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Impact of preoperative frailty on regaining walking ability in patients after cardiac surgery: Multicenter cohort study in Japan

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ABSTRACT

Background: This study aimed to examine the relationship between preoperative frailty and the reacquisition of walking ability in patients after cardiac surgery.

Methods: 450 patients who underwent cardiac surgery were included as subjects. We implemented the Short Physical Performance Battery (SPPB) before surgery and classified subjects into three groups according to the SPPB score: SPPB 10–12, SPPB 7–9, and SPPB 0–6. We examined the postoperative day and the rate of the reacquisition of walking ability after surgery, and compared them among three groups. In addition, we calculated the cutoff value for the SPPB score to regain walking ability by performing a receiver operating characteristic curve analysis.

Results: The postoperative day of the reacquisition of walking ability in SPPB 10–12 was earlier than other groups (SPPB 10–12: 4.0 days, SPPB 7–9: 4.5 days, SPPB 0–6: 6.0 days, $p < 0.01$), and SPPB 0–6 was lower than other groups in the rate of the reacquisition of walking ability (SPPB 10–12: 98.8%, SPPB 7–9: 96.4%, SPPB 0–6: 76.2%, $p < 0.01$). The cutoff value for SPPB was ≧9(Area under the curve: 0.85, sensitivity: 0.82, specificity: 0.71, $p < 0.001$).

Conclusion: Preoperative frailty affected the day of the reacquisition of walking ability in patients after cardiac surgery. The preoperative SPPB cutoff value which indicates the feasibility of reacquisition walking ability after surgery was ≧ 9.

1. Background

The number of cardiovascular surgeries in Japan has been steadily increasing, particularly the number of minimally invasive surgeries and complex surgeries for conditions such as valvular disease (Sakata, Fujii, & Kuwano, 2010; Sezai, Orime, & Tsukamoto, 2007). Despite remarkable advances in surgical techniques and medical management, increasing trends are observed in the age of patients and the number of high-risk cases such as patients with concomitant cerebrovascular diseases and motor disorders (JCS Joint Working Group, 2013). Given these circumstances, frailty is garnering considerable attention in the field of cardiac surgery. Frailty is a syndrome with many factors, and a state in which vulnerability to physical disability and death increases because of declining physiological functions, physical strength, and endurance (Campbell & Buchner, 1997; Hamerman, 1999), which can lead to disability or even death.

It has been reported that in frail patients, the incidence of postoperative major complications including pneumonia, infections, and reintubation increases (Dunne, Abah, & Scarci, 2014). Furthermore, one report suggests that short-term mortality during hospitalization within 30 days after surgery, as well as mid-term to long-term mortality within 1–1.8 years, increase (Bagnall, Faiz, Darzi, & Athanasiou, 2013). There are many reports on the impact of frailty on the incidence of complications and prognosis after cardiac surgery. However, there are no reports on the impact of frailty on regaining walking ability immediately after surgery both domestically and internationally. The authors reported that in a previously conducted multicenter survey, following cardiac surgeries, approximately 80% patients were able to walk independently 4 days after surgery (Takahashi et al., 2012). However, approximately 20% patients experienced a delay in the reacquisition of walking ability, due to cardiac conditions, such as prolonged heart failure and preoperative low activity of daily living (ADL) that was derived from a decline in physical function. In recent years, the age of patients undergoing surgery has

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increased, thus leading to an increased potential for a decline in physical function due to preoperative frailty, apart from prolonged heart failure, that affects the postoperative reacquisition of walking ability. We hypothesized that a decline in physical function caused by frailty affects the reacquisition of walking ability in patients after cardiac surgery. Therefore, the objective of this study was therefore to examine the relationship between preoperative frailty and the reacquisition of walking ability immediately following cardiac surgery.

2. Methods

2.1. Study design

A retrospective cohort of 1736 patients who underwent cardiovascular surgery between January 2013 and September 2014 at seven hospitals in Japan, such as The Sakakibara Heart Institute of Okayama, Sakakibara Heart Institute, Shizuoka Medical Center, Fukuyama Cardiovascular Hospital, Higashi Takarazuka Satoh Hospital, Kitano Hospital, Kishiwada Tokusyukai Hospital, registered with the Cardiovascular Surgery Physiotherapy Network (CPN) database was assembled. The number of patients in each hospital was 249 in The Sakakibara Heart Institute of Okayama, 607 in Sakakibara Heart Institute, 36 in Shizuoka Medical Center, 137 in Fukuyama Cardiovascular Hospital, 186 in Higashi Takarazuka Satoh Hospital, 17 in Kitano Hospital and 504 in Kishiwada Tokusyukai Hospital, respectively. The preoperative short physical performance battery (SPPB) was measured as the indicator of physical function, and the patient's characteristics, operative information, the process of the reacquisition of walking ability, and whether they have achieved a reacquisition of walking ability or not after surgery were surveyed from medical records. First, we conducted a multivariate analysis to determine the factors of the delay of the reacquisition of walking ability after surgery, with the dependent variable being the day of the reacquisition of walking ability after surgery and the independent variables being the patient's characteristics, including the SPPB score and operative information. In addition, the subjects were classified into three groups according to the severity of the SPPB score, and the process of the early mobilization, the rate of the reacquisition of walking ability, and the causes of a delay of the reacquisition of walking ability after surgery were compared in three groups. Second, we conducted a multivariate analysis in which the SPPB score was included to verify the factors of the reacquisition of walking ability after surgery. After that, the preoperative cutoff value for the SPPB score was analyzed to predict if the patient was able to regain walking ability after surgery.

