Reviews in Cardiovascular Medicine

Rev. Cardiovasc. Med. **2022**; 23(2): 077
http://doi.org/10.31083/j.rcm2302077

Original Research

Physical function examination at intensive care unit as predictive indicators for hospitalization-associated disability in patients after cardiovascular surgery

Kotaro Hirakawa[1], Atsuko Nakayama[2,*], Masakazu Saitoh[1,3], Takeshi Arimitsu[1], Keigo Iwai[1], Kentaro Hori[1], Tomoki Shimokawa[4,5], Shuichiro Takanashi[4,6], Go Haraguchi[7], Mitsuaki Isobe[8]

[1]Department of Rehabilitation, Sakakibara Heart Institute, 183-0003 Tokyo, Japan
[2]Department of Cardiology, Sakakibara Heart Institute, 183-0003 Tokyo, Japan
[3]Department of Physical Therapy, Faculty of Health Science, Juntendo University, 113-0033 Tokyo, Japan
[4]Department of Cardiovascular Surgery, Sakakibara Heart Institute, 183-0003 Tokyo, Japan
[5]Department of Cardiovascular Surgery, Teikyo University Hospital, 173-8606 Tokyo, Japan
[6]Department of Cardiovascular Surgery, Kawasaki Saiwai Hospital, 212-0014 Kanagawa, Japan
[7]Division of Intensive Care Unit, Sakakibara Heart Institute, 183-0003 Tokyo, Japan
[8]Sakakibara Heart Institute, 183-0003 Tokyo, Japan
*Correspondence: atsukonakanaka@gmail.com (Atsuko Nakayama)
Academic Editors: Kazuhiro P. Izawa and Peter H. Brubaker
Submitted: 16 November 2021 Revised: 18 December 2021 Accepted: 27 December 2021 Published: 22 February 2022

Abstract

Background: Following cardiovascular surgery, patients are at high risk of requiring systemic management in the intensive care unit (ICU), resulting in hospitalization-associated disability (HAD). Predicting the risk of HAD during the postoperative course is important to prevent susceptibility to cardiovascular events. Assessment of physical function during the ICU stay may be useful as a prediction index but has not been established. **Methods**: This prospective observational study conducted at a high-volume cardiovascular center included 236 patients (34% female; median age, 73 years) who required an ICU stay of at least 72 hours after surgery and underwent postoperative rehabilitation. HAD was defined as a decrease in the discharge Barthel index (BI) score of at least 5 points relative to the preadmission BI score. Physical Function ICU Test-scored (PFIT-s), Functional Status Score for the ICU (FSS-ICU), and Medical Research Council (MRC)-sumscore were used to assess physical function at ICU discharge. **Results**: HAD occurred in 58 (24.6%) of the 236 patients following cardiovascular surgery. The cut-off points for HAD were 7.5 points for the PFIT-s (sensitivity 0.80, specificity 0.59), 24.5 points for the FSS-ICU (sensitivity 0.57, specificity 0.66), and 59.5 points for the MRC-sumscore (sensitivity 0.93, specificity 0.66). Multivariate logistic regression analysis revealed a PFIT-s of >7.5 points (odds ratio [OR], 4.84; 95% CI, 2.39–9.80; $p < 0.001$) and an MRC-sumscore of >59.5 points (OR, 2.43; 95% CI, 1.22–4.87; $p = 0.012$) as independent associated factors. **Conclusions**: We demonstrate that the PFIT-s and MRC-sumscore at ICU discharge may be helpful as a predictive indicator for HAD in patients having undergone major cardiovascular surgery.

Keywords: hospitalization-associated disability; physical function assessment; intensive care unit; cardiovascular surgery

1. Introduction

The development of surgical techniques and advancements in perioperative management for cardiovascular surgery have enabled an improvement in life saving, a shortening of the postoperative hospital stay, and the start of early rehabilitation. The improved surgical techniques also enabled us to offer surgical options to older adults aged over 80 years and who had comorbidity. With the advancement of medical technology, the number of patients indicated for surgery is expanding [1].

The procedure's success rate and survival rate after surgery have been improving in older adult population. However, hospitalization-associated disability (HAD), such as increased catabolism due to invasion and postoperative bed rest, which leads to a decrease in physical function and activities of daily living (ADL) associated with inpatient postoperative care, has begun to be recognized as an important postoperative outcome [2]. The prevalence of HAD in older adults after surgery has been reported to be as high as 30% [3], and this group had an increased risk of poor post-discharge quality of life (QOL) and long-term life outcomes [4,5].

