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Original Article

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Weight Bearing Index Is Associated With Length of Hospital Stay in Patients Undergoing Cardiac Surgery

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Abstract

Background: It has been reported that weight bearing index (WBI) is associated with rehabilitation; however, there are few reports about its association with the length of hospital stay in patients who have undergone cardiac surgery.

Methods: We registered 108 patients who did not have preoperative contraindication of exercise and underwent both cardiac surgery and cardiac rehabilitation from April 2017 to May 2022 at Fukuoka University Hospital. We excluded seven patients whose hospital stays were prolonged due to severe infection or unstable hemodynamics after cardiac surgery. We investigated patient background, laboratory, respiratory, and echocardiographic examinations, physical functions, periprocedural complications, and postoperative outcomes. We divided the patients into two groups according to a cutoff value for walking (0.45 kgf/kg WBI).

Results: The patients' age was 69 (59 - 75) years, the percentage of males was 74.1% (n = 80), and their body mass index (BMI) was 23.4 ± 3.5 kg/m^2. The low WBI group consisted of 48 patients and the preserved WBI group consisted of 60 ones. The patients in the low WBI group showed a lower percentage of male. With regard to physical functions, grip strength, one-leg standing time, the Short Physical Performance Battery score, 10-m walking speed, walking distance for 2 min both pre- and post-cardiac surgery in the low WBI group were significantly low. After cardiac surgery, the New York Heart Association (NYHA) classification was high, and the strength of exercise tolerance at discharge was low in the low WBI group. There were no significant differences in the progression of cardiac rehabilitation until walking between the groups, but the length of hospital stay in the low WBI group was significantly long. WBI was an independent predictor of the length of hospital stay in a logistic regression analysis.

Conclusions: Preoperative WBI was associated with physical functions, NYHA classification, and length of hospital stay. Preoperative WBI could be a simple marker for detecting postoperative outcomes.

Keywords: Weight bearing index; Cardiac surgery; Hospitalization length

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Introduction

Aging of the population is progressing rapidly, especially in Japan, where one in three people will be over 65 years old in 2037 [1]. In this aging society, the number of cardiac surgeries has increased from 66,700 cases in 2015 to 71,500 in 2023 [2]. Cardiac surgical procedures have become less invasive thanks to advances in technology and perioperative management. However, there are still risks. It has been suggested that preoperative low physical activity is an important contributor to poor postoperative outcomes [3, 4]. Complications can lead to prolongation of the hospital stay, increasing cost, and even cause death [5-7]. Thus, it is important to assess preoperative physical function and perform postoperative cardiac rehabilitation for patients who undergo cardiac surgery [8-10].

Weight bearing index (WBI), which is the knee extension strength divided by body weight, is an assessment of physical activity. WBI is usually used to evaluate physical function regarding daily activities and sports. For instance, walking and jogging need WBI values of over 0.45 kgf/kg and 0.60 kgf/kg, respectively [11]. While it is easy to measure WBI, the clinical significance of WBI, especially its association with postoperative outcomes in patients with cardiac surgery, is not yet clear. In this study, we investigated whether WBI is associated with postoperative physical function and the length of hospital stay in patients who undergo cardiac surgery.

Materials and Methods

Study protocol

One hundred eight patients, who did not have preoperative

contraindication of exercise, underwent cardiac surgery, and performed cardiac rehabilitation at Fukuoka University Hospital from April 2017 to May 2022, were included. We excluded seven patients for whom the length of hospital stay was prolonged to 77.0 ± 15.8 days due to complications involving severe infection and unstable hemodynamics. WBI was calculated by the average both knee extension strengths divided by the body weight. We divided the patients into a low WBI group (under 0.45 kgf/kg, n = 48) and a preserved WBI group (0.45 kgf/kg or higher, n = 60), according to the cutoff value for walking [11] and compared the outcomes in the two groups. This retrospective study was approved by the ethics committee of Fukuoka University Hospital (2018M039). It was performed in accordance with the Declaration of Helsinki and the ethical standards of the Independent Review Board of Fukuoka University.

Patient background

Age, sex, body height, body weight, and body mass index (BMI) were investigated. The underlying diseases included hypertension, diabetes mellitus, dyslipidemia, and chronic obstructive pulmonary disease. The main operative procedures were valve replacement, valvuloplasty, coronary artery bypass grafting, left atrial appendage closure, and pulmonary vein isolation.

