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Comparison of Cardiopulmonary Exercise Test Outcomes in Patients with Coronary Artery Disease Completing Shorter and Longer Cardiac Rehabilitation Programs: A Retrospective Analysis

Daha Kısa ve Daha Uzun Kardiyak Rehabilitasyon Programlarını Tamamlayan Koroner Arter Hastalarında Kardiyopulmoner Egzersiz Testi Sonuçlarının Karşılaştırılması: Retrospektif Bir Analiz

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ABSTRACT Objective: This study aimed to compare changes in cardiopulmonary exercise test (CPET) parameters between coronary artery disease (CAD) patients who completed <18 sessions and those who completed ≥18 sessions of exercise-based cardiac rehabilitation (CR). **Material and Methods:** A retrospective analysis was conducted on 54 CAD patients. Participants were divided into 2 groups: Group 1 (<18 sessions, n=27) and Group 2 (≥18 sessions, n=27). Records of CPET assessments performed before and after CR were analyzed. **Results:** No significant differences were observed between the groups in baseline characteristics. Both groups showed improvements in peak oxygen uptake (VO_2), peak respiratory exchange ratio, VO_2 at anaerobic threshold, and 1-min heart rate recovery. Significant increase in the oxygen uptake efficiency slope (OUES) (p<0.001) and reduction in ventilatory equivalent for carbon dioxide (VE/VCO_2) slope (p=0.003) were found only in Group 2. Between-group comparisons revealed that Group 2 showed greater improvements in OUES (p=0.008) and VE/VCO_2 slope (p=0.027). A positive correlation was found between the number of sessions and the increase in OUES (rho=0.286; p=0.038), while a negative correlation was found with the decrease in VE/VCO_2 slope (rho=-0.317; p=0.021). **Conclusion:** Longer CR programs lead to greater improvements in ventilatory efficiency, as indicated by OUES and VE/VCO_2 slope, compared with shorter programs. These findings highlight the importance of the number of sessions in optimizing the aerobic capacity and ventilatory response in CAD patients.

Keywords: Cardiac rehabilitation; coronary artery disease; exercise test; oxygen uptake efficiency; ventilatory efficiency

ÖZET Amaç: Bu çalışma, <18 seans ve ≥18 seanslık egzersiz temelli kardiyak rehabilitasyonu (KR) tamamlamış koroner arter hastaları (KAH) arasında kardiyopulmoner egzersiz testi (KPET) parametrelerindeki değişiklikleri karşılaştırmayı amaçladı. **Gereç ve Yöntemler:** KAH hastalığına sahip 54 kişi üzerinde retrospektif bir analiz yapılmıştır. Katılımcılar 2 gruba ayrıldı: Grup 1 (<18 seans, n=27) ve Grup 2 (≥18 seans, n=27). KR öncesi ve sonrası uygulanmış KPET sonuçları analiz edildi. **Bulgular:** Gruplar arasında başlangıç özelliklerinde anlamlı bir fark bulunmadı. Her iki grup da zirve oksijen tüketimi (VO_2), zirve solunum değişim oranı, anaerobik eşikteki VO_2 ve 1 dk'lık kalp hızı toparlanması arttı. Oksijen tüketim verimlilik eğimi [oxygen uptake efficiency slope (OUES)] artışı (p<0.001) ve karbondioksit solunum eşleniği (VE/VCO_2) eğimindeki azalma (p=0.003) yalnızca Grup 2'de istatistiksel olarak anlamlı bulundu. Gruplar arası karşılaştırmalar, Grup 2'nin OUES'de daha büyük bir artış (p=0.008) ve VE/VCO_2 eğiminde daha fazla azalma (p=0.027) gösterdiğini ortaya koydu. Seans sayısı ile OUES artışı arasında pozitif (rho=0.286; p=0.038), VE/VCO_2 eğimindeki azalma ile ise negatif bir ilişki bulundu (rho=-0.317; p=0.021). **Sonuç:** Daha uzun süreli KR programları OUES ve VE/VCO_2 eğimi ile gösterilen ventilasyon verimliliğinde kısa programlara kıyasla daha belirgin iyileşmeler sağlamaktadır. Bu bulgular, KAH'ta aerobik kapasite ve ventilatör yanıtın optimize edilmesinde seans sayısının önemini vurgulamaktadır.

