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The combined effect of rowing exercise and the intake of functional foods containing inulin on muscle mass and bone mineral density in older Japanese women

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Aim: Aging decreases muscle mass and bone mineral density (BMD), especially in older women. It has been reported that rowing and inulin intake positively affect muscle and bone, respectively. We examined the synergistic effect of rowing and functional food intake, including inulin, on lean body mass, BMD, and physical function parameters in older Japanese women.

Methods: Fifty women aged 65–79 years were divided into four groups with or without inulin intake and rowing. The interventions were carried out for 12 weeks in each group. We assessed lean body mass and BMD using dual-energy X-ray absorptiometry at baseline and after the intervention and examined the changes in the values in each group.

Results: Lean body mass in all groups decreased, and the change in lean body mass in the group with rowing and inulin intake was significantly smaller than that in the group without them (−0.05 ± 0.61; −0.83 ± 0.59 kg; $P = 0.030$). The BMD in the three intervention groups increased after the 12-week intervention. The change in BMD in each of the three intervention groups showed significant differences compared with the control group (Rowing + Inulin: $P = 0.03$; Rowing + No inulin: $P = 0.01$; No rowing + Inulin: $P < 0.01$).

Conclusions: Rowing and the intake of functional foods, including inulin, synergistically prevented a decrease in lean body mass. These factors, individually and additively, might increase BMD in older Japanese women. **Geriatr Gerontol Int 2023; ••: ••–••.**

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Introduction

Aging decreases muscle mass[1,2] and muscle strength.[3,4] Sarcopenia is a progressive and generalized skeletal muscle disorder involving the accelerated loss of muscle mass and function and is associated with adverse health outcomes.[5] Further, it is associated with increased adverse outcomes, including falls, functional decline, frailty, and mortality.[6] It is prevalent in older individuals, especially in older women with lower muscle mass and muscle strength than men.[2] Aging also decreases bone mineral density (BMD).[7] Osteoporosis caused by decreasing BMD is a concern in older age.[8] The prevalence of osteoporosis is high in older women.[9] This may result in an increased risk of fracture and a greatly decreased quality of life owing to difficulties performing routine physical activities. Therefore, mitigating these negative effects is important.

Previous studies reported that resistance training and weight-bearing exercises such as squats could prevent age-related decreases in lean body mass (LBM)[10] and BMD.[11] However, these exercises are associated with the risk of injury in older women with severe knee osteoarthritis.[12] Rowing exercises are relatively safe for older individuals with impaired knee or leg function as they are performed while seated and exert little impact on the knee joints. Rowing involves most muscles, as it consists of the rhythmic extension and flexion of the arms, trunk, and legs.[13] Older rowing-trained men have larger trunk muscle volume and power than older untrained men.[14] Rowing can also prevent age-related muscle atrophy.[15]

The intake of nutrients is reported to be effective in maintaining bone health.[16] Inulin and oligofructose, which are water-soluble storage polysaccharides, belong to a group of non-digestible carbohydrates.[17] Some studies have reported that intake of these as functional ingredients contributes to bone health, including improvement in BMD, bone mineral content, and bone metabolism markers.[18,19] Some older individuals may have difficulty committing to and carrying out rowing or taking supplements.[20] If rowing and inulin intake could synergistically affect muscle mass and bone health, the positive effects may alleviate some of this burden. However, such synergistic effects have not been established yet.

This study examined the synergistic effect of rowing and the intake of functional foods containing inulin on muscle mass, BMD, and physical function parameters in older Japanese women. These interventions were hypothesized to have a positive synergistic effect and increase muscle mass and BMD.

Methods

Research design

Figure 1 presents the design of this study. The effect of rowing on LBM and BMD was investigated by comparing four parallel groups. Two initial groups were formed during the screening phase, according to the participants' ability to visit our laboratory for rowing once a week in a 12-week rowing exercise intervention. The intervention period in our study was set at 12 weeks, based on a previous major study examining the change of LBM.[10] However, previous studies that have examined BMD lasted longer than 6 months,[11] which is the time necessary to observe alterations in bone. Some bone metabolism markers were also measured, as these parameters tend to change faster than BMD.

Two groups, with and without rowing, were divided into two subgroups each to determine whether the intake of functional foods and inulin positively affected LBM and BMD. A double-blind, randomized, controlled intervention study was only conducted for the intake of functional foods, including inulin. This study was registered with the University Hospital Medical Information Network Center Clinical Trial Registry (URL: https://www.umin.ac.jp/ctr/index-j.htm; ID 000028144).

Participants

A total of 72 healthy, independent, and active women aged between 65 and 79 years, recruited from temporary employment agencies and the local community in the Tokorozawa metropolitan area, volunteered to participate in the study. We used G*Power (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany) to calculate the required sample size for our trial. Our target of 100 participants (effect size 0.25, power 0.5) was not met; however, we were able to continue with 50 (effect size 0.25, power 0.26).

