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ORIGINAL RESEARCH

Cardiovascular Health in Cardiac Rehabilitation: Applying the American Heart Association Life's Simple 7 Framework in a Center-Based Cohort

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BACKGROUND: Cardiac rehabilitation (CR) is a comprehensive secondary cardiovascular disease program with structured lifestyle interventions to reduce morbidity and mortality. The American Heart Association cardiovascular health (CVH) framework measures health-promoting behaviors and clinical factors, but it has not been rigorously evaluated in the CR setting.

METHODS: This retrospective cohort study analyzed patients attending CR from January 2018 to September 2020. Patients were evaluated at baseline (pre-CR) and completion (post-CR) using 3 clinical factors (blood pressure, cholesterol, and hemoglobin A1c) and 4 health behaviors (smoking, body mass index, physical activity, and diet). CVH score was computed as a composite of each Life's Simple 7 component by assigning 0 points for poor, 1 point for intermediate, or 2 points for ideal (range 0–14 points). CVH scores were further categorized as poor (0–6 points), intermediate (7–8 points), and ideal (9–14 points). Missing data in the analysis were accounted for using a multiple imputation procedure.

RESULTS: Patients (N=937) were aged 64.0±13.4 years old, 34% women, and attended 11±12 CR sessions. Pre-CR, 97.2% had poor CVH scores, 2.8% had intermediate scores, and none met ideal CVH criteria. Post-CR, there was a reduction in poor scores across all metrics except for hemoglobin A1c, which increased (40.6%–43.5%). Younger patients showed improvement in hemoglobin A1c, while older patients improved in body mass index and blood pressure.

CONCLUSIONS: Our study demonstrates the efficacy of CR in improving CVH but underscores the need for better blood glucose management. Tailored interventions based on age and sex may further optimize outcomes for CR participants.

Key Words: cardiac rehabilitation ■ cardiovascular health ■ health metrics ■ Life's Simple 7 ■ secondary prevention

Cardiac rehabilitation (CR) plays a crucial role in the recovery and long-term health of individuals with cardiovascular disease (CVD), offering a structured program that includes exercise training, education on heart-healthy living, and counseling to reduce stress and improve overall cardiovascular health (CVH).[1] By addressing the multifaceted needs of patients and promoting long-term cardiovascular wellness, CR represents a cornerstone of modern cardiovascular care, underscoring its significance in improving patient outcomes and reducing the burden of CVD worldwide.[2]

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CLINICAL PERSPECTIVE

What Is New?

- Cardiac rehabilitation improves overall cardiovascular health scores across multiple metrics, except for hemoglobin A1c.

What Are the Clinical Implications?

- Cardiac rehabilitation programs may need to incorporate targeted interventions for blood glucose management, particularly for hemoglobin A1c, to maximize comprehensive cardiovascular health improvement.
- Future research should explore tailored, age- and sex-specific interventions within cardiac rehabilitation to optimize blood glucose control and other cardiovascular health outcomes.

Nonstandard Abbreviations and Acronyms

AHA	American Heart Association
CR	cardiac rehabilitation
CVH	cardiovascular health
LS7	Life's Simple 7
PA	physical activity

Despite its benefits, older patients and women are less likely to participate in CR programs. For older individuals, factors such as physical frailty, comorbidities, and transportation challenges can impede participation. Women, on the other hand, may face unique barriers such as caregiver responsibilities, lower referral rates by health care providers, and a lack of awareness about the benefits of CR tailored to their specific health needs.[3–5]

In CR, preventive strategies including cardiovascular risk factor and lifestyle modification have become increasingly paramount. The American Heart Association (AHA) has long been at the forefront of promoting CVH and preventing CVD. One of their most significant initiatives is the Life's Simple 7 (LS7) framework, which outlines 7 health-promoting metrics. Introduced to track progress in reducing CVDs and enhancing overall well-being, the LS7 framework provides a clear guide to key health behaviors and factors crucial for maintaining CVH. These include managing blood pressure (BP), controlling cholesterol, reducing blood glucose, engaging in regular physical activity (PA), eating a healthy diet, maintaining a healthy weight, and avoiding smoking. Recently, the AHA has expanded this initiative by introducing Life's Essential 8, adding sleep health as a new critical component.[6] This expanded framework offers individuals a more comprehensive and actionable roadmap for achieving better CVH, while health care providers can use it to more effectively support their patients in reaching these vital CVH goals.[7,8]

At the same time, the updated AHA/American Association of Cardiovascular and Pulmonary Rehabilitation (AACVPR) Core Components of CR Scientific Statement[1] emphasizes a holistic approach to CVH by incorporating structured exercise training, dietary guidance, tobacco cessation counseling, psychosocial support, and risk factor management, including optimal BP, cholesterol, and glucose control. These components align closely with our use of the LS7 framework, which encompasses many of the same health behaviors and clinical risk factors.

