From effort intolerance to functional gain: double product and exercise response in heart failure rehabilitation

Carolina Castro Gómez[1A,B,D,F], Andrea Valencia-Orozco[2A,C,F], Helen Johana Ortiz Rojas[2B,C,E,F], Daniela López Gómez[3A,B,E], Harold Andrés Payán-Salcedo[*4D,E,F]

[1] Fundación Valle del Lili, Physical Medicine and Rehabilitation, Cardiac Rehabilitation Area , Cali, Colombia
[2] Fundación Valle del Lili, Clinical Research Center, Cali, Colombia
[3] Universidad del Valle, Faculty of Humanities, School of Literary Studies, Cali, Colombia
[4] Universidad del Valle, Faculty of Humanities, School of Literary Studies, Cali, Colombia

*** Corresponding author:** Harold Andrés Payán-Salcedo; Research Coordinator, Faculty of Health, Universidad Santiago de Cali, Cali, Colombia; e-mail: Haroldpayan00@usc.edu.co

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ABSTRACT

Introduction: Heart failure (HF) is associated with exercise intolerance, functional decline and frequent hospitalization. Although cardiac rehabilitation (CR) improves functional capacity, the double product (DP) remains a relevant marker of hemodynamic response.

Methods: This retrospective observational study included 79 patients older than 60 years with HF, who completed an outpatient CR program between 2017 and 2023. Functional capacity was assessed with the 6-minute walk test (6MWT) at baseline and after Phase IV, including distance walked, estimated VO_2 and metabolic equivalents (METs). DP and the rating of perceived exertion (RPE) were assessed during sessions across Phases II–IV. Baseline and final 6MWT changes were analyzed using the Wilcoxon signed-rank test, and DP with repeated-measures analysis of variance.

Results: Most participants were male (63.3%) and had a high comorbidity burden, mainly hypertension (62%), coronary heart disease (57%) and sedentary lifestyle (55.7%). Significant improvements were observed between baseline and final 6MWT assessments: distance increased from 419 m to 523 m, estimated VO_2 from 10.5 mL/kg/minute to 12.2 mL/kg/minute and METs from 3.0 to 3.5 ($p < 0.001$). RPE increased slightly from 11 to 12 ($p = 0.003$). DP showed no overall differences across phases ($p = 0.600$), but significant effects of time and phase-by-time interaction were found (both $p < 0.001$). No significant change was observed in Phase II, whereas significant increases occurred in Phases III and IV.

Conclusion: CR was associated with improved functional capacity in patients with HF. DP changes varied across phases and may help monitor exercise response. Controlled prospective studies are needed to confirm causality.

Keywords: cardiac rehabilitation, heart failure, rehabilitation, walk test

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INTRODUCTION

Heart failure (HF) is a clinical syndrome that represents one of the leading causes of morbidity, mortality and hospitalization worldwide. Its burden is especially significant in the low- and middle-income countries, leading to worse clinical outcomes and increased healthcare costs. Despite therapeutic advances, HF continues to be associated with high rates of rehospitalization and functional decline, highlighting the need to implement effective comprehensive management strategies[1,2].

In this context, cardiac rehabilitation (CR) has become established as a cost-effective intervention supported by scientific evidence and has been associated with improved clinical outcomes, including greater functional capacity and lower rates of hospitalization and mortality in select patient populations[2–6], enabling progressive functional recovery through supervised training, education and management of cardiovascular risk factors[3–7].

Among the parameters used for exercise assessment and prescription in this setting, the double product (DP), defined as the product of heart rate (HR) and systolic blood pressure (SBP), has been widely recognized as an indirect marker of myocardial oxygen consumption and cardiac workload. In patients with HF, this indicator has demonstrated clinical utility for evaluating the hemodynamic response to exercise and its relationship to functional capacity, particularly during tests such as the 6-minute walk test (6MWT) within CR programs[8]. Its clinical utility lies in its non-invasive nature and its ability to reflect myocardial stress during exercise, making it a relevant tool for risk stratification in patients[9,10]. Furthermore, the DP has been used to establish safe exercise limits and as a prognostic indicator in stress tests and cardiovascular training programs[10,11].

