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Clinical Research

Long-term Enrollment in Cardiac Rehabilitation Benefits Cardiorespiratory Fitness and Skeletal Muscle Strength in Men With Cardiovascular Disease

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ABSTRACT

Background: Despite known associations between fitness and recurrent cardiovascular events, changes in cardiorespiratory fitness (CRF) and muscle strength with long-term cardiac rehabilitation (CR) have not been extensively examined. The objectives of this study were to (1) examine changes in CRF and muscle strength associated with long-term CR program enrollment in men, and (2) compare these changes to previously published rates of decline (2.0% per year for CRF and 2.36% per year for muscle strength in healthy age-matched individuals).

Methods: Data were extracted from the program charts of 160 men (64 $\pm$ 9 years) who were enrolled $\geq$ 1 year in a maintenance-phase CR program and who completed $\geq$ 2 exercise tests. CRF was represented by peak oxygen consumption (VO_{2peak}, mL/min/kg). The skeletal muscle strength was assessed using 1-repetition maximum tests for

RÉSUMÉ

Contexte : Malgré l'association connue entre la forme physique et les récidives d'événements cardiovasculaires, les modifications des conditions cardiorespiratoires et de la force musculaire associées à la réadaptation cardiaque à long terme n'ont pas fait l'objet d'études approfondies. Les objectifs de cette étude étaient (1) d'examiner les modifications des conditions cardiorespiratoires et de la force musculaire associées à la participation à un programme de réadaptation cardiaque à long terme pour les hommes, et (2) de comparer ces modifications aux taux de diminution publiés dans le passé (2,0 % par année pour les conditions cardiorespiratoires et 2,36 % par année pour la force musculaire chez les sujets en santé appariés selon l'âge).

Méthodologie : Les données ont été extraites des diagrammes de 160 hommes (âgés de 64 ans $\pm$ 9 ans) inscrits à un programme de réadaptation cardiaque en phase de maintien pendant au moins un an

Cardiovascular disease (CVD) remains the leading cause of global mortality,[1] costing the global economy USD$863 billion.[2] In 2012, 17.5 million (31%) deaths worldwide were attributed to CVD, of which over 7 million were from coronary artery disease.[1]

The risk of recurrent events is high,[3] but exercise-based cardiac rehabilitation (CR) programs are well established, medically supervised, and effective for risk factor modification.[4] Several meta-analyses have established the effectiveness of CR for reducing cardiovascular[5] and all-cause mortality[6] and hospital admissions.[5] The exercise training component of CR is effective in improving measures of fitness, including cardiorespiratory fitness (CRF)[7] and skeletal muscle strength.[8] CRF, commonly measured by peak oxygen consumption (VO_{2peak}), is considered an important vital sign,[8] and higher CRF is protective against the risk of CVD and all-cause mortality.[9,10] CRF declines nonlinearly with age, at 1% per year from 40 to 49 years accelerating to over 2.5% per year in adults 70 years and older.[11] Higher skeletal muscle strength is also associated with improved quality of life and survival after CVD,[12] and its decline also accelerates with age, with little to no change from 40 to 49 years of age, 1.5% per year decline from 50 to 59 years, and 3% per year after age 60.[13,14]

Previous evidence supports short-term CR programs (2-12 months), demonstrating VO_{2peak} improvements by

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chest press, seated row, and knee extension. Mixed model analyses with polynomial functions were used to determine changes in CRF (up to 5.5 years) and muscle strength (up to 10 years).

Results: CRF increased nonlinearly up to 3 years (range, 0.33%-3.23% per year) and then declined nonlinearly to the 5.5-year endpoint (range, 1.03%-2.59% per year). Chest press and seated row strength declined at < 1% per year over 10 years, whereas knee extension increased nonlinearly by 0.18%-1.40% per year from baseline until 4 years and then declined nonlinearly at 1.00%-3.58% per year until the 10-year endpoint. All declines were similar to literature rates.

Conclusions: The results indicate that significant health benefits are associated with maintenance-phase CR programs for men. Enrollment was associated with preserved CRF and lower body muscle strength for 3-4 years.

et ayant effectué au moins deux épreuves d'effort. Les conditions cardiorespiratoires étaient représentées par la consommation maximale d'oxygène (VO_2 max, ml/min/kg). La force musculaire squelettique a été évaluée à l'aide de tests de force maximale sans répétition sur la presse à pectoraux, le rameur assis et l'entraîneur d'extension des genoux. Des analyses de modèles mixtes intégrant des fonctions polynomiales ont été utilisées pour déterminer l'évolution des conditions cardiorespiratoires (jusqu'à 5,5 ans) et de la force musculaire (jusqu'à 10 ans).