HAD is related to age, cognitive function, and other environmental changes due to preoperative background and surgical procedure [6]. In addition to these factors, advanced invasion, such as the use of cardiopulmonary prostheses and long-term intensive care unit (ICU) care, increases the risk of HAD in patients after cardiovascular surgery. Compared to preoperative factors, postoperative factors and course in the ICU in patients after surgery may

Copyright: © 2022 The Author(s). Published by IMR Press.
This is an open access article under the CC BY 4.0 license.

Publisher's Note: IMR Press stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

have a direct influence on their subsequent functional prognosis. Therefore, assessing patients' physical condition after surgery at the ICU before discharge could be very important in developing therapeutic strategies to prevent HAD.

In recent years, several methodologies for evaluating physical function in the ICU have been reported [7]. Due to highly variable clinical characteristics such as acute disease state and specific environment, a method for estimating the risk of HAD after cardiac surgery has not yet been established. Therefore, a reliable means to accurately assess physical function in the ICU and thus predict the HAD index is required. Physical function assessment at ICU discharge can be a useful indicator for reconstructing rehabilitation programs after ICU discharge and designing an individual home care plan following discharge.

Here, we aimed to investigate the postoperative and preoperative factors associated with HAD and the utility of assessing physical function at ICU discharge in patients who have undergone cardiovascular surgery.

2. Methods

2.1 Subjects

This prospective study was conducted at Sakakibara Heart Institute, the hospital with the highest number of cardiovascular surgeries and the largest cardiac rehabilitation center in Japan. We included 236 patients (median age, 73 years; 34% female) who required an ICU stay of at least 72 hours after undergoing cardiovascular surgery and underwent postoperative rehabilitation at our hospital between May 2018 and November 2020. The exclusion criteria were ICU stay <72 hours (n = 1392), postoperative cerebral infarction or spinal cord infarction (n = 38), hospital transfer within 7 days after surgery (n = 4), in-hospital death (n = 7), and no assessment of physical function at ICU discharge (n = 294) (Fig. 1). The criteria for ICU discharge was according to the ICU guideline [8].

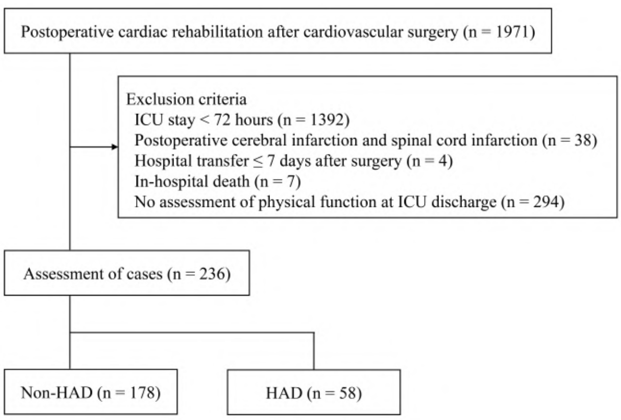

Fig. 1. Schematic presentation of study procedure. This study included 236 patients who required an ICU stay of at least 72 hours after undergoing cardiovascular surgery and underwent postoperative rehabilitation.

2.2 Definition of HAD

The Barthel index (BI) was used to assess ADL levels preoperatively and at discharge, and HAD was defined as a decrease in the BI score between discharge and prior to surgery of at least 5 points. The BI consists of 10 items: (1) feeding, (2) moving from wheelchair to bed and return, (3) personal toilet, (4) getting on and off the toilet, (5) bathing, (6) transferring, (7) ascending and descending stairs, (8) dressing, (9) controlling bowels, and (10) controlling bladder. Independence is scored as 0, 5, 10, and 15 points according to the degree, and the total score was calculated for each patient [9]. The preoperative ADL level was obtained either directly from the patient or from relatives, about the condition that was not exacerbated before admission.

2.3 Assessment of physical function

Physical Function ICU Test-scored (PFIT-s), Functional Status Score for the ICU (FSS-ICU), and Medical Research Council (MRC)-sumscore were used to assess physical function in the ICU. PFIT-s is composed of four items: (1) sit-to-stand assistance, (2) cadence, (3) shoulder flexion strength, and (4) knee extension strength; each item was scored to a sum of 0 to 3 points and evaluated on a 10-point scale converted to an interval scale [10]. FSS-ICU was scored from 0 to 7 (35 points total) for each of the five following actions: (1) rolling, (2) transfer from supine position to sitting, (3) sitting at the edge of bed, (4) transfer from sitting to standing, and (5) walking according to the degree of independence [11,12]. The MRC-sumscore classifies the muscular strength in shoulder abduction, elbow flexion, wrist dorsiflexion, hip flexion, knee extension, and ankle dorsiflexion, attributing a score from 0 to 5 [13]. Each assessment was measured one day before or on the day of ICU discharge. Physical function assessment at ICU discharge was performed by three physiotherapists with at least 5 years' clinical experience. Preoperative and discharge BIs are routinely assessed by our hospital's well-trained physiotherapists. Data were collected by researchers who were blinded to the predictive factors.

