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**Original Article**

# Peak oxygen consumption achieved at the end of cardiac rehabilitation predicts long-term survival in patients with coronary heart disease

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**Aims** Cardiac rehabilitation (CR) improves survival in patients with coronary heart disease (CHD), which is largely mediated by the improvements in cardiorespiratory fitness (CRF) defined as peak oxygen consumption ($VO_2$). Therefore, measuring CRF is essential to predict long-term outcomes in this population. It is unclear, however, whether peak $VO_2$ achieved at the end of CR (END-peak $VO_2$) predicts survival or whether the changes of CRF achieved during CR provide a greater prognostic value. To determine whether END-peak $VO_2$ independently predicts long-term survival in patients with CHD undergoing CR. We also aimed at identifying cut-offs for END-peak $VO_2$ that could be used in clinical practice.

**Methods and results** Retrospective analysis of 853 patients with CHD referred to CR who completed a maximal cardiopulmonary exercise test. Survival analysis was performed to examine the risk of all-cause mortality (average follow-up years: 6.65) based on peak $VO_2$. The Contal and O'Quigley's method was used to determine the optimal cut-off of END-peak $VO_2$ based on the log-rank statistic. END-peak $VO_2$ was inversely associated with mortality risk [hazard ratio (HR) = 0.84; 95% confidence interval (CI) = 0.78–0.90], independent of changes in peak $VO_2$ adjusted for the baseline peak $VO_2$. The estimated cut-off of END-peak $VO_2$ at ≥17.6 mL/kg/min best predicted the survival with high predictive accuracy and patients with END-peak $VO_2$ under the cut-off had a greater risk of mortality (HR = 2.93; 95% CI = 1.81–4.74).

**Conclusions** In patient with CHD undergoing CR, END-peak $VO_2$ is an independent predictor for long-term survival. Studies utilizing higher intensity CR programmes, with and without pharmacologic strategies, to increase peak $VO_2$ to a greater degree in those achieving a suboptimal END-peak $VO_2$, are urgently needed.

**Keywords** Cardiac rehab • Cardiorespiratory fitness • Exercise training • Coronary heart disease

## Introduction

Despite several improvements made in the last few decades in the treatment of coronary heart disease (CHD), long-term mortality in this population remains high.[1] Cardiac rehabilitation (CR) is the cornerstone therapy for patients with CHD as it improves cardiovascular and metabolic risk factors, and short- and long-term survival, despite its relatively short duration.[2–4] Most benefits of CR are mediated by improvements in cardiorespiratory fitness (CRF),[3,5–7] typically defined as peak oxygen consumption ($VO_2$) measured during

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maximal cardiopulmonary exercise testing (CPX).[8] Therefore, measuring peak $VO_2$ at the beginning and at the end of CR to predict long-term outcomes in these patients is of crucial importance.

Importantly, due to its strong prognostic value, CRF has been proposed as a new vital sign in healthy and diseased populations.[9–11] A large variability in terms of changes in CRF in response to CR exists, however, with some patients improving peak $VO_2$ to a greater degree than others (i.e. responders and non-responders).[3] Importantly, although changes in peak $VO_2$ are strong predictors of long-term survival, at this time it is unclear whether the peak $VO_2$ achieved at the end of CR (END-peak $VO_2$) predicts long-term survival, independent of the changes in CRF achieved during the CR programme.

In this study, we investigated whether END-peak $VO_2$ predicted long-term survival in patients with CHD. We also hypothesized that END-peak $VO_2$ would predict survival in this population, independent of the changes in CRF during CR. Finally, we investigated whether we could identify specific cut-offs for END-peak $VO_2$ that could be used in clinical practice to detect individuals that remain at increased risk for all-cause mortality.

# Methods

We conducted a retrospective analysis of patients with CHD treated medically with or without revascularization referred to CR between 1 January 2000 and 30 June 2013 at the Ochsner Medical Center in New Orleans, LA, as previously described.[3,12] The Ochsner Foundation Institutional Review Board approved the study.