Physical functions

Grip strength (TKK5401, Takei Scientific Instruments Co., Ltd, Niigata, Japan), quadriceps strength (MT-100W, SAKAI Medical Co., Ltd, Tokyo, Japan), WBI, 10-m walking speed, 2-min walking distance, one-leg standing time, and the Short Physical Performance Battery (SPPB) were investigated. WBI was calculated as quadriceps strength/body weight. We previously described the methods used to determine one-leg standing time and SPPB [12]. The one-leg standing time with eyes open test was performed with the hands on the waist until a maximum score of 60 s [13]. SPPB is designed to measure functional status and physical performance [14]. SPPB consists of three tests, each with a score of 0 to 4, and the sum final SPPB score ranges from 0 to 12. A higher score indicates a higher level of function.

Preoperative examinations

In laboratory examinations, hemoglobin, total protein, albumin, aspartate aminotransferase, alanine aminotransferase, lactate dehydrogenase, urea nitrogen, creatinine, estimated glomerular filtration rate (eGFR), hemoglobin A1c, and brain natriuretic peptide (BNP) were investigated. In echocardiography, left atrial diameter, left ventricular diastolic diameter, left ventricular systolic diameter, left ventricular ejection fraction, tricuspid regurgitation pressure gradient, and E/e' were investigated. In spirometry, vital capacity and forced expiratory volume % in 1 s were investigated.

Outcomes

We investigated the number of hospital days before starting cardiac rehabilitation, the number of days to a sitting position, ambulation, walking, and the number of days of hospitalization. We also investigated the rate of hospital transfer, New York Heart Association (NYHA) classification, and metabolic equivalents (METs) at discharge. METs were assessed from the exercise load by cycle ergometer or walking speed.

Statistical analysis

The Statistical Analysis System (SAS) software package (version 9.4, SAS Institute Inc., Cary, NC, USA) at Fukuoka University (Fukuoka, Japan) was used. We defined significance as a value of $P < 0.05$. Continuous variables with a normal distribution were expressed as mean ± standard deviation and compared by Student's *t*-test. Continuous variables with a non-normal distribution were expressed as median values (interquartile range) and compared by the Wilcoxon rank sum test. Categorical variables were expressed as number (%) and compared by a Chi-square analysis. A logistic regression analysis was performed to identify independent predictors of the length of hospital stay by WBI using age, sex, BMI, and delirium. The length of hospital stay was cut by the median value of 23.

Results

Baseline characteristics in the low and preserved WBI groups

Patient backgrounds are shown in Table 1. In all patients, age was 69 (59 - 75) years, the percentage of males was 74.1% (n = 80), and BMI was 23.4 ± 3.5 kg/m^2. There was no significant difference in age between the low and preserved WBI groups. The patients in the low WBI group showed a low percentage of males. There was no significant difference in BMI between the groups. With respect to the underlying diseases, the percentages of patients with hypertension, diabetes mellitus, dyslipidemia, and chronic obstructive pulmonary disease were 79.6%, 33.3%, 66.7%, and 8.3%, respectively. There were no significant differences between the two groups. The operative procedure is shown in Table 2. The percentages of patients undergoing valve operation, coronary artery bypass grafting, left atrial appendage closure, pulmonary vein isolation, and others were 57.4%, 54.6%, 23.1%, 11.1%, and 4.6%, respectively. There were no significant differences between the two groups.

Preoperative examinations in the low and preserved WBI groups

The results of preoperative examinations are shown in Table

Table 1. Baseline Characteristics in the Low and Preserved WBI Groups

Variables	All	Low WBI	Preserved WBI	P value
	N = 108	N = 48	N = 60	
Age, year	69.0 (59.0 - 75.0)	70.5 (62.5 - 76.0)	68.0 (58.0 - 73.0)	0.094
Male, n (%)	80 (74.1)	28 (58.3)	52 (86.7)	0.001
Height, cm	163 ± 9	161 ± 9	165 ± 9	0.026
Weight, kg	62.2 ± 11.9	62.7 ± 13.3	61.8 ± 10.7	0.714
BMI, kg/m^2	23.4 ± 3.5	24.1 ± 3.8	22.8 ± 3.2	0.051
Underlying diseases				
Hypertension, n (%)	86 (79.6)	40 (83.3)	46 (76.7)	0.393
Diabetes mellitus, n (%)	36 (33.3)	18 (37.5)	18 (30.0)	0.411
Dyslipidemia, n (%)	72 (66.7)	34 (70.8)	38 (63.3)	0.411
COPD, n (%)	9 (8.3)	4 (8.3)	5 (8.3)	1

There were no missing values. The P value reflects the comparison between the low WBI and preserved WBI groups. WBI: weight bearing index; BMI: body mass index; COPD: chronic obstructive pulmonary disease.