We also examined arousal (Richmond Agitation-Sedation Scale) [14], pain (Numerical Rating Scale) [15], circulatory dynamics (mean blood pressure, heart rate, and atrial fibrillation), respiratory status (percutaneous oxygen saturation), and ICU mobility scale [16] at the time of physical function assessment.

2.4 Postoperative cardiac rehabilitation

Postoperative cardiac rehabilitation was performed in compliance with the Guidelines for Rehabilitation in Cardiovascular Diseases established in 2012 [17] and in consultation with the attending physician. The days on which a patient was able to independently sit, stand, practice walking, and walk 100 m are referred to as the starting date of each of these activities. In addition, we assessed the extent of exercise performed in the cardiac rehabilitation room, con-

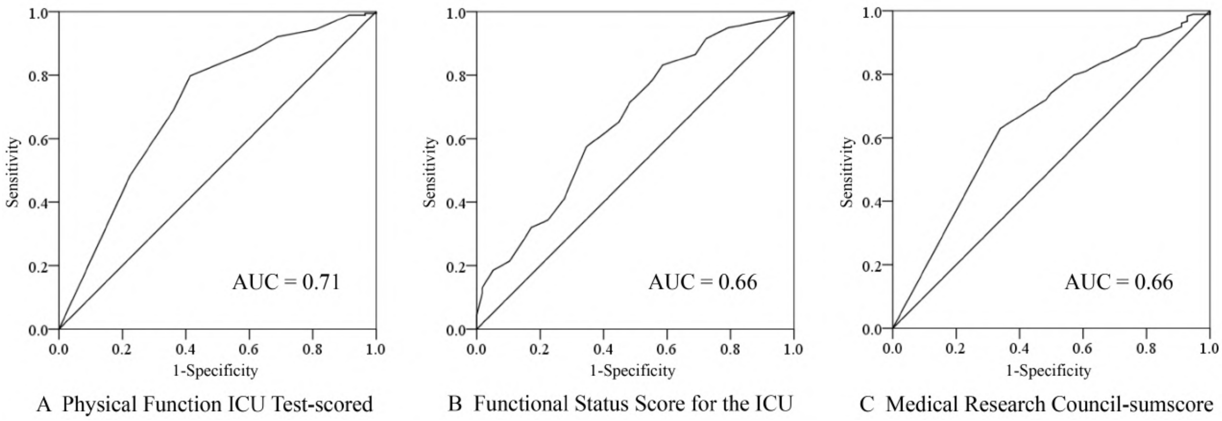

Fig. 2. Receiver-operating characteristic analysis of physical functional evaluation as a predictor of hospitalization-associated disability. The area under the curve was (A) 0.71 (95% CI, 0.63–0.79; $p < 0.001$) for the Physical Function ICU Test-scored, (B) 0.66 (95% CI, 0.57–0.74; $p < 0.001$) for the Functional Status Score for the ICU, and (C) 0.66 (95% CI, 0.57–0.74; $p < 0.001$) for the Medical Research Council-sumscore.

Table 1. Clinical characteristics.

	non-HAD	HAD	*p* value	OR	95% CI
	(n = 178)	(n = 58)			
Age, years	72 (65–78)	79 (68–82)	<0.01*	1.04	1.01–1.08
Female, n (%)	58 (32.6)	23 (39.7)	0.33	1.36	0.74–2.51
BMI, kg/m^2	23.6 (21.3–26.5)	22.0 (20.1–23.6)	<0.01*	0.88	0.81–0.96
Comorbidity, n (%)					
Hypertension	112 (62.9)	38 (65.5)	0.72	1.12	0.60–2.08
Diabetes mellitus	49 (27.5)	9 (15.5)	0.07	0.48	0.22–1.06
Coronary artery disease	28 (15.7)	10 (17.2)	0.79	1.12	0.51–2.46
Chronic kidney disease	39 (21.9)	16 (27.6)	0.38	1.36	0.69–2.67
Chronic heart failure	15 (8.4)	7 (12.1)	0.41	1.49	0.58–3.86
Chronic obstructive pulmonary disease	3 (1.7)	3 (5.2)	0.16	3.18	0.62–16.22
Musculoskeletal disorder	33 (18.5)	11 (19.0)	0.94	1.03	0.48–2.19
Cerebrovascular disorder	15 (8.4)	10 (17.2)	0.06	2.26	0.96–5.36
Blood biochemistry					
Hemoglobin, g/dL	12.9 (11.6–14.1)	11.9 (10.6–13.1)	<0.01*	0.76	0.65–0.89
Creatinine, mg/dL	0.96 (0.77–1.23)	1.04 (0.82–1.64)	0.16	1.09	0.97–1.22
Albumin, g/dL	3.9 (3.5–4.0)	3.6 (3.3–3.9)	<0.01*	0.41	0.21–0.78
CRP, mg/dL	0.26 (0.05–1.55)	0.19 (0.05–1.24)	0.83	1.01	0.93–1.09

*$p < 0.05$ (univariate logistic regression analysis).

