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ORIGINAL ARTICLE
Cardiac Rehabilitation

Grip Strength Is an Independent Predictor of Early Ambulation in Patients After Elective Cardiac Surgery With Extracorporeal Circulation

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Background: Grip strength is a simple predictor of cardiovascular events and their prognosis. Early ambulation is related to an increase in functional independence, shortening of hospital stay, and a decrease in the need for readmission in patients with cardiovascular disease. However, little is known about the relationship between grip strength and early ambulation after cardiac surgery.

Methods and Results: In this observational study, 92 patients who underwent scheduled cardiac surgery with extracorporeal circulation without unexpected complications and in whom grip strength was measured before surgery were included. We divided them into 48 low and 44 preserved grip strength groups according to the criterion for frailty and sarcopenia. Age, the percentage of females, and the New York Heart Association classification in the low grip strength group were significantly higher than in the preserved grip strength group. All of the measures of functional status were significantly low in the low grip strength group. There were no significant differences in perioperative procedures between the groups. In-hospital outcomes were poorer, step-ups of rehabilitation were significantly later and the hospitalization stays were significantly longer in the low grip strength group. In the multiple regression analysis, grip strength was an independent predictor of early ambulation.

Conclusions: The results suggest that grip strength is an independent predictor of early ambulation in patients after cardiac surgery with extracorporeal circulation.

Key Words: Cardiac surgery; Early ambulation; Grip strength

Long-term bed rest causes a decrease in lower-extremity strength, power, aerobic capacity, and physical activity.[1] It can also induce a reduction of stroke volume caused by both a reduction of preload and cardiac dysfunction.[2] An increased number of frailty factors increase the risk of hospitalization-associated disability in older patients after cardiac surgery;[3] for older patients with acute cardiovascular disease, the time spent being sedentary during hospitalization is associated with health-related issues in quality of life and functional status even after hospitalization.[4] However, patients who undergo cardiac surgery require bed rest to stabilize both hemodynamics and respiratory function,[5] and perioperative and postoperative complications of cardiac surgery with extracorporeal circulation, such as prolonged mechanical ventilation, reoperation, requirement for dialysis, stroke, and deep sternal wound infection, also necessitate long bed rest.[6]

Early ambulation is associated with a decrease in the duration of hospitalization and the rate of readmission within 30 days after discharge in patients with heart failure,[7–9] and for elderly heart failure patients, early ambulation is one of the strongest predictors of rehospitalization.[10] Early ambulation improves the physical function at discharge of patients post cardiac surgery.[11,12] The joint guidelines of the Japanese Society of Cardiology and Cardiac

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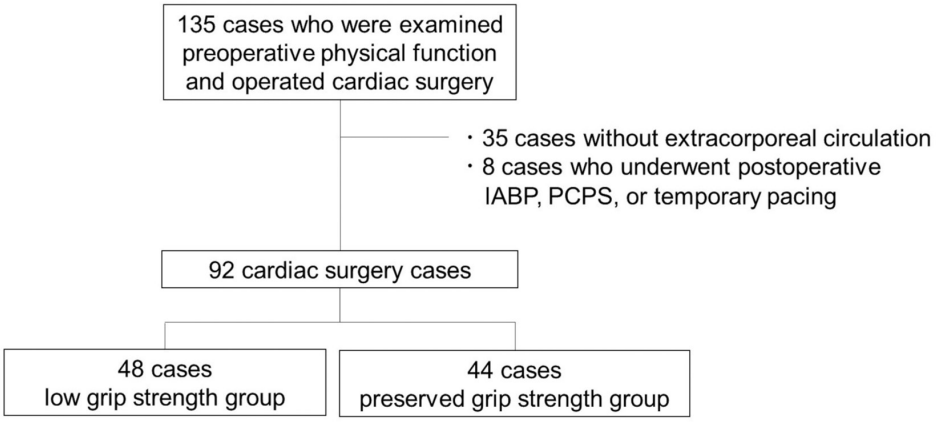

Figure. Study flow diagram. IABP, intra-aortic balloon pumping; PCPS, percutaneous cardiopulmonary support.