Anahtar Kelimeler: Kardiyak rehabilitasyon; koroner arter hastalığı; egzersiz testi; oksijen tüketim verimliliği; ventilasyon verimliliği

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Exercise-based cardiac rehabilitation (CR) is a crucial component of coronary artery disease (CAD) management.[1] Despite strong recommendations, participation and adherence rates in CR programs remain suboptimal worldwide. Phase 2 CR is commonly recommended to include 36 sessions of exercise training over a 12-week period.[2] In Türkiye, CR following CAD is covered by the social security institution for up to 30 sessions per year. Early initiation of CR improves patient outcomes however, long program durations often result in waiting lists, delaying rehabilitation.[3] Additionally, dropout rates in CR programs have been reported to reach as high as 75% within the 12-week period.[4] Barriers to CR include vocational restrictions, family responsibilities, transportation difficulties, and logistical challenges related to rehabilitation services.[5] In this context, it remains unclear whether short-term programs with fewer sessions, which could reach more patients in the early period, are sufficiently effective.[6]

One of the main goals of exercise-based CR is to improve aerobic capacity, also referred to as cardiorespiratory fitness (CRF).[4] Exercise enhances CRF by inducing physiological adaptations in the respiratory, circulatory, and musculoskeletal systems. The cardiopulmonary exercise test (CPET) is the gold-standard method for assessing the aerobic capacity (maximal oxygen consumption) and evaluating the physiological responses to exercise. However, a significant proportion of cardiac patients cannot achieve maximal exertion during exercise testing, leading to the use of peak oxygen uptake (VO_2) rather than maximal VO_2. CPET also provides insight into submaximal fitness levels, offering parameters such as the anaerobic threshold (AT), the ventilatory equivalent for carbon dioxide (VE/VCO_2), and the oxygen uptake efficiency slope (OUES). While VE/VCO_2 slope primarily reflects ventilatory efficiency, OUES is considered a broader indicator of cardiopulmonary function and aerobic capacity.[7] Notably, OUES has been identified as an effort-independent marker of aerobic capacity in patients with CAD and heart failure.[8-10] While peak VO_2 is a well-established independent predictor, emerging evidence highlights the predictive value of OUES for cardiovascular events and mortality.[11,12]

Although exercise at various intensities and durations has been shown to improve both maximal and submaximal CPET parameters in patients with CAD, the effect of the number of exercise sessions on these parameters remains unclear.[13] While the general consensus suggests that more sessions lead to greater benefits, few studies have examined the effectiveness of shorter CR programs (e.g., 4-6 weeks).[14,15] One study found that CAD patients who completed more than 24 CR sessions had a 68% lower risk of major adverse cardiac events over a 4-year follow-up compared to those who attended fewer than 12 sessions.[16] A better understanding of the relationship between the number of sessions and CPET parameter changes could provide deeper insights into the physiological effects of therapeutic exercise on CRF components. Additionally, understanding expected changes with long- versus short-duration CR programs could help establish patient-specific goals and contribute to the development of individualized CR strategies.

Therefore, this study aimed to compare CPET parameter changes in patients with CAD who underwent exercise-based CR for fewer than 6 weeks (<18 sessions) versus those who participated for more than 6 weeks (≥18 sessions). Given that the standard recommendation for phase 2 CR is 36 sessions over 12 weeks, we categorized patients based on whether they completed less or more than half of the recommended duration and session count.

MATERIAL AND METHODS

PATIENTS

This retrospective study was conducted using the records of patients who participated in CR at the Cardiopulmonary Rehabilitation Unit of the Gazi University Faculty of Medicine, Department of Physical Medicine and Rehabilitation, between January 2022-December 2024.

The inclusion criteria were as follows: (1) aged 18 years and older; (2) a diagnosis of CAD (myocardial infarction, coronary artery bypass surgery, percutaneous coronary intervention, stable angina pectoris with medical management); (3) at least 4 weeks of participation in CR, with 3 sessions of moderate-intensity aerobic exercise per week.

The exclusion criteria were as follows: (1) concomitant chronic pulmonary disease; (2) symptoms related to heart failure with an ejection fraction <50% and/or proBNP ≥300 pg/ml; (3) severe valvular stenosis or insufficiency; (4) presence of heart valve surgery or pacemaker; (5) termination of CPET due to myocardial ischemia or arrhythmias affecting hemodynamics; (6) termination of the CR program due to a medical condition that compromised exercise training.