HAD, hospitalization-associated disability; BMI, body mass index; CRP, C-reactive protein; OR, odds ratio; CI, confidence interval.

sisting mainly of aerobic exercise using a bicycle ergometer and treadmill as well as resistance training.

2.5 Additional assessments

The following data were collected from medical records: age, sex, body mass index (BMI), medical history of comorbidities, preoperative blood biochemistry examination, intraoperative records, Acute Physiology and Chronic Health Evaluation (APACHE) II score, duration of ventilator intubation, intra-aortic balloon pumping, continuous renal replacement therapy, noninvasive positive pressure ventilation (NPPV), and postoperative complications. Postoperative delirium was assessed using the Confusion Assessment Method for the ICU [18].

2.6 Statistical analysis

Continuous variables are reported as the median (interquartile range [IQR]), whereas categorical variables are expressed as percentages. The Shapiro–Wilk test was used to verify a normal distribution. In group comparisons, the Mann–Whitney U test were performed for continuous variables and the χ^2 test was used for categorical variables. Receiver operating characteristic (ROC) analyses were used to calculate cut-offs of physical functional evaluation as a pre-

Table 2. Intraoperative findings and postoperative course.

	non HAD (n = 178)	HAD (n = 58)	p value	OR	95% CI
Surgery type, n (%)			0.98	0.98	0.24–4.05
CABG	50 (28.1)	9 (15.5)			
Valve	17 (9.6)	3 (5.2)			
Thoracic aortic	44 (24.7)	26 (44.8)			
Multiple	59 (33.1)	19 (32.8)			
Other	8 (4.5)	1 (1.7)			
Emergent, n (%)	105 (59.0)	39 (67.2)	0.26	1.43	0.75–2.67
Operation time, min	280 (206–352)	311 (220–365)	0.05	1.18	1.00–1.38
CPB time, min	151 (104–192)	174 (116–214)	0.13	1.00	1.00–1.01
Bleeding, mL	230 (114–360)	259 (160–345)	0.72	1.00	1.00–1.00
IMV, h	26 (19–38)	40 (25–58)	0.10	1.00	1.00–1.01
APACHE II score, points	17 (14–21)	19 (16–22)	0.01*	1.08	1.02–1.16
IABP, n (%)	24 (13.5)	6 (10.3)	0.53	0.74	0.29–1.91
NPPV, n (%)	22 (12.4)	14 (24.1)	0.03*	2.26	1.07–4.77
CRRT, n (%)	7 (3.9)	4 (6.9)	0.36	1.81	0.51–6.42
Delirium, n (%)	28 (15.7)	23 (39.7)	<0.001*	3.52	1.81–6.83
ICU stay, days	5 (4–6)	6 (5–9)	<0.01*	1.13	1.04–1.22
Hospital stay, days	15 (12–22)	19 (10–29)	0.03*	1.03	1.00–1.05
Cardiac rehabilitation, days					
Sitting	2 (1–2)	2 (2–3)	0.06	1.16	0.99–1.36
Standing	2 (1–2)	2 (2–4)	<0.01*	1.36	1.12–1.67
Walking	4 (3–5)	5 (4–8)	<0.001*	1.23	1.11–1.37
100 m walking	6 (5–8)	8 (7–17)	<0.01*	1.08	1.02–1.14
Introduction of rehabilitation room	69 (38.8)	6 (10.3)	<0.001*	0.18	0.07–0.45
PFIT-s, points	8.8 (7.9–10.0)	7.1 (5.9–8.8)	<0.001*	0.65	0.55–0.77
FSS-ICU, points	25 (22–29)	22 (17–26)	<0.001*	0.90	0.85–0.95
MRC-sumscore, points	60 (56–60)	57 (52–60)	<0.01*	0.93	0.89–0.98
Barthel index, points					
Preoperative	100 (100–100)	100 (100–100)	0.19	0.91	0.79–1.05
Discharge	100 (100–100)	73 (55–90)	<0.001*	0.42	0.32–0.57

*$p < 0.05$ (univariate logistic regression analysis).

