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KINESIOLOGY & COACHING

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Impact of taekwondo on physiological markers of bone remodeling, muscle strength, and functional autonomy in older women: a randomized clinical trial

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Key words: activities of daily living, bone mineral density, combat sports, older

Abstract
Background. To verify the effects of taekwondo training on physiological markers of bone remodeling, muscle strength, and functional autonomy of older women.

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Problem and aim. Bone loss associated with a decline in muscle strength can impact the ability to perform the activities of daily living (ADLs) in older women. Therefore, this study is justified by presenting combat sports, specifically taekwondo, with the possibility of reducing risks to the health of older people associated with the loss of bone mass with aging. Thus, the aim of the present study was to analyze the effects of *taekwondo* training on physiological markers of bone remodeling, muscle strength, and functional autonomy in older women.
Methods. Twenty-seven older women inexperienced in taekwondo were randomly assigned to an experimental group (EG; n = 14) and a control group (CG; n = 13). The EG practiced taekwondo (3 times/week, 40 min/session) for 12 weeks. Muscle strength was analyzed by Rikli and Jones' elbow flexion and sit and stand tests. Functional autonomy was analyzed using the functional autonomy GDLAM protocol. Blood samples were collected for analysis of bone biomarkers (alkaline phosphatase, serum phosphorus, vitamin B12, vitamin D and parathyroid hormone [PTH]).
Results. ANOVA (2 x 2) with repeated measures showed that there was an increase in muscle strength in the EG ($p<0.05$) in the intragroup and intergroup comparison (post-intervention) in both tests (elbow flexion and sit and stand). There was an increase in functional autonomy ($p<0.05$) in the EG in the intragroup evaluation. In the evaluation of bone biomarkers, differences ($p<0.05$) were found in all variables analyzed in the intragroup comparison (pre vs. post) in the EG.
Conclusion. The results found in this experimental study support the effectiveness of taekwondo practice on physiological markers of bone remodeling, muscle strength, and functional autonomy in older women.

Introduction

Biological aging is associated with a reduction in reparative capacity and regenerative potential in tissues and organs. This reduction manifests as a decrease in physiological reserve in response to stress (referred to as homeostenosis), which is characterized by immunosenescence, considered a progressive degenerative process in the immune system [Abd El-Kader, Al-Shreef 2018; Cai, Abrahamson 2016; Khan *et al.* 2017].

In the context of aging, the pursuit of functional autonomy holds importance, and the loss of bone and muscle mass emerges as a detrimental factor in achieving this outcome. Within this context, osteoporosis presents itself as a public health concern, correlated with fracture risks due to fragility [Curtis *et al.* 2015]. In adult individuals, bones undergo changes, leading to a constant process of remodeling and resorption. Hence, specific bone markers can quantify these processes, serving as early indicators of pathological bone changes such as osteoporosis while also providing quicker data compared to bone measurements [Radut 2019].

A notable change associated with human aging is the gradual reduction in skeletal muscle mass and strength, known as sarcopenia, with an approximate loss of 6% per decade after middle age. [Ghiotto *et al.* 2022; Tournadre *et al.* 2019]. The annual percentage of muscle strength loss is 50-100% greater than the loss of muscle mass itself. This condition amplifies with age, particularly after the age of 65 [Ghiotto *et al.* 2022].

The prevalence of sarcopenia can range from 3% to 24%, depending on the diagnostic criteria employed, and it increases with age [Tournadre *et al.* 2019]. Consequently, sarcopenia can diminish muscle function and impede the performance of activities of daily living (ADLs) [Curtis *et al.* 2015]. In this context, older individuals need to preserve functional autonomy to optimize ADLs. Physical exercise can positively contribute to functional autonomy by decreasing the risk of falls and preventing non-communicable chronic diseases [Araujo-Gomes *et al.* 2020; Marcos-Pardo *et al.* 2019; Tylka, Wood-Barcalow 2015; Webb *et al.* 2015].