Rehabilitation have established criteria for early ambulation from bed and the early initiation of exercise for postoperative cardiovascular surgery patients in Japan, all of which are assessed according to the postoperative patient's condition and include few factors from the patient's preoperative status.[13] Hence, for patients undergoing cardiac surgery, the ability to predict early ambulation is important for predicting clinical outcomes.

Grip strength is a very simple and useful measure of muscle strength that reflects both total muscle mass and nutritional status.[13] It is also a predictor of cardiovascular events and their prognosis.[14–16] In patients requiring cardiac surgery, it has been reported that grip strength is associated with preoperative nutritional status and operative risk,[17] performance during hospitalization,[18] and long-term prognosis.[19] The association between grip strength and early ambulation has been reported in other surgical patients, but little is known about the relationship between grip strength and early ambulation in patients after cardiac surgery with extracorporeal circulation. It would be useful to understand prior to surgery which factors contribute to early discharge from hospital. Therefore, in this study we investigated the association between grip strength and early ambulation in patients after cardiac surgery with extracorporeal circulation.

Methods

Study Protocol

This retrospective study was approved by the Ethics Committee of Fukuoka University Hospital (2018M039) and performed in accordance with the Declaration of Helsinki and the ethical standards of the Independent Review Board of Fukuoka University. Grip strength was measured by a GRIP-D device (Takei Scientific Instruments Co., Ltd., Niigata, Japan). The patients twice measured the grip strength per one hand, and the higher value of grip strength was recorded. We then averaged the grip strength values for both hands, so the grip strength of the dominant and non-dominant hands was averaged. We divided the patients into a low grip strength group (n=48) and a preserved grip strength group (n=44) with cutoff values for grip strength of >28 kg (men) and 18 kg (women), which are the same criteria for frailty and sarcopenia.[20]

Survey Variables

We investigated the study patients' baseline characteristics including age, sex, body mass index (BMI), smoking, New York Heart Association (NYHA) classification, comorbidities (including hypertension, diabetes mellitus, dyslipidemia, cerebral infarction, and chronic kidney disease), cardiovascular disease (including ischemic heart disease and valvular heart disease), and the results of laboratory examination, spirometry, and cardiac echography.

To investigate physical function, we measured grip strength with a GRIP-D device and lower limb strength by μ Tas F-2 (ANIMA, Tokyo, Japan). The one-leg standing time with eyes open test[21] and the Short Physical Performance Battery (SPPB) were also performed.[22] Details have been previously reported.[23] We also used the 10-m walking test to evaluate step counts, stride, and walking speed.

We investigated perioperative variables, including anesthesia time, operative time, extracorporeal circuit time, aortic clamping time, intubation time, amount of bleeding, and the results of laboratory examination. The postoperative data collected included the number of hospital days before starting cardiac rehabilitation, the number of days limited to a seated position, the number of days before ambulation, the number of days until walking, the number of days in the care unit, the number of days of hospitalization, and the rate of discharge to home.

Statistical Analysis

The SAS (Statistical Analysis System) Software Package (Ver. 9.4, SAS Institute Inc., Cary, NC, USA) at Fukuoka University (Fukuoka, Japan) was used to analyze the differences between the grip strength groups. Continuous variables with a normal distribution are expressed as mean±standard deviation and were compared by Student's t-test. Continuous variables with a non-normal distribution are expressed as median values (interquartile range) and were compared by the Wilcoxon rank sum test. Categorical variables are expressed as number (%) and