A detailed description of the requirements and conditions was given; if participants did not fully understand the criteria, we excluded them from the study. Participants were screened via telephone interviews to discuss any medications that they were taking to prevent osteoporosis. Seventeen women did not fully understand that the osteoporosis medication prescribed to them interfered with the study's goals and were excluded from the study. Fifty-five women were still eligible for this study. Five additional participants were excluded due to absence, poor physical condition, or refusal to eat functional foods. The remaining 50 participants had been previously engaged in some sport or physical activity, and they were able to attend this study. Participants were screened for their ability to visit our lab for rowing with a rowing machine once a week. Twenty-two participants were able to attend, while 28 had difficulties attending. Each group was randomized for inulin intake after baseline measurements. After dividing the groups based on the participants' ability to visit our lab once a week, each group was then halved to create four groups, allowing for the randomization of

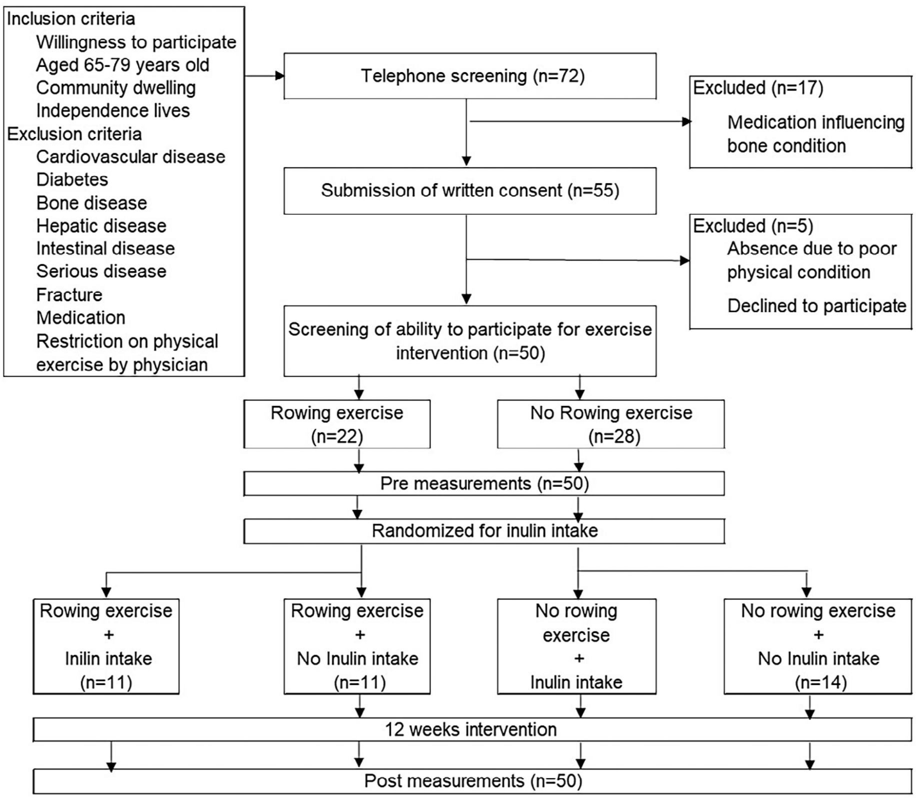

Figure 1 Study design: screening and randomization processes and measurements performed.

inulin intake. All 50 participants who reached the pre-measurement phase completed the 12-week intervention and were available to participate in the post-measurement phase. This random assignment of participants was performed by an independent researcher from our laboratory who was uninvolved in the measurement, intervention, and data analysis.

Measurements

Body composition and BMD

Height was measured using a stadiometer (YL-65, YAGAMI Inc., Nagoya. Japan), and body weight was measured using an electronic scale (MC-980, Tanita Corp., Tokyo, Japan). A whole-body dual-energy X-ray absorptiometry (DXA) scan (Horizon A, configured with APEX software version 5.6, Hologic Inc., Marlborough, MA, USA) was used to measure LBM and BMD. The estimated co-efficiency of the variation in DXA measurements from the test–retest analysis was determined to be <1%.[21]

Bone metabolism markers

Bone metabolism markers, total procollagen type I amino-terminal propeptide (T-P1NP), undercarboxylated osteocalcin (ucOC), and tartrate-resistant acid phosphatase 5b (TRCAP-5b) were measured in the blood to evaluate short-term changes in bone metabolism. Venous blood samples were collected by venipuncture after at least 12 h of overnight fasting. The serum levels of these markers were determined at BML, Inc. (Tokyo, Japan).

Nutritional intake

The nutritional intake of participants in the preceding month was assessed using a validated 58-item brief-type self-administered diet history questionnaire (BDHQ).[22–24] We carefully checked all the answers on the BDHQ to avoid misreporting.

Muscle strength

Leg extension power. Leg extension power was measured using a machine that applied a brake load (AnaeroPress 3500; Combi Corp., Tokyo, Japan). The participants were instructed to kick as hard and fast as possible and grip the levers on both sides. Their maximum values over the five repetitions were used for data analysis.