Despite its widespread application in clinical settings, recent evidence suggests that the interpretation of DP can be influenced by multiple clinical and contextual factors, including the duration of CR programs, the type of intervention and the characteristics of the population studied[12]. In this sense, a gap is identified in the literature regarding the role of DP and its relationship with functional capacity as a marker of adaptation to exercise in real clinical scenarios, especially in contexts of ambulatory CR.

Therefore, the present study aims to evaluate the behavior of functional recovery and DP response after CR in patients with HF.

MATERIALS AND METHODS

Study design

This is a retrospective observational study. The study was reported in accordance with the Reporting of studies Conducted using Observational Routinely-collected health data (RECORD) guidelines.

Data source and patient identification

Patient data were obtained from the electronic medical records of a fourth-level complexity clinic in Cali, Colombia. Patients with HF who attended the CR Program between 2017 and 2023 were identified from the institutional records of the program. Eligible patients were selected according to the predefined inclusion and exclusion criteria. Clinical and sociodemographic information was subsequently extracted from the patients' medical records using the institutional information systems.

Participant selection and description

Based on institutional records, a total of 210 patients with HF who attended the outpatient CR program were initially identified. Of these, 83 patients were excluded based on pre-established exclusion criteria, such as incomplete records (n = 15) and failure to complete the CR program (n = 68). The remaining 127 patients were considered potentially eligible. Subsequently, 48 patients were excluded for being under 60 years of age. Consequently, 79 patients met the eligibility criteria and were included in the study's final cohort. The inclusion criteria were: age 60 years or older, a medical diagnosis of HF, complete records of the 6MWT at both the beginning and end of treatment, and completion of the 36-session outpatient CR program.

Data access and data cleaning

The institution authorized access to electronic medical records. The integrity and consistency of the data were reviewed and in duplicate, or incomplete records were identified and excluded in accordance with the study criteria.

Ethical considerations

The study protocol (Protocol No. 2024.238) was approved on 18 September 2024, by the Biomedical Research Ethics Committee of Fundación Valle del Lili. The study was conducted in accordance with the ethical guidelines of the Declaration of Helsinki (2013). As this was a retrospective observational study involving analysis of historical medical records, the Ethics Committee granted an exemption from the informed consent requirement, ensuring that the research did not pose a physical or moral risk to the subjects. To protect confidentiality and privacy, all subjects were anonymized from the moment of data collection, with each patient assigned a sequential numerical code and any personally identifiable information removed, in compliance with data protection and confidentiality regulations.

Measurements

Patients who performed the 6MWT as a submaximal exercise test to assess functional capacity and exercise tolerance in patients with HF were recorded. This test measures the maximum distance a person can walk continuously for 6 minutes on a predetermined, flat surface 30 m long[13]. During this test, physiological parameters including HR, SBP, diastolic blood pressure (DBP) and oxygen saturation (SpO2) were recorded at both the beginning and end of CR. Measurements were taken using the NIHON KOHDEN OPV-1500K monitor. Estimated oxygen consumption (VO_2), metabolic equivalents (METs) and the distance covered in the 6MWT were assessed before and after CR therapy. Additionally, the subjective perception of exertion was recorded using the rating of perceived exertion (RPE)[6].

The 6MWT was performed on two occasions: at baseline (Phase II) and after completing Phase IV (36 sessions), in accordance with the institutional protocol.

Calculation of the DP

The DP measurements were **not derived from the 6MWT. I**nstead, DP was calculated from physiological measurements obtained during the daily supervised CR training sessions in Phases II–IV. For each phase, an initial and final DP were calculated using average HR and SBP values obtained at two specific points during the exercise sessions: (1) before starting the exercise, at rest and (2) immediately after completing the main training phase, representing peak physical exertion.