The number of CR sessions completed by the patients was recorded, and they were categorized into 2 groups: Group 1 (18 sessions) and Group 2 (18 or more sessions). Based on a 0.7 correlation between the dependent groups, a 5% error margin, and 90% power, the required sample size for each group to detect a statistically significant change in peak VO_2 was determined to be 24 participants.[16]

Because the study had a retrospective design, it was exempted from informed consent requirements. The study was conducted in accordance with the principles of the Helsinki Declaration, and personal data obtained from medical records were not shared with third parties. The study protocol was approved by the Gazi University Ethics Committee under number 06; date: April 15, 2025.

INTERVENTION

All patients underwent a warm-up and cool-down period, with 30-35 minutes of moderate-intensity aerobic exercise (treadmill walking with electrocardiography monitoring) 3 times a week. In addition, progressive resistance strengthening exercises for the upper and lower extremity proximal muscles were performed.[17] The aerobic exercise intensity was determined via the target heart rate range corresponding to 60-80% of the peak VO_2 obtained from the initial CPET. The exercise intensity was gradually increased during the weekly visits to achieve the target heart rate range.

Outcome Measures

The demographic and clinical data of the participants were obtained from the detailed pre-CR evaluation and CPET records. All participants underwent symptom-limited maximal CPET using the Modified Bruce Protocol on a treadmill in the week before CR and the week following the completion of CR by the same researcher (L.K.). Ergometric measurements were obtained using a Quark CPET ergospirometry device (Cosmed, Rome, Italy) with a breath-by-breath gas analysis system via a face mask. Participants were instructed to continue the exercise test until they reached an exertion level where they could not continue (Borg scale >17). Maximal exertion was defined as when participants reached ≥85% of their age-predicted maximum heart rate [Expected (maximum heart rate "MaxHR")=220 age] and a respiratory exchange ratio (RER=VCO_2/ VO_2) ≥1.1.[18]

The primary outcome measure was the change in the peak VO_2. Secondary outcomes included changes in peak RER, peak O2 pulse (VO_2/HR), VO2 at AT, VE/VCO_2 slope, OUES, resting HR, age-adjusted peak HR (%) calculated as 100 x (achieved peak HR/age-predicted MaxHR), peak double product (HR×systolic blood pressure), and HR recovery in 1 min (HRR-1-min).

VO_2 at AT, VE/VCO_2 slope, and OUES were considered submaximal parameters of the CRF. VO_2 at AT was determined using the V-slope method and confirmed by the corresponding inflections in the end-tidal PO_2 and VE/VO_2 traces while VE/VCO_2 remained stable (Figure 1).[19]

The VE/VCO_2 slope is a prognostic parameter that indicates respiratory efficiency during submaxi-

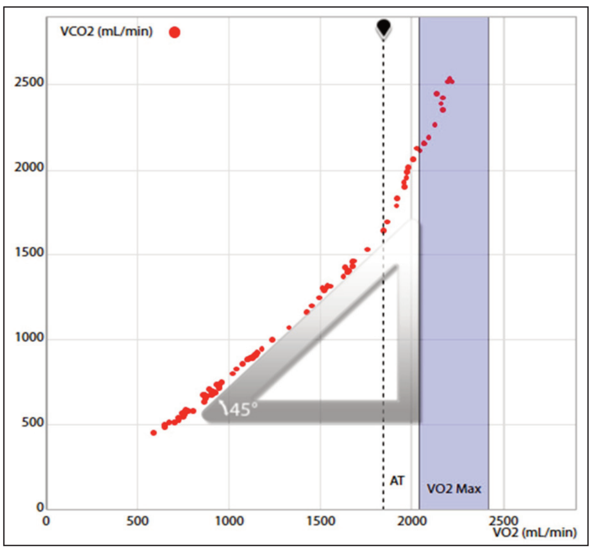

FIGURE 1: Determination of anaerobic threshold using the V-slope method

mal and maximal exercise tests. It is usually less than 30 in healthy individuals. An increase in this slope was associated with deconditioning, increased dead space ventilation, and an increased ventilatory response to exercise. In our study, the VE/VCO_2 slope was measured from exercise onset to the 2nd ventilatory threshold and during the entire exercise for patients who did not reach the second ventilatory threshold (Figure 2).[20]

OUES is a parameter that evaluates the relationship between VO_2 and VE, providing a comprehensive indicator of cardiovascular and pulmonary function during both submaximal and maximal exercise. It has been shown that OUES is a reliable parameter for assessing CRF and is strongly correlated with peak VO_2.[21] In our study, OUES was calculated using the equation VO_2=OUES×log(VE)+b during the peak exercise segment (Figure 2).

