Author manuscript. This version may differ from the published article: *Journal of Cardiopulmonary Rehabilitation and Prevention*, 2026, https://doi.org/10.1097/HCR.0000000000001074

Original Investigation

Title: Physiologic Stress During Walking and Cycling Early After Cardiac Surgery

Short Title: Physiologic Stress After Cardiac Surgery

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Data Availability Statement: The data used in this manuscript are publicly available.

Funding Statement: DJD is supported by funding from the American Heart Association. DJL is supported by funding from NHLBI 1K23HL171867-01.

Conflict of Interest Disclosure: DJD receives compensation from Philips Healthcare.

Author Confirmation: All authors have read and approved the manuscript.

Clinical Trial Registration: Not Applicable.

Key Words: Cardiac Rehabilitation, Exercise Tolerance, Heart Rate, Electrocardiography, Postoperative Care

Structured Abstract

Purpose: To characterize cardiac effort and heart rate (HR) responses during the 6-minute walk test (6MWT) early after cardiac surgery, compare HR patterns between walking and cycle ergometry, and evaluate differences by sex, frailty, and atrial fibrillation (A-fib) status.

Methods: We analyzed a publicly available PhysioNet dataset of adults ≥65 years with pre-frailty/frailty undergoing cardiac surgery who completed a 6MWT and symptom-limited cycle ergometry with continuous single-lead electrocardiogram (ECG) monitoring (Polar H10). Cardiac effort was defined as total 6MWT heartbeats divided by distance walked (beats/m). Associations with cycle-ergometry performance were assessed using Spearman correlations with bootstrap confidence intervals; paired t-tests compared HR responses between modalities; subgroup differences were evaluated using Welch t-tests and multivariable linear regression.

Results: Of 80 enrolled participants, 66 (83%) had analyzable 6MWT ECG recordings (mean age 73 ± 5 years; 67% male; 18 ± 8 days post-surgery). Mean 6-minute walking distance (6MWD) was 300 ± 79 m, and mean cardiac effort was 1.62 ± 0.52 beats/m. In 38 participants with paired cycle-ergometry data, HR responses were similar between walking and cycling. Greater 6MWD was associated with better cycle-ergometry performance, while higher cardiac effort was associated with lower cycle-ergometry performance. In multivariable analysis, female sex was independently associated with higher cardiac effort ($\beta = 0.34$ beats/m; $P = .042$), A-fib with lower average and end-of-test HR ($P \leq .035$), and greater frailty with shorter 6MWD ($P = .036$).

Conclusions: Cardiac effort is a feasible ECG-derived metric that complements 6MWD by integrating heart-rate response with functional performance early after cardiac surgery. In this frail, predominantly beta-blocked cohort, HR responses during walking closely mirrored cycle ergometry.

Condensed Abstract

In 66 older prefrail/frail cardiac surgery patients, mean 6-minute walking distance (6MWD) was 300 ± 79 m, and mean cardiac effort was 1.62 ± 0.52 beats/m. In 38 paired tests, walking and cycling heart rate responses were similar. Higher cardiac effort was associated with lower exercise capacity. These findings support cardiac effort as a complementary physiologic metric to 6MWD.

Key Perspective

What is novel?

- This study introduces cardiac effort (heartbeats/meter) as a simple, electrocardiogram (ECG)-derived metric that augments the 6-minute walk test (6MWT) by integrating physiologic demand with functional performance early after cardiac surgery.
- Continuous ECG monitoring demonstrates that heart rate responses during the 6MWT closely mirror those observed during cycle ergometry, despite differences in exercise modality, in a frail, predominantly beta-blocked population.
- Cardiac effort captures physiologic differences not reflected by 6-minute walking distance (6MWD) alone, including blunted chronotropic responses, and is independently higher in women, while greater frailty is associated with shorter walk distance but not cardiac effort.
- Atrial fibrillation is associated with lower sustained walking heart rates but does not significantly alter cardiac effort, suggesting preserved physiologic efficiency for a given distance.

What are the clinical and/or research implications?

- Incorporating cardiac effort into routine 6MWT interpretation may provide a more nuanced physiologic assessment of early postoperative recovery, particularly in identifying chronotropic limitation or inefficient cardiovascular response.
- Cardiac effort and 6MWD appear to capture complementary dimensions of recovery, supporting their combined use in clinical and research settings.
- Future studies should evaluate whether cardiac effort predicts recovery trajectories, guides beta-blocker titration, and informs personalized cardiac rehabilitation programming.