Handgrip. Handgrip strength was measured using a digital grip strength tester (T.K.K.5041, Takei Scientific Instruments Co., Ltd, Niigata, Japan). Participants performed two trials with the right and left hand alternately. Their maximum values of two trials were used for data analysis.

Walking speed. Walking speed was measured with a walking analysis system (YW-3, Yagami Co., Aichi, Japan). Participants were requested to walk straight ahead for ~10 m at their usual walking pace and at a brisker pace. To check the start and end points, light sensors were used. The time taken for the 10-m walk was recorded. This test was conducted twice for each gait modality, and hence a total of four times were recorded. The average speed of each walk was used in this study.

Baseline physical activity. The participants' physical activity (PA) was measured using an accelerometer (Lifecorder, Suzuken Co., Ltd, Nagoya, Japan) to examine the characteristics of usual activity. Participants were instructed to wear the accelerometer for at least 7 days on the waist throughout the day for a minimum of 10 h, except during sleep and water-related activity (e.g., swimming, bathing). The data from at least 4 days, 3 weekdays, and one weekend day for each participant were used in this study.

Intervention

Inulin intake

The 25 participants across the two inulin-intake groups were required to take functional foods containing 5 g of inulin (Fuji FF; Fuji Nihon Seito Co., Tokyo, Japan) per day over 12 weeks (energy, 110 kcal; protein, 3.5 g; fat, 2.8 g; and carbohydrate, 20 g – including inulin 5 g and calcium 200 mg). This functional food was made by adding 5 g of inulin to one package of Enjoy Mousse® (Morinaga Milk Industry Co. Ltd, Tokyo, Japan). The remaining 25 participants in the placebo groups were given a package of Enjoy Mousse® without inulin, and 5 g of maltodextrin was added instead (energy, 110 kcal; protein, 3.5 g; fat, 2.8 g; and carbohydrate, 17.5 g – including maltodextrin 5 g and calcium 200 mg). Participants were instructed to take one package of functional foods, including inulin, per day, as close to breakfast as possible.

Rowing exercise

Participants in the rowing groups were required to exercise using a rowing ergometer for 10 min weekly in a laboratory and to exercise at home using a resistance tube for 10 min twice weekly for 12 weeks. Rowing using rowing ergometers (e-Rowing, e-Rowing Inc., Toyota, Japan) consisted of preparation exercises, including ~5 min of stretching exercises and warm-up, followed by 5 min of warm-up using the rowing machine, 10 min of workout, ~2 min of cool-down rowing, and finishing with ~5 min of cool-down exercises, most of which involved stretching. The workout intensity was 30–80 W according to each participant's physical capacity. For the at-home exercise, we sourced low-cost resistance tubes (Elastic Extender, LIVEUP Sport, Nantong, China) easily obtained through major online marketplaces to ensure easy availability and replaceability. These resistance tubes were color-coded with three levels of resistance, represented by different colors: pink, green, and blue (soft, medium, and strong, respectively). Most participants used pink tubes with soft resistance. The tube exercise motions are shown in Fig. 2.[25]

The exercise involved 3-s repetitions consisting of bringing the second loop in their hands toward their chest in a rowing-like motion. They were asked to perform this 20 times per minute for 10 min. This could be achieved in one session or broken up into two or three parts, depending on their physical capacity.

Interview and participation check

Participants were interviewed by a registered dietitian and trainer each week during the intervention period regarding the frequency and duration of their rowing, inulin intake at home, and change in their condition. They were also required to submit their weekly rowing and inulin-intake records.

Statistical analysis

All statistical analyses were performed using SPSS, version 24.0 (IBM Corp., Armonk, NY, USA). Data were shown as means (± standard deviations) for parametric data and medians (interquartile ranges) for non-parametric data. Differences in baseline values or changes during intervention among the four groups were determined using a one-way analysis of variance for normally distributed data and the Kruskal–Wallis test for nonnormally