STATISTICAL ANALYSIS

Data analysis was conducted using IBM SPSS Statistics for Windows, Version 28.0. Armonk, NY: IBM Corp. Nominal variables were examined as frequencies and percentages, while continuous variables were examined as means and standard deviations (or median and interquartile range). The normality of the continuous variables was assessed using analytical (Kolmogorov-Smirnov/Shapiro-Wilk tests) and visual (histogram) methods. Fisher's exact test was applied to compare the frequencies of the nominal variables. Student's t-test and Mann-Whitney U test were used to compare baseline clinical characteristics between the groups. Within-group changes in the primary and secondary outcome measures were evaluated using paired t-tests and Wilcoxon signed-rank tests. Between-group comparisons of within-group changes were performed using the Student's t-test and Mann-Whitney U test. The relationship between the number of sessions and changes in CPET parameters was examined using Pearson and Spearman correlation analyses. A p value <0.05 was considered statistically significant.

RESULTS

The study flowchart is presented in Figure 3. A total of 54 patients were included, with 27 patients in each group (16 males in Group 1 and 22 males in Group 2). The clinical and demographic characteristics of the patients are summarized in Table 1. No significant differences were observed between the groups

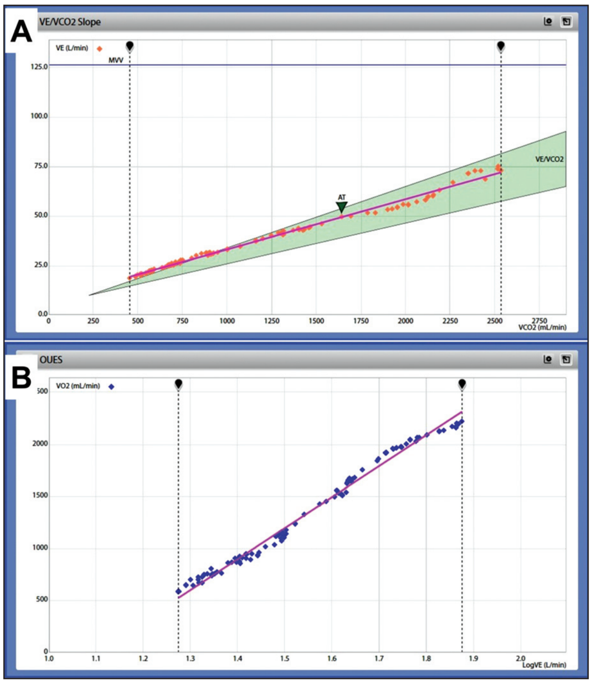

FIGURE 2: Measurements of VE/VCO_2 slope **(A)** and oxygen uptake efficiency slope-OUES **(B)**

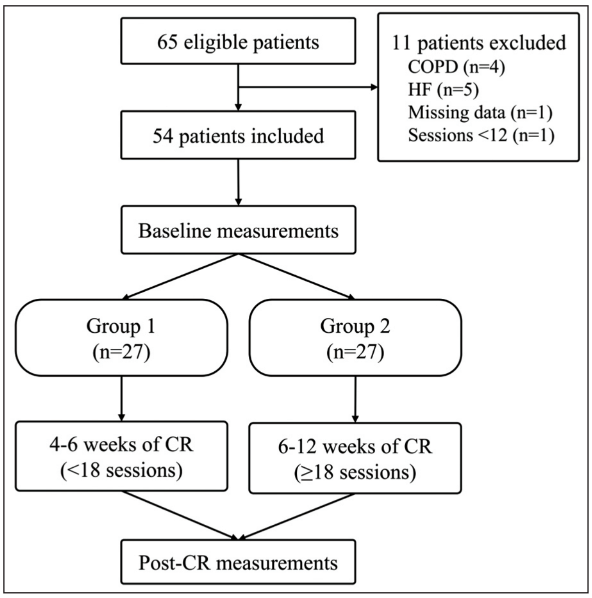

FIGURE 3: Study flowchart

COPD: Chronic obstructive pulmonary disease; HF: Heart failure; CR: Cardiac rehabilitation