Tailoring the CVH framework to individual patient capabilities may be essential to addressing their specific needs and risk factors. While this framework is invaluable for promoting CVH, its integration into CR programs is not without difficulties and requires substantial effort and resources from health care providers. CR patients often struggle with lifestyle changes attributable to various factors, such as psychological resistance (ie, unconsciously oppose changes when these changes are perceived as uncomfortable), lack of motivation, and preexisting unhealthy habits such as sedentarism or smoking habits.[9] Further, patients of lower socioeconomic backgrounds may face barriers such as limited access to healthy foods, safe exercise environments, and health care services.[10–13] Addressing these disparities is paramount for effectively promoting CVH in CR, necessitating a holistic approach beyond traditional medical care. Moreover, monitoring and evaluation are critical and thus, establishing effective metrics to assess the implementation and outcomes of CVH within CR is essential. This involves regularly tracking patient progress and adapting strategies to ensure sustained improvements in CVH, training health care professionals, ensuring continuity of care, and providing adequate support systems.

Previous research has consistently demonstrated that CR positively influences individual key aspects of CVH, including BP, cholesterol levels, blood glucose, smoking habits, exercise capacity, and diet.[14–18] However, the impact of CR on the conglomerate spectrum of CVH metrics has not been explored. This study aimed to examine the comprehensive effects of CR on all components of the LS7 framework in patients with CVD. Additionally, we investigated how sex and age may influence change in these metrics among those undergoing CR.

METHODS

Study Population

This is a retrospective cohort study of 937 adult patients (≥18 years old or older) who attended outpatient, phase II center-based CR from January 2018 to September 2020 at Mayo Clinic in Rochester, Minnesota. Admission diagnosis criteria included class I level A guideline-recommended cardiac and other related indications for CR[19] ST-segment elevation myocardial infarction (STEMI) and non–ST-segment elevation myocardial infarction (NSTEMI), heart failure, percutaneous coronary intervention, coronary artery bypass grafting surgery, rhythm devices, arrhythmias, valve replacement or repair surgery, peripheral artery disease, cardiac transplant, stable angina. The Mayo Clinic Institutional Review Board approved this study, and per Minnesota statute, only patients who had provided authorization to use their medical records for medical research were included. The data that support the findings of this study are available from the corresponding author (L.B.) upon reasonable request.

Cardiac Rehabilitation Program

The comprehensive outpatient CR program at Mayo Clinic follows the guidelines of the American Association of Cardiovascular and Pulmonary Rehabilitation.[20] Patients enrolled in this structured CR program typically attended 36 sessions over three 1-hour supervised sessions per week for 12 weeks. Each session included 20 to 45 minutes of structured cardio-aerobic exercise and 10 to 15 minutes of resistance training, individualized to the patient's physical capabilities and limitations. Patients were also encouraged to engage in at least 30 minutes of daily PA outside of the CR sessions. Additionally, the program provided guidance and education on the core components of CR, including social support networks, nutrition, medication management and adherence, stress management, and depressive symptom management.

Data Collection

Demographic, clinical, and behavioral data were extracted from electronic health records and CR program databases. Information collected included age, sex, race/ethnicity, medical history, cardiovascular risk factors, medication use, and attendance of CR sessions. CVH metrics (eg, smoking status, PA level, dietary habits, body mass index, BP, hemoglobin A1c [HbA1c], and lipid profile) were assessed before starting CR (pre-CR) and at completion (post-CR), with a mean time between measurements of 13.4±8.9 weeks.

Definition of Cardiovascular Health Metrics

Table 1 displays the definition of CVH components and corresponding metrics; however, modified definitions were used for fasting blood glucose and healthy diet score (Table 1). Instead of the proposed fasting blood glucose, HbA1c was used, which reflects average blood glucose levels over the past 2 to 3 months, providing a broader picture of blood glucose control over time. The "Rate Your Plate" dietary assessment is currently used as standard practice at the CR program at Mayo Clinic to evaluate dietary habits (Figure S1). Rate Your Plate is a user-friendly, self-administered tool designed to evaluate an individual's dietary habits and guide them toward healthier eating patterns.[21] This assessment involves a series of questions focusing on various aspects of diet, including the frequency and portion sizes of different food groups consumed, such as fruits, vegetables, grains, proteins, and fats. Participants rate their typical food choices and eating behaviors on a scale, allowing them to identify areas where their diet meets nutritional recommendations and areas needing

Table 1. Definition of American Heart Association Cardiovascular Health Metrics

Metrics	Categories		
	Ideal	Intermediate	Poor
Blood pressure (BP)	<120/80 mm Hg, without blood pressure-lowering medication	SBP 120–139 mm Hg or DBP 80–89 mm Hg or treated to <120/80 mm Hg	BP ≥140/90 mm Hg with or without treatment
Total cholesterol	<200 mg/dL without lipid-lowering medication	200–239 mg/dL or treated to <200 mg/dL	≥240 mg/dL
Blood glucose (HbA1c)	HbA1c <5.7% without glucose-lowering medication	HbA1c 5.7%–6.4% with or without glucose-lowering medication	HbA1c >6.4% with or without glucose-lowering medication
Smoking	Never smoker	Former smoker	Current smoker
Body mass index	<25 kg/m^2	25–29.9 kg/m^2	≥30 kg/m^2
Physical activity	≥150 min/wk	1–149 min/wk	No activity
Healthy diet (Rate Your Plate)	Rate Your Plate (64–81)	Rate Your Plate (46–63)	Rate Your Plate (27–45)