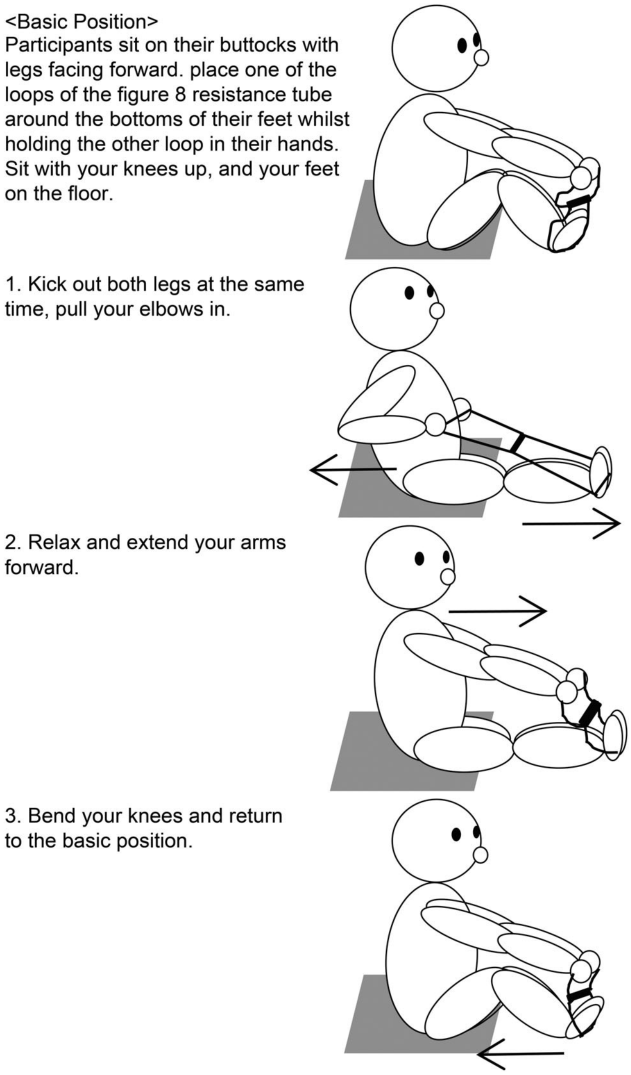

Figure 2 Protocol of the rowing exercise using a figure-eight resistance band. This exercise involves a 3-s movement consisting of the participant bringing the second loop of the resistance band in their hands toward their chest in a rowing-like motion. Participants are asked to perform these motions 20 times per min for 10 min. This can be achieved in one session or broken into two or three parts, depending on the physical capacity of the participants (adapted from Asaka[25]).

distributed data. When the Kruskal–Wallis test indicated a significant difference, the Bonferroni post hoc test was used to identify the two groups that showed significant differences. Significant differences in the values between baseline and post-intervention within each group were determined using Student's *t*-test. The significance level was set at $P < 0.05$.

Results

Baseline characteristics

The baseline characteristics of the participants in this study are shown in Table 1. There were no significant differences in age ($P = 0.16$), height ($P = 0.75$), body mass ($P = 0.70$), or body mass index (BMI; $P = 0.53$) among the four groups before intervention. There were no underweight or obese participants in this study, according to their BMI values. Moreover, there was no significant difference among the four groups in body fat percentage ($P = 0.79$), LBM ($P = 0.51$), BMD ($P = 0.45$), variables related to bone metabolism markers, nutritional intake (energy, protein, etc.), muscle strength, and Physical Activity (PA) levels.

Adherence and safety

The enforcement of rowing average success rate was 100% (97%–103%) in the Rowing + Inulin group and 94% (83%–100%) in the Rowing + No inulin group, and it was not significantly different between the two groups ($P = 0.10$). Some participants in the Rowing + Inulin group carried out rowing exercises, as instructed by us, more than three times per week. The average adherence rate was 100% (99%–100%) in the Rowing + Inulin group, 99% (92%–100%) in the Rowing + No inulin group, 100% (99%–100%) in the No Rowing + Inulin group, and 100% (99%–100%) in the No Rowing + No Inulin group. There was no significant difference among the four groups ($P = 0.33$). No injuries or serious adverse events related to either the rowing or the food supplementation occurred during the intervention.

Post-intervention measurements

Table 2 details the effect of rowing with the intake of functional foods containing inulin on LBM and BMD. This was assessed by comparing the change in values from baseline to post-intervention in total body mass, body fat percentage, body fat mass, LBM, and BMD. LBM ($P = 0.03$) and BMD ($P < 0.01$) showed significant differences among the four groups. All values of LBM measured at post-intervention decreased compared with their baseline values. The reduction in LBM in the Rowing + Inulin group was significantly smaller than that in the No rowing + No inulin group (control), according to the Bonferroni multiple comparisons ($P = 0.03$). The BMD in the three intervention groups increased after the intervention. The changes in BMD in each of these three groups showed significant differences compared with the control group, according to the Bonferroni multiple comparisons (Rowing + Inulin: $P = 0.03$, Cohen's $d = 0.99$; Rowing + No inulin: $P = 0.01$, Cohen's $d = 1.52$; No rowing + Inulin: $P < 0.01$, Cohen's $d = 1.32$). The changes during the intervention in bone metabolism markers, including T-P1NP, unOC, and TRACP-5b, and muscle strength and walking speed were not significantly different among the four groups. The changes in nutritional intake besides iron during the intervention were also not significantly different among the four groups (Table 3). Each participant's results during this intervention are shown in Fig. S1.

