

ORIGINAL RESEARCH ARTICLE

Effect of exercise prehabilitation on days alive and out of hospital after cardiac surgery: a secondary analysis of the randomised PREhabilitation for improving QUality of recovery after ELective cardiac surgery trial

Vivian N. M. Lau^{1,2}, Derek K. W. Yau^{1,3}, Floria F. Ng¹, Vicki W. S. Li², Kelly K. H. Wong², Christina H. L. Wong², Pik Yi Hou¹, Kwok Ming Ho¹ and Anna Lee^{1,*}

¹Department of Anaesthesia and Intensive Care, Chinese University of Hong Kong, Shatin, Hong Kong SAR, China, ²Department of Anaesthesia, Pain and Perioperative Medicine, Prince of Wales Hospital, Shatin, Hong Kong SAR, China and ³Department of Rehabilitation Sciences, Hong Kong Polytechnic University, Hung Hom, Hong Kong SAR, China

*Corresponding author: E-mail: annalee@cuhk.edu.hk,  [@AnnaLee_AIC](https://twitter.com/AnnaLee_AIC)



Abstract

Background: Postoperative healthcare utilisation and long-term survival are rarely evaluated after prehabilitation, limiting understanding of its sustained benefits. We investigated whether exercise-based prehabilitation improves percent days alive and out of hospital, a composite measure integrating recurrent hospitalisations and survival after cardiac surgery.

Methods: This secondary exploratory analysis included participants with very mild to moderate frailty from the PREhabilitation for improving QUality of recovery after ELective cardiac surgery (PREQUEL) RCT. The trial time period was from 2018 to 2023 with follow-up continued until 31 December 2024, with readmissions and vital status retrospectively obtained from electronic medical records. One-inflated beta regression, negative binomial regressions, and restricted mean survival time analysis were used to estimate the effects of prehabilitation on %DOAH days alive out of hospital, cumulative hospital bed days owing to readmissions, and survival, respectively.

Results: Among 136 participants (58 prehabilitation, 78 usual care), 94 (69.1%) were male, with a median age of 64 yr (IQR 59–69). Thirty-five (60.3%) prehabilitation and 52 (66.7%) usual care participants accounted for 119 and 165 readmissions, respectively. Prehabilitation was associated with a higher %DOAH days alive out of hospital in the unadjusted analysis (87.7% vs 81.5%; $P=0.032$), but this was not significant after adjustment (87.3% vs 83.6%; $P=0.131$). Cumulative hospital bed days did not differ significantly (incidence rate ratio 0.95, 95% confidence interval [CI]: 0.59–1.55). However, survival improved modestly at 4 yr (mean difference: 0.22 yr, 95% CI: 0.01–0.44; $P=0.044$) in favour of prehabilitation.

Conclusions: Exercise-based prehabilitation had little or no effect on long-term time spent at home but may confer a modest survival benefit, warranting further investigation in larger trials.

Keywords: cardiac surgical procedures; exercise therapy; frailty; patient readmission; preoperative care; survival analysis

Improving outcomes for frail patients undergoing cardiac surgery is a top priority for patients, carers, and clinicians.¹ Frailty substantially increases perioperative risks after cardiac surgery: longer hospital stays, a five-fold higher risk of non-home discharge, and nearly double the mid- to long-term

operative mortality compared with robust patients.² Yet, its association with readmissions remains unclear; although a systematic review of 19 studies ($n=66\ 448$) found no association with 30-day readmissions, other data suggest increasing frailty predicts 1-yr readmission rates.^{2,3}

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Individualised prehabilitation programs, including structured exercise training, nutrition counselling and supplementation, and psychological support in the weeks before surgery, aim to enhance physiological reserve and resilience to surgical stress. Trials reported early benefits, including improved functional recovery and reduced disability, although the effects on short-term quality of recovery remain uncertain.^{4–7} Our PREhabilitation for Improving QUality of Recovery after ELective Cardiac Surgery (PREQUEL) trial—a twice-weekly supervised physical prehabilitation programme over 5 weeks—for example, found no improvement in early quality of recovery (QoR-15) scores but demonstrated reduced disability at 90 days.⁵

Long-term outcomes after prehabilitation alone remain largely unexplored. Cardiac rehabilitation after coronary artery bypass grafting (CABG) confers survival benefits lasting up to 20 yr (hazard ratio [HR] 0.76, 95% confidence ratio [CI]: 0.68–0.84),⁸ and patients who undergo prehabilitation are more likely to engage in rehabilitation after surgery (70% vs 57%).⁹ This raises a compelling question: could prehabilitation alone deliver similar long-term advantages for frail cardiac surgical patients?

To address this gap, we evaluated the effect of exercise-based prehabilitation on percent days alive and out of hospital (%DAOH)—a composite metric integrating recurrent hospitalisations and survival—after elective cardiac surgery in patients with very mild to moderate frailty.¹⁰ We hypothesised that prehabilitation could improve long-term outcomes, given prior evidence of reduced disability at 90 days and the clinical plausibility of sustained benefits.

