todas as sessões de treinamento, além de oferecer maior segurança as participantes, permitiu que os movimentos fossem executados dentro de um padrão de qualidade adequado as limitações impostas a cada participante pelo processo degenerativo das articulações (cartilagens, tendões e cápsulas articulares). Em idosos diversos problemas como artrose, discopatia, tendinopatia e meniscopatia são bastante comuns e podem limitar alguns movimentos. Entretanto, a prática do TR nessas condições clínicas pode melhorar a estrutura muscular e fortalecer as articulações, promovendo redução das dores e melhoria da qualidade de vida do praticante. Desse modo, o programa de TR utilizado pode ser caracterizado como progressivo e supervisionado, o que confere maior consistência aos resultados encontrados nessa investigação.

Um outro aspecto importante e que merece destaque no presente estudo foi o monitoramento dos hábitos alimentares das participantes nas primeiras e nas últimas semanas de intervenção. Embora mudanças drásticas na alimentação de idosos sejam raras, uma vez que as preferências por determinados alimentos para um maior consumo diário tenham sido estabelecidas ao longo da vida, o processo de envelhecimento pode provocar muitas mudanças no consumo alimentar, tais como redução no apetite, diminuição da sensação de sede, dificuldade de mastigação, diminuição ou perda do olfato e paladar e problemas gastrointestinais. Assim, nossos resultados são suportados pelo comportamento alimentar relativamente similar, verificado entre os grupos, ao longo do período de intervenção.

Os resultados encontrados foram apresentados na forma de um conjunto de artigos que permitiu uma análise mais ampla de vários fenômenos que ocorreram simultaneamente e que guardam maior ou menor relação entre si. Tentaremos na sequência sumarizar os principais resultados encontrados, na tentativa de possibilitar uma análise combinada dos efeitos produzidos pela intervenção proposta.

Desse modo, os resultados do presente estudo indicaram que 24 semanas de TR em idosas fisicamente independentes e com diferentes níveis de força muscular promoveu:

a) Aumento da força muscular de membros superiores, tronco, membros inferiores;
b) Aumento da massa muscular, da massa isenta de gordura e de osso de membros superiores, tronco, membros inferiores;
c) Melhoria da qualidade muscular e da capacidade funcional;
d) Aumento do ângulo de fase, da hidratação corporal total e intracelular;
e) Redução da gordura corporal relativa e triglicérides;
f) Manutenção das concentrações de glicose, colesterol total, HDL-c, LDL-c e proteína C-reativa;
g) Manutenção da distribuição da gordura e da relação cintura-quadril;
h) Manutenção da PAS, PAD e PAM.

Adicionalmente, parte das respostas adaptativas encontradas aparentemente foram influenciadas pelo nível de força muscular, a saber:

a) Aumento da força muscular de membros inferiores foi maior no grupo MED;
b) Melhoria da qualidade muscular foi maior no grupo MED;
c) Melhoria da velocidade de caminhada foi maior no grupo UPP;

d) Melhoria da capacidade de levantar e sentar (potência muscular) foi maior no grupo LOW;
e) Redução dos triglicérides só ocorreu no grupo MED;
f) Redução da gordura corporal só ocorreu nos grupo MED e UPP;
g) Redução da gordura androide e no tronco só ocorreu no grupo MED;
h) Redução da gordura ginoide só ocorreu no grupo UPP.

Portanto, os resultados do presente estudo sugerem que o TR pode promover melhoria da força muscular, capacidade funcional e composição corporal, independente dos níveis de força muscular, embora a magnitude das respostas adaptativas após 24 semanas de intervenção tenha sido menos pronunciada em mulheres idosas que apresentavam níveis iniciais de força mais reduzidos. Tais informações nos levam a acreditar que a manutenção de níveis elevados de força na idade adulta pode contribuir para um envelhecimento mais saudável nas idades mais avançadas.

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APÊNDICES

APÊNDICE A

Entrevista – Projeto Idosas

NOME:____

TELEFONE:(___)________ IDADE:______ anos NASCIMENTO___/___/___

ENDEREÇO:____

ANAMNESE

1. Você possui algum problema cardiovascular ou metabólico?

(___)Sim (___)Não

(___)Hipertensão (___)Diabetes (___)Colesterol/Triglicérides Elevado (___)Hipoglicemia

2. Você está acima ou abaixo do seu peso desejado?

(___)Sim (___)Não Caso positivo, quanto?_________________________________

3. Você possui algum problema osteomuscular?

(___)Sim (___)Não

(___)Fibromialgia (___)Artrite (___)Artrose (___)Bico de papagaio (___)Hérnia de disco (___)Lesão Muscular (___)Desgaste Ósseo

4. Você vai com frequência (pelo menos uma vez ao ano) ao médico?

(___)Sim (___)Não Caso positivo, qual?____________________________________

5. Alguma vez o médico disse que você não pode fazer exercícios físicos?

(___)Sim (___)Não Caso positivo, porque?_________________________________

6. Você faz uso diário de algum medicamento?

(___)Sim (___)Não Caso positivo, qual e porquê?__________________________

7. Você é fumante?

(___)Sim (___)Não Caso positivo, quantos cigarros por dia?__________________

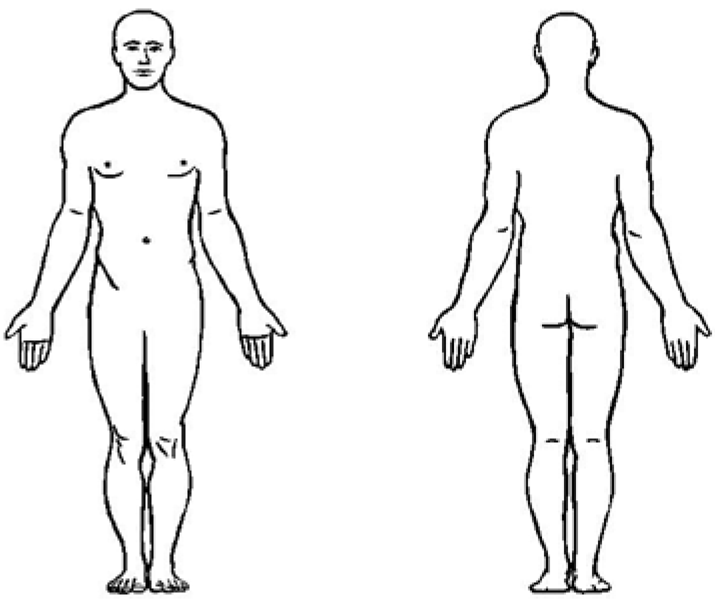
8. Você faz uso de bebida alcoólica com frequência (mais que duas vezes por semana)?

(___)Sim (___)Não Caso positivo, quanto?_________________________________

9. Você tem realizado exercício físico regularmente nos últimos seis meses?

(___)Sim (___)Não Caso positivo, qual?___________________________________

10. Utilizando o corpo desenhado logo abaixo, em qual parte você sente dor? Sinalize com uma seta o local e coloque o motivo.



11. Você tem alguma viagem/cirurgia marcada para os próximos 12 meses?

(___)Sim (___)Não Caso positivo, qual?__________________________________

12. Qual horário de treinamento a senhora pode participar?

(___)8:30 hs (___)9:30 hs (___)10:30 hs

APÊNDICE B

Instrumento de Pesquisa Utilizado na Coleta de Dados

Texto

ANEXOS

ANEXO A

Título do Anexo

Texto