2.2. Subjects

Subjects consisted of 1,736 patients who met the following exclusion criteria were excluded : (1) patients who had single or complex large vessel surgery, (2) patients aged < 65 years old, (3) patients who had emergency surgery, (4) patients whose preoperative frailty could not be evaluated for whatever reason, and (5) patients who were unable to walk independently before surgery regardless of a walking aid. Eventually, we were left with 450 patients as subjects (Fig. 1). Before beginning this study, we explained the objective, contents, and strict collective management of survey data to all subjects and obtained their informed consent. The ethics committees of each hospital and Hyogo university of health sciences also provided their approval for this study (approval number 12029).

2.3. Short physical performance battery (SPPB)

The SPPB tests lower limb function in three areas: static balance, gait speed, and getting in and out of a chair. To test static balance, subjects were instructed to stand with their feet together, hold a semi-tandem stance posture, and hold a tandem stance posture for 10 s each, in that order. To test gait speed, subjects walked a distance of 4 m at a comfortable speed and the time it took to walk that distance was measured to the nearest second and recorded. To test getting in and out of a chair, subjects stood up from a seated position on a standard-height chair repeatedly and as fast as possible without using their upper limbs, and the time it took to complete five repetitions was measured to the nearest second and recorded. Each test was scored from 0 to 4 points, where a score of 0 indicated that the test could not be performed or could not be completed, and a score of 4 meant that the test could be performed at a high level. Scores for the three tests were added to calculate exercise, which ranged from a score of 0 (low) to 12 (high). The reliability and utility of this test in showing the prognosis and physical function of patients have previously been verified. A score of 10–12 is good, 7–9 is fair, and 0–6 is poor (Guralnik et al., 1994; Puthoff, 2008; Rolland et al., 2006). In the present study, we implemented the SPPB before surgery and classified subjects into three groups according to the SPPB score: a 10–12 group (SPPB 10–12), a 7–9 group (SPPB 7–9), and a 0–6 group (SPPB 0–6).

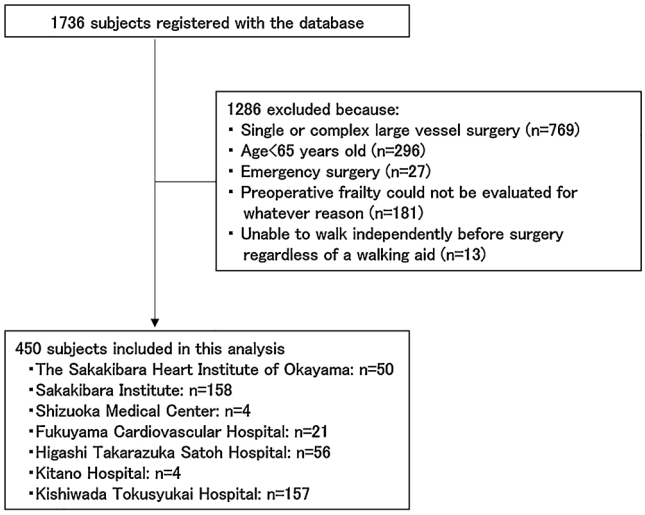

Fig. 1. The process of including subjects in this study.

2.4. The conditions of the reacquisition walking ability and the progress after cardiac surgery

We examined the conditions of early mobilization after cardiac surgery (the first postoperative day when the patient was able to sit on the side of the bed, stand and walk, and the day walking ability was regained), the reason for any delay in the reacquisition of walking ability, and the rate of postoperative reacquisition of walking ability during hospitalization. The definition for the reacquisition of walking ability was unified across all hospitals and defined as the state in which a patient is able to walk 100 m without supervision by medical staff regardless of the duration or use of a brace or walking aid. A delay in the reacquisition of walking ability was defined as a patient requiring 6 days or more after surgery to regain walking ability, and the causes for such a delay were classified into heart failure, arrhythmia, other cardiac causes, respiratory system-related, cerebrovascular disease, renal system-related, wound problems, low activities of daily living (ADL), and delirium, the incidences of which were all examined. Low ADL was defined as the state in which a patient is not able to walk independently after surgery because of unstable walking and a Barthel Index score not equal to 100 before surgery. If a patient could regain walking ability within 5 days, it was decided that there was no cause for the delay in the reacquisition of walking ability.