Discussion

This study examined whether rowing exercise and the intake of functional foods with inulin affected LBM and BMD in older Japanese women. The results partially supported our hypothesis that rowing exercise with inulin intake synergistically increases LBM and BMD. However, these effects were synergistic only for LBM. Although the Rowing + Inulin intake group did not show an increase in LBM, it showed significant prevention of the decrease in LBM compared with the control group. Moreover, except for the control group, which showed decreased BMD, the other three groups showed increased BMD. Therefore, the

Table 1 Baseline characteristics of the study participants

Variables	Rowing + Inulin (n = 11)	Rowing + No inulin (n = 11)	No rowing + Inulin (n = 14)	No rowing + No inulin (n = 14)	P-value*
Age (years)	72.6 ± 2.7	70.2 ± 3.8	73.1 ± 3.2	72.7 ± 3.6	0.16
Height (cm)	152.4 ± 3.4	151.9 ± 4.4	153.3 ± 5.0	153.7 ± 5.2	0.75
Body mass (kg)	52.6 (45.9–55.7)	53.3 (50.8–58.9)	51.7 (48.1–55.7)	51.8 (46.2–55.5)	0.70
Body mass index (kg/m^2)	23.5 (19.8–24.1)	23.4 (21.3–25.1)	22.4 (20.2–23.6)	22.4 (19.9–23.5)	0.53
Total body fat percentage (%)	30.4 (25.0–34.3)	30.8 (22.9–32.9)	28.8 (25.7–31.6)	28.6 (23.8–30.9)	0.79
Total body fat (kg)	14.2 (11.3–19.0)	16.3 (11.7–19.4)	14.8 (12.3–17.7)	15.4 (11.2–17.3)	0.89
Total lean body mass (kg)	36.3 ± 3.0	38.6 ± 3.0	37.4 ± 4.7	37.6 ± 3.1	0.51
Total bone mineral density (g/cm^2)	0.905 ± 0.055	0.942 ± 0.059	0.897 ± 0.075	0.905 ± 0.089	0.45
Bone metabolism marker					
T-P1NP (ng/mL)	46.7 (38.7–71.4)	42.1 (30.3–52.6)	50.0 (42.4–61.9)	54.0 (48.0–64.6)	0.47
ucOC (mU/mL)	4.95 (3.26–5.82)	3.85 (2.64–6.97)	5.16 (3.21–7.28)	3.92 (3.38–5.84)	0.88
TRACP-5b (ng/mL)	434 (319–539)	390 (330–445)	346 (305–513)	500 (376–640)	0.12
Nutritional intake					
Energy (kcal/day)	1931 (1627–2436)	1637 (1404–2027)	1799 (1146–2442)	1568 (1415–1861)	0.48
Protein (g/day)	96.1 (67.4–101.9)	75.1 (59.2–100.3)	84.0 (68.2–100.9)	76.2 (64.4–84.9)	0.60
Fat (g/day)	65.6 ± 16.1	61.5 ± 19.3	63.4 ± 20.4	60.3 ± 15.8	0.90
Carbohydrate (g/day)	228.6 (194.1–352.0)	212.2 (166.8–270.2)	212.0 (142.9–293.9)	200.3 (164.6–248.8)	0.35
Calcium (mg/day)	770 (671–1028)	623 (464–962)	779 (673–954)	712 (513–837)	0.42
Iron (mg/day)	11.3 (7.5–14.0)	7.9 (7.2–11.9)	10.0 (8.3–13.7)	10.9 (8.4–11.7)	0.52
Vitamin D (μg/day)	24.0 (13.2–31.6)	17.8 (9.7–26.0)	17.6 (11.3–37.4)	16.9 (9.6–26.0)	0.68
Vitamin K (μg/day)	504 (189–692)	395 (204–450)	463 (209–614)	470 (362–704)	0.38
Hand grip (kg)	22.2 (20.2–23.9)	21.9 (19.2–23.5)	24.8 (21.2–25.9)	23.8 (19.8–25.1)	0.20
Leg extension (W)	530 (463–733)	543 (494–669)	652 (480–805)	514 (462–727)	0.77
Walking speed (m/min)					
Normal	85.7 (84.7–91.2)	84.8 (76.6–93.5)	89.5 (81.7–96.7)	87.4 (83.3–93.0)	0.89
Brisk	110.8 (101.4–124.3)	116.3 (110.8–133.5)	113.5 (104.8–120.6)	107.5 (103.7–121.1)	0.63
Step counts (steps/day)	8447 ± 2373	10 450 ± 4317	9590 ± 2873	8713 ± 2957	0.60
Physical activity (METs, h/day)					
Sedentary	25.49 ± 1.48	24.05 ± 2.55	25.09 ± 2.04	25.72 ± 2.07	0.50
Low intensity	12.58 (10.88–13.97) 13.97)	12.85 (10.37–14.94)	12.15 (10.12–15.41)	13.55 (9.56–14.17)	0.91
Moderate intensity	2.33 (1.61–4.19)	3.32 (2.11–4.98)	3.29 (2.21–4.65)	1.66 (1.10–3.33)	0.17
High intensity	0.06 (0.03–0.15)	0.25 (0.09–0.34)	0.09 (0.03–0.16)	0.16 (0.03–0.30)	0.11

Note: Data are presented as means (±standard deviations) for normally distributed data or as medians (interquartile ranges) for nonnormally distributed data.

*P-values are obtained by one-way analysis of variance (normally distributed data) or by the Kruskal–Wallis test (nonnormally distributed data).

Abbreviations: METs, metabolic equivalents of task; Rowing + Inulin, rowing exercise with inulin intake group; Rowing + No inulin, rowing exercise without inulin intake group; No rowing + Inulin, inulin intake without rowing exercise group; No rowing + No inulin, no rowing without inulin intake group.

synergistic effect on BMD of rowing exercise and the intake of functional foods containing inulin was not shown in our study.