In bone remodeling, nutritional deficiencies, such as vitamin B12, can lead to severe conditions like oxidative stress [Huemer, Baumgartner 2019]. Another bone marker is serum phosphorus, where levels are influenced by parathyroid hormone, 23 fibroblast growth factor, and vitamin D in the kidneys, bones, and digestive system. Individuals aged 50 and above face heightened risks of bone-related diseases that elevate serum phosphorus, consequently increasing the risks of mortality and cardiovascular diseases [Suki, Moore 2016]. Supplementation with vitamin D3 has demonstrated positive outcomes in the musculoskeletal system of older adults, including an increase in the cross-sectional area of type II muscle fibers, muscle strength gain, and fall risk reduction [Antoniak, Greig 2017]. For maintaining bone health, an optimal intake of calcium, vitamin D, and proteins is recommended [Groenendijk *et al.* 2020]. Other markers, such as N-terminal propeptide of type 1 procollagen (P1NP) and osteocalcin are relevant in this context due to the correlation between bone metabolism impairments and elevated concentrations of alkaline phosphatase in various pathologies [Milioni *et al.* 2014].

Active aging, facilitated by regular physical activity, stimulates bone formation and boasts well-established protective effects on bone parameters. The utilization of physiological markers holds significance in the assessment of bone maturation [Benedetti *et al.* 2018; Honisett *et al.* 2016; Jakovljevic 2018).

Physical activity as a non-pharmacological intervention is recommended appropriately and over extended periods for osteoporosis treatment, as it yields no side effects [Zhang *et al.* 2019]. The level of effort for physical activity should be relative to the older adult's fitness and abilities [Mora, Valencia 2018]. Bones respond best to mechanical loads, leading to bone modifications and changes in muscle mass and strength [Karlsson, Rosengren 2020; Watson *et al.* 2018].

Among the various types of physical activities, combat sports like taekwondo have gained popularity over the past decades, attracting a growing number of participants. Taekwondo, a Korean martial art, involves kicking and punching movements combined with self-defense techniques, bringing together body, mind, and spirit while emphasizing self-control, posture, and respect for opponents. This combat sport is an important strategy for improving health across different populations, including the elderly [Kim *et al.*, 2022].

Regular taekwondo practice in older adults can enhance physical fitness and cognitive function [Cho *et al.* 2018; Kim *et al.* 2022; Ma *et al.* 2018; Norjali Wazir *et al.* 2019]. However, the effects of taekwondo on physiological markers of bone remodeling and muscle strength in older women remain unestablished in the literature. Bone loss associated with the decline in muscle strength can impact the ability to perform ADLs in the elderly. Therefore, this study is justified by presenting combat sports, specifically taekwondo, in the possibility of reducing the risks to the health of older people with the loss of bone mass with aging. Thus, the aim of the present study was to analyze the effects of taekwondo training on physiological markers of bone remodeling, muscle strength, and functional autonomy in older women.

Methods

Study design

This is experimental research with a design involving two groups evaluated pre and post the intervention period [Thomas *et al.* 2012]. The present study adheres to the recommendations of the Consolidated Standards of Reporting Trials (CONSORT) statement [Cuschieri 2019].

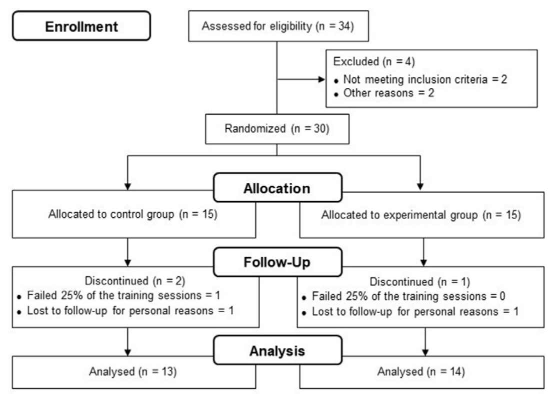
Sample

The sample consisted of older women residing in the city of Campos dos Goytacazes – Rio de Janeiro. The sample size estimated using G-Power software, version 3.1.9.4, was 24 individuals [Faul *et al.* 2007]. For this estimation, the following information was input: ANOVA with repeated measures for two groups at two assessment points, effect size of 0.30, alpha of 0.05, experiment power of 0.80, and a correlation between measures of 0.5 [Beck, 2013] (Figure 1).