Early mobility is safe and strongly associated with reductions in postoperative complications during recovery after cardiac surgery.[1,2] Functional capacity is typically assessed at the initiation of cardiac rehabilitation using the 6-minute walk test (6MWT), a simple submaximal assessment that closely reflects real-world activity.[3,4] Contemporary cardiac rehabilitation guidance emphasizes baseline functional assessment to individualize exercise prescription and monitor recovery trajectories.[5] Six-minute walking distance (6MWD) has been linked to important postoperative outcomes, including rehospitalization, morbidity, and long-term recovery.[6,7] However, 6MWD alone provides limited insight into the physiologic effort required to achieve a given distance and cannot distinguish whether reduced performance is due to chronotropic limitation,[8] impaired cardiac output,[9] respiratory inefficiency,[10] frailty,[11] or submaximal effort.

Wearable devices capable of continuous heart rate (HR) monitoring now allow dynamic HR responses to be incorporated into the interpretation of the 6MWT. Heart rate based approaches to exercise assessment have also been proposed as pragmatic tools for

estimating cardiorespiratory fitness when formal metabolic testing is not feasible.[12] **Cardiac effort, the number of heartbeats expended during the 6MWT divided by the distance walked (beats/m), integrates HR dynamics with ambulatory performance and has shown utility in pulmonary arterial hypertension and pulmonary embolism recovery.**[13-20] In prior studies, it has been associated with clinically relevant functional and disease-severity measures.[13-21] In the present context, it should be interpreted as a pragmatic HR-derived functional metric rather than a direct hemodynamic measure.

In this study, we evaluated cardiac effort and dynamic HR responses during the 6MWT early after cardiac surgery, compared HR patterns between the 6MWT and cycle ergometry, and assessed differences in cardiac effort by sex, atrial fibrillation (A-fib) status, and frailty with cardiac effort, 6MWD, and dynamic HR responses. We hypothesized that cardiac effort would complement 6MWD by providing additional physiologic context for walking performance during early postoperative recovery.

METHODS

This study utilized a de-identified, publicly available *Wearable Cardiac Rehabilitation and Frailty Dataset* from PhysioNet. The data can be downloaded at https://physionet.org/content/wearable-exercise-frailty/1.0.0/.[21,22] The methods have been previously described.[21] The study recruited patients from November 19, 2020, to January 2, 2022.[21] All patients provided informed consent for data sharing, and the current analysis was exempt from institutional review board approval because it used public, de-identified data. The inclusion criteria for this study were adult cardiac surgery patients (age ≥ 65 years) with pre-frailty or frailty (Edmonton Frail Scale [EFS] score ≥4.0) who agreed to participate.[21] Additionally, to ensure the 6MWT was adequately captured, participants had to have walked at least 150 meters to be included.[21] The study initially evaluated 337 patients for eligibility, but only 99 satisfied the inclusion criteria.[21] Nineteen patients were removed because electrocardiogram (ECG) or accelerometry signals were lost or incomplete.[21] The final dataset included 80 elderly patients with frailty who had undergone open-heart surgery (coronary artery bypass grafting or valve surgery).[21]

Each patient enrolled in the study underwent multiple exercise assessments at baseline as part of post-surgical rehabilitation, including a supervised symptom-limited cycle ergometry stress test and a standard 6MWT. The cycle ergometry utilized an Ergoline Viasprint 150P stationary bicycle, starting at a low workload (25 Watts). The resistance was increased by 12.5 W each minute until the patient reached exhaustion or met standard termination criteria (e.g., significant dyspnea, chest pain, fatigue, excessive blood pressure). Key outcomes recorded included total exercise duration and peak workload (in Watts). During the 6MWT, patients are instructed to walk as far as possible on a flat, straight course for 6 minutes. Total distance walked was measured in meters. Participants were permitted to slow down or rest if needed but were encouraged to resume walking as soon as they felt able. Continuous HR monitoring was performed with a Polar H10 chest sensor (Polar Electro). The sensor provided a single-lead ECG (sampling rate 130 Hz) and triaxial accelerometer (sampling rate 200 Hz). Participants wore the sensor during both the 6MWT and cycle ergometry. The device was positioned on the anterior chest using an elastic strap at the level of the lower sternum, consistent with manufacturer recommendations and prior validation studies. In addition, the dataset contained

patient demographics, clinical characteristics, including EFS scores, and the timing of each exercise test relative to the date of surgery.