Data from daily training sessions were used instead of those obtained during the 6MWT, due to the short duration of the latter. By contrast, the supervised training sessions lasted 1 hour, providing a much more representative and robust timeframe and hemodynamic stimulus for evaluating DP behavior across the 12, 24 and 36 sessions.

The DP—calculated as HR × SBP (bpm × mmHg)—was measured at two time points during each session: at rest (after 5 minutes of sitting, prior to the warm-up) and immediately following the main training phase (within a 30- to 60-second interval). Rehabilitation staff (a physiotherapist specializing in CR and a trained nursing assistant) recorded physiological parameters (HR, SBP, DBP and SpO_2) using the Nihon Kohden OPV-1500K monitor, in accordance with institutional protocols and clinical quality standards. Medication intake was not documented.

CR program

The outpatient CR program consisted of three phases (II–IV)[3,14], each comprising 12 sessions. These began with a medical evaluation performed by a physiatrist—including an initial electrocardiogram—followed by an assessment by a physical therapist specializing in CR. This professional measured vital signs (SBP, DBP, HR, SpO_2) and evaluated functional capacity using the 6MWT, applying the 2002 American Thoracic Society (ATS)[15] reference values and recording results in the institutional system, which automatically applied Troosters' formulas. The estimated VO_2 and METs were calculated based on the distance covered during the 6MWT. Following American College of Sports Medicine guidelines (ACSM)[16,17], velocity (V = distance/6 minutes) was entered into the equation estimated as $VO_2 = (0.1 \times V) + 3.5$, and METs were calculated as estimated $VO_2/3.5$. The program followed the frequency, intensity, type of exercise, time (FITT) model, approved by the rehabilitation coordination team and documented in institutional records, thereby ensuring compliance with quality and accreditation standards. Exercise intensity was determined using RPE of 6–20 (without using HR, as the effect of beta-blockers was not taken into account), and sessions were structured in three stages: warm-up (joint mobility exercises); main phase (functional limb exercises using colour-coded Theraband resistance bands—yellow for Phase II, green for Phase III and red for Phase IV—followed by work on aerobic machines such as treadmills, stationary bikes and ellipticals, with intensity progressively adjusted based on RPE; and cool-down (breathing, circulation and stretching exercises). Each 1-hour session accommodated groups of up to six patients under the supervision of a CR physiotherapist and a trained nursing assistant, and included personalized equipment set-up as well as calibrated monitoring at the beginning and end of each session.

Statistical analysis

Continuous variables were summarized using the median and interquartile range (IQR), and categorical variables using frequencies and percentages. The distribution of intra-individual changes was evaluated graphically using the Shapiro–Wilk test. Paired comparisons were performed using the Wilcoxon signed-rank test, reporting the median change with IQR and a 95% confidence interval (95% CI) obtained via percentile bootstrap with 10,000 resamples, and the biserial correlation of ranks as a measure of effect size. DP was analyzed using a two-way ANOVA with repeated measures (phase × time point), with Greenhouse-Geisser correction and partial eta-squared ($\eta^2 p$) as a measure of effect size. Multiple comparisons were adjusted using

the Holm method. No data imputation was performed. Analyses were restricted to participants aged 60 years or older; two-tailed tests were used and a p-value <0.05 was considered statistically significant. Analyses were performed in R 4.5.1, using RStudio 2026.09.0+174.