Table 1. Background Characteristics of the Grip Strength Groups

Variables	Low grip strength (n=48)	Preserved grip strength (n=44)	P value
Age, years	73 (66–77.5)	60 (53–69)	<0.001
Male, n (%)	26 (54.2)	37 (84.1)	0.002
Body mass index, kg/m^2	22.7±3.7	23.6±3.5	0.24
History of smoking, n (%)	26 (54.2)	29 (65.9)	0.25
NYHA, class	2 (2–2)	2 (1–2)	0.03
Primary disease			
Hypertension, n (%)	35 (72.9)	32 (72.7)	0.98
Diabetes mellitus, n (%)	16 (33.3)	8 (18.2)	0.10
Dyslipidemia, n (%)	33 (68.8)	23 (52.3)	0.11
Cerebral infarction, n (%)	11 (22.9)	5 (11.4)	0.14
Chronic kidney disease, n (%)	12 (25.0)	8 (18.2)	0.43
Cardiovascular disease			
Ischemic heart diseases, n (%)	21 (43.8)	16 (36.4)	0.47
Valvular heart disease, n (%)	34 (70.8)	34 (77.3)	0.48

There were no missing values. NYHA, New York Heart Association.

Table 2. Preoperative Examinations Results for the Grip Strength Groups

Variables	Low grip strength (n=48)		Preserved grip strength (n=44)		P value
	Missing	Data	Missing	Data	
Spirometry					
VC, %	5	93.7±13.7	8	96.9±14.2	0.31
FEV, %	5	78.0 (70.0–92.0)	8	76.2 (70.1–83.7)	0.44
Laboratory data					
Hb, g/dL	0	12.7±1.7	0	13.7±1.9	0.01
Albumin, mg/dL	0	4.06±0.44	0	4.18±0.41	0.18
eGFR, mL/min/1.73 m^2	0	58.1 (41.6–66.8)	0	60.1 (50.7–66.4)	0.30
HbA1c, %	1	5.80 (5.50–6.40)	5	5.90 (5.60–6.20)	0.63
BNP, pg/mL	2	174 (50–357)	1	104 (48–243)	0.21
UCG					
LAD, mm	0	44.6±9.8	0	44.5±9.2	0.93
LVDd, mm	0	49.8 (45.3–55.0)	0	54.6 (48.0–60.0)	0.01
LVEF, %	0	62.3 (49.5–70.0)	0	66.4 (52.1–71.3)	0.54
E/e′	6	14.4 (10.3–22.1)	5	11.1 (8.3–19.5)	0.09

BNP, B-type natriuretic peptide; eGFR, estimated glomerular filtration rate; FEV, forced expiratory volume; Hb, hemoglobin; HbA1c, hemoglobin A1c; LAD, left atrial diameter; LVDd, left ventricular diastolic diameter; LVEF, left ventricular ejection fraction; UCG, ultrasound cardiography; VC, vital capacity.

were compared by Chi-square analysis. The primary outcome was early ambulation. Because all patients achieved early ambulation and there was no censoring, and the distribution of the outcome was approximately normal, we considered that multiple regression analysis was appropriate to identify independent predictors of early ambulation by preoperative grip strength using age, sex, BMI, lower limb muscle strength, operative time, extracorporeal circuit time, amount of bleeding, intubation time and maximum serum level of C-reaction protein (CRP). P<0.05 was considered significant.

Results

Baseline Characteristics of the Grip Strength Groups

The study flowchart is shown in the **Figure**. The study population consisted of patients in whom grip strength was measured before elective cardiac surgery between June 2016 and July 2023. The main operative procedures were valve replacement, valvuloplasty, coronary artery bypass grafting, left atrial appendage closure, and pulmonary vein isolation. We excluded 92 patients who had severe aortic stenosis and were unable to have preoperative physical function tests and muscle strength measured due to the contraindication of exercise. From the 135 candidates, 35 patients who underwent cardiac surgery without extracorporeal circulation and 8 patients who were underwent postoperative intra-aortic balloon pumping, percutaneous cardiopulmonary support, or temporary pacing were excluded. Baseline characteristics of the final study group (n=92) are shown in **Table 1**. The mean age was 68 (58.5–74) years, the percentage of males was 68.5% (n=63), and the mean BMI was 23.1±3.6 kg/m^2. Cardiac surgery was necessitated by ischemic heart disease [n=37 (40.2%)] and

Table 3. Preoperative Physical Function Test Results for the Grip Strength Groups