Briefly, biochemical, anthropometrics, and body composition were collected at baseline and in the morning. Body fat (BF) was measured using the sum of the skinfold method.[13] Fat-free mass index (FFMI) was calculated by [1 - BF × body mass index ($kg/m^2$)], as previously described.[14] The patients were categorized into low and high BF using the cut-offs of ≤25% for men and ≤35% for women, and low and high FFMI based on the cut-offs of ≤18.9 $kg/m^2$ for men and ≤15.4 $kg/m^2$ for women, respectively.[15] Comorbidities such as hypertension and diabetes mellitus were retrieved from diagnostic codes. The CR included three sessions per week for 12 weeks, for a total of 36 sessions, with the intensity of each session chosen based on heart rate close to anaerobic threshold. Each session started with 10 min of warm-up exercises and approximately 30–40 min of aerobic exercise such as treadmill, bicycle, and elliptical machine, and isometrics, followed by 10 min of cool-down exercise. No differences in exercise prescription were given between men and women.

CRF was defined as peak $VO_2$ measured during a maximal CPX with gas exchange analysis (MedGraphics), at baseline and at the end of CR. The last CPX was only conducted if participants completed all 36 sessions of CR. The predicted peak $VO_2$ based on Wasserman–Hansen (W-H)[16] and FRIEND-Registry[17] prediction equations was calculated and the percent (%) achieved of predicted peak $VO_2$ was obtained.

The changes in CRF indicators, including peak $VO_2$, %W-H, and %FRIEND, were calculated by taking the difference between the baseline and the end of CR. The changing variable was then additionally adjusted for the baseline level of the respective indicator using the residual method[18] in order to control for the possible confounding effect of the baseline level of CRF on the change. The retrospective data contained the variables for a total of 1215 patients. Of those, 362 were excluded due to invalid follow-up time ($n = 27$), missing on peak $VO_2$ ($n = 36$), or the respiratory exchange ratio <1.0 ($n = 288$), or invalid/unreliable data ($n = 11$), which resulted in a final analytic sample of 853 (see Supplementary material online, *Figure S1* for a flow diagram). An average follow-up time of the final analytic sample was 6.55 years (standard deviation = 3.69; median = 6.66 years; range = 0.02–13.12 years), and the all-cause mortality was determined by the National Death Index.

## Statistical analysis

Descriptive characteristics of patients at pre- and post-CR were calculated. Two-tailed dependent sample *t*-test or Wilcoxon signed-rank test and the McNemar's test were used to examine pre- and post-differences in continuous and categorical variables, respectively. Two Cox proportional hazard (PH) regression models were sequentially established for each of three CRF indicators (i.e. peak $VO_2$, %W-H, and %FRIEND). Model 1 examined the risk of all-cause mortality in relation to the change in the level of CRF between pre- and post-CR while adjusting for age (years) at post-CR, sex, and body mass index (BMI) ($kg/m^2$) at post-CR. The follow-up Model 2 additionally included the level of CRF at post-CR to test the relative importance of CRF level at post-CR (i.e. END-peak $VO_2$) for the prediction of mortality over the CR-induced change in CRF.

Next, a split-sample approach was applied to determine the optimal prognostic cut-offs of CRF at post-CR predicting survival over time. We first randomly selected 70% of the original sample, stratified by survival status at the follow-up, as a development sample ($n = 597$; deceased = 74), and the remaining 30% was used as a validation sample ($n = 256$; deceased = 32). The Contal and O'Quigley's method,[19] which estimates the best cut-off based on the log-rank test statistics, was applied to the development sample using the '%FINDCUT' SAS macro.[20] The estimated cut-offs were then tested on the validation sample for its predictive accuracy in discriminating overall survival based on the bootstrapping method, in which 80% of the validation sample were bootstrapped 200 times. For each bootstrapped sample, time-dependent receiver operating characteristic curves were created to evaluate predictive accuracy at the follow-up years of 3, 5, and 10 based on the area under the curve (AUC), sensitivity (true positive), and specificity (true negative). Additionally, Uno's concordance index (C-index)[21] and integrated AUC were estimated to evaluate the overall accuracy of discrimination. The higher Uno's C-index and integrated AUC indicate the better performance of cut-offs in discriminating survival over time and the estimates were interpreted as poor (<0.6), moderate (0.6–0.75), and high (≥0.75) predictive accuracy.[22] The median and middle 95th percentile (2.5th–97.5th percentile) of the bootstrap distribution are reported.