Using the ECG data, we calculated cardiac effort for each 6MWT. Heartbeats (QRS complexes) were detected from the single lead ECG using the Pan–Tompkins algorithm, a well-validated real-time QRS detection method,[23] and RR intervals were used to derive instantaneous HR as 60/RR (in sec) after artifact handling; to reduce noise, HR was smoothed using a centered 4-second moving average. From this smoothed series, we calculated peak HR, HR at the end of the test, and average HR during the 6MWT and cycle ergometry. Total heartbeats during the 6MWT were obtained by RR interval counting across the 6-minute test window. We then divided this count by the distance walked (in meters) to yield cardiac effort, expressed in beats/meter.[14,17,24] During cycle ergometry, HR was calculated using the same methods. To avoid imputing unobserved beats, total heartbeats were not back-calculated from the mean HR when RR counting was missing or inconsistent with a complete 6-minute recording; in these instances, cardiac effort was treated as missing for analyses involving cardiac effort. As an exploratory analysis, Peak/Output was calculated as peak cycle-ergometry HR divided by maximal workload (beats/min/Watt). Age-predicted maximum HR was estimated as 220 – age (years) for the primary descriptive analysis.[25] Percent age-predicted maximum HR during the 6MWT was calculated as 100 × (peak 6MWT HR) / (220 – age). As a sensitivity analysis, percent age-predicted maximal HR was recalculated using 208 – 0.7 × age. The ECG from both tests were manually reviewed to annotate any irregular rhythms. Rhythm interpretation focused on the identification of A-fib and atrial flutter using standard electrocardiographic criteria, including the absence of organized P waves, the presence of irregularly irregular RR intervals, and, for atrial flutter, the presence of regular atrial activity with characteristic flutter waves and variable atrioventricular conduction. The ECG review was performed across the full exercise recording to identify sustained or intermittent atrial arrhythmias. Rhythm classification was based on clinical pattern recognition commonly used in routine telemetry and exercise-testing environments.

STATISTICAL ANALYSES

Continuous variables are reported as mean ± SD, and categorical variables as counts and percentages. Associations between continuous variables, including cardiac effort, 6MWD, and cycle-ergometry performance measures (exercise duration, maximal workload, and peak HR normalized to workload), were evaluated using Spearman rank correlation coefficients, with bootstrap 95% confidence intervals. Paired t-tests were used to compare HR parameters measured during the 6MWT and cycle ergometry within the same participants. Independent-samples comparisons between subgroups (sex; A-fib status) were performed using Welch's 2-sample t-test. To account for potential confounding among sex, A-fib, and frailty, we fit separate multivariable linear regression models for cardiac effort, 6MWD, average 6MWT HR, peak 6MWT HR, end-of-test 6MWT HR, and percent age-predicted maximal HR. Each model included sex, A-fib status, and EFS score entered simultaneously as predictors. Because some outcomes showed non-normality, inference from the regression models was based on heteroskedasticity-consistent robust standard errors. Models were fit using complete-case analysis for each outcome. As a sensitivity analysis, the percent age-predicted maximal HR model was repeated using the alternate formula 208 – 0.7 × age in place of 220 – age. All analyses were

2-sided, and statistical significance was defined as $P < .05$. All analyses were performed using Python and R, including the following R packages: *readr*, *dplyr*, *tidyr*, *stringr*, *purrr*, *ggplot2*, *logistf*, *flextable*, and *officer*.

RESULTS

A total of 80 participants were included. The primary analytic cohort consisted of 66 participants (83%) with analyzable ECG recordings during the 6MWT; this cohort was used for overall 6MWT descriptive statistics and subgroup comparisons. Of these 66 participants, 38 also had analyzable ECG recordings during cycle ergometry and comprised the paired cohort used for within-participant comparisons between walking and cycling and correlation analyses; the reduced sample reflects incomplete or unavailable cycle-ergometry recordings in the publicly available dataset. In the 6MWT analytic cohort, the mean age was 73 ± 5 years, 44 (67%) were male, and all were prefrail/frail (mean EFS score 6.0 ± 1.6). Testing occurred 18 ± 8 days after surgery, and nearly all participants were receiving beta-blocker therapy at the time of assessment. Baseline characteristics for the 6MWT analytic cohort (n = 66) and the paired cohort (n = 38) are shown in Table 1.