Methods

We conducted a secondary per-protocol analysis of the PREQUEL trial participants who underwent elective cardiac surgery at the university teaching hospital, Prince of Wales Hospital, Hong Kong, between July 2018 and March 2023, with follow-up to 31 December 2024. Ethics approval was granted by the Joint Chinese University of Hong Kong–New Territories East Cluster Clinical Research Ethics Committee (CREC 2024.618). Written informed consent was waived, as consent had been obtained during the original trial (CREC 2017.696-T; ChiCTR1800016098), and no direct participant contact was required. Reporting adheres to STROBE guidelines.¹¹

Participants

The PREQUEL trial enrolled 164 participants with very mild to moderate frailty (Clinical Frailty Scale [CFS] scores 4–6)^{12,13} undergoing CABG, aortic valve repair or replacement, mitral valve repair or replacement, or combined CABG with valve procedures, randomised (stratified by type of surgery) to receive either physical prehabilitation or usual care (control).⁵ Participants were excluded if they had unstable or recently unstable cardiac syndrome (New York Heart Association Class IV, critical left main coronary disease, hospitalisation for arrhythmias, congestive heart failure, or acute coronary syndrome before randomisation), severe left ventricular obstructive disease (severe aortic or mitral stenosis, dynamic left ventricular outflow obstruction), redo cardiac surgery, or any contraindications for prehabilitation (those with cognitive deficits unable to comply with study procedures, physical limitations precluding prehabilitation, and inability to regularly attend outpatient sessions).⁵

Exercise prehabilitation

The 5-week physical prehabilitation consisted of twice-weekly, outpatient, physiotherapist-supervised exercise training of participants undergoing 20–60 min of aerobic exercises with sufficient training intensity to achieve 40–80% of estimated oxygen uptake reserve (VO₂R), and resistance training of major muscle groups of upper and lower limbs.⁵ The exercise prescription for each participant was individualised and symptom-limited based on the American College of Sports Medicine guidelines.¹⁴ Additional details regarding home exercise and patient education for participants were previously reported.⁵

Participants in the control arm received usual care without the structured exercise program or exercise-specific health promotion advice.⁵ All participants received standardised surgical processes and perioperative care under existing protocols.⁵

Outcomes and variable definitions

The primary patient-centred outcome was %DAOH,¹⁰ a composite measure of survival and recurrent hospitalisations:

$$\begin{aligned} \%DAOH = 100 \times [& \text{Total potential follow} \\ & - \text{up days} - (\text{days in hospital} \\ & + \text{days dead}) / \text{Total potential follow} - \text{up days} \quad (1) \end{aligned}$$

Owing to variable lengths of follow-up duration, we opted for %DAOH instead of DAOH because it is generally easier for patients to interpret the proportion of time spent at home.¹⁰ Potential follow-up time was defined from discharge after index surgery to 31 December 2024. The duration of each readmission was summed to calculate the total days in hospital.¹⁰ For patients who died, the period from the date of death to the end of follow-up was defined as ‘days dead’. Secondary outcomes included reasons for early (<30 days) and late (≥30 days) readmissions and discharge destinations (home, rehabilitation hospital, nursing home).

Baseline demographic and perioperative characteristics were collected prospectively during the original trial.⁵ Frailty was assessed using three validated tools: CFS,^{12,13} 5 m gait speed test (GST),¹⁵ and Essential Frailty Toolset (EFT),¹⁶ as no universally accepted definition of frailty currently exists. However, we selected the EFT score (range: 0 = robust to 5 = frail) to adjust for confounders in the multivariable models, as this measure provides long-term prognostic value in older cardiac surgical patients.¹⁷ Readmissions involving hospital stays of <24 h after the index discharge were excluded. After obtaining approval from the local clinical research ethics committee, five authors (VNML, FFN, VWSL, KKH, and CHLW) independently and retrospectively collected data on early (<30 days post-discharge from the index admission) and late (≥30 days post-discharge) recurrent hospitalisations, discharge destinations, and mortality by reviewing electronic patient records.

Reasons for early and late readmissions were broadly classified into four categories, with specific indications listed in [Supplementary methods 1](#): (1) cardiac-related causes; (2) noncardiac comorbidities or frailty-related causes; (3) wound-related complications or cancer-related; and (4) other reasons.

The five assessors completed standardised data collection training before the study and were blinded to treatment allocation (prehabilitation vs usual care). Discrepancies in data collection between two assessors were reconciled by a senior anaesthesiologist (VNML). Inter-rater reliability assessment was described in the [Supplementary methods 2](#).^{18–20}

Sample size calculation

No new power calculation was performed; this analysis used data powered for QoR-15 scores on postoperative day 3. Secondary outcomes were not the basis for sample size, but observed event rates and CIs suggest the analyses were informative and hypothesis-generating.