Lastly, the established optimal cut-offs for the level of END-peak $VO_2$ was applied to the entire sample. Cox PH regression analysis was conducted to predict the risk of all-cause mortality while adjusting age (years) at post-CR, sex, and BMI ($kg/m^2$) at post-CR. The relative risk of mortality was presented as hazard ratio (HR) along with 95% confidence intervals. Graphical presentations of adjusted survival probability over time were performed using the SAS macro.[23] For all Cox PH regression models, the PH assumption was checked using time-dependent interaction terms of all covariates and the Schoenfeld residual plots. The sensitivity analyses were performed after excluding early deaths within 2 years of follow-up to address the potential bias due to the reverse causation (e.g. lower CRF due to poor health condition). All statistical analyses were conducted using the SAS v9.4 (SAS Institute, Cary, NC, USA) and the significance level was set at ≤.05.

# Results

The descriptive statistics of patient's characteristics at pre- and post-CR are presented in *Table 1*. Patients were on average 63.96 ± 10.32 years old (male = 64.00 ± 10.54 years old; female =

**Table 1 Descriptive characteristics of study sample at pre- and post-cardiac rehabilitation ($N = 853$)**

| | Pre-cardiac rehabilitation | Post-cardiac rehabilitation | *P*-value[a] |
|---|---|---|---|
| Age (years) | 63.96 (10.32) | 64.32 (10.32) | <0.001 |
| Sex | | | |
| Male | 677 (79.37%) | — | — |
| Female | 176 (20.63%) | — | — |
| Ejection fraction (%) | 54.29 (11.66) | — | — |
| BMI (kg/m$^2$) | 29.02 (5.07) | 28.75 (4.94) | <0.001 |
| Obesity (*n*, %)[b] | 305 (35.76%) | 281 (32.94%) | 0.004 |
| Body fat (%) | 27.92 (7.39) | 26.35 (7.54) | <0.001 |
| High (*n*, %)[c] | 451 (52.87%) | 371 (43.49%) | <0.001 |
| Fat-free mass index (kg/m$^2$) | 20.70 (2.83) | 20.96 (2.86) | <0.001 |
| High (*n*, %)[d] | 720 (84.41%) | 737 (86.40%) | 0.041 |
| Peak systolic BP (mmHg) | 170.41 (30.21) | 167.33 (30.61) | 0.002 |
| Peak diastolic BP (mmHg) | 82.17 (14.45) | 79.91 (13.63) | <0.001 |
| Respiratory exchange ratio | 1.15 (0.09) | 1.17 (0.10) | <0.001 |
| Peak $VO_2$ (mL/kg/min) | 18.85 (5.33) | 21.01 (6.25) | <0.001 |
| Predicted peak $VO_2$-W-H[e] | 28.32 (5.09) | 28.17 (5.08) | <0.001 |
| %W-H[f] | 66.97 (16.2) | 74.71 (17.85) | <0.001 |
| Predicted peak $VO_2$-F[g] | 41.00 (6.41) | 40.96 (6.42) | 0.007 |
| %FRIEND[h] | 46.09 (11.06) | 51.19 (12.01) | <0.001 |
| Total cholesterol (mg/dL) | 152.94 (34.85) | 153.11 (34.77) | 0.459 |
| HDL (mg/dL) | 39.60 (10.82) | 42.88 (11.16) | <0.001 |
| LDL (mg/dL) | 86.66 (27.89) | 86.80 (31.32) | 0.884 |
| Triglycerides (mg/dL)[i] | 114.00 (77.00) | 102.00 (71.00) | <0.001 |
| Fasting glucose (mg/dL)[i] | 103.00 (21.00) | 102.00 (21.00) | 0.479 |
| C-reactive protein (mg/dL)[i] | 2.40 (3.80) | 1.50 (2.50) | <0.001 |