In the 6MWT analytic cohort (n = 66), the average 6MWD was 300 ± 79 m, and the mean cardiac effort was 1.62 ± 0.52 beats/m. Dynamic HR responses during the 6MWT were blunted, with peak 6MWT HR averaging 88 ± 9 beats/min and representing 60% ± 6% of age-predicted maximum HR calculated using 220 − age (range, 45%–73%).

Among the 38 participants with paired cycle ergometry testing, 6MWD averaged 303 ± 74 m and cardiac effort averaged 1.62 ± 0.58 beats/m. During the 6MWT in this paired cohort, the average HR was 78 ± 10 beats/min, the peak HR was 89 ± 9 beats/min, and the end-of-test HR was 75 ± 13 beats/min. Cycle ergometry sessions lasted 157 ± 99 seconds on average, and the maximum workload reached was 50 ± 14 W. During cycle ergometry, average HR was 77 ± 11 beats/min, peak HR was 89 ± 11 beats/min, and end-of-test HR was 74 ± 11 beats/min. There were no significant differences in HR parameters between the 6MWT and cycle ergometry (Table 2).

Cardiac effort was numerically lower in males compared with females ($P = .05$, Table 3). Patients with A-fib demonstrated significantly lower average and end-of-test HR during the 6MWT than those without A-fib, whereas peak HR did not differ between groups (Table 4). Despite modestly shorter 6MWD in the group with A-fib, cardiac effort did not differ significantly between participants with and without A-fib ($P = .61$, Table 4), indicating comparable physiologic efficiency for a given walking distance (Table 4).

To account for potential overlap among sex, A-fib, and frailty, we performed multivariable analyses of 6MWT-derived outcomes (Table 5). Female sex was independently associated with higher cardiac effort (β = 0.34: 95% CI, 0.01 - 0.66 beats/m, $P = .042$), with a nonsignificant trend toward shorter 6MWD (β = -39.63: 95% CI, -82.26 to 3.00 m; $P = .068$). A diagnosis of A-fib was independently associated with lower average HR during the 6MWT (β = -8.17: 95% CI, -13.50 to -2.84 beats/min; $P = .003$) and lower end-of-test HR (β = -8.23: 95% CI, -15.88 to -0.58 beats/min; $P = .035$) but not with cardiac effort or 6MWD. Greater frailty was independently associated with shorter 6MWD (β = -10.55: 95% CI, -20.40 to -0.70 m per 1-point increase in EFS; $P = .036$) but not with cardiac effort, peak HR or percent age-predicted maximal HR. Sensitivity analysis using 208 − 0.7 × age to calculate age-predicted maximal HR yielded results that were materially similar.

In the paired cohort, Spearman rank correlations showed that longer 6MWD was associated with longer cycle-ergometry duration ($\varrho = 0.51$: 95% CI, 0.18 - 0.75; $P < .001$), higher maximal workload ($\varrho = 0.53$: 95% CI, 0.22 - 0.75; $P < .001$), and lower peak HR normalized to workload ($\varrho = –0.49$: 95% CI, –0.73 to –0.17; $P = .002$). Higher cardiac effort was associated with shorter cycle-ergometry duration ($\varrho = –0.47$: 95% CI, –0.68 to –0.17; $P = .003$), lower maximal workload ($\varrho = –0.48$: 95% CI, –0.70 to –0.20; $P = .003$), and higher peak HR normalized to workload ($\varrho = 0.50$: 95% CI, 0.20 - 0.71; $P = .002$) (Figure 1).