Variables	Low grip strength (n=48)		Preserved grip strength (n=44)		P value
	Missing	Data	Missing	Data	
Grip strength (right), kg	0	22.8±6.7	0	34.9±7.2	<0.001
Grip strength (left), kg	0	22.2±7.2	0	34.7±7.6	<0.001
Grip strength (mean), kg	0	22.5±6.7	0	34.8±7.2	<0.001
Muscle strength of lower limbs (mean), kg	2	21.8 (18.5–27.4)	0	34.9 (24.9–48.1)	<0.001
One-leg standstill time (mean), s	0	20.2 (8.3–47.8)	0	57.5 (23.1–60.0)	<0.001
10-m steps	0	15.0 (14.0–16.5)	0	14.0 (12.0–15.0)	<0.001
10-m strides, cm	0	66.7 (60.7–71.4)	0	71.4 (66.7–83.3)	<0.001
10-m walking speed, m/s	0	1.53±0.35	0	1.71±0.32	0.01
SPPB, score	1	12 (10–12)	0	12 (12–12)	0.01

SPPB, Short Physical Performance Battery.

Table 4. Perioperative Parameters for the Grip Strength Groups

Variables	Low grip strength (n=48)		Preserved grip strength (n=44)		P value
	Missing	Data	Missing	Data	
Anesthesia time, min	0	538±112	0	522±105	0.50
Operative time, min	0	426±107	0	407±106	0.40
Extracorporeal circuit time, min	0	189 (145–228)	0	206 (161–241)	0.17
Aortic clamping time, min	0	116 (0–154)	0	128 (44–159)	0.33
Bleeding amount, mL	0	434 (180–634)	0	310 (176–386)	0.12
Maximal level of serum CRP, mg/dL	1	17.5±4.9	0	17.0±5.1	0.65
Intubation time, h	1	20.0 (17.0–41.0)	1	17.0 (14.0–20.5)	0.01

CRP, C-reactive protein.

valvular heart disease [n=69 (73.9%)], with some overlap. Age and NYHA classification in the low grip strength group were significantly higher than in the preserved grip strength group, and the percentage of males was significantly lower.

The results of preoperative examinations are summarized in **Table 2**. In spirometry, vital capacity was 95.2±13.9% and forced expiratory volume 1.0% was 77.3 (70.0–89.0) % in all patients. The average values were within the normal ranges. In the laboratory examination, the estimated glomerular filtration rate was low 59.6 (47.9–66.5) mL/min/1.73 m^2 and the B-type natriuretic peptide level was high 135 (50–292) pg/mL in all patients. The level of hemoglobin in the low grip strength group was significantly lower than in the preserved grip strength group (low group: 12.7±1.7 g/dL, vs. preserved group: 13.7±1.9 g/dL, P=0.01), but both values were within the normal range. Regarding the results of cardiac echography, left ventricular (LV) ejection fraction was 63.6 (52.1–71.0) % and E/e′ was 13.7 (9.7–20.6) in all patients. The LV diastolic diameter in the low grip strength group was significantly shorter than that in the preserved group [49.8 (45.3–55.0) mm, vs. 54.6 (48.0–60.0) mm, P=0.01].

Preoperative Physical Functions in the Grip Strength Groups

The results for preoperative physical functions in the 2 groups are shown in **Table 3**. Right grip strength, left grip strength, and average grip strength in all patients were 28.6±9.2 kg, 28.2±9.6 kg, and 28.4±9.3 kg, respectively. We investigated muscle strength in the lower limbs, the one-leg standing time, 10-m walking test, and the SPPB. The low grip strength group showed significantly poor results for all of the tests.

Perioperative Parameters and Postoperative Outcomes in the Grip Strength Groups

The results regarding perioperative parameters are shown in **Table 4**. In all patients, anesthesia time, operative time, extracorporeal circuit time, and aortic clamping time were 530±108 min, 417±106 min, 197 (156–235) min, and 121 (0–158) min, respectively. There were no significant differences between the groups. The average amount of bleeding and the maximal serum level of CRP were 333 (180–485) mL and 17.3±5.0 mg/dL in all patients, and there were no significant differences between the groups. The average intubation time was 18.0 (15.5–25.0) h and the difference between the groups was significant [20.0 (17.0–41.0) h vs. 17.0 (14.0–20.5) h, P=0.01].