Values are presented as mean (standard deviation) for continuous variables and as *n* (%) for categorical variables unless otherwise specified.
BMI, body mass index; BP, blood pressure; FRIEND, Fitness Registry and the Importance of Exercise: A National Data Base; HDL, high-density lipoprotein; LDL, low-density lipoprotein; $VO_2$, oxygen consumption; W-H, Wasserman–Hansen predictive equation.
[a]*P*-values are estimated from within-group comparisons using dependent sample *t*-tests for continuous variables and McNemar's test for categorical variables. For the continuous variables with non-normal distribution, a non-parametric Wilcoxon signed-rank tests was performed.
[b]BMI ≥30 kg/m$^2$.
[c]Age- and sex-specific body fat (%) thresholds were used.[15]
[d]Fat-free mass index ≥18.9 kg/m$^2$ for male and ≥15.4 kg/m$^2$ for female.[15]
[e]Wasserman–Hansen prediction equation[16] was used.
[f]Percent (%) achieved of predicted peak $VO_2$ based on Wasserman–Hansen prediction equation.[16]
[g]FRIEND-Registry prediction equation[17] was used.
[h]Percent (%) achieved of predicted peak $VO_2$ based on FRIEND-Registry prediction equation.
[i]Values are presented as median (interquartile range) due to non-normal distribution.

63.80 ± 10.54 years old) when referred to the CR and largely predominated by men (79.37%). There were significant and positive changes in body composition during CR, in which average BMI and BF (%) were reduced from 29.02 kg/m$^2$ to 28.75 kg/m$^2$ and from 27.92% to 26.35%, respectively (*P*'s < 0.001). CR was associated with statistically significant improvements in CRF indicators, but also of cardiovascular biomarkers and risk factors, including total cholesterol, LDL-C, triglycerides, and C-reactive protein. Peak $VO_2$ was significantly increased by an average of 2.16 mL/kg/min during CR, and %W-H[16] and %FRIEND[17] also improved by an average of 7.74% and 5.1%, respectively (*P*'s < 0.001).

*Table 2* presents the results of Cox PH regression analyses examining the risk of all-cause mortality based on the change in CRF (Model 1) and the level of CRF at post-CR (Model 2) while adjusting for study covariates. The results demonstrated that greater improvements in CRF during the CR were significantly associated with lower risk of mortality (HRs = 0.92, 0.97, and 0.97 for changes in peak $VO_2$, %W-H, and %FRIEND, respectively). However, the observed associations were attenuated after introducing END-peak $VO_2$ in Model 2, in fact, the changes in CRF no longer predicted the risk of mortality. Greater END-peak $VO_2$, instead, remained significantly associated with lower risk of mortality (HRs = 0.84, 0.96, and 0.93 for peak $VO_2$, %W-H, and %FRIEND at post-CR, respectively).

*Figure 1* depicts absolute log-rank statistics across the levels of CRF indicators at post-CR estimated from developmental sample using the Contal and O'Quigley's method. The estimated optimal cut-offs maximizing absolute log-rank statistic were ≥17.6 mL/kg/min for peak $VO_2$ (|log-rank statistics| = 24.28, Q-statistics = 2.92, $P = 7.795 \times 10^{-8}$), ≥62.1% for %W-H (|log-rank statistics| = 19.87, Q-statistics = 2.39, $P = 2.170 \times 10^{-5}$), and ≥41.4% for %FRIEND (|log-rank statistics| = 24.33, Q-statistics = 2.93, $P = 7.255 \times 10^{-8}$).