2.5. Statistical analysis

We implemented the normality test in all data of this study using the Kolmogorov-Smirnov method.

A delay of the reacquisition of walking ability after surgery was analyzed by the stepwise method's multiple-linear regression analysis, where the day of the reacquisition of walking ability after surgery was the dependent variable and the SPPB score and clinical characteristics were independent variables.

Comparison of the clinical data between the three groups divided according to the severity of the SPPB score was done using the Kruskal-Wallis method and a multiple comparison test using the Bonferroni method was performed when a significant difference was detected. Chi-square tests were also used to compare the incidence of reasons for a delay in the reacquisition of walking ability and the rate of reacquisition of walking ability between the three groups, and a multiple comparison test using the Bonferroni method was performed when a significant difference was seen.

In order to identify the factors of the reacquisition of walking ability, subjects were grouped according to whether they achieved a reacquisition of walking ability (+) or not (−) after surgery, and the clinical characteristics, including the SPPB score, were compared between groups using the Mann–Whitney U test and chi-square tests. We also conducted the logistic regression analysis where clinical factors that are related to the reacquisition of walking ability by univariate analysis were incorporated as covariates.

The preoperative cutoff value for SPPB to predict if a patient is able to regain walking ability after cardiac surgery was found by performing a receiver operating characteristic (ROC) curve analysis. The level of significance was set to $p < 0.05$ for all the tests. All analyses were performed using IBM SPSS statistics version 25.

3. Results

Table 1 shows the clinical characteristics of subjects, while Table 2 presents the result of the stepwise method's multiple-linear regression analysis. Multicollinearity in this analysis was not recognized because the variance inflation factor (VIF) of all variables was < 1.3. In the result of analyzing the day of reacquisition of walking ability as a dependent variable, the SPPB score was calculated as one of independent variables ($R = 0.48$, $R^2 = 0.21$, F value;17.6, $p < 0.01$).

Patient data are presented in Table 3. Compared with the SPPB 10–12 group, the SPPB 7–9 group were significantly older, had a higher prevalence of diabetes mellitus (DM), orthopedic disease, peripheral arterial disease (PAD), chronic heart failure (CHF) and hemodialysis (HD). Furthermore, values for estimated glomerular filtration rate (eGFR) and albumin were low, whereas the duration of surgery and volume of blood loss were high in this group. The SPPB 0–6 group, meanwhile, were significantly older and included more females than the SPPB 10–12 group, with prevalence of orthopedic disease and HD also being higher. Values for eGFR and albumin were also low in this group.

Table 4 shows the conditions of early mobilization after surgery depending on the severity of preoperative SPPB and the rate of reacquisition of walking ability. Compared with other groups, early mobilization was more progressed in the SPPB 10–12 group. However, no difference in early mobilization was seen between the SPPB 7–9 and SPPB 0–6 groups. The SPPB 10–12 and SPPB 7–9 groups did not show differences in the rate of reacquisition of walking ability, but the SPPB 0–6 group did have a lower rate than the other groups.

Table 5 shows the incidence of each cause of a delay in the reacquisition of walking ability in the three groups. Compared with the other groups, the SPPB 10–12 had a lower incidence of all causes of a delay in the reacquisition of walking ability. The SPPB 7–9 group had a higher incidence of cerebrovascular disease delaying the reacquisition of walking ability than the SPPB 10–12 group. Meanwhile, the SPPB 0–6 group had a higher rate of respiratory system-related causes of a delay in the reacquisition of walking ability than the SPPB 10–12 group, whereas the rate of low ADL and delirium causing a delay in the reacquisition of walking ability was higher than in both the SPPB 10–12 and SPPB 7–9 groups.

Table 6 shows the result of the comparison of clinical characteristics, including the SPPB score in the reacquisition of walking ability. The group that achieved the reacquisition of walking ability (+) had a significantly higher SPPB score ($p < 0.01$), was younger ($p = 0.03$), had higher rate of hyperlipidemia ($p < 0.05$), lower rate of orthopedic disease ($p < 0.01$), and higher albumin ($p = 0.02$). The logistic

Table 1
Clinical characteristics of subjects.