CABG, coronary artery bypass grafting; CPB, cardiopulmonary bypass; IMV, invasive mechanical ventilation; APACHE, Acute Physiology and Chronic Health Evaluation; IABP, intra-aortic balloon pumping; NPPV, non-invasive positive pressure ventilation; CRRT, continuous renal replacement therapy; ICU, intensive care unit; PFIT-s, Physical Function ICU Test-scored; FSS-ICU, Functional Status Score for the ICU; MRC, Medical Research Council; OR, odds ratio; CI, confidence interval.

dictor of HAD at ICU discharge, and continuous variables were converted to categorical data. The cut-off value was calculated using the tangential method from the AUC. Multivariate logistic regression analysis was performed with the presence of HAD as the dependent variable and factors, both continuous and categorical variables. Age, BMI, APACHEII score, delirium, day of onset of standing, and each physical function that was significantly different in the univariate analysis were included as adjusted variables. The level of significance was set at <0.05, and all statistical analyses were performed using IBM SPSS Statistics 21 (IBM Corp., Armonk, NY, USA). There was no missing information.

3. Results

Preoperative characteristics, intraoperative findings, and postoperative course are shown in Tables 1,2. Of the 236 patients included in the analysis, 58 (24.6%) exhibited HAD. Compared with the non-HAD group, the HAD group had significantly lower PFIT-s, FSS-ICU, and MRC-sumscores at ICU discharge ($p < 0.01$). The physical examination of patients in the HAD group was conducted after a median of 5 postoperative days; we found that arousal and analgesic control were normal, and the respiratory and circulatory dynamics were stable. In addition, 97.5% of the patients reached $\geq$5 on the ICU mobility scale (Table 3). The cut-off point for HAD was 7.5 points for the

PFIT-s (sensitivity 0.80, specificity, 0.59), 24.5 points for the FSS-ICU (sensitivity, 0.57, specificity, 0.66), and 59.5 points for the MRC-sumscore (sensitivity, 0.93, specificity, 0.66) (Fig. 2). Multivariate logistic regression analysis revealed age, BMI, APACHE II score, postoperative delirium, the starting date of standing, PFIT-s, FSS-ICU, and MRC-sumscore at ICU discharge as independent variables. Furthermore, age (odds ratio [OR], 2.48; 95% CI, 1.21–5.08; p = 0.013), postoperative delirium (OR, 3.40; 95% CI, 1.60–7.23; p = 0.001), the starting date of standing (OR, 2.16; 95% CI, 1.06–4.46; p = 0.035), PFIT-s (OR, 4.84; 95% CI, 2.39–9.80; $p < 0.001$), and MRC-sumscore (OR, 2.43; 95% CI, 1.22–4.87; p = 0.012) were identified as relevant factors (Table 4). The trend of significance of each factor was similar with the results by logistic regression analysis with continuous variables (Table 5).

Table 3. Clinical status at the time of physical function evaluation.

	Overall (n = 236)
Postoperative day, days	5 (3–6)
Sedation (RASS)	0 (0–0)
Pain (NRS)	0 (0–2)
Delirium, n (%)	23 (9.7)
Mean arterial pressure, mmHg	83 (75–93)
Heart rate, bpm	80 (72–89)
Postoperative atrial fibrillation, n (%)	24 (10.2)
SpO_2, %	97 (96–98)
ICU mobility scale, n (%)	
4 (Standing)	6 (2.5)
5 (Transferring)	10 (4.2)
6 (Marching on spot)	43 (18.2)
≥7 (Walking)	177 (75.0)

RASS, Richmond Agitation-Sedation Scale; NRS, Numerical Rating Scale; SpO_2, oxygen saturation by pulse oximeter; ICU, intensive care unit; bpm, beats per minute; mm Hg, millimeters of mercury.

4. Discussion

4.1 Factors associated with HAD

In this study, the incidence of HAD was 24.6%, and age, postoperative delirium, the starting date of standing, and physical function at ICU discharge were identified as associated factors. There have been many previous reports of age-related decline in physical function [19,20], and the age-related decline in physical reserve and mental function, such as cognitive decline and depression, have been shown to be risk factors for HAD [6]. In addition, patients with HAD had significantly longer duration of ventilator intubation, increased NPPV usage, and longer ICU stay. In cases of unstable postoperative respiratory and circulatory dynamics, patients are forced to rest in bed and require long-term ICU management. Under these circumstances, postoperative delirium is more likely to develop and has been shown to be a risk factor for ADL reduction [21,22]. In the older adult population, environmental changes due to hospitalization may lead to decreased ADL independence and activity, resulting in HAD [6]. Recently, it was reported that if physical function and ADL were impaired during ICU stay, these impairments remained following ICU discharge [23,24]. It has also been shown that low physical function during the ICU stay is a predictor of a decrease in QOL and short-term and long-term prognosis after ICU discharge [4,5]. Although early mobilization can help to prevent a decline in physical function and ADL and improve the QOL [25–27], usually patients with HAD require postoperative recumbency and long-term ventilator management due to major surgery, leading to delays in the ability of standing and walking. Therefore, in addition to the marked decrease in physical function at the time of ICU discharge and delayed rehabilitation progression thereafter, the failure to transition from exercise therapy in the ward to that in the cardiac rehabilitation room may have prevented a re-acquisition of function until the time of discharge.