Statistical analysis

We performed a complete case analysis because missing data were minimal (<1%). Continuous variables are presented as mean (SD) or median (inter-quartile range [IQR]), as

appropriate. Frequencies (%) of early and late all-cause and cardiac-related recurrent hospitalisations are reported. Group comparisons used Student's *t*-test or Mann–Whitney *U*-test for continuous variables, and χ^2 or Fisher's exact test for categorical variables. One-inflated beta regression (univariate and multivariable) with robust standard error was applied to model the effect of prehabilitation on %DAOH, using the Stata macro *zoib*.¹⁰ Subgroup analyses by sex and type of cardiac surgery assessed heterogeneity of treatment effect on %DAOH by interaction modelling.

Quantile regression compared DAOH distributions. Modified Poisson regression with robust variance estimated the risk ratios (RRs, 95% CI) of readmissions. Negative binomial

Table 1 Baseline and intraoperative characteristics of patients by treatment groups. Data are presented as *n* (%), mean (SD), or median (IQR). *Missing data for one patient. 6MWT, 6-min walk test; APACHE, Acute Physiology and Chronic Health Evaluation; CABG, coronary artery bypass grafting; CPB, cardiopulmonary bypass; DAH₃₀, days alive and at home after surgery within 30 days; EuroSCORE, European System for Cardiac Operative Risk Evaluation.

Characteristics	No prehabilitation (N=78)	Prehabilitation (N=58)
Baseline		
Age (yr)	64 (58–69)	65 (60–69)
Male sex, <i>n</i> (%)	51 (65.4)	43 (74.1)
BMI (kg m ⁻²)	25.2 (23.0–28.5)	24.6 (22.5–27.8)
Occupation, <i>n</i> (%)		
Working	24 (30.8)	20 (34.5)
Housewife	22 (28.2)	16 (27.6)
Unemployed	8 (10.2)	3 (5.2)
Retired	24 (30.8)	19 (32.8)
Education, <i>n</i> (%)		
Primary or below	27 (34.6)	25 (43.1)
Secondary	46 (59.0)	32 (55.2)
University or above	5 (6.4)	1 (1.7)
Lives alone, <i>n</i> (%)	4 (5.1)	6 (10.3)
Cardiovascular disease risk factors, <i>n</i> (%)	61 (78.2)	44 (75.9)
Hypertension	46 (59.0)	37 (63.8)
Obesity	4 (5.1)	3 (5.2)
Dyslipidaemia	29 (37.2)	30 (51.7)
Diabetes	33 (42.3)	24 (41.4)
Cerebrovascular disease, <i>n</i> (%)	11 (14.1)	12 (20.7)
Pulmonary, <i>n</i> (%)	5 (6.4)	5 (8.6)
Anaemia, <i>n</i> (%)	21 (26.9)	17 (29.3)
Cancer, <i>n</i> (%)	6 (7.7)	3 (5.2)
Musculoskeletal disorders, <i>n</i> (%)	60 (76.9)	46 (79.3)
Ejection fraction (%)	58 (50–60)	60 (51–63)*
Clinical Frailty Scale	4 (4–4)	4 (4–4)
Essential Frailty Toolset score	1 (0–2)	1 (0–1)
5-m gait speed test (s)	5.6 (4.5–6.5)	5.4 (4.3–6.2)
Available time for training (weeks)	5.6 (3.7–8.9)*	6.6 (4.7–10.1)
Training time (weeks)	—	4.6 (2.8–6.5)
Baseline 6MWT distance (m), mean (SD)	340 (93)*	366 (90)*
Admission 6MWT distance (m), mean (SD)	328 (98)*	380 (94)*
Intraoperative		
ASA physical status ≥ 3 , <i>n</i> (%)	74 (96.1)*	51 (87.9)
Type of cardiac surgery, <i>n</i> (%)		
CABG with or without valve/other surgery	43 (55.1)	31 (53.4)
Valve with or without other surgery	35 (44.9)	27 (46.6)
Logistic EuroSCORE (%)	3.1 (1.5–6.8)	2.8 (1.8–4.8)
Duration of surgery (min)	255 (225–295)	246 (218–301)
Duration of anaesthesia (min)	303 (269–328)	291 (255–339)
Duration of CPB time (min)	114 (96–144)	114 (96–135)
APACHE III score	51 (41–60)*	49 (40–59)
Duration of mechanical ventilation (min)	528 (343–819)	447 (320–703)
Duration of ICU stay (h)	22.5 (19.6–24.0)	21.7 (19.8–23.5)
ICU readmission, <i>n</i> (%)	3 (3.8)	1 (1.7)
Duration of hospital stay (days)	10.0 (9.0–12.8)	11.0 (9.0–12.0)
DAH ₃₀	22.0 (14.3–23.0)	21.0 (17.8–22.0)

regression compared total readmissions and cumulative hospital bed days, expressed as incidence rate ratios (IRRs, 95% CI). All multivariable models adjusted for logistic EuroSCORE and EFT scores. Survival differences were assessed using the Kaplan–Meier and restricted mean survival time (RMST) analysis at 1, 2, 3, and 4 yr.²¹ RMST was chosen over Cox regression for its robustness and interpretability when event rates are low and proportional hazards assumptions may not hold. Analyses were conducted using StataNow 19.5 (StataCorp, College Station, TX, USA). Statistical significance was set at two-sided $P < 0.05$.