The participants were randomly allocated into two groups (Figure 1) using the random function in Microsoft Excel software, version 18.2303.1201.0, by Microsoft Corporation. Sedentary older women with no prior experience in taekwondo practice and who had not engaged in physical exercise for at least 6 months were included. Participants with contraindications for regular physical exercise, such as osteoarticular, metabolic, or cardiovascular conditions, those using medications for hormonal replacement, those identified as high risk in the pre-exercise screening proposed by the Physical Activity Readiness Questionnaire (PAR-Q) [Warburton *et al.* 2011], and those with less than 75% attendance during the intervention period were excluded.

All individuals who agreed to participate in this study signed the Informed Consent Form (ICF), in accordance with Resolution 466/12 of the National Health Council. The study was submitted to the Research Ethics Committee of the Pedro Ernesto University Hospital/UERJ, under the registration CAAE: 51572321.6.0000.5259, and was registered in the Brazilian Clinical Trials Registry (ReBEC) under the registration RBR-5jzcc5q.

Figure 1. Flow chart of the sample selection process.



Source: (https://www.equator-network.org/reporting-guidelines/consort/)

Data collection procedures

During the initial visit, the study procedures were explained to each individual. They were requested to complete the Informed Consent Form (ICF), the pre-exercise screening of the PAR-Q, provide a medical clearance attestation for engaging in physical exercise, and undergo anthropometric assessment.

On the second day of the visit, muscle strength and functional autonomy tests were conducted. On the third day of the visit, blood samples were collected from both the experimental and control groups to analyze physiological markers: alkaline phosphatase, vitamin B12, serum phosphorus, Vitamin D, and PTH, as well as the bone mineral density examination. Subsequently, the participants underwent a 12-week intervention specific to each group, and finally, a new data collection of all study variables was conducted, except for bone mineral density, which was assessed only prior to the intervention.

Anthropometric Assessment

To assess the total body mass and height of the participants, a Filizola® mechanical scale was used with a stadiometer with a one-centimeter interval, with a maximum capacity of 150 kg and a minimum of 2.5 kg, with a graduation of 100g. A single evaluator took measurements for all study participants, and these measurements were subsequently utilized to calculate the body mass index (BMI) [Randhawa *et al.* 2019].

Muscle strength

The elbow flexion and sit-to-stand tests were administered to assess upper and lower limb muscle strength, respectively [Rikli, Jones 1999, 2013; Preto *et al.* 2015]. In the elbow flexion test, the participant sits with feet on the ground, holds the weight with arms extended by the sides, and performs elbow flexion and extension movements while recording the maximum number of repetitions with an approximate weight of 2.27 kg in 30 seconds. In the sit-to-stand test, the participant transitions from a seated position in a chair to standing and back again, registering the maximum number of repetitions in 30 seconds.

Functional autonomy

In the assessment of functional autonomy, the Latin American Development Group for Maturity (GDLAM) protocol for functional autonomy specifically geared towards activities of daily living (ADLs) was utilized [Dantas *et al.* 2014; Dantas, Vale 2004]. This protocol comprises the following tests: 10-Meter Walk (W10m) [Sipila *et al.* 1996], Stand up from sitting position (SSP) [Guralnik *et al.* 1994], Standing up from the prone position (SPP) [Alexander *et al.* 1997], To put on and take off a T-shirt (PTS) [Vale *et al.* 2008], and Sit and get up from the chair and move around the house (SCMA) [Pechorro *et al.* 2011]. All tests were administered twice with a five-minute interval, and the best execution time in seconds was recorded. Subsequently, the GDLAM autonomy index (GI) was calculated for the overall analysis of functional autonomy using the following formula.

$$GI = [((C10m + LPS + LPDV + VTC) \times 2) + LCLC] \div 4$$

Blood collection and bone mineral density test

In the blood collection, the analysis of parathyroid hormone (PTH) was conducted using the chemiluminescence method. Vitamin B12 and vitamin D were assessed through high-performance liquid chromatography (HPLC). Alkaline phosphatase utilized the optimized kinetic method, and serum phosphorus was analyzed using the kinetic UV method [Pardini 2016].