TABLE 1: Demographic and clinical characteristics of patients

		Group 1 (n=27)	Group 2 (n=27)	p value
Gender	Female n (%)	11 (40)	5 (19)	0.135[a]
	Male n (%)	16 (60)	22 (81)	
Age (X̄±SD)		56.3±6.4	60.7±10.8	0.073[b]
BMI (X̄±SD)		27.3±4.7	28.8±4.9	0.261[b]
Referral diagnosis n (%)	Myocardial infarction	15 (55.6)	11 (40.7)	0.081[a]
	Coronary artery bypass surgery	1 (3.7)	6 (22.2)	
	Percutaneous coronary intervention	4 (14.8)	7 (25.9)	
	Stable angina pectoris	7 (25.9)	3 (11.1)	
Medications n (%)	Beta-blockers	25 (93)	22 (82)	0.420[a]
	ACE inhibitors	11 (41)	7 (26)	0.387[a]
	ARBs	9 (33)	8 (30)	1.0[a]
	CCBs	2 (7)	6 (22)	0.250[a]
	Statins	26 (96)	25 (93)	1.0[a]
	Antiplatelets/anticoagulants	27 (100)	27 (100)	1.0[a]
Regular exercise or walking history	Yes n (%)	14 (52)	14 (52)	1.00[a]
	No n (%)	13 (48)	13 (48)	
Education level n (%)	Primary or secondary education	8 (30)	5 (19)	0.692[a]
	High school education	8 (30)	9 (33)	
	University degree or higher	11 (40)	13 (48)	
Completed exercise sessions median (minimum-maximum)		14 (12-17)	23 (18-29)	**<0.001[c]**

[a]Fisher's exact test; [b]Student's t-test; [c]Mann-Whitney U Test; SD: Standard deviation; BMI: Body mass index; ACE: angiotensin-converting enzyme; ARBs: Angiotensin receptor blockers; CCB: Calcium channel blockers

in terms of gender, age, education level, prior regular exercise history, body mass index, cardiac disease diagnosis, or medication use. The median number of exercise sessions completed was 14 (range: 12-17) for Group 1 and 23 (range: 18-29) for Group 2 (p<0.001).

Regarding maximal effort, 54% of participants (n=29) reached the peak HR threshold of ≥85% of the age-predicted maximum before rehabilitation, which increased to 67% at the end of the program. When using a RER ≥1.1 as the criterion, 41% of participants (n=22) reached maximal effort at baseline, which increased to 74% (n=40) post-rehabilitation. In terms of pre-CR CPET parameters, the only significant difference observed between the groups was a lower HRR-1-min in Group 2 (p=0.017) (Table 2). After the CR program, both groups showed improvements in peak VO_2, peak RER, VO_2 at AT, and HRR-1-min. However, the increase in OUES (p<0.001) and the decrease in the VE/VCO_2 slope (p=0.003) were statistically significant only in Group 2 (Table 3).

TABLE 2: Comparison of CPET parameters before rehabilitation

Variables [X̄±SD]	Group 1 (n=27)	Group 2 (n=27)	p value[a]
Peak VO_2 (ml/kg/min)	21.7±4.3	19.8±5.5	0.152
Peak RER	1.09±0.07	1.07±0.09	0.272
Peak O_2 pulse (ml/kg/beat)	12.2±3.2	12.3±3.5	0.881
VO_2 at AT (ml/kg/min)	17.4±3.4	16.5±4.3	0.404
OUES (ml/min/L)	2153±542	2052±632	0.527
VE/VCO_2 slope	31.9±3.6	34.8±8	0.097
Resting HR (beat/min)	77.6±9.1	77.9±12.9	0.904
Age-adjusted peak HR (%)	86±8.9	84±10.6	0.408
Peak DP (mmHg•beat/min)	23116±3281	22173±4359	0.374
HRR-1-min (beat/min)	17.3±8.1	12.1±7.1	**0.017**

[a]Student's t-test; CPET: Cardiopulmonary exercise test; SD: Standard deviation; RER: Respiratory exchange ratio; VO_2: Oxygen uptake; VE/VCO_2: Ventilatory equivalent for carbon dioxide; AT: Anaerobic threshold; OUES: Oxygen uptake efficiency slope; HR: Heart rate; DP: Double product; HRR-1-min: 1-minute heart rate recovery

Between-group comparisons revealed that patients in Group 2 showed a greater increase in OUES (p=0.008) and a more significant decrease in the VE/VCO_2 slope (p=0.027) compared to those in Group 1. Correlation analyses demonstrated a signif-