Results

As previously reported,⁵ 620 patients were screened for the PREQUEL trial, of whom 456 were excluded (183 CFS not 4–6, 90 unavailable for prehabilitation, 70 severe left ventricular obstructive disease, 54 unstable cardiac syndrome, 19 declined participation, 10 surgery scheduled too soon, 10 other cardiac procedures, seven repeat surgeries, and 13 other reasons). Of the 164 randomised participants,⁵ 28 were further excluded (two had interrupted prehabilitation during COVID-19, 16 declined surgery, eight had surgery cancelled, and two died before surgery), leaving 136 participants for analysis (78 usual care, 58 prehabilitation) (Supplementary Fig. 1). Most patients were male ($n=94$, 69.1%) with a median age of 34 to 78 years (IQR 59–69) yr. Baseline and perioperative characteristics were similar between groups (Table 1), except prehabilitation participants walked farther on the 6-min walk test (6MWT) before surgery (mean difference [MD]: 39 m, 95% CI: 7–71; $P=0.019$). Median follow-up was 3.9 yr (IQR 3.1–4.8), with a maximum of 6.5 yr.

Time at home (percent days alive and out of hospital)

Overall, the median %DAOH was 99.6% (IQR: 97.4–100%), with a median time at home of 1303 days (IQR: 1043–1627). In univariable analysis, higher baseline frailty (–4.4%, 95% CI: –7.7% to –1.0%; $P=0.011$) and logistic EuroSCORE (–1.0%, 95% CI: –1.6% to –0.05%; $P < 0.001$) were associated with lower %DAOH. Participants with poor recovery (QoR-15 score < 90)²² and those with good recovery (QoR-15 score ≥ 90) had similar %DAOH (82.4% vs 86.3%; $P=0.289$). Prehabilitation was linked to higher %DOAH in unadjusted analysis (87.7% vs 81.5%; MD 6.2%, 95% CI: 0.5–11.9%; $P=0.032$). However, after adjusting for logistic EuroSCORE and baseline frailty levels, group differences were not significant for %DAOH (87.3% vs 83.6%; MD 3.7%, 95% CI: –1.1% to 8.5%; $P=0.131$; Fig. 1) or median DAOH (1410 vs 1271 days; MD 139 days, 95% CI: –70 to 348; $P=0.189$). No subgroup differences were observed by sex or type of surgery (Supplementary Table 1).

Recurrent hospitalisation

Number of patients and episodes of readmissions

Thirty (22.1%) participants had one readmission, and 57 (41.9%) had two or more readmissions during the follow-up period. Of the 58 participants in the prehabilitation group, 35 (60.3%) participants required 119 recurrent hospitalisation episodes. Fifty-two (66.7%) participants in the usual care group required 165 recurrent hospitalisation episodes. There was no difference between groups for the median (IQR) time to first readmission (prehabilitation: 63 [11–528] days vs usual care: 96 [11–495] days; $P=0.876$).

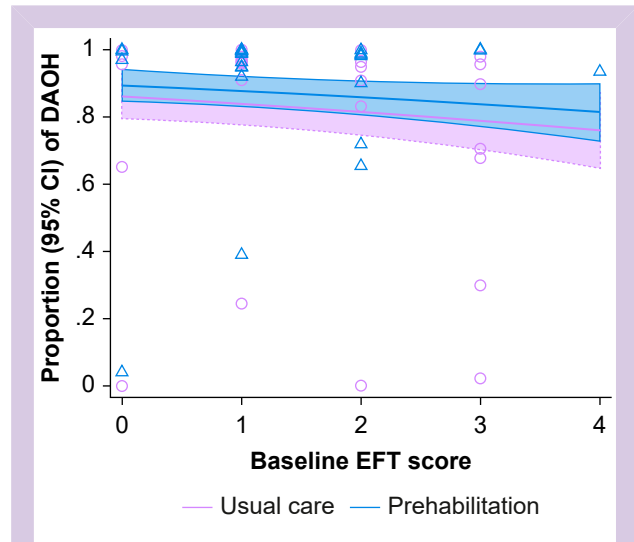


Fig 1. Estimated mean proportion (95% confidence interval [CI]) of days alive and out of hospital (DAOH) by treatment groups, adjusted for baseline Essential Frailty Toolset (EFT) scores and logistic EuroSCOREs. Purple hollow circle represents usual care data. Blue hollow triangles represent prehabilitation data.