The examination of bone mineral density of the lumbar spine and femoral neck was performed using a dual-energy X-ray absorptiometry (DXA) machine from the QDR brand (Hologic, Inc., Marlborough, MA, USA) [Lee *et al.* 2017; Porcelli *et al.* 2020].

Blood collection tests were conducted 24 hours before the commencement of the intervention and 72 hours after the intervention. Bone mineral density measurements were carried out prior to the intervention solely for sample characterization. All biochemical marker examinations were duplicated, and the coefficient of variation (CV) was less than 3%.

Biomarkers were collected by a trained nursing professional and analyzed by the Plinio Bacelar Clinical Research Laboratory, located in the city of Campos dos Goytacazes, State of Rio de Janeiro, Brazil.

Intervention

Taekwondo was administered 3 times a week, with each session lasting 40 minutes, over a period of 12 weeks. Each session comprised 5 minutes of warm-up, 30 minutes of taekwondo practice, and 5 minutes of cool-down.

The warm-up consisted of joint mobility exercises involving the wrists, elbows, shoulders, neck, hips, knees, and ankles, totaling 3 minutes. Active static stretching was performed on the wrists, shoulders, hips, knees, and ankles, totaling 2 minutes [McGorm *et al.* 2018; Thomas *et al.* 2018].

Table 1. Taekwondo training program.

Phase	Content	Time (min)
Warm-up	Joint mobility exercises and static stretching involving the wrist, elbow, shoulder, neck, hip, knee, and ankle joints.	5 min
Taekwondo	1–6 weeks; RPE: 2–4 7–12 weeks; RPE: 5–8	30 min
	Undulating movements (sinusoidal wave-like motions, consisting of a relaxed descent and ascent followed by a rapid descent applying force in the strike) performed in various stances of taekwondo. (Anun Sogi, Niunja sogi, Ogun Sogi); kicks (Najunde Chagi, Dollyo Chagi, Yop Dollyo Chagi, Ap Chagi, an chagi, neryo chagi) and punches (Gunnun So Baro Jirugi, Gunnun So Bandae Jirugi) lower and simpler than the conventional ones; forms (Tulls)	
Cool-down	Relaxation exercises in a standing position, followed by sitting and supine positions, involving the joints and muscles engaged in the proposed intervention.	5 min

Abbreviations: RPE = rating of perceived exertion (OMNI-RES).
Source: Created by the authors

The taekwondo exercises consisted of undulating movements, a specific technique in the style of the International Taekwondo Federation (ITF), performed with various stances of the lower limbs: modified kicks (lower and simpler than conventional ones) and adjusted punches (simpler movements), executed individually and in pairs; and the performance of forms (Tulls) (Table 1), which represent sequences of combined movements specific to ITF taekwondo [Choi 1995].

The cool-down phase involved relaxation exercises in a standing position, followed by sitting and supine positions, encompassing the joints and muscles engaged in the intervention, totaling 5 minutes [Calleja-Gonzalez *et al.* 2019]. The adjusted intensity control for the taekwondo sessions was determined by the rating of perceived exertion (RPE) using the OMNI-RES scale [Robertson *et al.* 2003], with levels between 3 and 4 during the initial 4 weeks of intervention and levels between 5 and 7 in the subsequent weeks. Equipment (kicking and punching pads) was utilized for executing the movements.

Participants in the control group engaged in educational lectures on health and quality of life topics once a week, with each lecture lasting 40 minutes, over a 12-week period. After the intervention period for the experimental group, the control group was invited to participate in the taekwondo training program.