TABLE 3: Analysis of changes in CPET parameters after rehabilitation

		Group 1 (n=27)		Group 2 (n=27)		
Variables		X̅±SD or minimum-maximum	p value	X̅±SD or minimum-maximum	p value	p value (Between groups Δ)
Peak VO_2 (ml/kg/min)	Pre	21.7±4.3	**0.012**[a]	19.8±5.5	**0.002**[a]	0.131[c]
	Post	22.4±4.8		21.2±5.5		
Peak RER	Pre	1.09±0.07	**0.008**[a]	1.07±0.09	**0.014**[a]	0.500[c]
	Post	1.12±0.08		1.11±0.09		
Peak O_2 pulse (ml/kg/beat)	Pre	12.2±3.2	0.333[a]	12.3±3.5	0.052[a]	0.309[c]
	Post	12.4±3.4		12.8±3.3		
VO2 at AT (ml/kg/min)	Pre	17.4±3.4	**0.008**[a]	16.5±4.3	**0.013**[a]	0.643[c]
	Post	18.3±3.3		17.6±4.5		
OUES (ml/min/L)	Pre	2153±542	0.635[a]	2052±632	**<0.001**[a]	**0.008**[c]
	Post	2172±570		2233±647		
VE/VCO_2 slope	Pre	31.4 (26.8-42.8)	0.989[b]	33.3 (16.1-54)	**0.003**[b]	**0.027**[d]
	Post	31.1 (26.9-38.3)		32±(17.9-54.6)		
Resting HR (beat/min)	Pre	77.6±9.1	0.981[a]	77.9±12.9	0.059[a]	0.396[c]
	Post	77.5±10		74.9±9.9		
Age-adjusted peak HR (%)	Pre	88.9 (60.5-99.4)	0.052[b]	84.4±(56.6-98)	0.137[b]	0.723[d]
	Post	91.3 (67.7-107.6)		87.7 (60.2- 101.8)		
Peak DP (mmHg•beat/min)	Pre	23116±3281	0.485[a]	22173±4359	0.804[a]	0.497[c]
	Post	23437±3190		22064±4403		
HRR-1-min (beat/min)	Pre	17.3±8.1	**0.002**[a]	12.1±7.1	**<0.001**[a]	0.817[c]
	Post	20.4±8.7		15.6±7.6		

[a]Paired sample T-test; [b]Wilcoxon signed rank test; [c]Student's t-test; [d]Mann-Whitney U test; VO_2: Oxygen uptake; VE/VCO_2: Ventilatory equivalent for carbon dioxide; CPET: Cardiopulmonary exercise test; SD: Standard deviation; RER: Respiratory exchange ratio; AT: Anaerobic threshold; OUES: Oxygen uptake efficiency slope; HR: Heart rate; DP: Double product; HRR-1-min: 1-minute heart rate recovery

TABLE 4: Correlation between the number of sessions completed and changes in CPET parameters

Variables	Spearman's rho	p value	95% CI
Δ Peak VO_2	0.010	0.941	(-0.266, 0.283)
Δ Peak RER	0.065	0.642	(-0.211, 0.337)
Δ Peak O_2 pulse	-0.010	0.944	(-0.277, 0.262)
Δ VO_2 at AT	-0.039	0.790	(-0.305, 0.236)
Δ OUES	0.286	**0.038**	**(0.015, 0.516)**
Δ VE/VCO_2 slope	-0.317	**0.021**	**(-0.551, -0.054)**
Δ Resting HR	-0.074	0.596	(-0.345, 0.207)
Δ Age-adjusted peak HR	-0.071	0.612	(-0.341, 0.209)
Δ Peak DP	-0.157	0.262	(-0.412, 0.112)
Δ HRR-1-min	0.142	0.310	(-0.126, 0.399)

[a]Paired sample t-test; [b]Wilcoxon signed rank test; [c]Student's t-test; [d]Mann-Whitney U test. VO_2: Oxygen uptake; VE/VCO_2: Ventilatory equivalent for carbon dioxide; CI: Confidence internal; RER: Respiratory exchange ratio; AT: Anaerobic threshold; OUES: Oxygen uptake efficiency slope; HR: Heart rate; DP: Double product; HRR-1-min: 1-minute heart rate recovery

icant positive relationship between the number of sessions and the increase in OUES (rho=0.286; p=0.038), as well as a significant negative relationship between the number of sessions and the decrease in VE/VCO_2 slope (rho=-0.317; p=0.021) (Table 4).

DISCUSSION

This study aimed to evaluate and compare the changes in maximal and submaximal CPET parameters resulting from longer versus shorter exercise-based CR programs in patients with CAD. Our findings demonstrated that while both short- and long-term CR programs led to improvements in peak VO_2, peak RER, VO_2 at AT, and HRR-1-min, significant enhancements in OUES and reductions in VE/VCO_2 slope were observed only in patients who completed more than 18 sessions. Furthermore, a positive correlation was found between the number of sessions and OUES improvement, whereas a negative correlation was observed with VE/VCO_2 slope reduction. These results suggest that although shorter CR programs may provide comparable improvements in aerobic capacity, a greater number of sessions may be necessary to achieve optimal ventilatory efficiency gains.