	Overall n:450
Age; years	75.4 ± 5.9
Gender: male [n(%)]	261(58.0)
BMI; kg/m^2	22.7 ± 3.5
DM [n(%)]	158(35.1)
Hypertension[n(%)]	310(68.9)
Hyperlipidemia[n(%)]	218(48.4)
Smoking [n(%)]	162(36.0)
COPD [n(%)]	44(9.8)
Orthopedics disease [n(%)]	97(21.6)
Stroke [n(%)]	61(13.6)
PAD [n(%)]	48(10.7)
HD [n(%)]	19(4.2)
LVEF (%)	60.3 ± 10.9
CHF[n(%)]	146(32.4)
Arrhythmia: AF, AFL or PAF [n(%)]	102(22.7)
eGFR	56.5 ± 17.2
Albumin; g/dl	4.0 ± 0.4
Diagnosis [n(%)]	
Coronary arterial disease	190(42.2)
Valvular disease	314(69.8)
Other	31(6.9)
Type of operation [n(%)]	
CABG	134(29.8)
Valve replacement or Valvuloplasty	231(51.3)
CABG + valvular surgery	78(17.3)
Other	8(1.8)
Operation time; min	274.1 ± 87.8
Bleed; ml	447.2 ± 503.1
SPPB score	10.5 ± 2.2
The day of the reacquisition of walking after surgery; days	4.9 ± 4.6

Numerical data are expressed as mean ± SD.
B.M.I., body mass index; D.M., diabetes mellitus; C.O.P.D., chronic obstructive pulmonary disease; H.D., hemodialysis; P.A.D., peripheral arterial disease; C.H.F., Chronic heart failure; A.F., atrial fibrillation; A.F.L., atrial flutter; P.A.F., paroxysmal atrial fibrillation; L.V.E.F., left ventricular ejection fraction; C.A.B.G., coronary artery bypass grafting, S.P.P.B., short physical performance battery.

Table 2
The result of stepwise method's multiple-linear regression analysis.

Independent variable; the day of the reacquisition of walking ability after surgery

Dependent variable	β	T value	β 95% confidence interval	p value
SPPB score	−0.5	−3.72	−0.77 – 0.24	< 0.01
Operation time (min)	0.01	4.06	0.006 – 0.018	< 0.01
eGFR	−0.06	−0.21	−0.086 – 0.025	< 0.01
CHF	1.27	0.14	0.244 – 2.49	0.02
α	10.1	5.39		

$R = 0.48$, $R^2 = 0.21$, F value;17.6, $p < 0.01$, Excluded dependent variables; Age, Gender, B.M.I., D.M., Hypertension, Hyperlipidemia, Smoking, C.O.P.D., Orthopedics disease, Stroke, P.A.D., H.D., L.V.E.F., Arrhythmia, Albumin, Type of operation and Bleed.

Table 3
Clinical characteristics of subjects according to SPPB score.

	SPPB 10-12 N:325	SPPB 7-9 N:83	SPPB 0-6 N:42	H Value	X^2 Value	p Value
Age; years	75(87-65)	78(90-65)**	79.5(94-76)**	34.9		< 0.01
Gender: male [n(%)]	202(62.2)	41(49.4)	18(42.9)*		8.8	0.01
BMI(kg/m^2)	22(39-14)	22(21-16)	22(29-19)	0.6		0.8
DM [n(%)]	102(31.4)	38(45.8)*	18(42.9)		7.2	0.03
Hypertension[n(%)]	215(66.2)	66(79.5)	29(69.0)		5.5	0.06
Hyperlipidemia[n(%)]	157(48.3)	47(56.6)	14 (33.3)$^+$			< 0.05
Smoking [n(%)]	128(39.4)	25(30.1)	9(21.4)		6.7	0.04
COPD [n(%)]	29(8.9)	11(13.3)	4(9.5)		1.4	0.5
Orthopedics disease [n(%)]	48(14.8)	29(34.9)**	20(47.6)**		34.5	< 0.01
Stroke [n(%)]	40(12.3)	12(14.5)	9(21.4)		2.7	0.3
PAD [n(%)]	48(10.7)	16(19.3)**	6(14.3)		9.5	< 0.01
HD [n(%)]	8(2.5)	6(7.2)	5(11.9)**		10.5	< 0.01
LVEF; %	63(83-23)	60(79-12)	63(76-30)	2.5		0.3
CHF[n(%)]	92(28.3)	40(48.2)**	14(33.3)		11.9	< 0.01
Arrhythmia[n(%)]	71(21.8)	20(24.1)	11(26.2)		0.52	0.8
eGFR	59(114-1)	57(86-6)**	48(95-6)**	13.6		< 0.01
Albumin; g/dl	4.1(5-3)	4.0(5-3)**	4.0(5-3)**	17.4		< 0.01
Diagnosis [n(%)]						
Coronary arterial disease	134(41.2)	39(47.0)	17(40.5)		0.9	0.6
Valvular disease	229(70.5)	55(66.3)	30(71.4)		0.6	0.7
Other	26(8.0)	3(3.6)	2(4.8)		2.3	0.3
Type of operation [n(%)]						
CABG	91(28.0)	31(37.3)	12(28.6)		2.8	0.3
Valve replacement or Valvuloplasty	175(53.8)	33(39.8)	23(54.8)		5.5	0.07
CABG + valvular surgery	56(17.2)	15(18.1)	7(16.7)		0.05	0.9
Other	7(2.2)	0	0			
Operation time; min	255(710-104)	303(587-140)*	278(466-183)	6.8		0.03
Bleed; ml	260(3200-10)	400(2730-10)*	360(860-190)	9.8		< 0.01