Statistical analysis

The data collected were processed using IBM SPSS Statistics 25 software and presented as mean and standard deviation. The independent samples t-test was applied at the study's outset to verify baseline differences between the groups. Data normality and sphericity were assessed using the Shapiro-Wilk and Bartlett tests, respectively. A repeated measures 2 × 2 analysis of variance (ANOVA), followed by adjusted Bonferroni post hoc testing, was employed to analyze potential differences among dependent variables. The study adopted a significance level of $p < 0.05$. Cohen's effect size (d) was utilized to assess clinical impact on the variables of interest, interpreted as follows: ≤ 0.2 (small), 0.21 – 0.79 (medium), and ≥ 0.8 (large) [Cohen 1992].

Results

Table 2 provides the characterization of the sample by groups. The independent samples t-test indicated that the groups were similar at the study's outset, as there were no differences ($p > 0.05$) among the analyzed variables.

ANOVA (2 x 2) with repeated measures showed the following results for the interactions between groups and the evaluation moments in the variables: Elbow Flexion ($F = 26.98$; $p < 0.001$), Sit-to-Stand test ($F = 107.54$; $p < 0.001$), W10m ($F = 18.64$; $p < 0.001$), SSP ($F = 20.15$; $p < 0.001$), SPP ($F = 9.83$; $p = 0.004$), PTS ($F = 15.56$; $p = 0.001$), SCMA ($F = 21.37$; $p < 0.001$), GI ($F = 51.99$; $p < 0.001$), Vitamin B12 ($F = 9.02$; $p = 0.006$), Vitamin D ($F = 77.71$; $p < 0.001$), Phosphorus ($F = 7.63$; $p = 0.011$), Alkaline Phosphatase ($F = 6.03$; $p = 0.035$) and, PTH ($F = 12.17$; $p = 0.002$).

Table 3 presents the results of muscle strength assessed through the elbow flexion and sit-to-stand tests. The mean values of the variables were compared to identify potential statistically significant differences at a significance level of $p < 0.05$.

Table 2. Basic participant characteristics.

Variables	CG (n=13)	EG (n=14)	p-value
Age (years)	66.00 ± 5.18	65.71 ± 5.65	0.892
TBM (kg)	67.64 ± 8.04	65.63 ± 9.03	0.548
Height (m)	1.63 ± 0.07	1.63 ± 0.06	0.906
BMI (kg/mt²)	25.60 ± 3.01	25.63 ± 3.99	0.981
BMD Lumbar (g/cm²)	0.910 ± 0.06	0.97 ± 0.06	0.085
BMD Femur (g/cm²)	0.856 ± 0.06	0.98 ± 0.06	0.054

Abbreviations: * p<0,05; TBM= total body mass; BMI= Body Mass Index; BMD: Body Mineral Density; CG= control group; EG= experimental group.

Table 3. Muscle strength analysis.

Variables	Group	Mean pre ± SD	Mean post ± SD	Δ%	*d*	p-value†	p-value*
Elbow Flexion	CG	20.77 ± 1.21	20.39 ± 1.08	-1.8	-0.31	0.403	0.015
	EG	16.14 ± 1.16	19.21 ± 1.04	19	2.65	**<0.001**	
Sit-to-Stand test	CG	18.54 ± 0.98	18.00 ± 0.75	-2.9	0.55	0.131	0.011
	EG	17.71 ± 2.64	21.36 ± 2.76	20.6	1.38	**<0.001**	

Abbreviations: * p < 0.05, pre vs. post; † p < 0.05, GC post vs. EG post; *d*= effect size (Cohen); SD= Standard deviation.

Table 4 displays the results of functional autonomy assessed using the GDLAM protocol. There was an improvement ($p < 0.05$) in functional autonomy (W10m, SSP, SPP, PTS, and GI) in the experimental group. The control group did not show any changes. In the intergroup analysis, the experimental group exhibited better results in the W10m, SSP, SPP tests, and the GI compared to the control group.

Table 4. Functional autonomy analysis (GDLAM).