3. In spirometry, vital capacity and FEV1 (forced expiratory volume % in 1 s) were 96.1±13.8% and 78.0% (69.8% - 91.4%), respectively. The vital capacity in the low WBI group was significantly lower than that in the preserved WBI group. In laboratory examinations, hemoglobin, albumin, aspartate aminotransferase, alanine aminotransferase, lactate dehydrogenase, eGFR, hemoglobin A1c, and BNP were 13.1 ± 1.9 g/dL, 4.07 ± 0.43 g/dL, 23.0 (18.5 - 29.5) U/L, 19.0 (14.0 - 32.0) U/L, 196 (172 - 223) U/L, 56.6 ± 21.4 mL/min/1.73 m^2, 5.85% (5.60% - 6.60%), and 124 (48 - 293) pg/mL, respectively. There were no significant differences between the two groups. In echocardiography, left atrial diameter, left ventricular diastolic diameter, left ventricular ejection fraction, tricuspid regurgitation pressure gradient, and E/e' were 42.0 (36.8 - 48.0) mm, 51.5 ± 9.4 mm, 60.9% (46.1% - 67.9%), 19.9 ± 13.1 mm Hg, and 13.5 (9.7 - 18.1), respectively. There were no significant differences between the two groups.

Pre- and postoperative physical functions in the low and preserved WBI groups

Pre- and postoperative physical functions are shown in Table 4. All preoperative physical functions in the preserved WBI group were significantly higher than those in the low WBI group. Thus, WBI correctly reflected physical function. With regard to postoperative physical functions, all physical functions in the preserved WBI group were significantly higher than those in the low WBI group.

Clinical outcomes in the low and preserved WBI groups

Clinical outcomes are shown in Table 5. The hospital day of starting cardiac rehabilitation, sitting position, ambulation, walking, and the length of hospital stay were 1.0 (1.0 - 1.0), 2.0 (2.0 - 3.0), 2.5 (2.0 - 4.0), 4.0 (3.0 - 5.0), and 23.0 (20.5 - 27.0) days, respectively. There were no significant differences in the hospital day of starting cardiac rehabilitation, sitting position, ambulation, or walking between the groups. The length of hospital stay in the preserved WBI group was significantly shorter than that in the low WBI group. In the preserved WBI group, the NYHA classification at discharge was significantly low and the METs at discharge were significantly high. WBI was an independent predictor of the length of hospital stay in a logistic regression analysis (Fig. 1).

Table 2. Operative Procedures in the Low and Preserved WBI Groups

Variables	All	Low WBI	Preserved WBI	P value
	N = 108	N = 48	N = 60	
Valve operation, n (%)[a]	62 (57.4)	27 (56.3)	35 (58.3)	0.828
CABG, n (%)	59 (54.6)	28 (58.3)	31 (51.7)	0.489
LAC, n (%)	25 (23.1)	15 (31.3)	10 (16.7)	0.074
PVI, n (%)	12 (11.1)	6 (12.5)	6 (10.0)	0.681
Others, n (%)[b]	5 (4.6)	2 (4.2)	3 (5.0)	0.838

[a]Valve operation included valve replacement and valvuloplasty. [b]Others included patent foramen ovale closure, partial lung resection, and Morrow surgery. There were no missing values. P value refers to the comparison between the low WBI and preserved WBI groups. WBI: weight bearing index; CABG: coronary artery bypass grafting; LAC: left atrial appendage closure; PVI: pulmonary vein isolation.