Numerical data are expressed as median(range).
*, comparison with SPPB 10-12, $p < 0.05$; **, comparison with SPPB 10-12, $p < 0.01$; $^+$, comparison with SPPB 7-9, $p < 0.05$.

Table 4
Comparisons of early mobilization and the rate of the reacquisition of walking ability according to the severity of the SPPB score.

	SPPB 10-12	SPPB 7-9	SPPB 0-6	H value	X^2 value	p Value
First day of sitting on the edge of the bed; days	1.0(5-1)	1.0(7-1)	1.0(2-1)**	12.0		< 0.01
First day of standing; days	1.0(7-1)	2.0(7-1)**	2.0(3-1)**	26.2		< 0.01
First day of walking: days	2.0(32-1)	2.0(9-1)**	2.5(5-1)**	22.6		< 0.01
The day of reacquisition of walking ability; days	4.0(26-2)	4.5(27-2)*	6.0(30-2)*	13.8		< 0.01
The rate of reacquisition of walking ability [n(%)]	321(98.8)	80(96.4)	32(76.2)**$^+$		52.1	< 0.01

Numerical data are expressed as median(range).
*,comparison with SPPB 10-12 group, $p < 0.05$; **, comparison with SPPB 10-12 group, $p < 0.01$; $^+$, comparison with SPPB 7-9 group, $p < 0.01$.

regression analysis, where clinical factors of the reacquisition of walking ability including the SPPB score, age, hyperlipidemia, orthopedic disease, and albumin were used as covariates, revealed that the SPPB score was a determinant of the reacquisition of walking ability after surgery (odds ratio, 1.55; 95% confidence interval, 1.28–1.87; $p < 0.01$) (Table 7).

Table 5
The incidence of each cause of a delay in the reacquisition of walking ability according to the severity of the SPPB score.

	SPPB10-12 n:325	SPPB7-9 n:83	SPPB0-6 n:42	X^2 Value	p Value
Heart failure[n(%)]	15(4.6)	9(10.8)	2(4.8)	4.8	0.09
Arrhythmia [n(%)]	10(3.1)	4(4.8)	1(2.4)	0.8	0.7
Other cardiac causes [n(%)]	3(0.9)	2(2.4)	0(0)	1.9	0.4
Respiratory system-related [n(%)]	7(2.2)	3 (3.6)	4(9.5)*	6.8	0.03
Cerebrovascular disease [n(%)]	0(0.0)	2(2.4)*	1(2.4)	7.8	0.02
Renal system-related [n(%)]	2(0.6)	1(1.2)	0(0)	0.7	0.7
Wound problems [n(%)]	1(0.3)	1(1.2)	0(0)	1.4	0.5
Low ADL [n(%)]	2(0.6)	2(2.4)	14(33.3)**$^+$	104.3	< 0.01
Delirium [n(%)]	5(1.5)	1(1.2)	4(9.5)**$^+$	11.4	< 0.01
Other [n(%)]	11(3.4)	5(6.0)	3(7.1)	2.1	0.3

*Comparison with SPPB 10-12 group, $p < 0.05$; **, comparison with SPPB 10-12 group, $p < 0.01$; $^+$, comparison with SPPB 7-9 group, $p < 0.01$.
A.D.L., activity of daily living.

Table 6
Comparison of clinical Characteristics including SPPB score with subjects according to reacquisition of walking ability (+) or no reacquisition of walking ability (−).