Résultats : Les conditions cardiorespiratoires se sont améliorées de façon non linéaire jusqu'à trois ans (fourchette : 0,33 % - 3,23 % par année) puis se sont détériorées de façon non linéaire jusqu'à 5,5 ans, soit la fin de la période à l'étude (fourchette : 1,03 % - 2,59 % par année). La force mesurée à la presse à pectoraux et au rameur assis a diminué au rythme de < 1 % par année au cours des 10 années, tandis que la force d'extension des genoux a augmenté de façon non linéaire de 0,18 % à 1,40 % par année du début de l'étude jusqu'à 4 ans, puis a diminué de façon non linéaire de 1,00 % à 3,58 % par année jusqu'à 10 ans, soit la fin de la période à l'étude. Toutes les diminutions de taux étaient semblables aux taux présentés dans les publications.

Conclusions : Les résultats indiquent que des bienfaits importants pour la santé sont associés aux programmes de réadaptation cardiaque en phase de maintien pour les hommes. La participation aux programmes a été associée au maintien des conditions cardiorespiratoires et de la force des muscles du bas du corps pendant 3 à 4 ans.

11%-35%,[15,16] with the largest gains seen in the least fit individuals.[17] However, much less is known about the changes in CRF with long-term CR programs. To date, only 1 study[18] has investigated changes in CRF in 43 adults with coronary heart disease (mean entry age, 72 years) with enrollment in a long-term CR program, which reported an overall decline in metabolic equivalents (METs) by 2.2% per year over 12-13 years of follow-up.[18]

Previous studies have shown improvement in muscle strength with short-term CR interventions.[19,20] A recent meta-analysis (22 trials, n = 1095) found that 4-28 weeks of resistance training resulted in an improved lower and upper extremity muscle strength in individuals with coronary artery disease.[19] Short-term CR programs (<12 months) are effective in improving knee extension strength by 35%-39% and arm extension strength by 14%.[20] However, changes in muscle strength with long-term CR programs (>12 months) have not been previously examined.

The objectives of this study were to (1) examine changes in the primary outcome of CRF measured as the change in VO_{2peak} (mL/kg/min) and the secondary outcomes of upper and lower body muscle strength after at least 12 months of enrollment in a maintenance-phase CR program, and (2) compare these changes to previously published age-specific annualized rates of decline.[11-13] Based on the literature, it is hypothesized that fitness will increase after program commencement, but subsequently decline at rates slower than literature comparisons.

Methods

This study was a retrospective chart review of data for members in a community-based, maintenance phase, exercise program—focused CR program. The study was approved by the Hamilton Integrated Research Ethics Board (#2017-1248).

Study eligibility

Participants' data were included in this analysis if they had VO_{2peak} data from at least 2 cardiopulmonary exercise tests (CPETs) conducted using matching modalities for each one. Because we were interested in the effects of long-term enrollment in CR, data were only included for individuals with at least 12 months of enrollment.

CR program

This maintenance-phase, exercise-based CR program was offered to community-dwelling individuals ≥18 years old with CVD who have completed early-phase CR programs. Participants were eligible to participate in the program with cardiologist or family physician referral and after completion of a formal CPET.

In this CR program, initial exercise prescriptions were based on the results of CPETs and physical assessments. All members were prescribed a comprehensive program of aerobic and resistance training on program entry, but the initiation of upper body resistance training was typically delayed by 6-8 weeks in individuals after surgery. Minor adjustments to the intensity and duration of exercise prescriptions were made as needed to accommodate for changes in fitness, health, and functional capacity. In addition to exercise training, blood pressure was regularly monitored and heart-healthy living education was provided via brochures and knowledge translation seminars.

Members were recommended to perform both aerobic and resistance exercise components at the program facility 2 times per week under staff supervision, and encouraged to exercise 3 days per week outside the program. They were prescribed 30 minutes of aerobic training at 60%-65% of heart rate reserve. For the resistance training component, members were encouraged to perform 1-3 sets of 12 repetitions in all major muscle groups 2 days per week while being supervised by staff. Resistance training loads were prescribed at 30%-40% and 50%-60% of 1-repetition maximum (1RM) for upper and lower extremities, respectively.