Table 3. Preoperative Examinations in the Low and Preserved WBI Groups

Variables	All N = 108	Missing[a]	Low WBI N = 48	Missing[a]	Preserved WBI N = 60	Missing	P value
Spirometry							
VC, %	96.1 ± 13.8	13	92.5 ± 13.6	4	99.1 ± 12.9	9	0.020
FEV1, %	78.0 (69.8 - 91.4)	13	78.0 (71.4 - 91.4)	4	74.5 (68.9 - 91.1)	9	0.354
Laboratory examinations							
Hemoglobin, g/dL	13.1 ± 1.9	0	12.9 ± 1.8	0	13.3 ± 1.9	0	0.266
Total protein, g/dL	7.02 ± 0.53	0	7.05 ± 0.54	0	7.00 ± 0.54		0.609
Albumin, g/dL	4.07 ± 0.43	0	4.07 ± 0.38	0	4.08 ± 0.46	0	0.837
AST, U/L	23.0 (18.5 - 29.5)	0	21.5 (19.0 - 25.5)	0	24.5 (18.0 - 33.0)	0	0.074
ALT, U/L	19.0 (14.0 - 32.0)	0	18.0 (14.0 - 23.5)	0	21.5 (14.0 - 34.0)	0	0.122
LDH, U/L	196 (172 - 223)	0	190 (170 - 220)	0	203 (177 - 226)	0	0.291
BUN, mg/dL	18.0 (15.0 - 23.0)	1	18.5 (14.5 - 22.5)	0	18.0 (16.0 - 23.0)	1	0.965
Creatinine, mg/dL	0.95 (0.83 - 1.19)	0	0.90 (0.81 - 1.18)	0	0.98 (0.84 - 1.19)	0	0.174
eGFR, mL/min/1.73m^2	56.6 ± 21.4	0	57.5 ± 19.6	0	55.9 ± 22.9	0	0.705
Hemoglobin A1c, %	5.85 (5.60 - 6.60)	6	5.90 (5.50 - 6.70)	2	5.85 (5.60 - 6.35)	4	0.917
BNP, pg/mL	124 (48 - 293)	3	207 (57 - 305)	2	104 (48 - 243)	1	0.252
Echocardiography							
LAD, mm	42.0 (36.8 - 48.0)	0	41.4 (36.7 - 47.2)	0	43.0 (37.5 - 48.7)	0	0.583
LVDd, mm	51.5 ± 9.4	0	49.6 ± 9.6	0	53.1 ± 9.0	0	0.054
LVDs, mm	34.4 (29.3 - 42.9)	0	3.05 (29.7 - 41.8)	0	33.8 (28.8 - 43.9)	0	0.798
LVEF, %	60.9 (46.1 - 67.9)	0	58.1 (47.3 - 67.8)	0	63.1 (45.4 - 70.0)	0	0.611
TRPG, mm Hg	19.9 ± 13.1	2	17.3 ± 12.3	1	22.0 ± 13.5	1	0.063
E/e'	13.5 (9.7 - 18.1)	10	13.9 (10.1 - 21.1)	6	12.3 (9.1 - 16.8)	4	0.316

[a]Missing means missing value. P value refers to the comparison between the low WBI and preserved WBI groups. WBI: weight bearing index; VC: vital capacity; FEV1: forced expiratory volume % in 1 s; AST: aspartate aminotransferase; ALT: alanine aminotransferase; LDH: lactate dehydrogenase; BUN: urea nitrogen; eGFR: estimated glomerular filtration rate; BNP: brain natriuretic peptide; LAD: left atrial diameter; LDVd: left ventricular diastolic diameter; LVDs: left ventricular systolic diameter; LVEF: left ventricular ejection fraction; TRPG: tricuspid regurgitation pressure gradient.

Discussion

We investigated the effectiveness of WBI for predicting the length of hospital stay in patients with cardiac surgery. In this study, the preserved WBI group showed high physical functions, including grip strength, quadriceps strength, 10-m walking speed, 2-min walking distance, one-leg standing time, and SPPB in both preoperative and postoperative checks. The preserved WBI group showed a low NYHA classification and high METs at discharge and a short length of hospital stay. WBI was an independent predictor of the length of hospital stay.

Lower limb strength is a foundation of daily basic movement and is especially important in maintaining a standing position and keeping balance [15]. Previous studies have shown that the score of SPPB was associated with the ability to regain walking postoperatively and the prognosis in patients who have undergone cardiac surgery [16, 17]. Our study showed similar results. WBI, which is based on lower limb strength, is associated with SPPB, balance ability, and walking function in patients who have undergone cardiac surgery.

Exercise tolerance is associated with cardiac function, pulmonary function, and muscle metabolic function [18]. In the frailty cycle proposed by Fried, a decrease in exercise tolerance causes fatigability, hyposthenia, and deceleration of walking speed, and leads to a decrease in activity [19]. Physical factors affect frailty in that reduced muscle strength leads to reduced agility and falls and a reduced physiological reserve accelerates the vulnerability to stress seen with aging [20]. It has been reported that frailty affected lower exercise tolerance in cardiovascular patients [21]. It has also been reported that patients who are frail 1 month before surgery exhibit noticeably reduced exercise tolerance at discharge [22]. In our study, the low WBI group showed low vital capacity. This low pulmonary function would cause low exercise tolerance and low tolerance against stress due to cardiac surgery and might lead to a high NYHA classification and a low METs at discharge.