	Reacquisition of walking ability				
	(+) n = 433	(−) n = 17	U value	X^2 value	p value
Age; years	75(94-65)	79.0(90-65)	2526.5		0.03
Gender: male [n(%)]	254(58.7)	7(41.2)		2.1	0.2
BMI; kg/m^2	22.7(38.8-9.6)	21.8(30.1-16.1)	4205.0		0.3
DM [n(%)]	154(35.6)	4(23.5)		1.0	0.3
Hypertension[n(%)]	297(68.6)	13(76.5)		0.5	0.5
Hyperlipidemia[n(%)]	214(49.4)	4(23.5)		4.4	< 0.05
Smoking [n(%)]	156(36.0)	6(35.3)		0.01	1.0
COPD [n(%)]	42(9.7)	2(11.8)		0.1	0.7
Orthopedics disease [n(%)]	89(20.6)	8(47.1)		6.8	< 0.01
Stroke [n(%)]	58(13.4)	3(17.6)		0.3	0.7
PAD [n(%)]	45(10.4)	3(17.6)		0.9	0.4
HD [n(%)]	17(3.9)	2(11.8)		2.5	0.2
LVEF ; %	62.6(83.0-10.0)	61.7(79.0-34.2)	3590.5		0.9
CHF [n(%)]	139(32.1)	7(41.2)		0.6	0.4
Arrhythmia [n(%)]	96(22.2)	6(35.3)		1.6	0.2
eGFR	56.0(114.4-1.0)	54.1(73.0-3.0)	3646.0		0.3
Albumin; g/dl	4.0(5.0-2.0)	3.7(4.0-3.0)	4331.5		0.02
Type of operation [n(%)]					
CABG	131(30.3)	3(17.6)		1.3	0.4
Valve replacement or Valvuloplasty	221(51.0)	10(58.8)		0.4	0.5
CABG + valvular surgery	75(17.3)	3(17.6)		0.01	1.0
Other	7(1.6)	1(5.9)		1.7	0.2
Operation time; min	265(710-104)	243(429-130)	3553.5		0.8
Bleed; ml	300(3200-20)	348(750-55)	1577.0		0.7
SPPB score	12(12-2)	6.0(12-1)	6263.5		< 0.01

Numerical data are expressed as median(range).

Table 7
Logistic regression analysis for factors of reacquisition of walking ability after surgery.

	β	Odds ratio	95% confidence interval	p
SPPB score	0.43	1.55	1.28 – 1.87	< 0.01
Age	−0.04	0.96	0.87 – 1.06	0.38
Hyperlipidemia	0.89	2.45	0.69 – 8.65	0.16
Orthopedics disease	−0.19	0.83	0.26 – 2.68	0.76
Albumin	0.40	1.49	0.46 – 4.87	0.50
α	1.06	2.89		

Hosmer and Lemeshow's test: X^2 value;5.23, p = 0.73.

Fig. 2 shows the results of the ROC curve analysis of postoperative reacquisition of walking ability and preoperative SPPB scores. Based on the results of the evaluation of the cutoff value by the shortest distance from the upper-left corner to the curve, the cutoff value for preoperative SPPB score to predict if a patient can regain walking ability after cardiac surgery was ≧9 (Area under the curve: 0.85; p < 0.001, sensitivity: 0.82, specificity: 0.71) which was from moderate to high predictive accuracy.

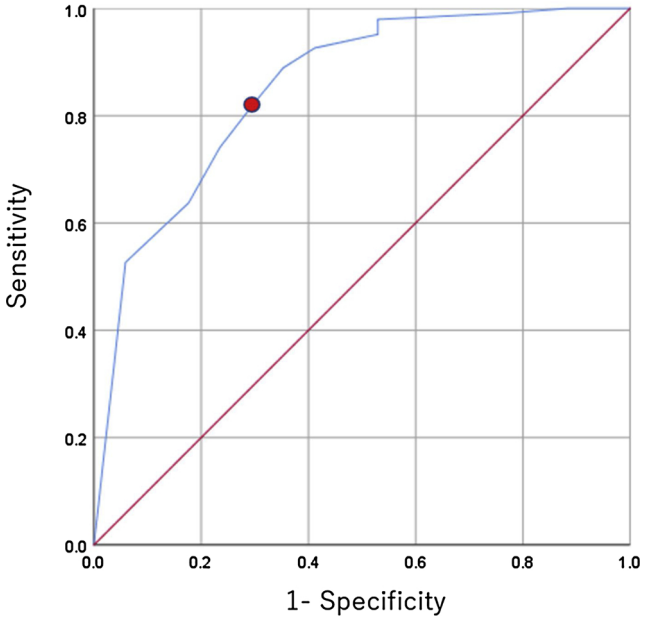

Fig. 2. Receiver operating characteristic (ROC) curve analysis for the reacquisition of walking ability after surgery (Area under the curve: 0.85, p < 0.001, Cutoff value≧9, Sensitivity: 0.82, Specificity: 0.71).

4. Discussion

In the present study, we evaluated preoperative frailty of cardiac surgery patients by using the SPPB and thereby clarified the relationship between the severity of frailty, postoperative early mobilization, and the rate of reacquisition of walking ability. This was the first study to find the cutoff value for preoperative SPPB to predict postoperative reacquisition of walking ability.