RESULTS

Participant selection flow

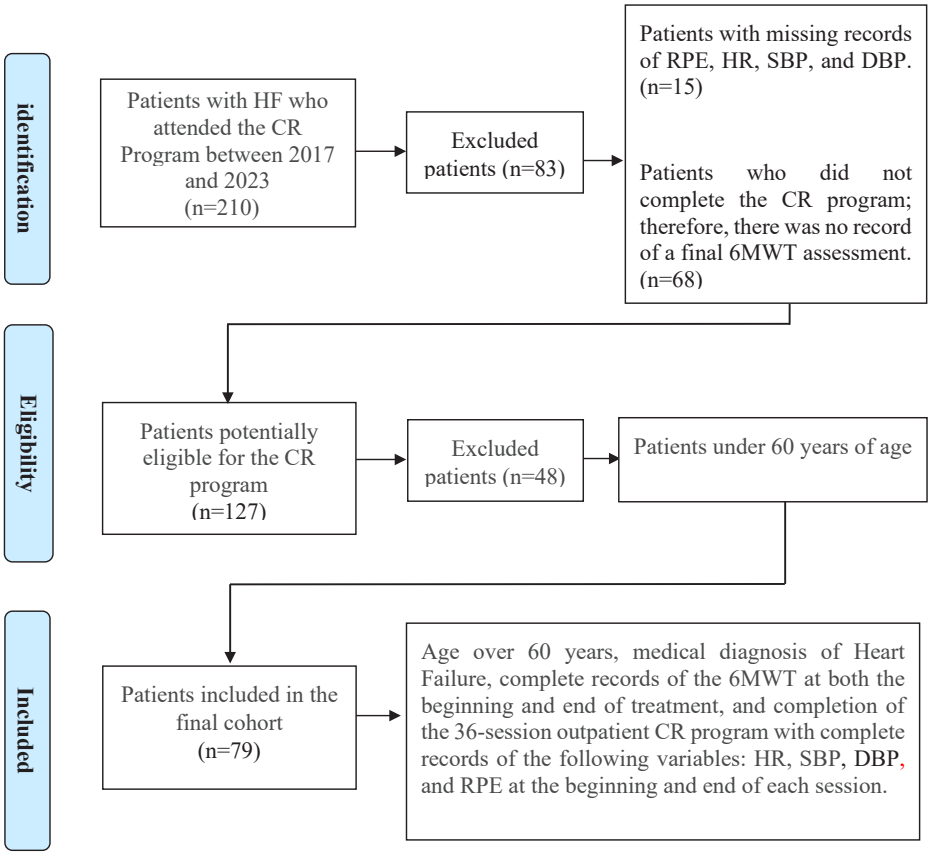


Figure 1. Patient selection flowchart

6MWT - 6-minute walk test, CR - cardiac rehabilitation, DBP - diastolic blood pressure, HF - Heart failure, HR - heart rate, RPE - Rating of Perceived Exertion, SBP - systolic blood pressure.

Baseline characteristics

In the analysis of the baseline characteristics of the study population (n = 79), a predominance of males was observed, representing 63.3% (n = 50) of the participants.

The population presented a high burden of cardiovascular and metabolic comorbidities. Hypertension was the most prevalent condition, affecting 62.0% of the subjects (n = 49), followed by coronary artery disease at 57.0% (n = 45) and sedentary lifestyle at 55.7% (n = 44). A significant group of patients presented a metabolic profile composed of obesity, dyslipidemia and diabetes mellitus, each with a prevalence of 40.5% (n = 32). A history of smoking was documented in 36.7% (n = 29) of the participants, and a history of sudden death in 26.6% (n = 21) (Table 1).

Table 1. Sociodemographic characteristics, comorbidities and family history of the study population

Variable	*N* = 79[a]
Age (years)	71.0 (66.0–75.0)
Sex	
Female	29 (36.7)
Male	50 (63.3)
Height	165.0 (158.5, 170.0)
Weight	69.0 (63.5, 75.9)
BMI[b]	25.9 (23.7, 29.4)
Comorbidities[c]	
Hypertension	49 (62.0)
Coronary artery disease	45 (57.0)
Sedentary lifestyle	44 (55.7)
Diabetes mellitus	32 (40.5)
Obesity	32 (40.5)
Dyslipidemia	32 (40.5)
Smoking	29 (36.7)
Sudden cardiac death	21 (26.6)