Outcomes

Assessments of VO_{2peak}, the primary outcome, were conducted at 2 sites. Of these, 1 site was also equipped with equipment to assess muscle strength. Thus, strength results were available for a subset of the CRF data (n = 70/160, 44%). Testing equipment and protocols for VO_{2peak} assessment were standardized between the 2 sites. Medications were not withheld. VO_{2peak} (mL/kg/min) was measured using Vmax CareFusion indirect calorimetry[11] on the Ergoline cycle ergometer and conducted by a cardiovascular technologist with physician supervision. The workload started at 100 kpm/min and increased by increments of 100 kpm/min every minute until endpoint, where the single highest value of oxygen consumed represented VO_{2peak}. Resting and peak heart rate (beats/min) and systolic and diastolic blood pressure (mm Hg), and peak aerobic power (kpm/min) were also assessed.

Skeletal muscle strength assessments were performed 30 minutes before VO_{2peak} assessments. 1RM chest press, seated back row, and knee extension were assessed using a standardized protocol and performed in a seated position on the Hydrafitness Omnikinetics strength machine (Hydrafitness Omnikinetics, Belton, TX). The technician demonstrated the exercise motions, monitored the participant's form and effort, and adjusted the weight accordingly to achieve the highest lift.

Data extraction

Data from member files from January 1985 to December 2016 were extracted during the period of January to April 2017. Demographic information included age (years), height (cm), weight (kg), date of cardiovascular event or surgical procedure, time postevent (years), reason for enrollment, date of exercise test(s), and duration of enrollment (years). Exercise data were extracted for all available time points for VO_{2peak} (mL/kg/min), and 1RM (kg) for chest press, seated back row, and knee extension. Resting and peak heart rate (beats/min) and blood pressure (mm Hg), and test modality (treadmill or cycle) were also extracted.

Statistical analysis

All analyses were performed using Stata 14 (2015; StataCorp LP, College Station, TX). Descriptive statistics (means ± standard deviation) and frequencies (n, %) were used to describe demographic information and baseline characteristics.

After controlling for age, mixed model analyses for longitudinal data were applied to address the relationship between the dependent variables (relative VO_{2peak} and 3 muscle strength outcomes: 1RM chest press, seated back row, and knee extension) and the independent variable (enrollment time [years]). Mixed model analyses were used in this study as they are highly flexible and allow for the analysis of data with missing measurements from person to person, unequal number of measurements/person, and varying gaps in time between measurements. To build the model, we first established the relationship between the dependent variable and enrollment time (ie, linear or nonlinear) via lowess curves and mixed model analyses (testing for polynomial terms) and tested for an interaction between enrollment time and covariate of baseline age. Finally, we identified random effects (such as random intercepts and random slopes) and the most appropriate covariance structure. The Bayesian information criteria and log likelihood ratio tests were used to identify the best-fitting mixed model.

Age-adjusted annualized rates of change in CRF and muscle strength were calculated and compared with previously published literature rates (−2% per year in VO_{2peak}[11] and −2.36% per year in muscle strength 1RM chest press, seated back row, and knee extension[12,13]) using 1-sample proportion tests. Because of differing fitness declines with each decade of life, the literature comparison rates were weighted to the specific decade-ages of members at CR program entry (ie, 40s, 50s, 60s, and 70s).

Results

A flowchart representing the data extraction and inclusion process is shown in Figure 1. Data from 599 member charts were extracted, and 199 met eligibility criteria. There were 39 women with available VO_{2peak} data, of whom only 18 had skeletal muscle strength data, thereby limiting the generalizability of the results. Moreover, long-term enrollment data, particularly beyond 3 years of enrollment, were insufficient with too much missing data to build a meaningful mixed

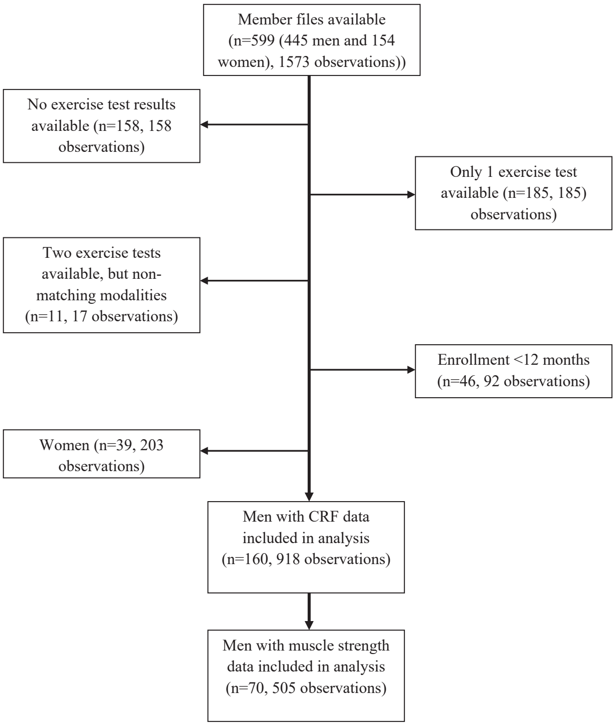

Figure 1. Flow of data extracted and included in the analysis. CRF, cardiorespiratory fitness.

model with nonlinear trends. Thus, women were not included in the analysis. VO_{2peak} data from 160 men (160/199; 80.4%) were included for analysis to examine changes in the primary outcome of CRF over time.