The American Heart Association definitions for ideal, intermediate, and poor health were used. Modified definitions applied for glucose (only HbA1c) and healthy diet (Rate Your Plate). BP indicates blood pressure; DBP, diastolic blood pressure; HbA1c, hemoglobin A1c; and SBP, systolic blood pressure.

improvement. By providing a straightforward and accessible way to assess dietary habits, Rate Your Plate facilitates personalized dietary feedback and promotes incremental changes toward a balanced, nutritious diet. This method focuses on the frequency and quality of food choices rather than precise nutrient quantities, making it accessible and practical for large-scale screenings. Studies have demonstrated its effectiveness in identifying dietary patterns and providing a basis for nutritional counseling.[21]

The CVH score was constructed by summing the number of ideal health components/metrics achieved, assigning 0 points for poor, 1 point for intermediate, or 2 points for ideal CVH (range 0–14 points). The total CVH score was further categorized as poor (0–6 points), intermediate (7–8 points), and ideal (9–14 points).

Statistical Analysis

Descriptive statistics were used to summarize the demographic, clinical, and behavioral characteristics of the study population. Categorical variables were presented as frequencies and percentages, while continuous variables were expressed as means ± SD. Missing data were determined to be significant for each of the 7 individual metrics. The proportion of patients who were missing observations at 1 or both time points varied from 35.8% (smoking status) to 83.5% (glucose), with most metrics >50% missing. Only 4.6% of patients had complete data where both "pre-CR" and "post-CR" values were present for all 7 metrics. To remedy this issue, missing values for the individual metrics, overall numeric CVH score, and CVH component category were imputed using the mice package in R.[22] A total of 20 imputations were run using proportional odds logistic regression to predict the ordered levels of each individual metric as well as the overall CVH component category and using predictive mean matching to predict the overall numeric CVH score. After completing the multiple imputations, the completed data sets were analyzed to test for an association between time (pre-CR/post-CR) and CVH metric using ordinal logistic regression with mixed effects to account for the time series nature of the data using a random term for patient ID in the models. Parameter estimates were then pooled over the results and combined using Rubin's rules and reported.

Subgroups analyses were completed for age, sex, and number of CR sessions attended. Each subgroup was analyzed separately to examine specific trends within subgroups. Similar analysis techniques were used as in the main cohort. This exploratory post hoc analysis was considered descriptive in nature and no adjustments were made for multiple comparisons.

To enhance the rigor and transparency of our methodology, we included additional details of the imputation procedure in Tables S1 and S2 provides a comprehensive summary of CVH metrics, highlighting the distribution of missing data across the data set and the subsequent imputed values generated to address these gaps. This robust approach aimed to ensure an unbiased estimation of population-level trends despite substantial missingness.[23–25] Additionally, given that the imputation analysis was dependent on the missing at random assumption, a sensitivity analysis was performed in order to explore alternate scenarios for the missing data. The analysis was performed by assigning a 15% chance of a one-level increase (delta shift) in each CVH metric for any imputed value, and a separate analysis was performed assigning a 15% chance of a 1-level downward shift (see Table S5).

P-values <0.05 were considered statistically significant. The analysis was performed using R version 4.2.2 (R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Baseline clinical characteristics, comorbid conditions, and CVH metrics of this study population are presented in Table 2. Mean age was 64.0±13.4 years, and 34.2% were women. Most (86.6%) patients were White. Prevalent traditional cardiovascular risk factors included hyperlipidemia (79.6%), hypertension (70.2%), and diabetes (47.4%). Half of the patients (51.3%) had a history of coronary artery disease. The top 3 indications for CR were percutaneous coronary intervention (35.5%), heart valve replacement or repair (15%), or coronary artery bypass grafting (14.7%). On average, patients attended 11.1±12.5 CR sessions.

CVH Metrics

Among the 937 study participants, 181 had complete pre-CR data to calculate a pre-CR overall CVH score. Of these 181 patients, the majority (97.2%) had poor overall CVH scores, while 2.8% had intermediate overall scores, and none met the ideal criteria for overall CVH score, as detailed in Table 3. Stratified analysis of CR session attendance (Table S3) revealed a dose–response relationship, with participants attending >24 sessions demonstrating the most significant improvements across CVH metrics compared with those attending fewer sessions.