**Table 2 Multivariate Cox proportional hazard regression analyses ($N = 853$; deceased = 106)**

| | Model 1[a] | | Model 2[a] | |
|---|---|---|---|---|
| | HR (95% CI) | *P*-value | HR (95% CI) | *P*-value |
| Based on peak $VO_2$ (mL/kg/min) | | | | |
| Changes in peak $VO_2$[b] | 0.92 (0.86–0.98) | 0.010 | 1.01 (0.93–1.10) | 0.766 |
| Peak $VO_2$ at post-CR | — | — | 0.84 (0.78–0.90) | <0.001 |
| Based on the % achieved of predicted peak $VO_2$ (Wasserman-Hansen prediction equation) | | | | |
| Changes in %W-H[b,c] | 0.97 (0.95–0.98) | 0.001 | 1.01 (0.98–1.03) | 0.712 |
| %W-H at post-CR[c] | — | — | 0.96 (0.94–0.97) | <0.001 |
| Based on the % achieved of predicted peak $VO_2$ (FRIEND-Registry prediction equation) | | | | |
| Changes in %FRIEND[b,d] | 0.97 (0.95–0.99) | 0.020 | 1.01 (0.97–1.04) | 0.721 |
| %FRIEND at post-CR[d] | — | — | 0.93 (0.91–0.96) | <0.001 |

CI, confidence interval; CR, cardiac rehabilitation; HR, hazard ratio.
[a]Models were adjusted for age (years) at post-CR, sex, ejection fraction (%), and body mass index (kg/m$^2$) at post-CR.
[b]Change variables were adjusted for the respective pre-CR levels using residual method.[18]
[c]Percent (%) achieved of predicted peak $VO_2$ based on Wasserman–Hansen prediction equation.
[d]Percent (%) achieved of predicted peak $VO_2$ based on FRIEND-Registry prediction equation.

*Table 3* presents the predictive accuracies of the established cut-offs tested among the validation sample using the bootstrapping method. The median of the bootstrap distribution estimated for Uno's C-index was 0.75 for both peak $VO_2$ (middle 95th percentile: 0.66–0.81) and %FRIEND (middle 95th percentile = 0.66–0.81) and lowest for %W-H (median = 0.68; middle 95th percentile: 0.57–0.72). Similarly, the median of the bootstrap distribution estimated for integrated AUC was highest for %FRIEND (0.73), followed by Peak $VO_2$ (0.70) and %W-H (0.62). Pertaining to the predictive accuracy at follow-up years of 3, 5, 10 years, the median values of the bootstrap distribution estimated for time-dependent AUC were ranged between 0.62 and 0.71 for peak $VO_2$, between 0.50 and 0.59 for %W-H, and between 0.66 and 0.70 for %FRIEND, respectively. The highest median values of specificity were observed for %FRIEND across all follow-up years (0.79, 0.79, and 0.83 at follow-up years of 3, 5, and 10, respectively). The lowest sensitivity values were estimated for %W-H showing the sensitivity of 0.23, 0.29, and 0.43 at follow-up years of 3, 5, and 10, respectively.

The results of Cox PH regression analysis among the entire sample and the adjusted survival probability curves stratified by the optimal cut-offs established for CRF level at post-CR are presented in *Figure 2*. The relative risks of all-cause mortality were significantly greater for patients who had CRF levels at post-CR below the established cut-offs (HRs = 2.93, 2.94, and 3.28 for peak $VO_2$, %W-H, and %Friend's cut-offs, respectively).

# Discussion

In the current study, we have shown that END-peak $VO_2$ is a strong predictor for long-term survival in patients with CHD undergoing CR. Importantly, these effects were independent of the changes of CRF adjusted for the baseline level of CRF. In fact, consistently with prior studies, baseline peak $VO_2$ and changes in peak $VO_2$ were strong predictors of survival[3]; however, these effects were no longer significant after statistical adjustments for END-peak $VO_2$ in our sample. The protective effects of END-peak $VO_2$ were also independent of age, sex, and BMI, suggesting that independent of the patient's characteristics, achieving a greater peak $VO_2$ at the end of CR should perhaps remain the primary goal of CR.