WBI was an independent predictor of the length of hospital stay. It has been reported that lower limb strength - such as knee extension and flexion - contributes to improved activities of daily living (ADL), and the strength of isometric knee extension is associated with expanding the range of in-

Table 4. Pre- and Postoperative Physical Functions in the Low and Preserved WBI Groups

Variables	All N = 108	Missing	Low WBI N = 48	Missing	Preserved WBI N = 60	Missing	P value
Preoperative							
Grip strength, kg	28.0 ± 9.2	0	24.1 ± 8.5	0	31.0 ± 8.7	0	< 0.001
Quadriceps strength, kg	27.4 (20.2 - 37.8)	0	20.0 (17.4 - 22.7)	0	37.2 (30.4 - 47.1)	0	< 0.001
One-leg standing time, s	27.6 (12.1 - 57.5)	0	16.9 (7.1 - 37.1)	0	48.0 (20.1 - 60.0)	0	< 0.001
10-m walking speed, m/s	1.57 ± 0.37	0	1.38 ± 0.32	0	1.72 ± 0.34	0	< 0.001
SPPB, score	12.0 (11.0 - 12.0)	1	12.0 (10.0 - 12.0)	1	12.0 (12.0 - 12.0)	0	< 0.001
2-min walking distance, m	182 (163 - 200)	21	170 (150 - 181)	8	194 (180 - 204)	13	< 0.001
Postoperative							
Grip strength, kg	24.6 ± 9.2	0	21.0 ± 8.0	0	27.5 ± 9.2	0	< 0.001
Quadriceps strength, kg	25.7 (18.3 - 34.1)	0	18.9 (14.8 - 25.6)	0	32.8 (25.4 - 41.8)	0	< 0.001
One-leg standing time, s	21.9 (8.3 - 58.0)	0	15.6 (6.1 - 37.8)	0	39.1 (13.1 - 60.0)	0	0.002
10m walking speed, m/s	1.47 ± 0.38	0	1.31 ± 0.35	0	1.6.0 ± 0.35	0	< 0.001
SPPB, score	12.0 (11.0 - 12.0)	1	12.0 (10.0 - 12.0)	1	12.0 (11.0 - 12.0)	0	0.02
2-min walking distance, m	170 (146 - 195)	22	160 (130 - 179)	9	184 (153 - 200)	13	0.001

P value refers to the comparison between the low WBI and preserved WBI groups. WBI: weight bearing index; SPPB: Short Physical Performance Battery.

Table 5. Clinical Outcomes in the Low and Preserved WBI Groups

Variables	All N = 108	Low WBI N = 48	Preserved WBI N = 60	P value
Start of cardiac rehabilitation, hospital days	1.0 (1.0 - 1.0)	1.0 (1.0 - 1.0)	1.0 (1.0 - 1.5)	0.826
End sitting position, hospital days	2.0 (2.0 - 3.0)	2.0 (2.0 - 4.0)	2.0 (2.0 - 3.0)	0.387
Ambulation, hospital days	2.5 (2.0 - 4.0)	3.0 (2.0 - 4.0)	2.0 (2.0 - 4.0)	0.757
Walking, hospital days	4.0 (3.0 - 5.0)	4.0 (3.0 - 5.0)	3.5 (3.0 - 5.0)	0.510
Delirium, n (%)	6 (5.6)	1 (2.1)	5 (8.3)	0.159
Hospitalization, days	23.0 (20.5 - 27.0)	24.5 (22.0 - 27.5)	22.0 (20.0 - 27.0)	0.022
Hospital transfer, n (%)	7 (6.5)	4 (8.3)	3 (5.0)	0.485
NYHA class at discharge	1 (1 - 2)	1 (1 - 2)	1 (1 - 1)	0.030
METs at discharge, METs	3.1 (2.9 - 3.5)	3.0 (2.7 - 3.3)	3.25 (2.9 - 3.6)	0.006

There were no missing values. P value refers to the comparison between the low WBI and preserved WBI groups. WBI: weight bearing index; NYHA: New York Heart Association; METs: metabolic equivalents.