Notably, reductions in the proportion of patients in the poor category were observed post-CR across most CVH components except HbA1c, which increased from 40.6% (201/495) to 43.5% (80/184). Changes in BP and body mass index were not statistically significant (*P*=0.478 and 0.549, respectively). The mean CVH score changed from 7.0±1.7 (n=181) pre-CR to 6.4±2.5 (n=126) post-CR (*P*=0.597), remaining within the intermediate range (Table 3). To provide context beyond the categorical framework, Table S4 presents continuous data for metrics such as BP, cholesterol, and HbA1c,

Table 2. Patient Sociodemographics, Comorbid Conditions, and Cardiovascular Health Metrics at Baseline in the Overall Cohort

	N=937
Age, mean±SD	64.0±13.4
Age, %	
18–64 y	53.3
≥65 y	46.7
Sex, %	
Male	65.8
Female	34.2
Race, %	
White	86.6
Black	2.6
Others	10.9
Marital status, %	
Married	65.2
Others	34.8
Education level, %	
<12th grade	10.4
≥12th grade	89.6
Comorbidities, %	
Hyperlipidemia	79.6
Hypertension	70.2
Coronary artery disease	51.3
Diabetes	47.4
Cardiac rehabilitation	
No. of sessions, mean±SD	11.1±12.5
Percent sessions attended, mean±SD	30.8±34.8
Cardiac rehabilitation indication, %	
Percutaneous coronary intervention	35.5
Open valve surgery (replacement, repair)	15.0
CABG	14.7
NSTEMI	6.5
Stable angina	6.4
Heart failure	6.4
Other	6.1
Heart transplant	4.5
TAVI/TAVR	4.2
STEMI	0.6
Cardiovascular health metrics, %	
Blood pressure, mm Hg (%)	
≥140/90	10.0
120–139/80–89 or treated to goal	81.6
<120/80 untreated	8.3
Total serum cholesterol, mg/dL (%)	
≥240	6.3
200–239 or treated to <200	93.1
<200 untreated	0.7
Hemoglobin A1c, %	
>6.4	40.6
5.7–6.4	28.9
<5.7 untreated	30.5
Smoking, %	
Current	7.6
Former	42.8
Never	49.6
Body mass index, kg/m^2 (%)	
≥30	49.7
25–29.9	33.0
<25	17.3
Physical activity, %	
No activity	7.7
1–149 min/wk	74.6
≥150 min/wk	17.7
Healthy diet, %	
Rate Your Plate score 27–45	13.8
Rate Your Plate score 46–63	75.6
Rate Your Plate score 64–81	10.7

CABG indicates coronary artery bypass grafting; NSTEMI, non–ST-segment elevation myocardial infarction; STEMI, ST-segment elevation myocardial infarction; and TAVI/TAVR, transcatheter aortic valve implantation/replacement.

offering additional insight into the modest but clinically relevant changes.

Given that the reported results are based on an imputation strategy that assumes data were missing at random, a sensitivity analysis was conducted to assess the robustness of findings under alternative assumptions. As presented in Table S5, this analysis demonstrated that 2 CVH metrics, BP and smoking, were particularly sensitive to variations in imputed values. For instance, BP metric, which was not statistically significant under the original model (P=0.478), became significant following a simulated one-level downward shift (P=0.004). Conversely, the smoking metric shifted from statistical significance (P=0.003) to nonsignificance (P=0.204) under a one-level upward adjustment. In contrast, metrics such as PA, healthy diet, and HbA1c demonstrated consistent robustness across all imputation scenarios. Further methodological details and complete sensitivity estimates are provided in the Methods and Supplemental sections.

CVH Metrics Across Age Groups

Table 4 provides a detailed subanalysis of CVH metrics before and after CR by age groups (younger group: ≤65 years old and older group: >65 years old). The metrics with the highest proportion of individuals classified as "poor" at the start of CR, regardless of age, were HbA1c (39.4% [104/264] in the younger group, 42.0% [97/231] in the older group), and body mass

Table 3. Cardiovascular Health Metrics from Pre- to Post-Cardiac Rehabilitation in the Overall Cohort

	Pre-CR (N=937)	Post-CR (N=937)	*P* value
Cardiovascular health metrics, n (%)			
Blood pressure			0.478
No. missing	11	399	
Ideal	77 (8.3)	44 (8.2)	
Intermediate	756 (81.6)	453 (84.2)	
Poor	93 (10.0)	41 (7.6)	
Total serum cholesterol			0.008
No. missing	346	557	
Ideal	4 (0.7)	2 (0.5)	
Intermediate	550 (93.1)	372 (97.9)	
Poor	37 (6.3)	6 (1.6)	
Hemoglobin A1c			<0.001
No. missing	442	753	
Ideal	151 (30.5)	49 (26.6)	
Intermediate	143 (28.9)	55 (29.9)	
Poor	201 (40.6)	80 (43.5)	
Smoking			0.002
No. missing	2	335	
Ideal	464 (49.6)	327 (54.3)	
Intermediate	400 (42.8)	258 (42.9)	
Poor	71 (7.6)	17 (2.8)	
Body mass index			0.549
No. missing	1	406	
Ideal	162 (17.3)	89 (16.8)	
Intermediate	309 (33.0)	188 (35.4)	
Poor	465 (49.7)	254 (47.8)	
Physical activity			<0.001
No. missing	445	434	
Ideal	87 (17.7)	276 (54.9)	
Intermediate	367 (74.6)	227 (45.1)	
Poor	38 (7.7)	0 (0.0)	
Healthy diet			<0.001
No. missing	94	481	
Ideal	90 (10.7)	103 (22.6)	
Intermediate	637 (75.6)	335 (73.5)	
Poor	116 (13.8)	18 (3.9)	
Cardiovascular health score			
No. missing	756	811	0.006
Ideal	0 (0.0)	11 (8.7)	
Intermediate	5 (2.8)	10 (7.9)	
Poor	176 (97.2)	105 (83.3)	
No. missing	756	811	0.597
Mean±SD)	7.0±1.7	6.4±2.5	
Range	2.0–12.0	0.0–11.0	