Previous studies regarding the positive effects of resistance training on LBM in older women did not use inulin and focused solely on the effects of resistance training; these trials resulted in increased or maintained LBM of the participants.[10] Our study used functional foods containing inulin to explore the synergistic effect of rowing exercise combined with inulin intake. Although the LBM of all groups in our study decreased during the intervention period, the reduction in LBM in the Rowing + Inulin group was significantly lower than that in the control group ($P = 0.03$; Table 2). The results of this study provide noteworthy evidence that the combination of rowing exercise and intake of functional foods containing inulin can prevent a reduction in LBM.

No significant difference was shown among the four groups for LBM at baseline or for the effect of nutritional intake besides iron alone on the change of LBM during the intervention. Only iron intake during the intervention was significantly different among the four groups ($P = 0.04$), and multiple comparisons showed that the Rowing + No inulin group had significantly higher iron intake than the No rowing + Inulin group. We considered that the result of this statistical analysis of the change in iron intake during the intervention was not necessarily significant when examining the synergistic effects of rowing and inulin intake. Consideration was made during the post-intervention dietary survey that the period in which this intervention was held coincided with the beginning of Japanese winter, a time of year when people experience an increased appetite, and iron-rich foods such as green vegetables and fish become a part of the average diet, maybe particularly so amongst older Japanese women.

There may, however, be a synergistic effect of rowing and inulin intake in preventing the reduction of LBM during the intervention. Although the participants' PA outside of rowing during this intervention should have been measured, this could not be carried out because there was a possibility that using a PA measurement device might encourage participants to exercise beyond the norm.

Table 2 Comparison of the changes by intervention among the four groups

Change	Rowing + Inulin (n = 11)	Rowing + No inulin (n = 11)	No rowing + Inulin (n = 14)	No rowing + No inulin (n = 14)	P-value*
Total body mass (kg)					
Post	53.5 (46.7–56.5)	52.5 (50.5–59.2)	52.0 (49.8–55.9)	52.0 (46.5–55.5)	
Post-intervention change	0.3 (−0.2–0.7)	0.1 (−1.0–0.4)	0.2 (−0.3–0.6)	−0.4 (−0.9–0.3)	0.18
Total body fat percentage (%)					
Post	29.4 (25.1–34.9)	31.6 (23.2–33.0)	30.7 (24.8–32.1)	29.3 (26.1–31.2)	
Post-intervention change	0.5 (−0.5–1.2)	0.1 (−0.3–0.9)	0.8 (0.6–1.5)	0.8 (0.6–2.2)	0.22
Total body fat (kg)					
Post	14.5 (11.9–19.5)	16.6 (12.7–19.5)	15.4 (12.7–17.7)	15.6 (12.1–17.7)	
Post-intervention change	0.4 (−0.1–0.6)	0.0 (−0.4–0.6)	0.6 (0.3–0.9)	0.4 (0.2–1.0)	0.29
Total lean body mass (kg)					
Post	36.3 ± 3.1	38.2 ± 3.0	37.0 ± 4.6	36.7 ± 3.1	
Post-intervention change	−0.0 ± 0.6*	−0.3 ± 0.6	−0.4 ± 0.8	−0.8 ± 0.6	**0.04**
Total bone mineral density (g/cm^2)					
Post	0.907 ± 0.063	0.950 ± 0.057	0.900 ± 0.077	0.892 ± 0.084	
Post-intervention change	0.002 ± 0.013**	0.008 ± 0.011***	0.004 ± 0.009***	−0.013 ± 0.016	**<0.01**
T-P1NP (ng/mL)					
Post	44.4 (34.0–58.0)	44.3 (29.2–57.4)	49.2 (42.7–56.1)	60.3 (43.3–71.4)	
Post-intervention change	−2.3 (−10.0–2.9)	1.3 (−8.8–6.5)	−0.5 (−8.4–4.7)	−0.6 (−6.8–3.7)	0.49
ucOC (mU/mL)					
Post	3.50 (2.49–4.85)	4.02 (2.02–5.30)	4.24 (3.36–7.52)	4.00 (3.30–6.90)	
Post-intervention change	−0.67 (−1.93–2.9)	−0.60 (−1.00–0.09)	−0.14 (−1.28–0.34)	−0.35 (−0.55–0.35)	0.22
TRACP-5b (ng/mL)					
Post	404 (308–524)	317 (281–459)	346 (290–539)	500 (376–640)	
Post-intervention change	−24 (−31–11)	−17 (−47–13)	−6 (−56–39)	−28 (−64–70)	0.97
Hand grip (kg)					
Post	22.3 (20.2–24.7)	21.2 (19.3–23.1)	22.7 (21.3–25.7)	23.4 (20.6–26.1)	
Post-intervention change	0.4 (−1.2–1.2)	−0.7 (−1.2–0.8)	−0.2 (−1.7–0.3)	−0.2 (−1.0–1.1)	0.44
Leg extension (W)					
Post	467 (354–680)	545 (441–651)	599 (457–738)	562 (418–691)	
Post-intervention change	−109 (−155–5)	−39 (−104–36)	−71 (−130–−7)	−9 (−128–84)	0.21
Walking speed normal (m/min)					
Post	82.2 (79.1–87.8)	86.8 (79.4–91.2)	88.5 (82.6–94.2)	85.8 (79.8–93.8)	
Post-intervention change	−4.2 (−7.7–−2.6)	1.9 (−4.8–3.0)	−1.7 (−4.0–2.7)	−0.5 (−3.4–2.3)	0.27
Walking speed brisk (m/min)					
Post	104.4 (97.3–118.1)	116.1 (104.4–128.6)	111.7 (105.6–121.0)	112.0 (102.6–116.6)	
Post-intervention change	−6.3 (−11.5–−3.1)	−4.9 (−7.9–1.9)	1.5 (−10.4–5.8)	−3.9 (−7.3–2.5)	0.40