Prior studies from our group have shown that greater changes in CRF during CR (i.e. responders) would present a more favourable long-term prognosis.[3] Herein, however, we further expanded our understanding of CRF in patients with CHD undergoing CR. In fact, we detected cut-offs for peak $VO_2$ and % predicted peak $VO_2$ using clinically available predictive equations. We identified that achieving an END-peak $VO_2$ ≥17.6 mL/kg/min at the end of CR predicts favourable long-term survival compared to those who achieve a lower END-peak $VO_2$. Moreover, we have found that ≥62.1% and ≥41.4% predicted END-peak $VO_2$ using the W-H and the FRIEND predictive equations, respectively, were also associated with a favourable outcome.

Our findings would propose that individuals who achieve a level of CRF (i.e. END-peak $VO_2$) that is sub-optimal, hence, lower than our identified cut-offs, would benefit from additional therapeutics targeted at improving CRF. A longer CR programme could potentially allow to achieve such level of CRF needed to improve long-term survival, however, it would be plausible to hypothesize that high-intensity CR, while maintaining the relative short duration of the programme, might also be efficacious in this population.[24] Many individuals would therefore benefit from additional strategies aimed at improving peak CRF further.

On the other hand, however, individuals who improve their peak $VO_2$ only minimally during CR, or do not experience any improvements or even a decline in CRF, yet have an END-peak $VO_2$ above the above identified threshold, might still present a more favourable long-term prognosis compared to those with a lower END-peak $VO_2$, even if they have experienced significant improvements in CRF. Moreover, our study provided additional evidence highlighting the importance of measuring CRF using peak $VO_2$ in patients with CHD undergoing CR due to its ability in predicting long-term clinical outcomes.