Variables	Group	Mean pre ± SD	Mean post ± SD	Δ%	*d*	p-value*	p-value†
W10m	CG	6.16 ± 0.83	6.18 ± 0.84	0.3	0.02	0.938	**0.039**
	EG	6.77 ± 1.11	5.62 ± 0.44	-17.0	-1.04	**< 0.001**	
SSP	CG	9.70 ± 0.82	9.64 ± 0.84	-0,6	-0,07	0.796	**<0.001**
	EG	9.06 ± 2.01	7.54 ± 1.50	-16.8	-0.76	**< 0.001**	
SPP	CG	5.27 ± 1.03	5.29 ± 1.06	0.4	0.02	0.915	**0.002**
	EG	4.35 ± 1.74	3.74 ± 1.28	-14.0	-0.35	**< 0.001**	
PTS	CG	13.05 ± 1.94	12.45 ± 3.00	-4.6	-0.31	0.244	0.642
	EG	15.34 ± 4.28	12.02 ± 2.62	-21.6	-0.78	**< 0.001**	
SCMA	CG	34.26 ± 4.62	34.18 ± 4.34	-0.2	-0.02	0.890	0.431
	EG	36.80 ± 3.00	33.18 ± 1.73	-9.8	-1.21	**< 0.001**	
GI	CG	25.66 ± 1.77	25.32 ± 2.10	-1.3	-0.19	0.401	**0.003**
	EG	26.96 ± 3.68	22.76 ± 2.03	-15.6	-1.14	**< 0.001**	

Abbreviations: W10m: 10-Meter Walk; SSP: Stand up from sitting position; SPP: Standing up from the prone position; PTS: To put on and take off a T-shirt; SCMA: Sit and get up from the chair and move around the house; * p < 0.05, pre vs. post; † p < 0.05, CG post vs. EG post; *d*= effect size (Cohen); SD= Standard deviation.

Table 5 examined the bone biomarkers (Vitamin B12, Vitamin D, Phosphorus, Alkaline Phosphatase, and PTH). The control group did not show any changes. In the intergroup analysis, the experimental group exhibited better results compared to the control group.

Table 5. Bone biomarkers analysis.

Variables	Group	Mean pre ± SD	Mean post ± SD	Δ%	*d*	p-value*	p-value†
Vitamin B12 (pg/ ml)	CG	263.31 ± 121.21	261.69 ± 121.72	-0.62	-0.01	0.912	**0.002**
	EG	268.50 ± 39.40	324.64 ± 78.33	20.91	1.42	**< 0.001**	
Vitamin D (ng/ml)	CG	29.16 ± 5.58	28.95 ± 5.88	-0.7	-0.04	0.796	**0.002**
	EG	28.36 ± 4.05	37.89 ± 7.04	33.6	2.35	**0.005**	
Phosphorus (mg/ dl)	CG	4.08 ± 0.85	4.25 ± 1.19	4.2	0,20	0.796	**0.003**
	EG	4.07± 0.56	3.47 ± 0.42	-14.74	-1.07	**0.005**	
Alkaline Phosphatase (U/L)	CG	74.08 ± 13.05	74.15 ± 13.26	0.1	0.01	0.407	**0.025**
	EG	83.5 ± 16.54	90.93 ± 21.82	8.90	0.45	**0.018**	
PTH (pg/ ml)	CG	51.85 ± 17.66	52.92 ± 17.11	2.1	0.06	0.791	**0.033**
	EG	55.21 ± 30.98	36.86 ± 19.6	-33.2	-0.59	**< 0.001**	

Abbreviations: *p < 0.05, pre vs. post; † p < 0.05, CG post vs. EG post; *d*= effect size (Cohen); SD= Standard deviation; PTH= parathyroid hormone.

Discussion

This randomized clinical trial aimed to analyze the effects of 12 weeks of taekwondo training on physiological markers of bone remodeling, muscle strength, and functional autonomy in older women. The taekwondo intervention yielded positive responses in all the analyzed variables.