Note: Data are presented as means (±standard deviations) for normally distributed data or as medians (interquartile ranges) for nonnormally distributed data. *P-values are obtained by one-way analysis of variance (normally distributed data) or by the Kruskal–Wallis test (nonnormally distributed data). Significant Bonferroni post hoc test: **different from No rowing + No inulin (P < 0.05), ***different from No rowing + No inulin (P < 0.01).

Additionally, there could have been a risk of them forgetting to wear the device. Changes in muscle strength assessed by handgrip and leg extension did not show significant differences among the four groups, unlike the results for LBM.

A previous systematic review of the test–retest reliability of grip strength measures obtained from older people showed that the relative test–retest reliability of grip strength measures obtained by dynamometry was good to excellent but that relatively large percentage changes in grip strength may be necessary to confidently conclude that a real change has occurred over time in some populations.[26] The rate of change in grip strength over the intervention period seen by this study may have been small. It is also possible that the rate of change in muscle strength assessed by leg extension was similarly small. The decrease in LBM during the 12 weeks of this study might have been caused mainly by aging: a previous study concluded that a 0.18-kg annual decline in LBM may occur.[27] However, the decline of the control group during the 12 weeks of this study was 0.8 kg and, hence, much larger than the 0.18-kg decrease shown in the previous study.

Another possible reason for the decrease of LBM in the control group was a change in PA and body composition due to seasonal climatic conditions. A previous study on older adults in Japan reported that walking speed and body fat percentage were greater in winter than in summer and concluded that the seasonal climatic environment of the geographic area affected the PA level of the participants.[28] Our study carried out baseline measurements in September, with relatively comfortable climate conditions, and the post-measurements were carried out in December under increasingly colder conditions. The change in climate conditions between baseline and post-measurements could have affected the decline of LBM more than what was reported by the previous study.[27] Further studies related to the decline of LBM through aging might be required.

A possible mechanism underlying the favorable effect of inulin intake on LBM is an improvement in calcium absorption.

Table 3 Comparison of the change in nutritional intake by intervention among the four groups

Change for nutrients	Rowing + Inulin (n = 11)	Rowing + No inulin (n = 11)	No rowing + Inulin (n = 14)	No rowing + No inulin (n = 14)	P-value*
Energy (kcal/day)					
Post	1796 (1493–2179)	1752 (1477–2084)	1507 (1154–1956)	1454 (1312–1811)	
Last 1-month change	−49 (−379–233)	−61 (−155–78)	−149 (−547–89)	−150 (−361–88)	0.69
Protein (g/day)					
Post	87.0 (71.4–111.5)	77.9 (60.6–100.5)	74.2 (58.5–100.5)	72.3 (57.0–83.9)	
Last 1-month change	−3.7 (−12.5–6.7)	5.2 (−5.5–7.2)	−13.8 (−17.2–8.2)	−1.9 (−13.6–2.6)	0.60
Fat (g/day)					
Post	59.5 ± 19.5	59.1 ± 15.5	53.5 ± 21.8	55.1 ± 16.8	
Last 1-month change	−6.1 ± 11.3	−2.3 ± 12.0	−9.8 ± 20.3	−5.3 ± 14.8	0.68
Carbohydrate (g/day)					
Post	246.6 (178.9–312.2)	211.4 (156.6–273.1)	184.7 (124.9–244.2)	190.1 (163.6–216.7)	
Last 1-month change	−15.6 (−50.2–24.6)	4.7 (−22.6–28.0)	−23.6 (−54.0–15.1)	−22.1 (−33.9–6.4)	0.43
Calcium (mg/day)					
Post	829 (547–982)	589 (481–881)	631 (548–878)	643 (513–817)	
Last 1-month change	−46 (−121–48)	38 (−64–127)	−94 (−177–65)	−54 (−181–89)	0.74
Iron (mg/day)					
Post	10.8 (7.6–13.5)	9.6 (6.8–11.8)	8.9 (7.7–13.3)	9.2 (7.5–11.5)	
Last 1-month change	−0.2 (−1.4–0.8)	0.2 (−0.1–2.2)*	−0.9 (−1.6–0.2)	−0.7 (−2.3–0.0)	**0.04***
Vitamin D (μg/day)					
Post	27.5 (7.0–30.3)	15.4 (8.9–22.5)	16.1 (8.3–31.2)	13.8 (8.6–23.0)	
Last 1-month change	−4.1 (−4.9–5.1)	−0.6 (−7.2–5.0)	−0.2 (−14.8–5.7)	1.4 (−11.3–3.8)	0.99
Vitamin K (μg/day)					
Post	472 (293–638)	356 (224–451)	480 (194–602)	387 (284–565)	
Last 1-month change	30 (−149–103)	−7 (−38–34)	−14 (−120–36)	−56 (−163–31)	0.36