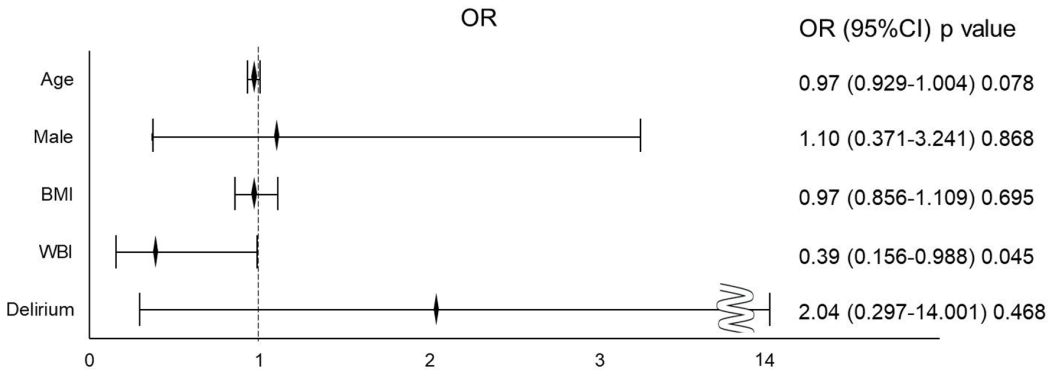

Figure 1. A logistic regression analysis for independent predictors of the length of hospital stay. A logistic regression analysis was performed to identify independent predictors of the length of hospital stay by WBI using age, sex, BMI, and delirium. The length of hospital stay was cut by the median value of 23. OR: odds ratio, BMI: body mass index, WBI: weight bearing index.

dependent movement and improving ADL [23-25]. In patients who have undergone cardiovascular surgery, an association has been reported between skeletal muscle mass and postoperative outcomes. It has been suggested that patients with a low lean body mass had a low tolerance of stress caused by surgery, an increase in the production of inflammatory cytokines and continued to exhibit systemic inflammation after surgery, and these factors contribute to an increase in the risks of postoperative complications [26, 27]. An increase in inflammatory cytokines such as interleukin (IL)-6 causes hyper-catabolism of muscle protein, a decrease in muscle strength, a decrease in physical functions, and a decrease in the ability to perform ADLs [28-30]. In our study, WBI reflected reductions in skeletal muscle mass, physical functions, and ADL as mentioned above, and a low WBI could add to the length of hospital stay in patients who have undergone cardiac surgery.

Limitations

This study has several limitations. First, this is a single-center and small sample size observational study. Future studies will be needed to gather more evidence. Second, we excluded patients with preoperative contraindication of exercise and severe postoperative complications, which might underestimate the impact of low WBI. Third, we did not compare WBI with the other protectors of outcomes. Finally, further prospective studies will be needed to identify the effects of preoperative intervention on WBI.

Conclusions

Preoperative WBI was associated with physical functions, NYHA classification, and the length of hospital stay, and it was an independent predictor of the length of hospital stay in patients who had undergone cardiac surgery. Preoperative WBI could be a simple marker for detecting postoperative outcomes.

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Financial Disclosure

None to declare.

Conflict of Interest

The authors have no conflict of interest to declare.

Informed Consent

Informed consent was obtained.

Author Contributions

Conceptualization: I. Otoyama, R. Teshima, M. Fujita, S. Nishimura, and A. Aramaki. Data curation: I. Otoyama, R. Teshima, M. Fujita, S. Nishimura, and A. Aramaki. Formal analysis: I. Otoyama, R. Teshima, and Y. Suematsu. Methodology: I. Otoyama, R. Teshima, and Y. Suematsu. Project administration: I. Otoyama, Y. Suematsu, R. Teshima, M. Fujita, S. Nishimura, A. Aramaki, K. Fujimi, H. Wada, S. Kamada, and S. Miura. Supervision: K. Fujimi, H. Wada, S. Kamada, and S. Miura. Writing - original draft: I. Otoyama, R. Teshima, and Y. Suematsu. Writing - review and editing: K. Fujimi, H. Wada, S. Kamada, and S. Miura.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

WBI, weight bearing index; BMI, body mass index; SPPB, Short Physical Performance Battery; NYHA, New York Heart Association; METS, metabolic equivalents; eGFR, estimated glomerular filtration rate; BNP, brain natriuretic peptide; ADL, activities of daily living

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