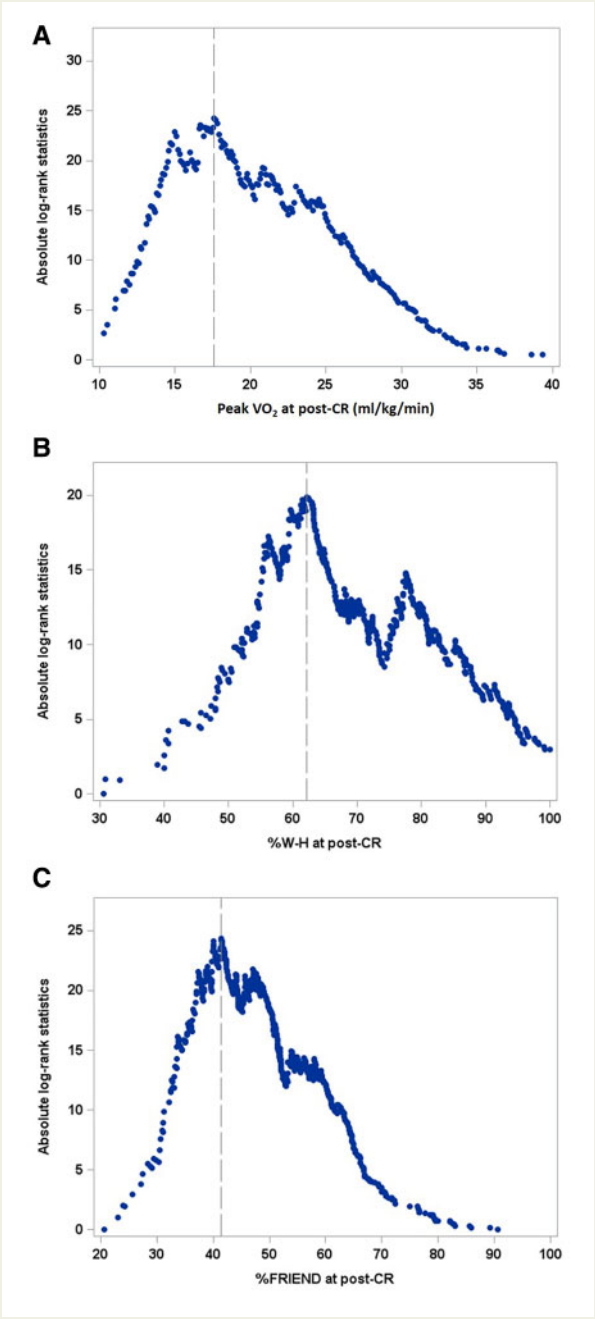


**Figure 1** Absolute log-rank statistics by the level of cardiorespiratory fitness at post-cardiac rehab. Peak $VO_2$ ≥17.6 mL/kg/min (*A*), % predicted peak $VO_2$ using W-H (cut-off: ≥62.1%) (*B*), and (*C*) %% predicted peak $VO_2$ using FRIEND (cut-off: ≥41.4%) (*C*) among development sample ($n = 597$; deceased = 74). Vertical lines indicate the optimal cut-offs maximizing absolute log-rank statistics based on the Contal and O'Quigley's method. FRIEND, Fitness Registry and the Importance of Exercise: A National Data Base; $VO_2$, oxygen consumption; W-H, Wasserman–Hansen predictive equation.

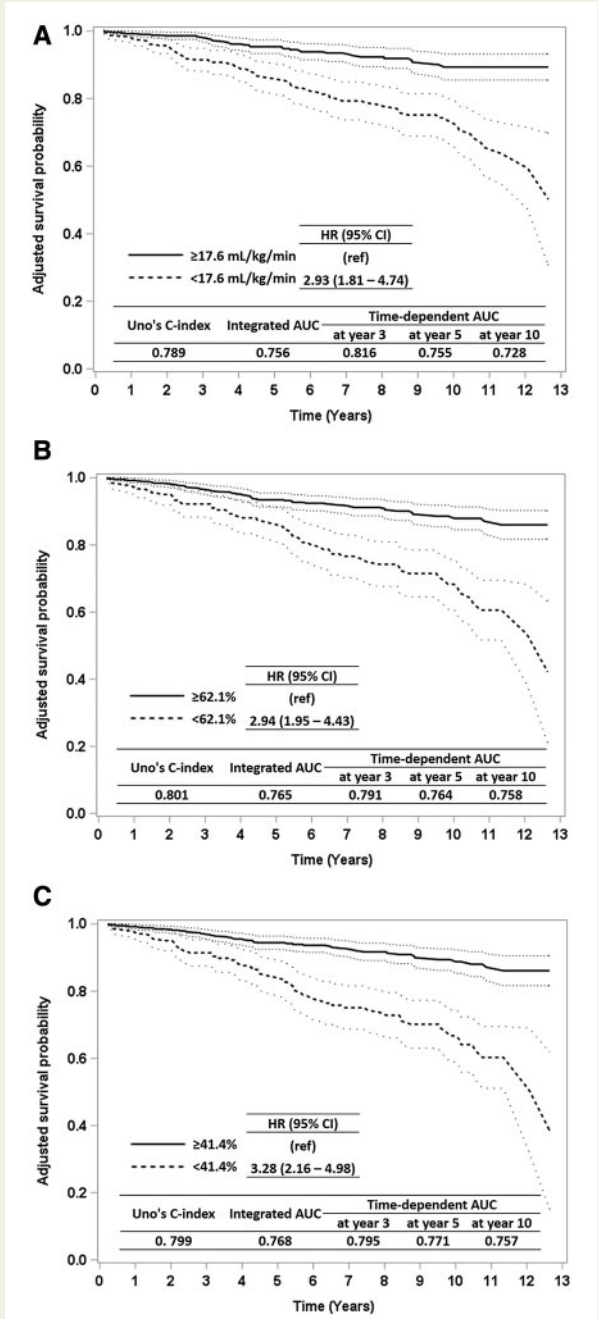


**Figure 2** Survival curves. Adjusted survival curves stratified by the optimal cut-offs of cardiorespiratory fitness level at post-cardiac rehab among the entire sample ($n = 853$; deceased = 106). Peak $VO_2$ ≥17.6 mL/kg/min (*A*), % predicted peak $VO_2$ using W-H (cut-off: ≥62.1%) (*B*), and (*C*) %% predicted peak $VO_2$ using FRIEND (cut-off: ≥41.4%) (*C*). The survival probability was estimated from Cox proportional hazard regression models adjusting age (years) at post-cardiac rehab, sex, ejection fraction (%), and body mass index ($kg/m^2$) at post-cardiac rehab. FRIEND, Fitness Registry and the Importance of Exercise: A National Data Base; $VO_2$, oxygen consumption; W-H, Wasserman–Hansen predictive equation.