DISCUSSION

In this first evaluation of cardiac effort after cardiac surgery, we found that dynamic HR responses during the 6MWT closely mirrored those observed during cycle ergometry, despite the differing modalities. In this heavily beta-blocked cohort, peak 6MWT HR averaged only approximately 60% of the age-predicted maximum, consistent with blunted chronotropic responses during early recovery. In unadjusted analyses, cardiac effort was higher in women than in men, whereas cardiac effort did not differ by A-fib status (Tables 3 and 4). However, A-fib was associated with lower average and end-of-test walking HR, and in adjusted analyses, female sex remained associated with higher cardiac effort, A-fib with lower walking HR, and greater frailty with shorter 6MWD (Table 5). These findings suggest that 6MWD, cardiac effort, and dynamic HR responses capture overlapping but nonidentical aspects of early postoperative functional status. Given the feasibility of acquiring analyzable single-lead ECG data during routine testing, cardiac effort may serve as a practical adjunctive physiologic descriptor during early postoperative functional assessment.

Although both 6MWT and cycle ergometry are commonly used to evaluate postoperative functional capacity, performance metrics alone cannot differentiate why an individual underperforms. Reduced 6MWD after cardiac surgery is associated with increased mortality.[26] In this cohort, continuous HR monitoring during the 6MWT and cycle ergometry demonstrated a markedly blunted chronotropic response. It remains unclear whether this reflects postoperative chronotropic insufficiency after cardiac surgery, potentially exacerbated by beta-blocker therapy,[27] or whether non-cardiovascular factors such as limited effort, sternal discomfort, or frailty contributed to the reduced exercise performance. Notably, in a fitter inpatient cardiac rehabilitation population, chronotropic insufficiency did not meaningfully influence improvement in 6MWD, with both impaired and preserved chronotropic groups gaining approximately 140 meters following rehabilitation.[8]

Continuous ECG-based HR monitoring, including peak HR measurement and cardiac effort calculation, provides additional physiologic context by integrating HR dynamics with ambulatory performance. This approach provides a complementary physiologic context alongside distance alone. In our cohort, HR responses during ambulation closely mirrored those observed during cycle ergometry. Notably, cycle ergometry testing identified previously undocumented A-fib in 2 participants, illustrating that ECG monitoring during functional testing may uncover clinically relevant atrial arrhythmias that might otherwise go unrecognized. The true prevalence of transient or exertional atrial arrhythmias in postoperative patients remains uncertain, but the use of single-lead ECG devices during functional testing represents a simple and effective method to detect such abnormalities.

By quantifying the physiologic "toll" of walking, cardiac effort may provide a useful HR-based complement to traditional distance-based assessment during early postoperative recovery. Prior work in pulmonary arterial hypertension has used cardiac effort as a clinically informative metric, including proposed goal values in that disease context (in pulmonary arterial hypertension goal cardiac effort <1.4 beats/m[17,28]); however, those thresholds should not be extrapolated directly to postoperative cardiac surgery patients. In the present study, greater frailty was independently associated with shorter 6MWD, whereas female sex was independently associated with higher cardiac effort, supporting the view that distance and HR expenditure capture related but distinct aspects of recovery. Importantly, prior work in pulmonary arterial hypertension has shown that photoplethysmography-derived HR data can introduce measurement error during the 6MWT when compared with ECG-based monitoring,[14,28] underscoring the value of ECG-derived metrics in this context. In our dataset, 17% of 6MWT ECG recordings were lost or incomplete using the Polar H10, highlighting the importance of reviewing signal quality before testing begins.

This study has several limitations. This was a post hoc analysis from a single center, and the sample size with paired cycle ergometry testing was small. The cohort was uniformly frail or prefrail, which may limit generalizability to fitter postoperative patients. In addition, participants had substantial multimorbidity, including heart failure, chronic obstructive pulmonary disease, and oncologic disease, which may have influenced frailty, exercise performance, and HR responses and could not be fully disentangled in this secondary analysis. Nearly all participants were receiving beta-blocker therapy, which substantially affects chronotropic response and may have attenuated differences between subgroups. In addition, age-predicted maximal HR was estimated using the traditional 220 − age equation for the primary descriptive analysis; this formula has recognized limitations in older adults and beta-blocked patients with cardiovascular disease and may overestimate relative exercise intensity compared with alternative formulas, although sensitivity analysis using 208 − 0.7 × age yielded materially similar adjusted findings. Electrocardiogram recordings were unavailable for a small fraction of participants. Finally, because the study was cross-sectional within an early recovery window, we could not evaluate longitudinal changes in cardiac effort or their relationship with longer-term outcomes.