CR indicates cardiac rehabilitation.

index (51.5% [257/499] in the younger group, 47.6% [208/437] in the older group). Across younger patients, there was a lower proportion of patients classified in the poor CVH category post-CR compared with pre-CR in some metrics, such as smoking (3.6% [11/304] versus 10.7% [53/497], *P*=0.001), PA (0.0% [0/240] versus 9.1% [25/275], *P*<0.001), and healthy diet (5.8% [12/207] versus 16.4% [71/432], *P*<0.001). In contrast, the older group showed meaningful improvements (as judged by the same criteria) in BP (7.7% [21/274] versus 13.7% [59/432], *P*=0.122), PA (0% [0/263] versus 6.0% [13/217], *P*<0.001), and healthy diet (2.4% [6/249] versus 10.9% [45/411], *P*<0.001) metrics.

CVH Metrics in Patients Across Sex

Table 5 provides a detailed subanalysis of CVH metrics before and after CR by sex. There was a lower proportion of female and male patients classified in the poor CVH category post-CR compared with pre-CR in some metrics such as cholesterol (women 2.5% [3/119] versus 9.5% [18/190], *P*=N/A; men 1.1% [3/261] versus 4.7% [19/401]; *P*=0.056), PA (women 0.0% [0/181] versus 8.2% [13/158], *P*<0.001; men 0.0% [0/322] versus 7.5% [25/334], *P*<0.001) and healthy diet (women 0.0% [0/156] versus 8.4% [24/284], *P*<0.001; men 6.0% [18/300] versus 16.5% [92/558], *P*<0.001). After participation in CR, improvements in smoking habits were observed in both sexes; however, only the male group was statistically significant (2.8% [11/396] versus 8.0% [40/615], *P*=0.011).

DISCUSSION

Our retrospective cohort study involving 937 patients provides insights on the effectiveness of CR programs in improving CVH metrics. Most participants (97.2%) initially had poor CVH scores, with only a small fraction (2.8%) presenting with intermediate scores. None of the participants met the ideal criteria across all 7 components of CVH metrics. Our results demonstrated significant improvements in CVH scores after CR participation. Notably, there was a reduction in the proportion of patients classified within the poor category for each CVH metric, except HbA1c levels, which remained unchanged. This indicates that CR effectively enhanced various aspects of CVH, though managing HbA1c remained challenging. These improvements underscore the potential of structured CR programs to facilitate meaningful progress in patients' CVH, moving them from poor to better CVH categories. Despite the overall positive trend, the persistent difficulty in improving HbA1c levels suggests a need for targeted interventions focusing specifically on blood glucose management within the context of CR. Programs may benefit from integrating specialized strategies to tackle this aspect more effectively, ensuring a more holistic improvement in CVH outcomes for patients.

While prior research has consistently shown that CR positively affects specific CVH components,[26,27]

Table 4. Cardiovascular Health Metrics from Pre- to Post-Cardiac Rehabilitation by Age Group

	Age ≤65y			Age >65y		
	Pre-CR (N=499)	Post-CR (N=499)	*P* value	Pre-CR (N=438)	Post-CR (N=438)	*P* value
Cardiovascular health metrics, n (%)						
Blood pressure			0.693			0.122
No. missing	5	235		6	164	
Ideal	61 (12.3)	32 (12.1)		16 (3.7)	12 (4.4)	
Intermediate	399 (80.8)	212 (80.3)		357 (82.6)	241 (88.0)	
Poor	34 (6.9)	20 (7.6)		59 (13.7)	21 (7.7)	
Total serum cholesterol			N/A*			0.069
No. missing	173	323		173	234	
Ideal	1 (0.3)	1 (0.6)		3 (1.1)	1 (0.5)	
Intermediate	299 (91.7)	170 (96.6)		251 (94.7)	202 (99.0)	
Poor	26 (8.0)	5 (2.8)		11 (4.2)	1 (0.5)	
Hemoglobin A1c			0.001			0.009
No. missing	235	421		207	332	
Ideal	88 (33.3)	21 (26.9)		63 (27.3)	28 (26.4)	
Intermediate	72 (27.3)	27 (34.6)		71 (30.7)	28 (26.4)	
Poor	104 (39.4)	30 (38.5)		97 (42.0)	50 (47.2)	
Smoking			0.001			0.116
No. missing	2	195		0	140	
Ideal	256 (51.5)	176 (57.9)		208 (47.5)	151 (50.7)	
Intermediate	188 (37.8)	117 (38.5)		212 (48.4)	141 (47.3)	
Poor	53 (10.7)	11 (3.6)		18 (4.1)	6 (2.0)	
Body mass index			0.332			0.909
No. missing	0	243		1	163	
Ideal	90 (18.0)	46 (18.0)		72 (16.5)	43 (15.6)	
Intermediate	152 (30.5)	77 (30.1)		157 (35.9)	111 (40.4)	
Poor	257 (51.5)	133 (52.0)		208 (47.6)	121 (44.0)	
Physical activity			<0.001			<0.001
No. missing	224	259		221	175	
Ideal	54 (19.6)	148 (61.7)		33 (15.2)	128 (48.7)	
Intermediate	196 (71.3)	92 (38.3)		171 (78.8)	135 (51.3)	
Poor	25 (9.1)	0 (0.0)		13 (6.0)	0 (0.0)	
Healthy diet			<0.001			<0.001
No. missing	67	292		27	189	
Ideal	46 (10.6)	51 (24.6)		44 (10.7)	52 (20.9)	
Intermediate	315 (72.9)	144 (69.6)		322 (78.3)	191 (76.7)	
Poor	71 (16.4)	12 (5.8)		45 (10.9)	6 (2.4)	
Cardiovascular health score			0.555			0.863
No. missing	398	439		358	372	
Mean±SD	6.8±1.8	6.0±2.8		7.3±1.7	6.7±2.2	
Range	2.0–10.0	0.0–11.0		4.0–12.0	1.0–11.0	