[a]n (%); Median (Q1, Q3), [b]BMI - body mass index, [c]Comorbidity categories were not mutually exclusive, therefore, patients could present with more than one condition, and percentages may sum to more than 100%

6MWT functional capacity outcomes

Statistically significant changes were between the baseline and final 6MWT assessments. The distance covered in the 6MWT increased from a median of 419.0 m (IQR: 311.0–481.5) to 523.0 m (IQR: 447.5–602.0). The median increase in distance covered was 113 m (IQR: 86.0–153.5; 95% CI: 100.0–137.0; $p < 0.001$), with a large effect size ($r = 0.997$). Consistently, estimated VO_2 increased from 10.48 to 12.22, with a median change of 2.30 (IQR: 1.50–3.44; 95% CI: 1.86–2.70; $p < 0.001$; $r = 0.976$), while METs increased from 2.99 to 3.49, with a median change of 0.66 (IQR: 0.42–0.98; 95% CI: 0.53–0.78; $p < 0.001$; $r = 0.976$). RPE showed a smaller change, with medians of 11.0 (IQR: 9.0–13.0) at baseline and 12.0 (IQR: 11.0–13.0), although it reached statistical significance (adjusted $p = 0.003$; $r = 0.457$) (Table 2).

Table 3 shows changes in the DP measured during supervised training sessions across CR Phases II–IV. No overall differences in the DP were observed across the rehabilitation phases ($p = 0.600$). A significant effect of measurement time and a phase × time interaction were observed (both $p < 0.001$), indicating that the magnitude of change between the initial and final assessments depended on the rehabilitation phase. In Phase II, no significant changes were observed (adjusted $p = 0.325$), whereas in Phases III and IV, the DP increased significantly by the end of the sessions (adjusted $p = 0.003$ and $p < 0.001$, respectively).

Table 2. Changes in the 6MWT

Variable	*N*	Baseline, median (IQR)	Final, median (IQR)	Change, median (IQR)	95% CI for median change	Rank-biserial *r*	*p*-value*
6MWT distance (m)	79	419.00 (311.00–481.50)	523.00 (447.50–602.00)	113.00 (86.00–153.50)	100.00–137.00	0.997	<0.001
Estimated VO_2	79	10.48 (8.68–11.53)	12.22 (10.96–13.71)	2.30 (1.50–3.44)	1.86–2.70	0.976	<0.001
METs	79	2.99 (2.49–3.29)	3.49 (3.13–3.92)	0.66 (0.42–0.98)	0.53–0.78	0.976	<0.001
RPE	79	11.00 (9.00–13.00)	12.00 (11.00–13.00)	0.00 (0.00–2.00)	0.00–1.00	0.457	0.0032

*Holm-adjusted *p*-values. Change was calculated within each participant as Final − Baseline. Paired comparisons were performed using the Wilcoxon signed-rank test. Rank-biserial correlation is reported as the effect-size measure. CIs for the median change were obtained using percentile bootstrap with 10,000 resamples. Multiplicity across the four functional outcomes was addressed using the Holm procedure

6MWT - 6-minute walk test, CI - confidence interval, IQR - interquartile range, METs - metabolic equivalents, RPE - rating of perceived exertion

Table 3. DP across CR phases

Phase	*N*	Initial DP, median (IQR)	Final DP, median (IQR)	Change, median (IQR)	Adjusted *p*-value*
Phase II	79	8736.0 (7655.0–10072.0)	8976.0 (7683.0–9834.0)	96.0 (−463.0 to 614.0)	0.325
Phase III	79	8626.5 (7419.5–9767.0)	8783.5 (7780.8–10195.0)	426.0 (−256.2 to 883.2)	0.003
Phase IV	79	8441.0 (7324.0–9698.8)	8722.0 (8014.8–10286.5)	701.5 (188.2 to 1071.8)	<0.001