In summary, cardiac effort is a feasible ECG-derived adjunct to the 6MWT during early postoperative recovery after cardiac surgery. In this frail, predominantly beta-blocked cohort, women had higher cardiac effort, A-fib was associated with lower sustained walking HR, and greater frailty was associated with shorter 6MWD. These findings support cardiac effort as a complementary descriptive physiologic measure alongside 6MWD rather than a direct hemodynamic or prognostic tool. Larger longitudinal studies are needed to determine whether cardiac effort tracks recovery trajectories or predicts clinically meaningful outcomes.

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Table 1. Baseline Demographics of Patients Following Cardiac Surgery Undergoing a 6MWT, 2020 – 2022[a]

Demographics	6MWT/Cardiac Effort Cohort (N = 66)	6MWT/Cardiac Effort Cohort with Veloergometry (N = 38)
Age, yr	73 ± 5	72 ± 5
Male sex	44 (67%)	28 (74%)
Body mass index, kg/m^2	27 ± 4	27 ± 4
Edmonton Frail Scale Score	6.0 ± 1.6	6.0 ± 1.7
Type of surgery		
Coronary artery bypass grafting	37 (56%)	23 (61%)
Isolated valve	8 (12%)	5 (13%)
Combined	21 (32%)	10 (26%)
Days after surgery	17.6 ± 8	18.2 ± 10
Class III or IV heart failure	13 (20%)	7 (18%)
Atrial fibrillation	20 (30%)	8 (21%)
Chronic obstructive pulmonary disease	3 (5%)	1 (3%)
Depression	1 (2%)	1 (3%)
Oncological diseases	10 (15%)	8 (21%)
ACE inhibitors	49 (74%)	29 (76%)
Beta blockers	65 (98%)	37 (97%)
6-minute walking distance, m	300 ± 79	303 ± 74
Cardiac effort, beats/m	1.62 ± 0.52	1.62 ± 0.58

[a]Data are presented as mean ± SD or n (%).

Abbreviations: 6MWT, 6-min walk test; ACE, angiotensin enzyme converting inhibitor.

Table 2. Comparison between 6MWT/Cardiac Effort and Cycle Ergometry in Patients Following Cardiac Surgery, 2020 – 2022[a]

Metrics	6MWT (N = 38)	Veloergometry (N = 38)	Mean Difference ± SD[b]	*P* Value[c]
Average HR, beats/min	78 ± 10	77 ± 11	1.6 ± 7.7	.20
Peak HR, beats/min	89 ± 9	89 ± 11	-0.5 ± 5.8	.59
End of test HR, beats/min	75 ± 13	74 ± 11	1.5 ± 15.3	.57
6-min walking distance, m	303 ± 74	-	-	-
Cardiac effort, beats/m	1.62 ± 0.58	-	-	-
Test duration, sec	-	157 ± 99	-	-
Peak output, Watts	-	50 ± 14	-	-
Peak HR/output, beats/min/Watt	-	1.90 ± 0.49	-	-

[a]Data are presented as mean ± SD.

[b]Mean difference is the within-participant difference, calculated as 6MWT – cycle ergometry, and is presented as mean ± SD of paired differences.

[c]*P* values from paired t-tests.

Abbreviations: 6MWT, 6-min walk test; HR, heart rate.

Table 3. Comparison of 6MWD and Cardiac Effort in Male and Female Patients Following Cardiac Surgery, 2020 – 2022[a]

Metric	Male (N = 44)	Female (N = 22)	Mean Difference (SE)[b]	*P* Value[c]
Average HR, beats/min	77 ± 10	79 ± 11	2 (3)	.48
Peak HR, beats/min	87 ± 10	90 ± 8	4 (2)	.12
End of test HR, beats/min	77 ± 13	77 ± 14	-0.2 (3.7)	.96
6MWD, m	314 ± 78	274 ± 76	-39 (20)	.06
Cardiac effort, beats/m	1.51 ± 0.41	1.83 ± 0.65	0.32 (0.16)	.05

[a]Data are presented as mean ± SD for subgroup values and mean difference (SE) for between-group comparisons.

[b]Mean difference is female - male.

[c]*P* values from Welch's 2-sample t-test.

Abbreviations: 6MWD, 6-min walking distance; HR, heart rate.