The postoperative outcomes are shown in **Table 5**. The average step-up days for cardiac rehabilitation, including when to start, when the patient was no longer limited to an edge sitting position, the number of days until ambulation, the number of days until walking, and the number of days in the care unit and under hospitalization were 1.0 (1.0–2.0) days, 2.0 (2.0–3.0) days, 3.0 (2.0–4.0) days, 4.0 (3.0–4.5) days, 4.1 (3.0–6.1) days, and 23.0 (19.5–26.0) days, respectively. Although there was no significant difference between the groups in the starting day of cardiac rehabilitation, the low grip strength group showed a slower step-up of cardiac rehabilitation. The number of days before the patient was not limited to an edge sitting position, the

Table 5. Postoperative Outcomes of the Grip Strength Groups

Variables	Low grip strength (n=48)	Preserved grip strength (n=44)	P value
Cardiac rehabilitation, hospital days	1.0 (1.0–2.0)	1.0 (1.0–2.0)	0.97
Sitting position, hospital days	2.0 (2.0–3.5)	2.0 (1.0–3.0)	0.04
Ambulation, hospital days	3.0 (2.0–4.0)	2.0 (2.0–3.0)	0.04
Walking, hospital days	4.0 (3.0–5.0)	3.0 (2.0–4.0)	0.002
Staying care unit, days	4.6 (3.7–6.7)	4.0 (2.9–5.4)	0.30
Hospitalization, days	24.0 (21.5–28.5)	20.5 (19.0–23.5)	0.003
Discharge to home, n (%)	42 (87.5)	42 (95.5)	0.18

Table 6. Multiple Regression Analysis for Independent Predictors of Early Ambulation

Variables	Partial regression coefficient	SE	t value	β	95% CI	P value
Intercept	2.83	1.61	1.75	0	(–0.39 to 6.05)	0.08
Average grip strength	0.02	0.03	–2.04	–0.25	(–0.10 to –0.001)	0.04
Age	0.01	0.01	–0.21	–0.01	(–0.03 to 0.02)	0.83
Male	0.41	0.42	0	–0.00	(–0.84 to 0.83)	0.99
Body mass index	0.04	0.04	0.87	0.06	(–0.04 to 0.10)	0.39
Average lower limb strength	0.01	0.01	0.98	0.08	(–0.01 to 0.04)	0.33
Operative time	0.002	0.002	–1.79	–0.16	(–0.01 to 0.0003)	0.08
Extracorporeal circuit time	0.002	0.002	1.43	0.12	(–0.001 to 0.01)	0.16
Bleeding amount	0.0002	0.0002	–0.12	–0.01	(–0.0004 to 0.0003)	0.91
Intubation time	0.004	0.004	10.13	0.78	(0.03 to 0.05)	<0.001
Maximal CRP	0.03	0.03	0.04	0.00	(–0.05 to 0.05)	0.97

CI, confidence interval; CRP, C-reactive protein.

number of days until ambulation, the number of days until walking and the number of days of hospitalization in the low grip strength group were significantly greater than those in the preserved grip strength group. The average percentage of discharge to home was 91.3% (n=84) and there was no significant difference between the groups.

Independent Predictors of Early Ambulation

The results of a multiple regression analysis to identify independent predictors of early ambulation are shown in **Table 6**. After correction for confounding factors, grip strength (P=0.04) and intubation time (P<0.001) were independent predictors of early ambulation in patients after cardiac surgery with extracorporeal circulation.

Discussion

In this study, preserved grip strength was associated with early step-up days of cardiac rehabilitation, and grip strength was an independent predictor of early ambulation in patients after elective cardiac surgery with extracorporeal circulation. These findings suggest that preoperative measurement of grip strength may be able to predict postoperative outcomes.