Values are presented as median (IQR). Change was calculated within each participant as final − initial. Two-way repeated-measures ANOVA showed no overall phase effect ($p = 0.600$; $\eta^2 p = 0.006$), a significant measurement-time effect ($p < 0.001$; $\eta^2 p = 0.167$) and a significant phase × measurement–time interaction ($p < 0.001$; $\eta^2 p = 0.203$). *Adjusted *p*-values correspond to post hoc comparisons between initial and final measurements within each phase using the Holm method

ANOVA - analysis of variance, CR - cardiac rehabilitation, DP - double product, IQR - interquartile range

DISCUSSION

This study observed a significant change in functional capacity between the baseline and final 6MWT assessments among patients who completed a CR program, as evidenced by changes in distance walked, estimated VO_2 and METs. These findings have been described in the literature, noting that CR is an intervention that promotes musculoskeletal conditioning and helps increase vascular conductance—thereby reducing the risk of cardiovascular events and hospitalization—while optimizing quality of life, especially in patients with HF, for whom functional capacity is an independent predictor of mortality and hospitalization[4,5,18].

The magnitude of change observed in the distance covered during the 6MWT is clinically relevant, as increases in this test have been associated with a better prognosis and a reduction in adverse events in patients with HF[3,19]. In this regard, the manual for the 6MWT in Colombia establishes that a clinically important difference in the test consists of a minimum difference of 34 m between the baseline and final assessments[20]. However, this should not be interpreted solely as an improvement in physical performance, but rather as a sign of cardiorespiratory and peripheral integration, which could imply greater efficiency in oxygen transport and utilization[19]. Nevertheless, the patient's cardiorespiratory capacity might be underestimated, given that the 6MWT is a submaximal test performed by the patient at their own pace[21].

The observed increase in estimated VO_2 during the submaximal test may be consistent with physiological adaptations described in the context of exercise training; however, the study design does not allow us to determine whether these adaptations were responsible for the observed change[4].

Previous studies attribute improvements in estimated VO_2 to multifactorial adaptations: cardiac, through increased stroke volume; pulmonary, by optimizing arterial oxygen content and, consequently, its delivery to tissues; muscular, which increase exercise tolerance and peripheral oxygen extraction; and vascular, characterized by reduced arterial resistance, increased capillary density and more efficient blood flow distribution. These adaptations have been associated with improved integration of cardiac, pulmonary and muscular function and may contribute to the changes observed in VO_2[5].

Patients reported an RPE of between 11 and 12, corresponding to moderate perceived exertion. However, this change should not be interpreted alone as evidence of improved exercise tolerance, as RPE reflects the subjective perception of exercise intensity. This scale has been validated for prescribing and monitoring exercise intensity in patients with HF. This finding aligns with studies indicating that functional improvement in CR is accompanied by an increased capacity for higher-intensity exertion, without necessarily implying clinical deterioration[3,5,17].

One of the study's findings was that the pattern of change in DP differed across the CR phases. Importantly, the DP measurements reported in Table 3 were obtained during supervised training sessions in Phases II–IV, rather than during 6MWT. Therefore, these measurements reflect the hemodynamic response to the daily exercise sessions and should be interpreted independently of the changes observed in the baseline and final 6MWT assessments.

Repeated-measures ANOVA showed no significant overall effect of phase ($p = 0.600$; $\eta^2 p = 0.006$), indicating that DP levels did not differ significantly among Phases II–IV when considered independently of the measurement time. By contrast, there was a significant main effect of measurement time ($p < 0.001$; $\eta^2 p = 0.167$), indicating an overall difference between the initial and final DP measurements. A significant phase × measurement–time interaction was also observed ($p < 0.001$; $\eta^2 p = 0.203$), indicating that the magnitude of change in DP from initial to final differed according to the rehabilitation phase. Post hoc comparisons showed no significant change in Phase II (adjusted $p = 0.325$), whereas DP was significantly higher in the final, than in the initial in Phases III and IV (adjusted $p = 0.003$ and $p < 0.001$, respectively). These findings indicate that the initial to final changes in DP observed during supervised training sessions differed across rehabilitation phases, without evidence of an overall difference in DP levels between phases.