Table 4. Comparison of 6MWD and Cardiac Effort in Patients with and without Atrial Fibrillation Following Cardiac Surgery, 2020 – 2022[a]

Metric	No Atrial Fibrillation (N = 46)	Atrial Fibrillation (N = 20)	Mean Difference (SE)[b]	*P* Value[c]
Average HR, beats/min	80 ± 11	72 ± 9	-8 (3)	.003
Peak HR, beats/min	89 ± 9	86 ± 9	-3 (2)	.32
End of test HR, beats/min	79 ± 13	71 ± 12	-8 (4)	.03
6MWD, m	308 ± 75	282 ± 86	-26 (22)	.25
Cardiac effort, beats/m	1.64 ± 0.54	1.56 ± 0.48	-0.07 (0.14)	.61

[a]Data are presented as mean ± SD for subgroup values and mean difference (SE) for between-group comparisons.

[b]Mean difference is atrial fibrillation – no atrial fibrillation.

[c]*P* values from Welch's 2-sample t-test.

Abbreviations: 6MWD, 6-min walking distance; HR, heart rate.

Table 5. Multivariable Associations of Sex, Atrial Fibrillation, and Frailty with 6MWT–Derived Outcomes in Patients Following Cardiac Surgery, 2020-2022

Outcome	N	β (95% CI)[a]	*P* Value
Cardiac effort, beats/m			
Female sex (vs. male)	63	0.34 (0.01 to 0.66)	.042
Atrial fibrillation (vs. no atrial fibrillation)	63	-0.12 (-0.46 to 0.21)	.456
Edmonton Frail Scale, per 1-point increase	63	0.04 (-0.02 to 0.09)	.217
6MWD, m			
Female sex (vs. male)	66	-39.63 (-82.26 to 3.00)	.068
Atrial fibrillation (vs. no atrial fibrillation)	66	-17.81 (-65.29 to 29.67)	.456
Edmonton Frail Scale, per 1-point increase	66	-10.55 (-20.40 to -0.70)	.036
Average HR during 6MWT, beats/min			
Female sex (vs. male)	66	2.76 (-2.50 to 8.02)	.299
Atrial fibrillation (vs. no atrial fibrillation)	66	-8.17 (-13.50 to -2.84)	.003
Edmonton Frail Scale, per 1-point increase	66	-0.13 (-1.71 to 1.44)	.867
Peak HR during 6MWT, beats/min			
Female sex (vs. male)	66	3.94 (-0.83 to 8.71)	.103
Atrial fibrillation (vs. no atrial fibrillation)	66	-3.16 (-8.32 to 2.00)	.225
Edmonton Frail Scale, per 1-point increase	66	0.63 (-0.81 to 2.06)	.386
End-of-test HR during 6MWT, beats/min			
Female sex (vs. male)	62	0.27 (-6.79 to 7.33)	.939
Atrial fibrillation (vs. no atrial fibrillation)	62	-8.23 (-15.88 to -0.58)	.035
Edmonton Frail Scale, per 1-point increase	62	-0.13 (-2.30 to 2.04)	.904
% age-predicted maximal HR (220-age)			
Female sex (vs. male)	66	2.60 (-0.71 to 5.91)	.122
Atrial fibrillation (vs. no atrial fibrillation)	66	-1.78 (-5.33 to 1.77)	.320
Edmonton Frail Scale, per 1-point increase	66	0.79 (-0.17 to 1.75)	.107

[a]Values are β coefficients (95% CI) from separate multivariable linear regression models with heteroskedasticity-consistent robust standard errors. Each model included sex, atrial fibrillation status, and Edmonton Frail Scale score simultaneously. N varied by outcome because of missingness.

Abbreviations: 6MWD, 6-min walking distance; 6MWT, 6-min walk test; HR, heart rate.

Figure Legends

Figure 1. Associations between 6MWD, cardiac effort, and exercise performance metrics in patients following cardiac surgery, 2020-2022. Top panels show relationships between 6MWD and cycle ergometry duration, maximal workload, and peak heart rate normalized to workload (beats/min/Watt). Bottom panels show relationships between cardiac effort (beats/m) and the same cycle ergometry metrics. Spearman rank correlation coefficients (ρ), bootstrap 95% CI, *P* values, and sample size (n) are shown in each panel. Solid blue lines are included for visualization of the overall trend. Abbreviation: 6MWD, 6-min walking distance.