Muscle strength was one of the variables investigated in this study, with elbow flexion and sit-to-stand tests used. In the experimental group (EG), significant increases (p < 0.05) in muscle strength were found in both intragroup and intergroup (post-test) comparisons. The control group (CG) did not exhibit significant differences in muscle strength evaluation. Consistently, a study conducted by [Ku *et al.* 2021] assessed 16 women (CG=8/EG=8) with a mean age of 50 years using Taekwondo as an intervention applied over 12 weeks, 3 times per week, for 60 minutes per day. No differences (p > 0.05) in muscle strength were found in the intergroup comparison. According to [Araujo-Gomes *et al.* 2020], muscle strength is crucial for improving the quality of life in older individuals, as increased muscle strength enhances the performance of ADLs.

Another parameter evaluated was functional autonomy using the GDLAM protocol. In the experimental group (EG), there was a significant increase (p < 0.05) in intragroup evaluation in the following tests: W10m, SSP, PTS, SPP, SCMA, and GI. These results are reflected in reductions in the mean execution times of the tests. In the intergroup comparison, the experimental group showed improvement (p < 0.05) compared to the control group (CG) in the C10m, LPS, LPDV tests, and the IG. It's important to highlight that functional autonomy provides older individuals with the possibility of freedom, dignity, and integrity, and is essential for improving and maintaining health [Borges *et al.* 2018]. Supporting the findings of this study, [Cardoso *et al.* 2021] analyzed 13 women with a mean age of 61 years who performed multicomponent exercises with resistance training, functional training, and adapted Judo in the same session for 12 weeks. They observed improvements (p < 0.05) in all functional autonomy variables using the GDLAM protocol in the intragroup comparison. Similarly, a clinical trial conducted by [Borba-Pinheiro *et al.* 2016] analyzed 50 older women with a mean age of 57 years, divided into 3 groups: Group 1 (Karate), Group 2 (Judo), and Group 3 (Control), for 9 months, 3 times a week, and 60 minutes per session. They found improvements in functional autonomy using the GDLAM protocol as the testing procedure.

For the assessment of bone biomarkers, samples of Vitamin B12, Vitamin D, Phosphorus, Alkaline Phosphatase, and PTH were collected. Significant differences (p < 0.05) were found in all analyzed variables in the intragroup comparison (pre vs. post) within the experimental group (EG), while the control group (CG) did not exhibit significant differences (p > 0.05). In terms of the intergroup comparison, improvements were observed in all variables within the EG compared to the CG. Specifically, Vitamin B12, Vitamin D, and Alkaline Phosphatase levels showed increases (p < 0.05), while Phosphorus and PTH exhibited reductions (p < 0.05) within the GE in the intragroup comparison. In the intergroup comparison, there were increases (p < 0.05) in Vitamin D and Alkaline Phosphatase levels in the GE when compared to the GC. Supporting these findings, a study conducted by [Shen *et al.* 2012] involving 171 women with a mean age of 57 years who practiced the martial art Tai Chi Chuan for 6 months, 3 times a week, and 60 minutes per day, showed improved bone formation biomarkers, including PTH, and enhanced bone turnover rate. Another study by [Groenendijk *et al.* 2020] examined 180 older individuals of both sexes (mean age: 61 years) who underwent muscular strength, balance, and aerobic exercises for 12 and 24 weeks, 2 times per week, and 60 minutes per day. They demonstrated improvements in bone formation biomarkers (PTH and Vitamin B12) and bone turnover rate.

A low number of clinical trials [Feehan, Waller 1995; Valdes-Badilla *et al.*, 2023] have used taekwondo as an intervention in the older population. The study by [Feehan, Waller 1995] focused on cognitive function as the primary outcome variable, while the study by [Valdes-Badilla *et al.*, 2023] examined outcomes such as blood pressure, morphological variables, postural balance, quality of life and handgrip strength. None of these studies analyzed specific biomarkers of bone remodeling and functional autonomy, variables that were investigated in this randomized clinical trial.

The study's limitations included the absence of analysis for other biomarkers (pyridinoline, hydroxyproline, osteocalcin, type I collagen propeptides), which could have enhanced the robustness of the results obtained in this study. Additionally, certain studies that did not employ taekwondo or combat sports as interventions were used to discuss the outcomes of this experimental study due to the scarcity of clinical research involving taekwondo applied to the older population.