Association of Grip Strength and Preoperative Physical Functions

Grip strength reflects total muscle mass,[13] and is also associated with the ability of frail elderly patients to compensate during hospitalization.[24] The results of our study are consistent with those in previous studies. The low grip strength group showed lower values for right grip strength, left grip strength, mean grip strength, mean lower limb muscle strength, mean time standing on one leg, 10-m stepping, 10-m stride length, 10-m walking speed, and SPPB score. Lower limb muscle strength is associated with postural stability in the early postoperative gait, so preoperative measurement of grip strength could be useful for estimating total muscle mass, which is associated with early postoperative ambulation.

Association of Grip Strength and Early Ambulation

In our multiple regression analysis, grip strength (P=0.04) and intubation time (P<0.01) were independent predictors of early ambulation. A previous study showed that reduced grip strength is an indicator of increased postoperative complications, longer hospital stay, higher readmission rates and worse physical status.[25] Our study showed similar results in patients after cardiac surgery with extracorporeal circulation. Early ambulation is important, especially in patients with a severe condition. Intubation time would directly influence the ambulation period. Even under management with a ventilator, early ambulation has been associated with a shortening of delirium, early weaning from the ventilator, and an increase in physical function at discharge.[26] Early ambulation leads to early step-up days in rehabilitation. A reliable predictor of early ambulation could be useful for obtaining better postoperative outcomes. Grip strength is a simple preoperative test and a very useful indicator among other preoperative tests of physical function. It could be useful to include a measurement of grip strength as an indicator of a patient's potential for early

ambulation.

With regard to baseline characteristics, the low grip strength group was older and had a higher proportion of females. In this study, we applied cutoff values for grip strength in each sex, which were the criteria for frailty and sarcopenia,[20] but the grip strength in older Japanese females would be expected to be low. In laboratory examinations, the level of hemoglobin in the low grip strength group was low and this could have been influenced by the high proportion of females, but the average level of hemoglobin was within the normal range. On echocardiography, the LV diastolic diameter was short in the low grip strength group, and this could have been influenced by the high proportion of females, who tend to have smaller physiques. There was no difference in LV systolic function between the groups, as there were no significant differences in the LV ejection fraction. To adjust for confounding factors, we performed a multiple regression analysis, which showed that grip strength was an independent predictor of early ambulation.

Regarding the perioperative course, the low grip strength group had a longer intubation time, which would have led to a prolonged administration of sedatives and muscle relaxants that could have affected postoperative patient arousal and the timing of rehabilitation. Although there was no significant difference in the results of preoperative spirometry between the groups, the preserved grip strength group might have had stable respiratory management. Grip strength was associated with early ambulation in patients with gastrointestinal tumors undergoing laparoscopic surgery,[27] and grip strength was discussed as a reflection of the body's main store of protein and nutritional status. In our study, the better nutritional status of the preserved grip strength group might have also affected early ambulation. An extracorporeal circuit causes pulmonary injury through the systemic inflammatory response,[28] and pulmonary injury might affect the intubation time in patients after cardiac surgery with extracorporeal circulation. With regard to attenuating the systemic inflammatory response, pharmacological propionyl-L-carnitine treatment has shown Level B evidence.[29] Because skeletal muscle cells contain large amounts of L-carnitine, the systemic inflammatory response in the preserved grip strength group might have been attenuated due to the presence of L-carnitine.

Study Limitations

This was a single-center observational study and excluded patients with unexpected complications. Moreover, other critical factors, such as nutritional and psychological status might influence early ambulation. Further study is needed to establish the effect of grip strength in cardiac surgery patients. We did not investigate the effect of training on grip strength. The training effect on grip strength for postoperative outcomes in patients after cardiac surgery is unknown, because grip strength reflects total muscle mass and nutritional status. Further studies are needed to determine the effects of training.

In conclusion, preoperative measurement of grip strength could help to predict early ambulation in patients after cardiac surgery with extracorporeal circulation.

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Disclosure

S.M. is a member of *Circulation Reports*' Editorial Team.

IRB Information

This retrospective study was approved by the Ethics Committee of Fukuoka University Hospital (2018M039).

Data Availability

The data generated in this study are available from the corresponding author upon reasonable request.

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