The lack of measures of adherence to the individual sessions of CR and the time when data collection was obtained, are limitations of our study, as the change in the management of patients with CHD might have impacted our findings. Moreover, we have not validated our findings in a different cohort and possibly with a larger number of women, diverse races, and ethnicities. Finally, these data were obtained with exercise gas exchange and precisely measuring

**Table 3 Predictive accuracy of the estimated optimal cut-offs based on the bootstrapped validation sample model[a]**

| | Peak $VO_2$ at post-CR (cut-off: ≥17.6 mL/kg/min) | %W-H at post-CR (cut-off: ≥62.1%) | %FRIEND at post-CR (cut-off: ≥41.4%) |
|---|---|---|---|
| Uno's C-index | 0.75 (0.66–0.81) | 0.68 (0.57–0.72) | 0.76 (0.64–0.80) |
| Integrated AUC | 0.70 (0.63–0.78) | 0.62 (0.55–0.67) | 0.73 (0.65–0.78) |
| Time-dependent AUC | | | |
| Follow-up year 3 | 0.71 (0.65–0.78) | 0.50 (0.44–0.55) | 0.70 (0.64–0.78) |
| Follow-up year 5 | 0.62 (0.57–0.68) | 0.52 (0.48–0.56) | 0.66 (0.61–0.70) |
| Follow-up year 10 | 0.67 (0.63–0.72) | 0.59 (0.54–0.63) | 0.69 (0.65–0.73) |
| Sensitivity (true positive) | | | |
| Follow-up year 3 | 0.74 (0.63–0.87) | 0.23 (0.13–0.32) | 0.62 (0.49–0.78) |
| Follow-up year 5 | 0.58 (0.49–0.69) | 0.29 (0.21–0.38) | 0.53 (0.44–0.62) |
| Follow-up year 10 | 0.65 (0.59–0.73) | 0.43 (0.35–0.50) | 0.55 (0.46–0.62) |
| Specificity (true negative) | | | |
| Follow-up year 3 | 0.68 (0.66–0.71) | 0.77 (0.74–0.79) | 0.79 (0.77–0.81) |
| Follow-up year 5 | 0.67 (0.63–0.70) | 0.75 (0.72–0.78) | 0.79 (0.76–0.81) |
| Follow-up year 10 | 0.70 (0.65–0.75) | 0.74 (0.69–0.79) | 0.83 (0.80–0.87) |

Eighty percent of validation sample ($n = 256$; deceased = 32) was bootstrapped 200 times with replacement while maintaining the proportion of deceased to be equal to the proportions in the entire sample. Values are the median and middle 95th percentile (2.5th and 97.5th) obtained from the bootstrapped distribution of the estimates.
AUC, area under the curve; C-index, concordance index; CR, cardiac rehabilitation.

exercise capacity, and these results may not be applicable to estimating exercise capacity based on treadmill speed and incline or estimated metabolic equivalents.

In conclusion, the END-peak $VO_2$ is a strong and independent predictor of long-term survival in patients with CHD. This proposes that additional strategies aimed at improving peak $VO_2$ further in patients undergoing CR should be implemented. Clearly, further study of factors to improve peak $VO_2$ are needed.

## One sentence summary

Peak oxygen consumption, a measure of cardiorespiratory fitness, achieved at the end of cardiac rehabilitation in patients with coronary heart disease predicted long-term survival, independent of the changes of peak oxygen consumption adjusted for the baseline level, proposing that greater effort should be placed by clinicians to achieve the identified cut-offs for peak oxygen consumption at the end of cardiac rehab.

## Supplementary material

Supplementary material is available at *European Heart Journal – Quality of Care and Clinical Outcomes* online.

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**Conflict of interest:** The authors have nothing to disclose.

## Data availability

The anonymized data underlying this article will be shared on reasonable request to the corresponding author.

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