4.2 Assessment of physical function at ICU discharge

In this study, the traditionally widely used PFIT-s, FSS-ICU, and MRC-sumscore were utilized as an assessment index for physical function in the ICU. Although the FSS-ICU was identified as a significant factor in univariate analysis, the significance was lost in multivariate analysis. Drains and infusions are often placed in the long term after cardiovascular surgery, inhibiting physical activity and movement in ICU patients. FSS-ICU was scored based on the degree of independence in movement, but the postoperative placement decreased the movement at ICU discharge, resulting in a lower score indicating that the assessment as a physical function lacked validity. The MRC-sumscore evaluates limb muscle strength, whereas the PFIT-s comprehensively assesses and scores physical performance and endurance in addition to muscle strength. Therefore, we believe that the PFIT-s was more helpful as a method to predict HAD in this study.

Generally, safety and validity are considered when assessing physical function in the ICU [28]. In the immediate postoperative period, exacerbation of pain and variations in respiratory and circulatory dynamics are likely to occur during the evaluation, and these effects may be reflected in the evaluation results. In this study, at the time of evaluating physical function, the arousal level and analgesic control were close to normal and respiratory and circulatory dynamics were stable. In addition, 97.5% of the patients with HAD were able to secure until transferring, suggesting that the restriction of activities did not affect the evaluation of physical functions. Altogether, to prevent HAD, we believe

Table 4. Factors associated with hospitalization-associated disability (categorical variables).

	Univariate			Multivariate		
	OR	95% CI	*p* value	OR	95% CI	*p* value
Age (>73 years)	2.63	1.41–4.91	<0.01	2.48	1.21–5.08	0.01
BMI (<22.9 kg/m^2)	2.25	1.19–4.27	0.01	1.54	0.72–3.28	0.27
APACHE II score (>17 points)	2.02	1.10–3.72	0.02	1.59	0.78–3.22	0.20
Delirium	3.52	1.81–6.83	<0.001	3.40	1.60–7.23	<0.01
Standing (>2 days)	2.91	1.56–5.43	<0.01	2.16	1.06–4.46	0.04
Physical function						
PFIT-s (<7.5 points)	5.59	2.95–10.57	<0.001	4.84	2.39–9.81	<0.001
FSS-ICU (<25 points)	2.55	1.38–4.73	<0.01	1.94	0.97–3.89	0.06
MRC-sumscore (<60 points)	3.31	1.76–6.21	<0.001	2.43	1.22–4.87	0.01

BMI, body mass index; APACHE, Acute Physiology and Chronic Health Evaluation; PFIT-s, Physical Function ICU Test-scored; FSS-ICU, Functional Status Score for the ICU; MRC, Medical Research Council; OR, odds ratio; CI, confidence interval.

Table 5. Factors associated with hospitalization-associated disability (continuous variables).

	Univariate			Multivariate		
	OR	95% CI	*p* value	OR	95% CI	*p* value
Age (years)	1.04	1.01–1.08	<0.01	1.04	1.00–1.08	0.03
BMI (kg/m^2)	0.88	0.81–0.96	<0.01	0.97	0.87–1.07	0.52
APACHEII (point)	1.09	1.02–1.16	<0.05	1.06	0.98–1.14	0.14
Delirium	3.52	1.81–6.83	<0.001	2.93	1.40–6.15	<0.01
Standing (point)	1.36	1.12–1.67	<0.01	1.14	0.94–1.39	0.18
Physical function						
PFIT-s (point)	0.65	0.55–0.77	<0.001	0.69	0.57–0.84	<0.001
FSS-ICU (point)	0.90	0.85–0.95	<0.001	0.91	0.86–0.97	<0.01
MRC-sumscore (point)	0.93	0.89–0.98	<0.01	0.95	0.90–1.00	0.05

BMI, body mass index; APACHE, Acute Physiology and Chronic Health Evaluation; PFIT-s, Physical Function ICU Test-scored; FSS-ICU, Functional Status Score for the ICU; MRC, Medical Research Council; OR, odds ratio; CI, confidence interval.

that assessing physical function at ICU discharge could be suitable to design a rehabilitation program following major surgery and a subsequent stay in the ICU.