We found no difference in readmissions risk between groups (risk difference –6.4%, 95% CI: –22.4% to 9.7%; Table 2). After adjustment for logistic EuroSCOREs and baseline EFT scores, prehabilitation was not significantly associated with reductions in readmission rates (IRR 0.87, 95% CI: 0.69–1.11) or cumulative hospital bed days (IRR 0.95, 95% CI: 0.59–1.55) (Table 2).

Reasons for readmissions

There were 34 (25.0%) participants with 40 (14.1%) early readmissions and 81 (59.6%) participants with 244 (85.9%) late readmissions. No overall group differences in the type of early and late readmissions (cardiac-related, noncardiac-related, wound-related/cancer-related, and other causes; early $P=0.786$ and late $P=0.569$) were found in Figure 2. Indications for early and late readmissions are shown in Figure 3a and b, respectively. The most common indications for early readmissions were atrial fibrillation/flutter or other arrhythmia (14.7%) and pleural effusions (17.6%). For late readmissions, the most common indications were non-respiratory and non-wound-related infections and frailty-related causes (both 17.3%). Of the 31 medication adjustment episodes, the majority (83.9%) were related to managing appropriate warfarin dosing.

Discharge destinations

In the 58 (23 no readmission, 35 readmissions) prehabilitation participants, there were 138 (97.2%) hospital discharges to home, three (2.1%) died in hospital, and one (0.7%) was transferred to a rehabilitation hospital. In contrast, in the 78 (26 no readmissions, 52 readmissions) usual care participants, there were 167 (87.4%) hospital discharges to home, 16 (8.4%) to a rehabilitation hospital, seven (3.7%) died in hospital, and one (0.5%) transferred to an aged care home. After adjusting for logistic EuroSCOREs, baseline frailty scores, and any

Table 2 All-cause recurrent hospitalisations between groups. *Comparison of proportions to estimate relative risk. †Modified Poisson regression with robust standard error variance model to estimate risk ratio (RR) after adjusting for logistic EuroSCORE and Essential Frailty Toolset (EFT) score. ‡Negative binomial regression model for readmission count to estimate incidence rate ratio (IRR). §Negative binomial regression model to estimate readmission count IRR after adjusting for logistic EuroSCORE and EFT score. ¶Negative binomial regression model to estimate the average bed day ratio. ‖Negative binomial regression model to estimate the average bed day ratio after adjusting for logistic EuroSCORE and EFT score. #Modified Poisson regression with robust standard error variance model to estimate RR after adjusting for logistic EuroSCORE, EFT score, and any readmissions. CI, confidence interval; EuroSCORE, European System for Cardiac Operative Risk Evaluation.

	Prehabilitation	Usual care	Unadjusted estimate (95% CI)	P-value	Adjusted estimate (95% CI)	P-value
Patients readmitted, n (%)	35 (60.3)	52 (66.7)	0.91 (0.70–1.18)*	0.448	0.91 (0.72–1.16)†	0.443
Total number of readmissions	119	165	0.86 (0.55–1.36)‡	0.516	0.91 (0.58–1.42)¶	0.677
Hospital bed days, mean (SD)	27.3 (40.2)	40.7 (84.0)	0.66 (0.40–1.10)§	0.112	0.95 (0.59–1.55)‖	0.852
Patients discharged to home, n (%)	115 (96.7)	145 (87.9)	1.10 (1.03–1.17)*	0.009	1.07 (0.99–1.15)#	0.090