Table 1 summarizes the baseline characteristics of the 160 men included in the final analysis. Members started the CR program with an average VO_{2peak} of 22.7 mL/kg/min, which is lower than reference values for average healthy men without CVD (range: 28-33 mL/kg/min).[11]

The mean program duration was 6.6 years, but on closer inspection, we found that there were only 37 men (23%) with durations exceeding 10 years for VO_{2peak}, and thus fewer observations towards the upper limits of enrollment time. To maximize the nonmissing observations and thus improve generalizability of the mixed models, VO_{2peak} data were truncated at 5.5 years to preserve 75% available data. Similarly, muscle strengths, which contained more repeated observations and thus allowed for a longer truncation, were truncated at 10 years to preserve 75% available data.

Figure 2 shows the lowess smoother curve depicting the trajectory of VO_{2peak} over the truncated 5.5 years of enrollment time. The data show a nonlinear increase in VO_{2peak} from years 0-3 of program enrollment, followed by a nonlinear decline beyond 3 years.

To capture the polynomial shape of these data, we added a quadratic term in enrollment time (years[2]) to the mixed model effects. Based on the Bayesian information criteria, the polynomial model of years-years[2] with random intercepts and slopes best captured the change in VO_{2peak} over time observed in the lowess curve. Table 2 shows age-adjusted, nonlinear changes in VO_{2peak} for the truncated enrollment time (years 0-5.5) with no observed enrollment time × age interaction. The random effects variance components in this model included a random intercept and slope. Initial CRF levels varied between participants; thus a random intercept was included (variance estimate [standard error (SE)], 35.1 [4.3]; 95% confidence interval [CI], 27.6, 44.6). The rate of change in CRF after baseline also varied between participants and, as such, a random slope was included (variance estimate [SE], 0.63 [0.18]; 95% CI, 0.42, 1.01). Furthermore, a random effect on the years[2] term was tested, but it was found to be nonsignificant, indicating that the growth rate in CRF accelerated and decelerated at a similar rate in all participants (variance estimate [SE], 3.4×10^{-21} [1.4×10^{-20}]; 95% CI, 1.5×10^{-24}, 8.0×10^{-18}). An independent covariance structure was identified as there was no correlation between the random intercept and random slope in this model.

Figure 3 depicts the nonlinear changes in VO_{2peak} over enrollment time, and Table 3 compares time interval—specific changes to the literature value of −2% per year.[11] CRF

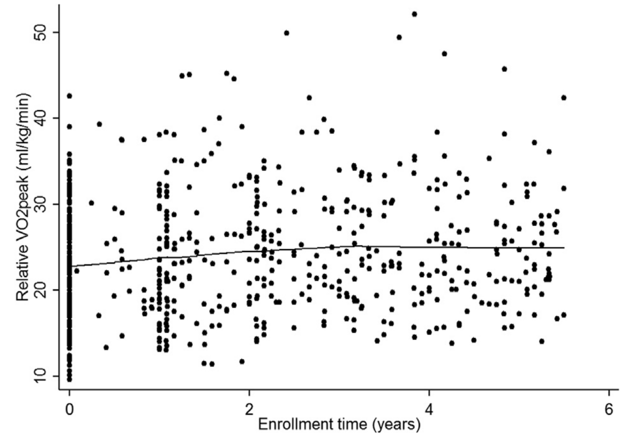

Figure 2. Trajectory of peak oxygen consumption (VO_{2peak}) (n = 160 men, 595 observations).

Table 1. Baseline characteristics of 160 men enrolled in the cardiac rehabilitation program