An important consideration in evaluating the CPET results is the extent to which peak VO_2 accurately reflects the true aerobic capacity. In our study, approximately half of the patients could achieve maximal effort during the initial evaluation, with this proportion increasing following exercise training. The concurrent increase in peak VO_2 and RER suggests that improvements may not solely reflect physiological adaptations but also greater patient familiarity with exercise testing and the ability to exert higher effort levels. Therefore, assessing submaximal parameters such as AT, VE/VCO_2 slope, and OUES provides a more comprehensive evaluation of CRF improvements.[22] Both VE/VCO_2 slope and OUES are associated with myocardial remodeling and neurohormonal changes in ischemic heart disease, independent of peak VO_2.[23]

Improvements in HRR and heart rate variability are key indicators of autonomic adaptations induced by aerobic exercise training. Previous studies have suggested that increased HRR in CAD patients typically occurs in programs exceeding 24 sessions.[23] However, our findings indicate that HRR improved independently of the number of sessions, aligning with the findings of El Missiri et al., who reported similar HRR improvements in both 6-week and 12-week CR programs in myocardial infarction patients.[24] This suggests that cardiac autonomic adaptations may occur earlier during CR, regardless of the program duration.

One of the key mechanisms underlying exercise adaptations is the enhancement of mitochondrial biogenesis and metabolic flexibility in the peripheral muscles. Regular exercise increases fat oxidation while reducing carbohydrate utilization, delaying lactate accumulation and elevating AT.[19] This improves exercise tolerance and functional capacity, playing a crucial role in the prognosis of conditions such as heart failure and CAD.[25] Our findings suggest that even CR programs with fewer than 18 sessions may contribute to AT improvement. However, significant improvements in VE/VCO_2 slope and OUES were only observed in patients who completed more than 18 sessions. Prado et al. suggested that improvements in VE/VCO_2 slope and OUES with exercise-based CR occur in parallel with increases in aerobic capacity.[8] In contrast, Myers et al. reported that OUES may be more sensitive to CRF enhancement than VE/VCO_2 slope in patients with heart failure.[26] Despite these findings, there is limited evidence comparing the specific effects of short- versus long-duration CR programs on these parameters.[10] Our results suggest that while peripheral metabolic adaptations, such as AT improvement, may occur earlier in CR, a longer duration may be needed for significant ventilatory efficiency enhancements.

This study has several strengths, notably the evaluation of both maximal and submaximal CPET parameters and its investigation into the specific effects of CR session number on ventilatory efficiency. The findings contribute to the limited literature on this topic, providing insights into the differential impact of short- versus long-duration CR programs. However, some limitations should be acknowledged. The study's retrospective design may introduce selection bias, and groups were formed based on a predefined cut-off point rather than random allocation, leading to a relatively wide range of session numbers within each group. Additionally, we lacked data on the reasons why patients discontinued CR prematurely, which could provide further insights into adherence factors. The relatively small sample size also precluded subgroup analyses based on CAD diagnosis.

CONCLUSION

Our findings suggest that while shorter CR programs may be beneficial for improving aerobic capacity, longer programs (≥18 sessions) may be necessary to optimize ventilatory efficiency. This highlights the importance of tailoring CR programs to patient needs, particularly for those at risk of an impaired ventilatory response to exercise. Future research should focus on prospective, randomized studies comparing different CR durations to better define the optimal session number for improving both aerobic and ventilatory parameters. Additionally, studies exploring patient-specific predictors of CR adherence and response would provide valuable insights for individualized rehabilitation strategies. Investigating the long-term effects of CR on ventilatory efficiency and autonomic function would further enhance our understanding of its sustained benefits in CAD patients.

Source of Finance

During this study, no financial or spiritual support was received neither from any pharmaceutical company that has a direct connection with the research subject, nor from a company that provides or produces medical instruments and materials which may negatively affect the evaluation process of this study.

Conflict of Interest

No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.