CR indicates cardiac rehabilitation.
*Model did not converge.

comprehensive evaluations of the impact of CR on the full spectrum of CVH metrics are limited. Our results are both confirmatory and novel. This is particularly important in the context of secondary prevention of CVD, where the goal is not just to prevent recurrence but to improve overall CVH and quality of life.

The overall improvement in CVH metrics was expected based on existing literature. CR typically involves structured PA, dietary counseling, and lifestyle education, all of which are known to contribute to better cardiovascular outcomes. PA improves cardiovascular fitness, lowers BP, and enhances lipid profiles,

Table 5. Cardiovascular Health Metrics from Pre- to Post-Cardiac Rehabilitation by Sex

	Women			Men		
	Pre-CR (N=320)	Post-CR (N=320)	*P* value	Pre-CR (N=617)	Post-CR (N=617)	*P* value
Cardiovascular health metrics, n (%)						
Blood pressure			0.735			0.263
No. missing	9	125		2	274	
Ideal	31 (10.0)	13 (6.7)		46 (7.5)	31 (9.0)	
Intermediate	242 (77.8)	162 (83.1)		514 (83.6)	291 (84.8)	
Poor	38 (12.2)	20 (10.3)		55 (8.9)	21 (6.1)	
Total serum cholesterol			N/A*			0.056
No. missing	130	201		216	356	
Ideal	1 (0.5)	0 (0.0)		3 (0.7)	2 (0.8)	
Intermediate	171 (90.0)	116 (97.5)		379 (94.5)	256 (98.1)	
Poor	18 (9.5)	3 (2.5)		19 (4.7)	3 (1.1)	
Hemoglobin A1c			0.010			0.001
No. missing	146	257		296	496	
Ideal	55 (31.6)	15 (23.8)		96 (29.9)	34 (28.1)	
Intermediate	50 (28.7)	20 (31.7)		93 (29.0)	35 (28.9)	
Poor	69 (39.7)	28 (44.4)		132 (41.1)	52 (43.0)	
Smoking			0.065			0.011
No. missing	0	110		2	225	
Ideal	190 (59.4)	134 (63.8)		274 (44.6)	193 (49.2)	
Intermediate	108 (33.8)	70 (33.3)		292 (47.5)	188 (48.0)	
Poor	22 (6.9)	6 (2.9)		49 (8.0)	11 (2.8)	
Body mass index			0.396			0.870
No. missing	0	124		1	282	
Ideal	68 (21.2)	33 (16.8)		94 (15.3)	56 (16.7)	
Intermediate	73 (22.8)	57 (29.1)		236 (38.3)	131 (39.1)	
Poor	179 (55.9)	106 (54.1)		286 (46.4)	148 (44.2)	
Physical activity			<0.001			<0.001
No. missing	162	139		283	295	
Ideal	22 (13.9)	81 (44.8)		65 (19.5)	195 (60.6)	
Intermediate	123 (77.8)	100 (55.2)		244 (73.1)	127 (39.4)	
Poor	13 (8.2)	0 (0.0)		25 (7.5)	0 (0.0)	
Healthy diet			<0.001			<0.001
No. missing	35	164		59	317	
Ideal	39 (13.7)	41 (26.3)		51 (9.1)	62 (20.7)	
Intermediate	222 (77.9)	115 (73.7)		415 (74.4)	220 (73.3)	
Poor	24 (8.4)	0 (0.0)		92 (16.5)	18 (6.0)	
Cardiovascular health score			0.307			0.900
No. missing	262	284		494	527	
Mean±SD	7.0±1.7	6.3±2.4		7.0±1.8	6.4±2.6	
Range	3.0–11.0	0.0–11.0		2.0–12.0	1.0–11.0	

CR indicates cardiac rehabilitation; and HbA1c, hemoglobin A1c.
*Model did not converge.

while dietary interventions help reduce body weight and improve nutritional status.[28,29] The psychological support provided during CR can also reduce stress and improve overall well-being, further contributing to better health outcomes.[30]

However, our study contributes new insights by examining a more comprehensive range of CVH metrics, including HbA1c levels, and by highlighting the specific challenge of improving HbA1c through CR. The persistence of poor HbA1c levels despite other improvements was somewhat unexpected. This finding suggests that while CR is effective in enhancing most aspects of CVH, it may not be sufficient in addressing the complexities of HbA1c management.