Variable	n	Value
Age, y	160	64.3 ± 9.3
Weight, kg	136	83.8 ± 13.1
Height, cm	137	174.7 ± 7.2
Smoking history, n (%)	73	
Never smoked		23 (31.5)
Ever smoked		50 (68.5)
Medications (yes), n (%)	156	
Blood pressure		136 (87.2)
Cholesterol		118 (75.6)
Diabetes		23 (14.7)
Reason for enrollment, n (%)	160	
CABG		63 (39.3)
Coronary angioplasty		36 (22.5)
Other heart surgery		9 (5.6)
Myocardial infarction		34 (21.3)
Cardiomyopathy		6 (3.8)
Other		12 (7.5)
Time postevent, y	152	1.7 (3.0)
Enrollment duration, y	160	6.6 ± 5.2
Resting HR, beats/min	127	69 ± 12
Resting systolic BP, mm Hg	154	127 ± 18
Resting diastolic BP, mm Hg	154	77 ± 11
Peak HR, beats/min	160	132 ± 23
Percent of predicted peak HR achieved	160	81 ± 14
Peak systolic BP, mm Hg	109	177 ± 32
Peak diastolic BP, mm Hg	108	80 ± 11
VO_{2peak}, mL/kg/min	160	22.7 ± 7.1
Peak aerobic power, kpm	152	915 ± 292
1RM chest press, kg	70	68 ± 20
1RM seated back row, kg	70	54 ± 17
1RM leg extension, kg	70	57 ± 17

Continuous variables are presented as means ± standard deviations. Categorical variables are presented as frequencies (percentage).

1RM, 1-repetition maximum; BP, blood pressure; CABG, coronary bypass grafting; HR, heart rate; VO_{2peak}, peak oxygen consumption.

Table 2. Mixed model analysis on changes in VO_{2peak} levels over 5.5 years after controlling for age (n = 160, 595 observations)

Fixed and random effects components from 0 to 5.5 y of enrollment			
Fixed effects variables	β (SE)	95% CI	*P* value
IV1: years	0.912 (0.23)	0.46, 1.36	< 0.001*
IV2: years[2]	−0.167 (0.04)	−0.26, −0.08	< 0.001*
Covariate: baseline age	−0.295 (0.05)	−0.40, −0.19	< 0.001*
Constant	41.9 (3.4)	35.2, 48.7	< 0.001*
Random effects variance Components	Estimate (SE)	95% CI	
Slope, y	0.63 (0.18)	0.42, 1.01	
Intercept	35.1 (4.3)	27.6, 44.6	
Residual	6.96 (0.56)	5.9, 8.2	
Model fit statistics	Statistics		
−2 Log likelihood	−1702.5		
Bayesian information criteria	3449.7		

CI, confidence interval; IV, independent variable; SE, standard error; VO_{2peak}, peak oxygen consumption.

* Indicates $P > 0.05$.

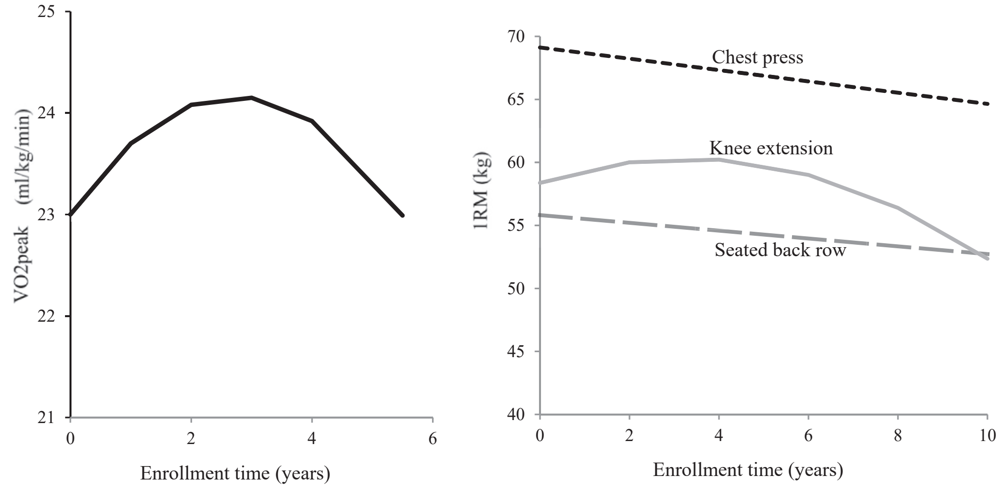

Figure 3. Mixed model graph of changes in VO_{2peak} and muscle strength over time. 1RM, 1-repetition maximum; VO_{2peak}, peak oxygen consumption.

increased for the first 3 years of enrollment, and then in years 3-5.5, CRF declined at rates similar to the literature value.

Lowess smoother curves (not shown) were used to determine the trajectory of the change in 1RM chest press, seated back row, and knee extension. Both chest press and seated back row showed a linear decline over enrollment time. Table 4 presents mixed model results for these changes in 1RM chest press and seated back row using a random intercept model only. The rates of decline were lower, but not significantly different, compared with previously published rates[12,13] (chest press: −0.65 vs −2.36% per year, $P = 0.174$; seated back row: −0.55% per year vs −2.36% per year, $P = 0.161$) (see Fig. 3 and Table 5).