Note: Data are presented as means (± standard deviations) for normally distributed data or as medians (interquartile ranges) for nonnormally distributed data. *P-values are obtained by one-way analysis of variance (normally distributed data) or by the Kruskal–Wallis test (nonnormally distributed data). Significant Dunn–Bonferroni post hoc test: *different from No rowing + Inulin (P < 0.05).

Previous studies have reported that inulin intake increases calcium absorption by the intestine,[19] and ionized calcium plays an important role in muscular functions such as muscle contraction.[29] It has also been reported that low serum calcium levels may predict significant muscle decrease among adults aged >50 years, while low calcium intake may predict muscle decrease in women.[30] Furthermore, it has been reported that calcium intake in older women is inadequate.[31,32] Therefore, inulin intake may have beneficial effects on the overall muscle condition of older women via improvement in calcium absorption, and it appears sufficient to mitigate the natural reduction in their LBM.

Rowing may be effective in maintaining muscle volume in older women because the muscle groups targeted by rowing and the movements involved are not commonplace in their daily activities. A previous study on older rowers suggested that rowing was a favorable training modality for the trunk muscles and that it improves thigh muscle size and function.[14] Our results showed that muscle decrease was prevented by rowing and the intake of functional foods containing inulin. However, this muscle decrease was not prevented by rowing or inulin-containing functional food intake separately. Therefore, rowing might be required in addition to the intake of functional foods containing inulin to prevent muscle decrease.

We hypothesized that undertaking rowing and consuming inulin-containing functional food would synergistically affect LBM and BMD. Our results of an absence of their synergistic effect on BMD were unexpected because a previous study had shown that resistance training and weight-bearing exercises could prevent a decrease in LBM and BMD[10] and that inulin intake effectively improved bone metabolism by increasing ionized calcium absorption by the intestine.[33] However, our result that the rowing-exercise-only intervention or the intake of inulin-containing functional foods also increased BMD was expected. In older women, bone tissue is more prone to resorption than formation.[34] BMD may decrease naturally in older women. All groups, except for the control group, showed increased BMD in our study. Although the synergistic effect of inulin intake and rowing for BMD was not shown, there was a significant effect on the BMD in each of these groups compared with the control group.

Improving bone metabolism by inulin intake, such as via increased calcium absorption, may lead to increased BMD. The physical stimulation and stress exerted upon bones during rowing may also have a strengthening effect and thus increase BMD. However, this synergistic effect was not observed in our study on BMD. One reason may be the inadequate duration of the intervention as compared with what is recommended to observe changes in LBM. As proteins metabolize faster, it may be possible that the synergistic effect of rowing and inulin intake is more easily assessed for LBM. However, elucidating the synergistic effects on BMD may require more time, as bone metabolism is slower. Further studies are required to examine the synergistic effects of inulin intake and rowing on BMD.

This study had some limitations. First, the sample size was small. Second, there was a discrepancy among the participant numbers in the four groups. Two groups contained 11 participants, while the other two had 14. Two additional limitations are constituted by the fact that the exercises required to be performed by the participants may have been quite arduous for some, and that some participants did not have access to convenient public transportation to travel to our laboratory to receive rowing training. Therefore, we could not increase the number of interventions in the rowing groups.

Furthermore, the duration of this study was a relatively short 12-week period, and bone metabolism markers could not detect changes in bone metabolism in such a short time. Finally, studies of this nature involving older individuals may be more effective if conducted over a longer intervention period owing to their slowing metabolism.

In conclusion, our results suggest that rowing and the intake of functional foods containing inulin may synergistically prevent the decrease in LBM, and that these interventions, individually or additively, may increase BMD in older Japanese women.

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Disclosure statement

M.H. has had a holding of 20% of the stock of e-Rowing Inc. since 2022. All the other authors declare no conflict of interest.

Ethics statement

All participants provided written informed consent before enrolment in this study, which was approved by the Research Ethics Committee of Waseda University (reference number 2017-097). This study was conducted in accordance with the principles of the Declaration of Helsinki.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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Supporting Information

Additional supporting information may be found in the online version of this article at the publisher's website:

Figure S1. Individual changes in lean body mass (LBM) and bone mineral density (BMD) from baseline to post-intervention in the various groups.

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