Rather, the results indicate that the increase in DP from the beginning to the end of the session was more pronounced during the more advanced training phases. The increase in DP observed during training sessions—especially in Phases III and IV—may be consistent with changes in cardiovascular workload in response to exercise, given that DP is calculated from HR and SBP. However, variations in DP should not be interpreted as evidence of greater myocardial efficiency, as that was not the objective of the present study. This hemodynamic response occurred alongside improvements in functional capacity, including an increase in distance covered, as well as higher estimated VO_2 and MET values during the 6MWT. It should be noted that the DP measurements presented in Table 3 were obtained during supervised training sessions, not during the 6MWT. The phase-specific increase in DP during training sessions, combined with improvements in functional capacity, may reflect progressively greater hemodynamic demands as the CR program progressed[22,23].

In our results, from a physiological perspective, the observed functional improvement can be explained by central and peripheral including improved chronotropic efficiency, optimized stroke volume, decreased peripheral vascular resistance, improved peripheral oxygen extraction and changes in skeletal muscle function[24]. These adaptations are especially relevant in HF, where exercise limitation is often multifactorial and not solely dependent on ventricular function.

Our results suggest that, in the real-world clinical settings, DP may be a useful complementary tool for assessing exercise response and prescribing training in CR program, particularly from a safety and hemodynamic control perspective. However, its interpretation in isolation may be limited in fully determining exercise-induced cardiovascular adaptations. Factors such as program duration, interindividual variability, sample size and the submaximal nature of the tests used should be considered when interpreting these results. Future studies with prospective designs and maximum assessments could provide greater clarity on the role of DP as a marker of cardiovascular workload and the exercise response in patients with HF.

Strengths and limitations

This study features several strengths supporting its internal validity, including standardized functional and hemodynamic assessments, predefined participant selection criteria, systematic data quality reviews and paired within-subject comparisons between baseline and follow-up evaluations, all of which enhance measurement consistency and reduce information bias. However, the work is subject to limitations inherent to its retrospective and observational design, preventing causal inference, as well as a small sample size and single-institution approach that restrict generalizability, and the selection of patients over 60 years of age with complete program records, which may introduce selection bias. Furthermore, the absence of detailed clinical data—including left ventricular ejection fraction (LVEF) and specific pharmacological treatment—further limits the study's depth and applicability.

In addition to the above, we consider the lack of integration of a Sex- and Gender-Based Analysis (SGBA) into the research design to be a limitation. Due to methodological and scope constraints, the data were not disaggregated by biological sex nor adjusted for sociocultural gender variables. As a result, the findings provide a generalized perspective and do not allow for the identification of potential differences in the effects, responses or impact of the studied variable that may be influenced by biological factors (sex) or sociocultural roles and constructs (gender). This limits the generalizability of the results to diverse populations and the ability to formulate highly personalized recommendations.

Prospective controlled studies, including randomized controlled trials, are needed to further determine the extent to which changes in functional capacity and hemodynamic response are attributable to participation in CR program.

CONCLUSIONS

The study observed a significant change in functional capacity between the baseline and final assessments of 6MWT in patients with HF who completed a CR program. With regard to DP, the overall effect of the CR phase was not significant, whereas the effect of measurement time point and the interaction between phase and measurement time point were significant, indicating that the magnitude of

the change in DP from baseline to follow-up varied across the different phases of CR. The retrospective observational design does not allow the observed changes to be attributed specifically to participation in CR. Prospective controlled studies, including randomized controlled trials, are needed to determine whether these changes are attributable to CR.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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