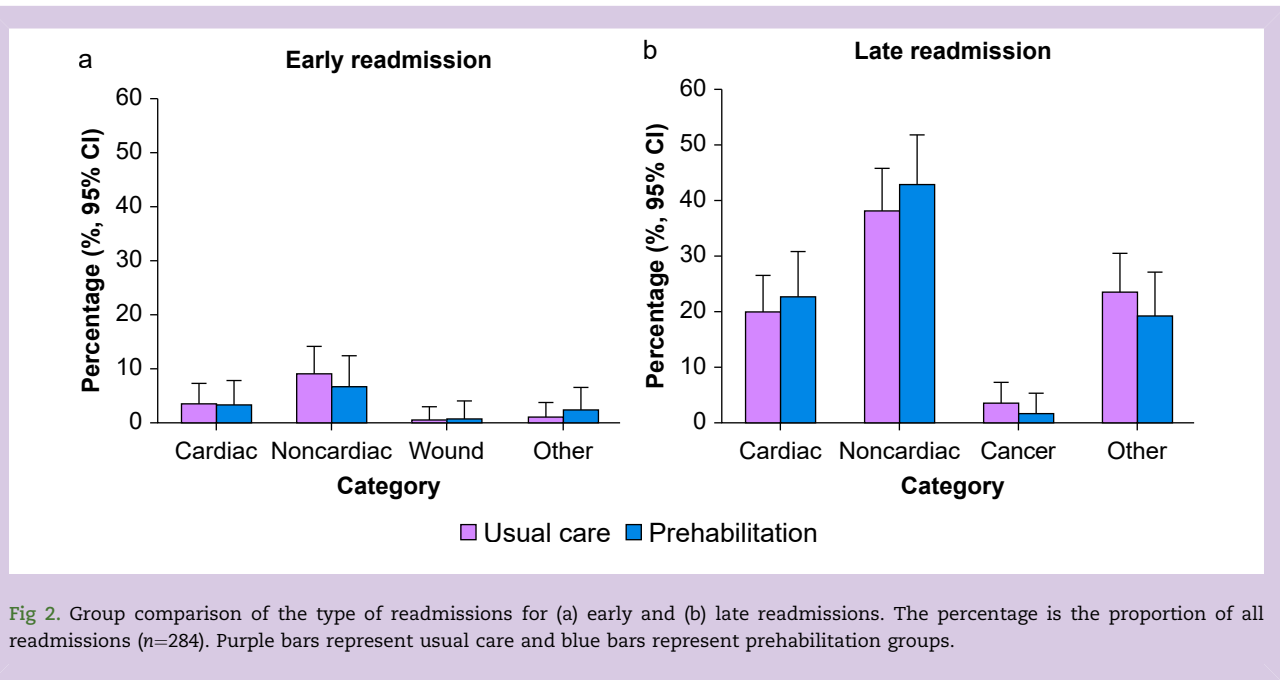


Fig 2. Group comparison of the type of readmissions for (a) early and (b) late readmissions. The percentage is the proportion of all readmissions (n=284). Purple bars represent usual care and blue bars represent prehabilitation groups.

readmissions, the treatment effect was significant (RR 1.09, 95% CI: 1.02–1.16; risk difference 7.8%, 95% CI: 1.8–13.8%). However, in a sensitivity analysis restricted to participants who had been readmitted, there was no difference between groups in the likelihood of being discharged home in the adjusted analysis (Table 2).

Long-term survival

There were four (6.9%) deaths in the prehabilitation group and 10 (12.8%) deaths in the usual care group at the end of 520 patient-years follow-up. We found no difference ($P=0.218$) in the mortality rate per 1000 person-years between prehabilitation (16.9, 95% CI: 6.4–45.1) and usual care groups (35.3, 95% CI: 19.0–65.5). The Kaplan–Meier curve (Fig. 4) illustrates the survival rates of the groups throughout the entire follow-up period. RMSTs were higher for prehabilitation participants (RMST difference at 1 yr: 0.03 yr, 95% CI: 0.00–0.06 yr,

$P=0.051$; RMST difference at 2 yr: 0.10 yr, 95% CI: 0.01–0.18 yr, $P=0.029$; RMST difference at 3 yr: 0.16 yr, 95% CI: 0.01–0.30 yr, $P=0.032$; RMST difference at 4 yr: 0.22 yr, 95% CI: 0.01–0.44 yr, $P=0.044$) compared with usual care participants.

Discussion

This exploratory analysis of the PREQUEL trial is among the first to evaluate long-term outcomes of prehabilitation in cardiac surgery. Prehabilitation had minimal impact on time spent at home, suggesting that baseline frailty and surgical risk (logistic EuroSCORE) are stronger determinants. The treatment effect on %DAOH was consistent across sex and type of surgery. Although two-thirds of participants were readmitted, often within 3 months for noncardiac reasons, prehabilitation was associated with a modest survival advantage of ~11 weeks over 4 yr.