In contrast, a nonlinear change in knee extension strength was observed over time, expressed as a function of years-years[2] (Table 4 and Fig. 3). In this model, we identified a random intercept and random slope with an independent covariance structure. Knee extension strength showed an increase in the first 4 years of enrollment, followed by a decline at rates similar to those previously published[12,13] (Table 5).

Discussion

Our retrospective analysis of long-term CR demonstrates that enrollment in a structured maintenance-phase, exercise-focused CR program, with individualized exercise prescriptions and supervision by trained staff, is associated with improved trajectories of change in fitness compared with previously published rates of decline in men. These findings support the use of long-term exercise opportunities as strategies for secondary CVD risk prevention in this high-risk population of sedentary individuals.[3]

There is a strong body of evidence supporting short-term (≤12 months) enrollment in CR programs for increasing CRF[7,15,16] and skeletal muscle strength,[7,8,19,20] but a paucity of analogous research for long-term enrollment in CR programs. The lack of studies examining long-term CR may be attributed to the methodological challenges of conducting longitudinal research, but may also be a product of the barriers to CR service provision. Low physician referrals, lack of financial assistance, and lack of available and accessible programs in the community have been contributed to low enrollment in CR.[6] In fact, only 1 CR spot is available per 4.55 patients with heart disease,[21] and of the 20%-58% of eligible individuals who receive physician referrals,[22,23] only 34% actually enrol.[23] These low numbers in early CR can lead to even lower enrollment rates in maintenance-phase programs as fewer individuals can be followed over the long term. Consequently, there is little research available on longer term outcomes of these programs. With early CR typically lasting only 5 months,[6] the transition to maintenance-phase CR programs is critical for maintaining healthy, active lifestyles.

The current study offers novel insight into changes in CRF and skeletal muscle strength, which can help maintain healthy, active lifestyles after cardiovascular events. Specifically, we were able to identify nonlinear trajectories of change in some outcomes. We observed increases in CRF and lower body muscle strength (knee extension) for 3 and 4 years of program enrollment, respectively. These results suggest that the initial years of maintenance-phase CR programs may successfully counteract the expected age-related declines in fitness in individuals with CVD. It is known that cardiovascular and musculoskeletal system function diminishes with age, including reduced peripheral oxygen utilization and skeletal muscle oxidative capacity, diminished oxygen delivery due to reduced cardiac output and lower maximum heart rate,[24] and sarcopenia resulting in muscle fibre loss and atrophy, decreased testosterone, and increased catabolic hormones.[25] However, exercise can improve coronary artery

Table 3. Computed %/y changes in VO_{2peak} by enrollment time interval compared with calculated age-specific literature values (−2%/y)[11]

Time, y	Observed change, %/y	Literature value, %/y	*P* value
0-1	+3.23		< 0.001*
> 1-2	+1.73		< 0.001*
> 2-3	+0.33	−2	0.018*
> 3-4	−1.03		0.212
> 4-5.5	−2.59		0.298

VO_{2peak}, peak oxygen consumption.
* Indicates $P < 0.05$.

Table 4. Mixed model analysis on changes in muscle strength over 10 years of program members, after controlling for age (n = 70, 411 observations)

Fixed and random effects components from 0 to 10 years of enrolllment			
Chest press			
Fixed effects variables	β (SE)	95% CI	*P* value
IV: years	−0.448 (0.18)	−0.79, −0.10	0.011*
Covariate: baseline age	−1.21 (0.22)	−0.1.63, −0.80	< 0.001*
Constant	146 (13)	119, 173	< 0.001*
Random effects variance Components	Estimate (SE)	95% CI	
Intercept	203 (38)	141, 295	
Residual	94.0 (7.2)	81, 109	
Model fit statistics	Statistics		
−2 Log likelihood	−1604.8		
Bayesian information criteria	3245.6		
Seated back row			
Fixed variables	β (SE)	95% CI	*P* value
IV: years	−0.310 (0.15)	−0.61, −0.01	0.041*
Covariate: baseline age	−0.945 (0.17)	−1.28, −0.61	< 0.001*
Constant	116 (11)	94, 138	< 0.001*
Random effects variance Components	Estimate (SE)	95% CI	
Intercept	131 (24)	91, 190	
Residual	70.3 (5.4)	61, 82	
Model fit statistics	Statistics		
−2 Log likelihood	−1540.4		
Bayesian information criteria	3110.9		
Knee extension			
Fixed effects variables	β (SE)	95% CI	*P*-value
IV1: years	1.17 (0.41)	0.36, 1.98	0.007*
IV2: $years^2$	−0.177 (0.04)	−0.26, −0.09	< 0.001*
Covariate: baseline age	−0.960 (0.18)	−1.32, −0.60	< 0.001*
Constant	120 (12)	97, 143	< 0.001*
Random effects variance Components	Estimate (SE)	95% CI	
Intercept	151 (28)	104, 218	
Slope, y	0.67 (0.35)	0.25, 1.8	