Prior studies support this observation. A study by Tatulashvili et al found that despite the overall benefits of CR on cardiovascular risk factors, HbA1c levels often remain stubbornly high, indicating the need for more targeted interventions in glycemic control.[31] Another study highlighted that increased HbA1c variability is strongly associated with adverse cardiovascular outcomes, regardless of whether patients are at glycemic targets or not, emphasizing the challenge of managing blood glucose levels effectively even with intensive CR programs.[32] Additionally, the ACCORD (Action to Control Cardiovascular Risk in Diabetes study demonstrated that patients with higher HbA1c variability faced significantly higher risks of cardiovascular events. This suggests that current CR programs might need to incorporate more specialized strategies to effectively manage blood glucose levels, potentially in partnership with endocrinology care teams.[33] This is especially important given that close to 50% of CR patients within our study have a diagnosis of type 2 diabetes and nationally the prevalence has been estimated as high as 30% among older adult patients.[34]

To provide a deeper understanding of changes that are not captured by categorical frameworks, we included continuous metrics in our analysis. Table S4 highlights these findings, demonstrating significant reductions in mean total cholesterol levels from 162.8 mg/dL at intake to 141.9 mg/dL at discharge (P<0.001), as well as substantial improvements in PA, with mean exercise duration increasing from 101.7 to 171.8 minutes/week (P<0.001). Although these changes may not correspond to shifts in categorical classifications, they are clinically meaningful and underscore the importance of continuous data in providing a more detailed and nuanced evaluation of the impact of CR on CVH outcomes.

The limited improvement in HbA1c levels among CR patients likely reflects both programmatic and patient-related factors. The American Diabetes Association identifies HbA1c as a primary screening tool for glucose metabolism disorders,[35] as it reflects average glucose levels over the preceding 2 to 3 months. However, this temporal scope restricts its sensitivity to detect significant changes during the typical 12-week CR program, which aligns with the mean duration in our study (13.4±8.9 weeks). Participants with shorter program durations or higher baseline HbA1c levels may require more intensive or tailored interventions to achieve meaningful improvements.

Our findings underscore the complexity of managing glucose metabolism within standard CR frameworks and highlight the need for targeted, multidisciplinary approaches. Strategies could include closer collaboration with endocrinologists, incorporation of continuous glucose monitoring technologies, and widespread use of novel pharmacological agents such as sodium-glucose cotransporter-2 (SGLT2) inhibitors and glucagon-like peptide-1 receptor agonists, which offer both glycemic and cardiovascular benefits.[35,36] Furthermore, continued research is essential to enhance CR protocols and optimize metabolic outcomes in this patient population.

Our subanalysis across different age groups revealed that younger patients exhibited significant improvements in several CVH metrics, including HbA1c. In contrast, the older cohort showed considerable progress in other metrics, though glucose control remained unchanged. Similar results were described by Pavasini et al[37] and later by our team.[38] Moreover, CR participants irrespective of sex also demonstrated significant improvements in cholesterol levels, PA, and healthy diet, with a substantial number of individuals transitioning from poor to intermediate or ideal CVH categories after CR participation. These outcomes align with findings from previous studies, which have consistently highlighted the broad efficacy of CR in enhancing various health metrics across diverse patient populations.[28,39] These findings highlight the efficacy of CR in addressing sex- and age-specific challenges and enhancing various aspects of CVH. The differential impact observed between sex and age groups underscores the need for tailored CR interventions that cater to the distinct needs of each demographic, thereby optimizing health outcomes across the lifespan.

Regarding CVH, our findings revealed a slight but not statistically significant decline in CVH after CR, despite individual improvements in specific CVH components. Although unexpected, these results are consistent with previous studies. For example, Lieu et al reported that stroke survivors did not experience improvements in CVH attributable to secondary prevention measures, and instead, they observed a significant decline over a 4-year follow-up period despite intensified efforts. Similarly, an analysis by Enserro et al[40] analyzed 20-year trends in the AHA CVH score. The researchers found a significant decline in ideal CVH scores over time, primarily because of worsening trends in body mass index, BP, cholesterol, and blood glucose levels. Lower CVH scores were linked to an increased risk of both subclinical and clinical CVD, highlighting the importance of maintaining ideal CVH metrics to prevent future cardiovascular events. These trends, observed by other researchers as well,[41] could help explain our findings, particularly as we encountered significant challenges in managing blood glucose among our patient population. Furthermore, evidence from diverse populations indicates that, despite public health efforts, overall CVH scores have not significantly improved. These studies suggest that socioeconomic disparities, age, and lifestyle factors, including income and education levels, contribute to this stagnation, highlighting the need for targeted interventions to achieve meaningful changes at the individual level.[42–44]