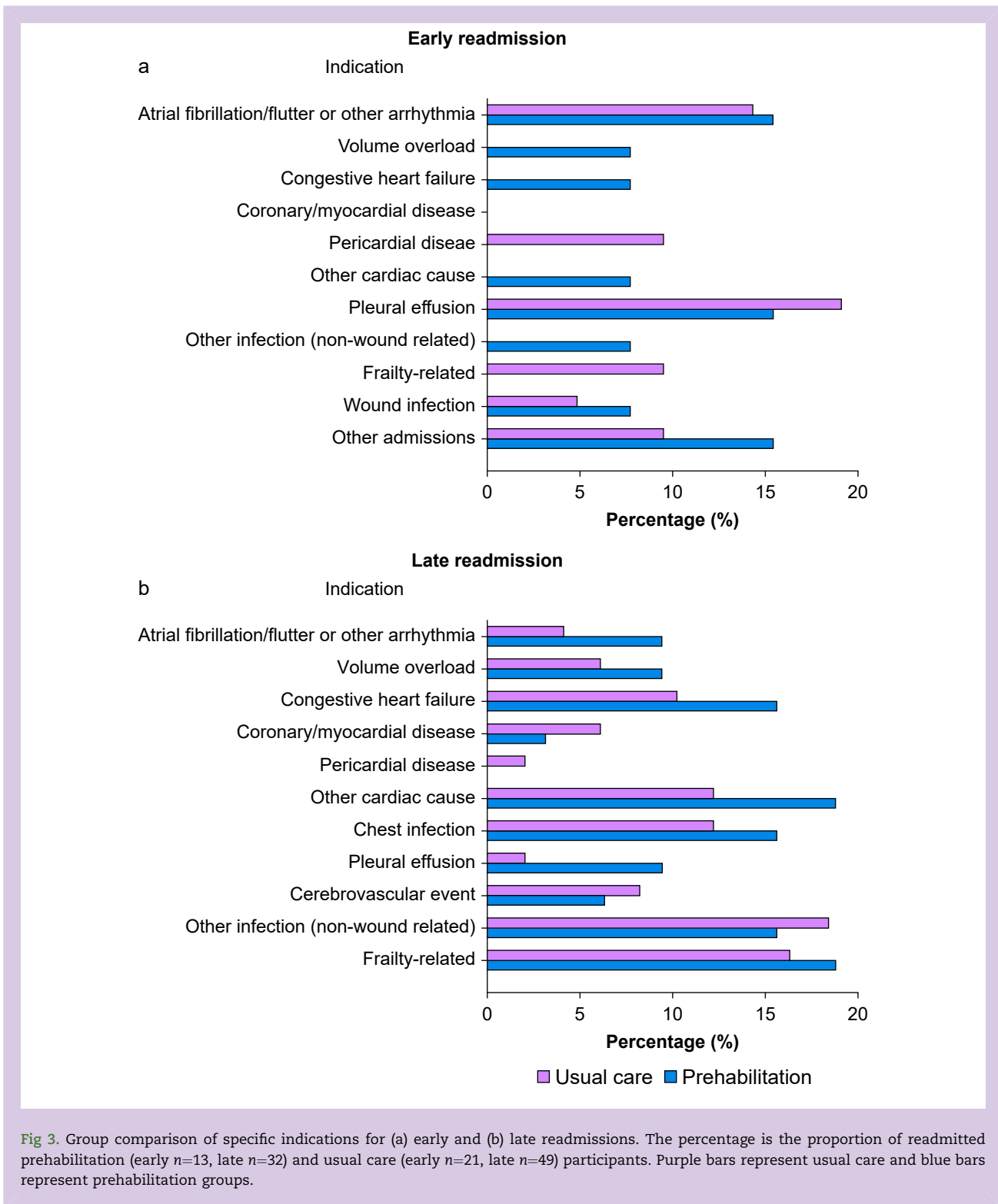


Fig 3. Group comparison of specific indications for (a) early and (b) late readmissions. The percentage is the proportion of readmitted prehabilitation (early $n=13$, late $n=32$) and usual care (early $n=21$, late $n=49$) participants. Purple bars represent usual care and blue bars represent prehabilitation groups.

%DAOH integrates survival and healthcare utilisation, offering a patient-centred measure of recovery. Low %DAOH may reflect early mortality or multiple prolonged readmissions. Although readmission after surgery is a key quality indicator of patient morbidity, hospital care, and transitional

arrangements from hospital to community,^{23 24} it is rarely reported in prehabilitation studies. Notably, a recent cardiac multimodal tele-prehabilitation trial demonstrated a lower risk of cardiac-related readmissions in the first year (RR 0.35, 95% CI: 0.14–0.85) compared with usual care.⁷

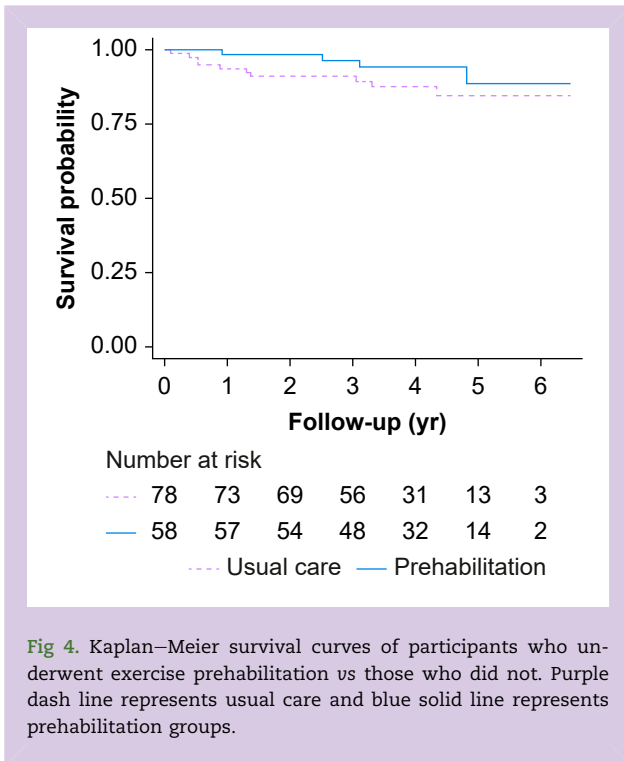


Fig 4. Kaplan–Meier survival curves of participants who underwent exercise prehabilitation vs those who did not. Purple dash line represents usual care and blue solid line represents prehabilitation groups.