4.1. The relationship between the SPPB score and the day of the acquisition of walking ability after cardiac surgery

Frailty is evaluated using various methods including the SPPB (Dunne et al., 2014), a phenotype of frailty (Fried et al., 2001), and walking speed (Afilalo et al., 2010). In this study, we used the SPPB as an index of frailty. Patients with a low SPPB score are said to go on to move into nursing homes at a higher rate than patients with higher SPPB scores, and, compared with patients with a score of 10–12, patients with a score of 7–9 are at a 1.8 times greater risk for developing disabilities (Guralnik et al., 1994). In a report on cardiac surgery that focused on postoperative walking speed, which is one of the areas evaluated by the SPPB, patients who required ≥6 s to walk 5 m

(0.83 m/s) preoperatively showed more major complications including death, renal failure, and follow-up surgery than patients who required < 6 s, and many were transferred to other hospitals or nursing homes (Afilalo et al., 2010). The SPPB evaluates a 4-m walk and consists of three items (walking speed, balance, and standing). While the SPPB differs from other tests in its composition, the fact that SPPB scores are reduced when walking speed is 0.83 m/s or slower is a common aspect. The results of the present study are; thus. similar to those of previous studies, in which preoperative SPPB was analyzed as a factor of the day of reacquisition of walking ability after surgery. We therefore consider the high incidence of complications to have had an impact on early mobilization and the reacquisition of walking ability.

4.2. The relationship between the severity of the SPPB score and the causes of a delay in the reacquisition of walking ability

The main cause of delayed reacquisition of walking ability in the SPPB 7–9 group was cerebrovascular disease. The SPPB 7–9 group had lower physical functionality compared with the SPPB 10–12 group, and was also older, had a higher prevalence of DM, PAD, CHF and Orthopedics disease, and lower eGFR and albumin values according to preoperative data. In addition, according to surgical data, the SPPB 7–9 group had a longer duration of surgery and larger volume of blood loss. In previous studies, old age, DM, PAD, and decreased renal function have been reported as factors that increase the onset of postoperative cerebrovascular disease, delayed withdrawal of artificial ventilators, and adverse events excluding infections (Motomura, Miyata, Tsukihara, Okada, & Takamoto, 2008; Shahian et al., 2009). Preoperative data in the SPPB 7–9 group may therefore influence the onset of complications. Frailty is a syndrome caused by multiple factors (Campbell & Buchner, 1997; Hamerman, 1999) and accompanies conditions including malnutrition, weight loss, muscle weakness, and decreased walking speed primarily in elderly patients or patients with chronic diseases (Fried et al., 2001). The SPPB 7–9 group had a high prevalence of motor disorders and a low albumin value, which suggests a state of decreased physical function and malnutrition. Therefore, in addition to the impact of invasive surgery, the SPPB 7–9 group was affected by a state of frailty with an advanced age, a history of chronic disease, malnutrition, and decreased physical functionality, which likely affected the onset of complications and delayed reacquisition of walking ability.

The delayed reacquisition of walking ability in the SPPB 0–6 group was mainly caused by respiratory system-related such as pneumonia and delayed withdrawal from artificial ventilation, low ADL, and delirium. The SPPB 0–6 group had lower physical functionality than the SPPB 7–9 group and was older, included more women, had a higher prevalence of motor disorders and PAD, and had lower eGFR and albumin values compared with the SPPB 10–12 group. Furthermore, of the three groups, the SPPB 0–6 group was the oldest, had the highest proportion of women and prevalence of motor disorders, and tended to have low eGFR and albumin values. The high proportions of older patients, female patients, and patients with PAD and decreased renal function in the SPPB 0–6 group are reported to be factors that delay withdrawal of artificial ventillators (Shahian et al., 2009). These factors may therefore have influence on the delay in withdrawing artificial ventilation. However, the reasons for the addition of pneumonia to delayed withdrawal of artificial ventilation as a respiratory complication in our study and the delay to the withdrawal of artificial ventilation in previous studies are unclear. Further study is therefore needed into the occurrence of respiratory complications in this study, including examination of physical functionality according to the SPPB and prevalence of motor disorders, and nutritional state according to albumin levels. Patients with a SPPB score of ≤8 are considered to have sarcopenia, which is a state deteriorated physical functionality and skeletal muscle strength worse than frailty (Cruz-Jentoft et al., 2010). Izawa et al. examined the relationship between nutritional state and walking speed in cardiovascular disease patients by adjusting for age and reported lower walking speeds in patients with poor nutritional state (Izawa, Watanabe, & Oka, 2015). Patients are reported to be more susceptible to infection when their nutritional state deteriorates because this causes their immunity to decrease (Ikuta et al., 2003). Furthermore, according to another report, low preoperative physical functionality in cardiac surgery or other thoracic surgery patients can become a factor for postoperative complications including infection (such as pneumonia), and reattachment or delayed withdrawal of artificial ventilators (Tsiouris et al., 2012; Van Venrooij et al., 2011). On the basis of these previous studies, the reasons for the greater number of respiratory complications in the SPPB 0–6 group in the present study were likely poorer physical functionality and nutritional state and more severe frailty than in the other groups.