5. Limitations

Since this study included severe cases requiring an ICU stay of at least 72 hours after performing cardiovascular surgery, our results may not apply to patients who are discharged from the ICU earlier. However, the strategy for preventing HAD after surgery should be applied for patients with a long ICU stay. We also excluded patients with an early hospital transfer, those who died in the hospital due to serious complications after surgery, and those who required treatment by other departments preferentially; therefore, patients with severe complications, such as multiple organ failure, were not considered, so that the impact of physical examination on the risk of HAD in such cases remains unclear. Because general physical ability of older adult population is increasing in Japan [29], and our hospital is one of the largest cardiovascular centers in Japan, many patients are referred by other hospitals as candidates for surgery with better preoperative physical function (high BI before surgery).

In addition to physical functions, such as muscle strength, various functional components, including dexterity and cognitive function, are associated with basic ADL [30]; however, these functional assessments were not performed in this study.

6. Conclusions

Physical function at ICU discharge was an independent factor associated with HAD in critically ill postoperative cardiovascular surgery patients. Moreover, it was shown that the PFIT-s and MRC-sumscore may be useful predictors of HAD and feasible tools in assessing physical function in the ICU.

Author contributions

KHi, AN, MS, TA, KI, KHo, TS, ST, GH and MI were involved in the conceptualization and methodology of the study. KHi, TA, KI, and KHo performed the study. KHi, AN, and MS designed the study. AN, MS, TS, ST, GH and MI provided help and advice on the study. KHi and AN analyzed the data. KHi and AN wrote the manuscript. All authors contributed to editorial changes in the manuscript and read and approved the final manuscript.

Ethics approval and consent to participate

This study was approved by the Ethics Committee of Sakakibara Heart Institute (Approval ID: 18-010). Participants of this study were informed in advance regarding the purpose, content, and handling of survey results, and consent was obtained. We adhered to the Declaration of Helsinki and the Ethical Guidelines for Research in the Department of Life Sciences and Medical Sciences for People.

Acknowledgments

We would like to thank the members of the Department of Cardiac Rehabilitation for their assistance in the preparation of this manuscript.

Funding

This study was supported by Grants-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology in Japan (No. 19K19828).

Conflict of interest

The authors declare no conflicts of interest.

References

[1] Shemin RJ. The Future of Cardiovascular Surgery. Circulation. 2016; 133: 2712–2715.

[2] Zisberg A, Shadmi E, Gur-Yaish N, Tonkikh O, Sinoff G. Hospital-associated functional decline: the role of hospitalization processes beyond individual risk factors. Journal of the American Geriatrics Society. 2015; 63: 55–62.

[3] Loyd C, Markland AD, Zhang Y, Fowler M, Harper S, Wright NC, *et al*. Prevalence of Hospital-Associated Disability in Older Adults: a Meta-analysis. Journal of the American Medical Directors Association. 2020; 21: 455–461.e5.

[4] Needham DM, Davidson J, Cohen H, Hopkins RO, Weinert C, Wunsch H, *et al*. Improving long-term outcomes after discharge from intensive care unit: report from a stakeholders' conference. Critical Care Medicine. 2012; 40: 502–509.

[5] Kaarlola A, Tallgren M, Pettilä V. Long-term survival, quality of life, and quality-adjusted life-years among critically ill elderly patients. Critical Care Medicine. 2006; 34: 2120–2126.

[6] Covinsky KE, Pierluissi E, Johnston CB. Hospitalization-Associated Disability. The Journal of the American Medical Association. 2011; 306: 1782–1793.

[7] Parry SM, Denehy L, Beach LJ, Berney S, Williamson HC, Granger CL. Functional outcomes in ICU – what should we be using? – an observational study. Critical Care. 2015; 19: 127.

[8] Nates JL, Nunnally M, Kleinpell R, Blosser S, Goldner J, Birriel B, *et al*. ICU Admission, Discharge, and Triage Guidelines. Critical Care Medicine. 2016; 44: 1553–1602.

[9] Mahoney FI, Barthel DW. FUNCTIONAL EVALUATION: THE BARTHEL INDEX. Maryland State Medical Journal. 1995; 14: 61–65.

[10] Denehy L, de Morton NA, Skinner EH, Edbrooke L, Haines K, Warrillow S, *et al*. A physical function test for use in the intensive care unit: validity, responsiveness, and predictive utility of the physical function ICU test (scored). Physical Therapy. 2013; 93: 1636–1645.

[11] Dodds TA, Martin DP, Stolov WC, Deyo RA. A validation of the functional independence measurement and its performance among rehabilitation inpatients. Archives of Physical Medicine and Rehabilitation. 1993; 74: 531–536.