CI, confidence interval; IV, independent variable; SE, standard error.
* Indicates $P < 0.05$.

blood flow and fitness[26,27] after CVD by reducing myocardial oxygen demand, which prevents the development of ischemia via decreased rate pressure product during physical exertion.[27] Exercise-related preservations in muscle strength may be due to improved protein turnover,[28] blood flow, and oxidative capacity of the working skeletal muscles and reduced endothelial dysfunction in skeletal muscle vasculature.[28]

Of note, this study is the first to report that the CRF increased nonlinearly up to 3 years of enrollment time. In contrast, Gayda et al.[18] used a pre-post design and reported a linear 2.2% per year decline in CRF. Arguably, the rate cited by Gayda et al. was underestimated as the initial 5.4% increase observed in the first year of their study was included in the overall calculation. The current study adds to this previous work by including a larger sample size, more CRF assessment time points using the superior method of peak oxygen uptake with indirect calorimetry, and using mixed model analyses to account for random effects estimates and nonlinear trajectories. Taken together, both of these studies suggest that it is important to use strategies to maintain exercise and physical activity behaviours in individuals with CVD over the long term.

The comparison rates for changes in fitness from the literature were from values observed in healthy adults,[11-13] as there are no established analogous rates available in CVD. We postulated that at minimum, these comparisons would be conservative, as individuals with CVD engage in less physical activity and thus are less fit than their non-CVD counterparts.[3] Emerging longitudinal evidence suggests no differences in CRF changes by physical activity level.[11,24,29]

The retrospective design of the current study prevented the examination causal links and insights to be gained through program attendance, adherence, and physical activity records as this information was not available. As a retrospective design, we were limited by the sample size and acknowledge that follow-up data for clinical events were not available. However, the dataset provided a high number of repeated observations, thereby permitting mixed model analyses, which were not possible in previous pre-post studies. The analysis allowed for identification of random effects and a method of modeling a more complete picture of the nonlinear changes over time, thus improving the interpretability and generalizability of the observations and conclusions.

This was the first study to report increases in both CRF and muscular strength during the first several years of long-term, maintenance-phase CR program enrollment in men, and subsequent rates of decline that were comparable to, or slower than, literature values. Prospective cohort studies are warranted to confirm the findings, identify potential mechanisms, and study the association between observed fitness changes in long-term CR and clinical outcomes.

Table 5. Computed %/y changes in 1-repetition maximum muscle strength outcomes compared with the calculated age-specific literature value (−2.36%/y)[12,13]

Time	Observed change, %/y	Literature value, %/y	*P* value
Chest press, y			
0-10	−0.65		0.174
Seated back row, y			
0-10	−0.56		0.161
Knee extension, y			
0-2	+1.40	−2.36	0.020*
> 2-4	+0.18		0.081
> 4-6	−1.00		0.227
> 6-8	−2.22		0.468
> 8-10	−3.58		0.251

* Indicates $P < 0.05$.

Disclosures

The authors have no conflicts of interest to disclose.

References

1. Moran AE, Forouzanfar MH, Roth GA, et al. The global burden of ischemic heart disease in 1990 and 2010: the Global Burden of Disease 2010 Study. Circulation 2014;129:1493-501.

2. Harvard School of Public Health: The global economic burden of non-communicable diseases. Available at: http://www3.weforum.org/docs/WEF_Harvard_HE_GlobalEconomicBurdenNonCommunicableDiseases_2011.pdf. Accessed January 24, 2017.

3. Kaasenbrood L, Boekholdt S, van der Graaf Y, et al. Distribution of estimated 10-year risk of recurrent vascular events and residual risk in a secondary prevention population. Circulation 2016;134:1419-29.

4. Kachur S, Chongthammakun V, Lavie CJ, et al. Impact of cardiac rehabilitation and exercise training programs in coronary heart disease. Prog Cardiovasc Dis 2017;60:103-14.

5. Anderson L, Oldridge N, Thompson D, et al. Exercise-based cardiac rehabilitation for coronary heart disease: Cochrane systematic review and meta-analysis. J Am Coll Cardiol 2016;67:1-12.

6. Taylor RS, Brown A, Ebrahim S, et al. Exercise-based rehabilitation for patients with coronary heart disease: systematic review and meta-analysis of randomized controlled trials. Am J Med 2004;116:682-92.