Low ADL was the main cause of delayed reacquisition of walking ability in the SPPB 0–6 group. Preoperative frailty in cardiac surgery patients increases the likelihood of transfer to another facility in addition to increasing the duration of postoperative hospitalization (Afilalo et al., 2010). Lee et al. have reported that frail patients have decreased physical reserve, diminished ability to maintain homeostasis, and reduced walking ability and mobility, which makes these patients more prone to complications including infection and reintroduction of artificial ventilation, and in need of a longer time for recovery and medical management (Lee, Buth, Martin, Yip, & Hirsch, 2010). On the basis of these previous studies, in addition to low preoperative physical functionality, the SPPB 0–6 group required more time to recover physical functionality further diminished by surgery, and may therefore have taken more days until walking ability was regained. Patients who were unable to regain walking ability during hospitalization may also have had notably reduced physical functionality because of complications. In fact, the SPPB 0–6 group in this study included 10 patients who were unable to regain walking ability during hospitalization, and in six of these patients the main reason for delayed reacquisition of walking ability was low ADL. However, additional reasons also included heart failure, infection, and delayed withdrawal of artificial ventilation. The factor that delayed reacquisition of walking ability in the other four patients was low ADL; however, none of these patients experienced complications and were either discharged or transferred because they required more time to reacquire walking ability during hospitalization.

Postoperative delirium was the main factor that delayed reacquisition of walking ability in the SPPB 0–6 group. Jung et al. examined preoperative factors for postoperative delirium in 133 cardiac surgery patients and reported that a SPPB score of ≤9 or 4–6 was an independent predictive factor for postoperative delirium, whereas a score of 7–9 was not (Jung et al., 2015). The SPPB 0–6 group in the present study had a significantly higher incidence of postoperative delirium than the other two groups, thus supporting the results of previous studies. The mechanisms behind diminished physical functionality and the onset of postoperative delirium remain mostly unknown. A recent report has stated that a relationship exists between cognitive function and physical function in elderly people (Macuco et al., 2012), which indicates the need for further study into the relationship between the onset of delirium and preoperative cognitive function.

4.3. The relationship between SPPB score and the rate of the reacquisition of walking ability after surgery

In this study, the preoperative SPPB was analyzed as a determinant of the rate of the reacquisition of walking ability, and the cutoff value for the preoperative SPPB score to predict the reacquisition of walking ability after surgery was ≧9. Camara et al. have reported that a SPPB score of ≤9 is strongly correlated with frailty in patients (Da Câmara, Alvarado, Guralnik, Guerra, & Maciel, 2013). Bandinelli et al. similarly define a SPPB score of ≤9 as indicative of frailty (Bandinelli et al., 2006). The results of the present study showed that walking ability was reacquired later in the SPPB 7–9 and SPPB 0–6 groups than in the SPPB 10–12 group, and that the rate of acquisition of walking ability

decreased as the SPPB score dropped. The SPPB 10–12 group also re-acquired walking ability after 4.0 days postoperatively, which is a good outcome compared with the overall condition of walking ability throughout Japan (JCS Joint Working Group, 2014). The SPPB score at which postoperative reacquisition of walking ability was feasible in the present study was ≧9, which according to Camara et al. and Bandinelli et al. is equivalent to a condition without frailty and is thus considered valid.

5. Conclusions

Preoperative SPPB score is a factor that affects the day of re-acquisition of walking ability in patients after cardiac surgery. Early postoperative mobilization in patients with frailty, those with the SPPB score of ≤9, is delayed compared with that in patients with non-frailty because of postoperative complications. In addition, preoperative SPPB score is an independent predictor of the rate of reacquisition of walking ability postoperatively, and this study has shown that the preoperative SPPB cutoff value that indicates the feasibility of reacquisition of walking ability postoperatively is ≥9.

5.1. Limitations

The subjects of this study were evaluated for frailty and classified according to the SPPB, which is an index of physical function. Frailty is defined from various aspects including physical, social, and psychological aspects, and no single standard currently exists to clearly judge frailty despite various methods of evaluations. In addition, although patients who underwent elective cardiac surgery were included as subjects, we did not survey drug information. Therefore, the general condition of subjects, including medical treatment, is partly unclear.

Conflict of interest

All authors declare that there is no conflict of interest.

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