Our readmission rate (66%) exceeded that of the CORONARY trial (30% over 5 yr), likely reflecting differences in case mix, frailty, and healthcare systems.²⁵ In contrast, our early readmission rate (14.1%) was comparable with recent UK (12.9%) and Australasian (15.1%) studies.^{23,24} The most frequent early causes—arrhythmia and pleural effusion—were consistent with prior reports.^{24,26,27} One in six late readmissions was frailty-related, similar in frequency to non-respiratory and non-wound infections, a leading cause of late readmission.^{26,27} These findings highlight patient vulnerability and ongoing deconditioning that prehabilitation alone cannot fully address. Late readmissions, typically considered adverse events, may also signal unmet rehabilitation needs for new or existing disabilities in activities of daily living (ADL) after the index hospitalisation. Unmet ADLs (HR 1.37, 95% CI: 1.03–1.82) and three to five ADL disabilities (HR 1.41, 1.05–1.89) were associated with readmissions.²⁸ Multidisciplinary transitional care may help reduce this burden.^{29–31}

Cardiac surgical patients face a long-term mortality risk three times higher than the general population in Hong Kong.³² Prehabilitation yielded a statistically significant but clinically modest survival benefit. The mechanisms remain unclear, and we hypothesise that multimodal interventions combining prehabilitation with rehabilitation may provide more durable benefits—a question future trials should address.^{33,34}

This study has several limitations. Firstly, we did not measure uptake of cardiac rehabilitation services, which are not part of the routine perioperative pathway. The absence of continuity between prehabilitation and postoperative rehabilitation reflects a structural gap that may explain the observed disconnect—where gains in functional capacity and physiological reserve during prehabilitation did not necessarily translate into long-term reductions in healthcare

utilisation. Although perioperative team composition and clinical protocols remained consistent over the 5-yr study period, subtle, undocumented variations in practice might have introduced treatment heterogeneity. Secondly, our findings may not be generalisable to settings with different patient characteristics, lifestyle risk factors, frailty profiles, case mix, and healthcare systems.³⁵ Selection bias might also have occurred in a small subgroup (<10%) whose surgeries were scheduled earlier than planned, limiting their opportunity for full prehabilitation. Thirdly, residual confounding from unmeasured factors may persist despite adjustment for logistic EuroSCORE and baseline frailty. Fourthly, the study might have been underpowered to detect differences in %DAOH and related outcomes, as the sample size was based on the original PREQUEL trial.⁵ We found no significant heterogeneity of treatment effects on %DAOH, likely reflecting limited statistical power, though high inter-rater reliability suggests minimal measurement bias. Finally, we did not adjust for multiple comparisons in subgroup and RMST analyses, raising the possibility of Type I errors. These findings should therefore be regarded as exploratory and hypothesis-generating rather than confirmatory.

The modest survival signal in the absence of reduced healthcare utilisation highlights a dissociation well recognised in rehabilitation populations, where physiological gains may extend survival without reducing subsequent encounters. This warrants further investigation in adequately powered trials. Future research should evaluate perioperative changes in cardiovascular risk profiles and incorporate long-term %DAOH and survival into integrated prehabilitation and rehabilitation programmes. Such interventions must ensure adequate frequency, intensity, and duration ('dose') and be tested in well-designed, adequately powered trials. Whether modest reductions in frailty and clinically meaningful improvements in preoperative functional capacity (e.g. 6MWT 'responders') translate into fewer readmissions, improved survival, and higher %DAOH remains uncertain.^{35–37} Frailty was treated as a confounder in this analysis, but its role of frailty as an effect modifier, mediator, or mediated moderator warrants further study.

In conclusion, a 5-week supervised exercise programme before cardiac surgery had little or no effect on long-term time spent at home. Frailty and surgical risk appeared to outweigh the influence of prehabilitation on %DAOH. These results highlight the importance of developing integrated, multimodal strategies that extend beyond prehabilitation, and point towards future research to establish durable benefits in recovery trajectories.

Authors' contributions

Study design: VNML, FFN, PYH, KMH, AL

Data collection: VNML, DKWY, FFN, VWWSL, KKHWH, CHLW

Data analysis: VNML, DKWY, KMH, AL

Data interpretation: VNML, DKWY, KMH, AL

Writing the first draft of the paper: AL

Review of the manuscript for important intellectual content and final approval of the version to be published: all authors
Agreed to be accountable for all aspects of the work, thereby ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved: all authors

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Patient and public involvement

Patients and the public were not involved in the development of the research question, design of the study, or dissemination plans of this research.

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Declaration of interests

The authors declare no competing interests.

Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.bjao.2026.100540>.

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