Conclusion

The results found in this experimental study support the effectiveness of taekwondo practice on physiological markers of bone remodeling, muscle strength, and functional autonomy in older women. Bone remodeling biomarkers (alkaline phosphatetase, serum phosphorus, vitamin B12, Vitamin D, and PTH) exhibited positive outcomes following the 12-week intervention, which holds significance within this population due to the degenerative processes attributed to senescence. Increased muscle strength in both the lower and upper limbs, along with enhanced functional autonomy, were observed.

Based on the outcomes obtained in this experiment, the incorporation of Taekwondo into clubs, fitness centers, and similar environments for the older population is recommended. These findings substantiate the benefits to the physical fitness of this population, leading to improved functional autonomy.

Studies involving longer intervention periods and the incorporation of additional bone remodeling markers (such as pyridinoline, hydroxyproline, osteocalcin, type I collagen propeptides) are recommended to further validate the findings observed in this study.

Authorship Statement

We declare that the article entitled "Impact of *taekwondo* on physiological markers of bone remodeling, muscle strength, functional autonomy in older women: a randomized clinical trial" is original, unpublished, and has not been submitted to another journal, and that all authors participated in the preparation of this work.

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Wpływ taekwondo na fizjologiczne markery przebudowy kości, siłę mięśni i autonomię funkcjonalną u starszych kobiet: randomizowane badanie kliniczne

Słowa kluczowe: codzienne czynności życiowe, gęstość mineralna kości, sporty walki, osoby starsze

Streszczenie

Tło. Weryfikacja wpływu treningu taekwondo na fizjologiczne markery przebudowy kości, siłę mięśni i autonomię funkcjonalną u osób starszych.

Problem i cel. Utrata masy kostnej związana ze spadkiem siły mięśniowej może wpływać na zdolność do wykonywania codzi-

ennych czynności życiowych (ADL) u osób starszych. Niniejsze badanie jest uzasadnione poprzez przedstawienie sportów walki, w szczególności taekwondo, w możliwości zmniejszenia ryzyka dla zdrowia osób starszych z utratą masy kostnej wraz ze starzeniem się. Dlatego celem niniejszego badania była analiza wpływu treningu taekwondo na fizjologiczne markery przebudowy kości, siłę mięśni i autonomię funkcjonalną u starszych kobiet.
Metody. Dwadzieścia siedem starszych kobiet niećwiczących taekwondo zostało losowo przydzielonych do grupy eksperymentalnej (EG; n = 14) i grupy kontrolnej (CG; n = 13). Grupa EG ćwiczyła taekwondo (3 razy w tygodniu, 40 min/sesję) przez 12 tygodni. Siłę mięśni analizowano za pomocą testów zginania łokcia Rikli i Jonesa oraz siadania i stania. Autonomię funkcjonalną analizowano za pomocą protokołu autonomii funkcjonalnej GDLAM. Pobrano próbki krwi do analizy biomarkerów kostnych (fosfataza alkaliczna, fosfor w surowicy, witamina B12, witamina D i parathormon [PTH]).
Wyniki. ANOVA (2 x 2) z powtarzanymi pomiarami wykazała, że nastąpił wzrost siły mięśni w EG ($p<0,05$) w porównaniu wewnątrzgrupowym i międzygrupowym (po interwencji) w obu testach (zgięcie łokcia oraz siad i stanie). Nastąpił wzrost autonomii funkcjonalnej ($p<0,05$) w EG w ocenie wewnątrzgrupowej. W ocenie biomarkerów kostnych stwierdzono różnice ($p<0,05$) we wszystkich zmiennych analizowanych w porównaniu wewnątrzgrupowym (przed i po) w EG.
Wnioski. Wyniki uzyskane w tym badaniu eksperymentalnym potwierdzają skuteczność treningu taekwondo na fizjologiczne markery przebudowy kości, siłę mięśni i autonomię funkcjonalną u starszych kobiet.