In summary, our findings support the updated AHA/AACVPR core components of CR,[1] demonstrating the effectiveness of CR in improving CVH metrics across a range of measures, including PA, dietary habits, and lipid profiles. These improvements align with the established benefits of structured, multidisciplinary CR interventions that target lifestyle modifications as a cornerstone of CVH. However, our results also accentuate areas requiring further focus, particularly the persistent challenge of managing blood glucose levels. The lack of improvement in HbA1c metrics highlights the complexity of addressing glucose metabolism within the standard CR framework. This finding emphasizes the importance of tailored, multifaceted strategies to glycemic control, which could include enhanced collaborative care with endocrinology teams, the incorporation of continuous glucose monitoring, or the use of advanced therapeutic interventions. By addressing these gaps, CR programs can better align with the call of the updated core components of CR for personalized strategies to optimize patient outcomes, ensuring a more comprehensive impact on overall CVH. The inclusion of complementary markers such as fasting glucose or oral glucose tolerance test in future studies may better capture short-term glucose metabolism changes. We emphasize the need for further research into refining glucose assessment in CR populations, where traditional HbA1c measurements may not align with the relatively short intervention duration.

One key point to acknowledge is that while our findings demonstrate that LS7 is an excellent tool for assessing CVH, it may not apply uniformly across all populations, particularly those participating in CR. The specific characteristics and treatment regimens of CR patients, such as the common use of guideline-directed pharmacologic therapies, may necessitate adjustments or alternative scoring models. Furthermore, the lack of sufficient data on the validity and applicability of LS7 in the CR setting underscores the need for further research to refine and adapt this tool to better reflect CVH in these patients.

STRENGTHS AND LIMITATIONS

This large population-based study provides clinically relevant insight into the characteristics of nearly a thousand patients participating in CR. All data have been automatically collected and analyzed with limited opportunity for operator error. While prior studies have demonstrated the benefits of CR, they typically focus on isolated CVH components without providing a comprehensive analysis across all metrics. This narrow focus has left gaps in our understanding of the broader impact of CR. Our study addresses these limitations by offering a more comprehensive evaluation of the effects of CR on all CVH metrics, revealing not only its positive impact on traditional metrics but also its shortcomings in areas like HbA1c.

Our results revealed that age disparities exist in CVH metrics, with exacerbated differences noted by a lack of improvement in some metrics, including BP and cholesterol in younger patients. Our insights provide opportunities to explore areas in CR for improvement to promote equitable CVH.[45] These findings are crucial for clinicians, CR program administrators, and patients, highlighting the importance of a personalized approach in CR programs to enhance health outcomes for those at high risk of CVD.

There are several methodological factors to consider when interpreting our findings. First, the retrospective design of our study introduces potential biases; however, every effort was made to mitigate these during our analysis. To address selection bias, we implemented several strategies. We included a broad and diverse population of patients referred to CR, regardless of their baseline characteristics, comorbidities, or socioeconomic status. Selection bias could still be an issue, as our study only included patients who participated in CR at a single center. This may affect the generalizability of our results but not their internal validity.

Missing data may also impact the robustness and generalizability of our findings. Missing data within our data set arose from patient nonresponses or lack of collection of specific assessments (eg, diet, glucose, PA levels, etc) leading to potential biases and reduced statistical power. Our results should be interpreted with caution because of the potential impact of limited power in detecting small but clinically meaningful differences. We used multiple imputations to address missing data, which may overcome bias that could be introduced by excluding patients with incomplete data, but the amount of missing data was large and the analysis is dependent on the assumption that the missing data is missing at random. Sensitivity analysis (Table S5) showed that model results for some CVH metrics (BP, smoking) were sensitive to a 15% chance that an imputed value was increased or decreased by one level, which provides additional evidence that these results should be interpreted with caution. Despite these efforts, we acknowledge that residual selection bias may remain, as patients who complete CR or attend more sessions may systematically differ from those who do not. While we employed statistical methods to address missing values, such as imputation techniques, the inherent uncertainty associated with missing data remains a challenge for large retrospective studies.

Future research should aim to minimize missing data by implementing more rigorous data collection and management practices to enhance the reliability and validity of study outcomes. Lastly, the population in Olmsted County is predominantly White, meaning our cohort lacks the diversity found in other geographic areas. However, Olmsted County residents' epidemiological characteristics and mortality rates have been well-documented and are comparable to those of the broader United States.[46]

CONCLUSIONS

Our study demonstrates the efficacy of CR programs in improving CVH across multiple domains. While younger patients showed more significant improvement in glycemic control, older patients benefited more in weight reduction and BP management. However, the persistent poor HbA1c levels post-CR indicate a need for enhanced focus on blood glucose management. Tailored interventions considering age- and sex-specific responses could further optimize the outcomes of CR programs. Our study highlights the critical areas where CR programs succeed and where they need to evolve, ensuring better health outcomes for all patients regardless of age and sex.

ARTICLE INFORMATION

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Disclosures

None.

Supplemental Material

Tables S1–S5
Figure S1

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