7. Sumide T, Shimada K, Ohmura H, et al. Relationship between exercise tolerance and muscle strength following cardiac rehabilitation: comparison of patients after cardiac surgery and patients with myocardial infarction. J Cardiol 2009;54:273-81.

8. Nishitani M, Shimada K, Masaki M, et al. Effect of cardiac rehabilitation on muscle mass, muscle strength, and exercise tolerance in diabetic patients after coronary artery bypass grafting. J Cardiol 2013;61:216-21.

9. Kodama S, Saito K, Tanaka S, et al. Cardiorespiratory fitness as a quantitative predictor of all-cause mortality and cardiovascular events in healthy men and women: a meta-analysis. JAMA 2009;301:2024-35.

10. Martin BJ, Arena R, Haykowsky M, et al. Cardiovascular fitness and mortality after contemporary cardiac rehabilitation. Mayo Clin Proc 2013;88:455-63.

11. Fleg JL, Morrell CH, Bos AG. Accelerated longitudinal decline of aerobic capacity in healthy older adults. Circulation 2005;112:674-82.

12. Artero EG, Lee DC, Lavie CJ, et al. Effects of muscular strength on cardiovascular risk factors and prognosis. J Cardiopulm Rehabil Prev 2012;32:351-8.

13. von Haehling S, Morley JE, Anker SD. An overview of sarcopenia: facts and numbers on prevalence and clinical impact. J Cachex Sarcopenia Muscle 2010;1:129-33.

14. Keller K, Engelhardt M. Strength and muscle mass loss with aging process. Age and strength loss. Muscle Ligaments Tendons J 2013;3:346-50.

15. Greco EM, Guardini S, Citelli L. Cardiac rehabilitation in patients with rate responsive pacemakers. Pacing Clin Electrophysiol 1998;21:568-75.

16. Sandercock G, Hurtado V, Cardoso F. Changes in cardiorespiratory fitness in cardiac rehabilitation patients: a meta-analysis. Int J Cardiol 2013;167:894-902.

17. Tucker WJ, Haykowsky MJ. Predictors of cardiorespiratory fitness improvements with cardiac rehabilitation: lower baseline fitness with the most to gain, gains the most. Can J Cardiol 2018;34:819-20.

18. Gayda M, Juneau M, Levesque S, et al. Effects of long-term and ongoing cardiac rehabilitation in elderly patients with coronary heart disease. Am J Geriatr Cardiol 2006;15:345-51.

19. Yamamoto S, Hotta K, Ota E, et al. Effects of resistance training on muscle strength, exercise capacity, and mobility in middle-aged and elderly patients with coronary artery disease: a meta-analysis. J Cardiol 2016;68:125-34.

20. Fragnoli-Munn K, Savage PD, Ades PA. Combined resistive-aerobic training in older patients with coronary artery disease early after myocardial infarction. J Cardiopulm Rehabil 1998;18:416-20.

21. Tran M, Pesah E, Turk-Adawi K, et al. Cardiac rehabilitation availability and delivery in Canada: how does it compare with other high-income countries. Can J Cardiol 2018;34(Suppl 2):S252-62.

22. Ndegwa S. Support Services for Cardiac Rehabilitation in Canada 2010: 1-8. Ottawa: Capital Guide Publishers, 2010.

23. Mazzini MJ, Stevens GR, Whalen D, et al. Effect of an American Heart Association Get With the Guidelines program-based clinical pathway on referral and enrollment into cardiac rehabilitation after acute myocardial infarction. Am J Cardiol 2008;101:1084-7.

24. Hakola L, Komulainen P, Hassinen M, et al. Cardiorespiratory fitness in aging men and women: the DR's EXTRA study. Scand J Med Sci Sport 2011;21:679-87.

25. Sharkley BJ, Gaskill SE, eds. Fitness and Health. 6th ed. Champaign, IL: Human Kinetics, 2007.

26. Bruning RS, Sturek M. Benefits of exercise training on coronary blood flow in coronary artery disease patients. Prog Cardiovasc Dis 2015;57:443-53.

27. Leon AS. Exercise following myocardial infarction: current recommendations. Sports Med 2000;29:301-11.

28. Hambrecht R, Gielen S, Linke A, et al. Effects of exercise training on left ventricular function and peripheral resistance in patients with chronic heart failure: a randomized trial. JAMA 2000;283:3095-101.

29. Stathokostas L, Jacob-Johnshon S, Petrella RJ, et al. Longitudinal changes in aerobic power in older men and women. J Appl Physiol 2004;97:781-9.