[12] Zanni JM, Korupolu R, Fan E, Pradhan P, Janjua K, Palmer JB, *et al*. Rehabilitation therapy and outcomes in acute respiratory failure: an observational pilot project. Journal of Critical Care. 2010; 25: 254–262.

[13] Kleyweg RP, van der Meché FG, Schmitz PI. Interobserver agreement in the assessment of muscle strength and functional abilities in Guillain-Barré syndrome. Muscle & Nerve. 1991; 14: 1103–1109.

[14] Ely EW, Truman B, Shintani A, Thomason JWW, Wheeler AP, Gordon S, *et al*. Monitoring sedation status over time in ICU patients: reliability and validity of the Richmond Agitation-Sedation Scale (RASS). The Journal of the American Medical Association. 2003; 289: 2983–2991.

[15] Williamson A, Hoggart B. Pain: a review of three commonly used pain rating scales. Journal of Clinical Nursing. 2005; 14: 798–804.

[16] Hodgson C, Needham D, Haines K, Bailey M, Ward A, Harrold M, *et al*. Feasibility and inter-rater reliability of the ICU Mobility Scale. Heart & Lung. 2014; 43: 19–24.

[17] JCS Joint Working Group. Guidelines for rehabilitation in patients with cardiovascular disease (JCS 2012). Circulation Journal. 2014; 78: 2022–2093.

[18] Ely EW, Inouye SK, Bernard GR, Gordon S, Francis J, May L, *et al*. Delirium in mechanically ventilated patients: validity and reliability of the confusion assessment method for the intensive care unit (CAM-ICU). The Journal of the American Medical Association. 2001; 286: 2703–2710.

[19] Balzi D, Lauretani F, Barchielli A, Ferrucci L, Bandinelli S, Buiatti E, *et al*. Risk factors for disability in older persons over 3-year follow-up. Age and Ageing. 2010; 39: 92–98.

[20] Itagaki A, Saitoh M, Okamura D, Kawamura T, Otsuka S, Tahara M, *et al*. Factors related to physical functioning decline after cardiac surgery in older patients: a multicenter retrospective study. Journal of Cardiology. 2019; 74: 279–283.

[21] Rudolph JL, Inouye SK, Jones RN, Yang FM, Fong TG, Levkoff SE, *et al*. Delirium: an independent predictor of functional decline after cardiac surgery. Journal of the American Geriatrics Society. 2010; 58: 643–649.

[22] Abelha FJ, Luís C, Veiga D, Parente D, Fernandes V, Santos P, *et al*. Outcome and quality of life in patients with postoperative delirium during an ICU stay following major surgery. Critical Care. 2013; 17: R257.

[23] Desai SV, Law TJ, Needham DM. Long-term complications of critical care. Critical Care Medicine. 2011; 39: 371–379.

[24] Ohtake PJ, Lee AC, Scott JC, Hinman RS, Ali NA, Hinkson CR, *et al*. Physical Impairments Associated with Post-Intensive Care Syndrome: Systematic Review Based on the World Health Organization's International Classification of Functioning, Disability and Health Framework. Physical Therapy. 2018; 98: 631–645.

[25] Ramos Dos Santos PM, Aquaroni Ricci N, Aparecida Bordignon Suster É, de Moraes Paisani D, Dias Chiavegato L. Effects of early mobilisation in patients after cardiac surgery: a systematic review. Physiotherapy. 2017; 103: 1–12.

[26] Zhang L, Hu W, Cai Z, Liu J, Wu J, Deng Y, *et al*. Early mobilization of critically ill patients in the intensive care unit:

A systematic review and meta-analysis. PLoS One. 2019; 14: e0223185.

[27] Anekwe DE, Biswas S, Bussières A, Spahija J. Early rehabilitation reduces the likelihood of developing intensive care unit-acquired weakness: a systematic review and meta-analysis. Physiotherapy. 2020; 107: 1–10.

[28] Nordon-Craft A, Schenkman M, Edbrooke L, Malone DJ, Moss M, Denehy L. The physical function intensive care test: implementation in survivors of critical illness. Physical Therapy. 2014; 94: 1499–1507.

[29] National Survey on Physical and Motor Abilities by The Japan Sports Agency. 2021. Available at: https://www.mext.go.jp/sports/b_menu/toukei/chousa04/tairyoku/kekka/k_detail/1421920_00003.htm (Accessed: 18, December, 2021). (In Japanese)

[30] Honda Y, Takahashi K, Sasanuma N, Itani Y, Nagase M, Uchiyama Y, *et al*. Predictors of Functional Decline in Activities of Daily Living at Discharge in Patients after Cardiovascular Surgery. Circulation Journal. 2021; 85: 1020–1026.