REFERENCES

1. Taylor RS, Fredericks S, Jones I, et al. Global perspectives on heart disease rehabilitation and secondary prevention: a scientific statement from the Association of Cardiovascular Nursing and Allied Professions, European Association of Preventive Cardiology, and International Council of Cardiovascular Prevention and Rehabilitation. Eur Heart J. 2023;44:2515-25. [PubMed] [PMC]
2. Vooturi S, Anil P, Monica Y. Effects of exercise training and physical activity in patients with coronary artery disease. Indian Journal of Clinical Cardiology. 2023;4:98-100. [Crossref]
3. Candelaria D, Zecchin R, Ferry C, et al. Shorter wait times to cardiac rehabilitation associated with greater exercise capacity improvements: a multisite study. J Cardiopulm Rehabil Prev. 2021;41:243-8. [Crossref] [PubMed]
4. Nichols S, McGregor G, Breckon J, et al. Current insights into exercise-based cardiac rehabilitation in patients with coronary heart disease and chronic heart failure. Int J Sports Med. 2021;42:19-26. [PubMed]
5. Iyngkaran P, Appuhamilage PY, Patabandige G, et al. Barriers to cardiac rehabilitation among patients diagnosed with cardiovascular diseases-a scoping review. Int J Environ Res Public Health. 2024;21:339. [PubMed] [PMC]
6. Dibben GO, Faulkner J, Oldridge N, et al. Exercise-based cardiac rehabilitation for coronary heart disease: a meta-analysis. Eur Heart J. 2023;44:452-69. [PubMed] [PMC]
7. Defoor J, Schepers D, Reybrouck T, et al. Oxygen uptake efficiency slope in coronary artery disease: clinical use and response to training. Int J Sports Med. 2006;27:730-7. [PubMed]
8. Prado DM, Rocco EA, Silva AG, et al. Effects of continuous vs interval exercise training on oxygen uptake efficiency slope in patients with coronary artery disease. Braz J Med Biol Res. 2016;49:e4890. [PubMed] [PMC]
9. Van Laethem C, Van de Veire N, De Sutter J, et al. Prospective evaluation of the oxygen uptake efficiency slope as a submaximal predictor of peak oxygen uptake in aged patients with ischemic heart disease. Am Heart J. 2006;152:297.e9-15. [PubMed]
10. Van Laethem C, Van De Veire N, De Backer G, Bihija S, Seghers T, Cambier D, et al. Response of the oxygen uptake efficiency slope to exercise training in patients with chronic heart failure. Eur J Heart Fail. 2007;9:625-9. [PubMed]
11. Peterman JE, Novelli DS, Fleenor BS, et al. Oxygen uptake efficiency slope as a predictor of mortality risk: The Ball State Adult Fitness Longitudinal Lifestyle Study (BALL ST). J Cardiopulm Rehabil Prev. 2023;43:282-9. [Crossref] [PubMed]
12. Buys R, Coeckelberghs E, Cornelissen VA, et al. Prognostic value of the post-training oxygen uptake efficiency slope in patients with coronary artery disease. Eur J Prev Cardiol. 2016;23:1363-71. [PubMed]
13. Du L, Zhang X, Chen K, et al. Effect of high-intensity interval training on physical health in coronary artery disease patients: a meta-analysis of randomized controlled trials. J Cardiovasc Dev Dis. 2021;8:158. [Crossref] [PubMed] [PMC]
14. Jelinek HF, Huang ZQ, Khandoker AH, et al. Cardiac rehabilitation outcomes following a 6-week program of PCI and CABG Patients. Front Physiol. 2013;4:302. [PubMed] [PMC]
15. Li J, Liu B, Wang Z, et al. Efficacy of a 6-week home-based online supervised exercise program conducted during COVID-19 in patients with post percutaneous coronary intervention: a single-blind randomized controlled trial. Front Cardiovasc Med. 2022;9:853376. [PubMed] [PMC]
16. Scherrenberg M, Janssen J, Lauwers A, et al. Is there an optimal dose of cardiac rehabilitation in coronary artery disease patients? Int J Cardiol. 2021;330:7-11. [PubMed]
17. Hollings M, Mavros Y, Freeston J, et al. The effect of progressive resistance training on aerobic fitness and strength in adults with coronary heart disease: a systematic review and meta-analysis of randomised controlled trials. Eur J Prev Cardiol. 2017;24:1242-59. [Crossref] [PubMed]
18. Veneman T, Koopman FS, Oorschot S, et al. Validity of cardiopulmonary exercise testing for assessing aerobic capacity in neuromuscular diseases. Arch Phys Med Rehabil. 2024;105:1846-53. [PubMed]
19. Poole DC, Rossiter HB, Brooks GA, et al. The anaerobic threshold: 50+ years of controversy. J Physiol. 2021;599:737-67. [PubMed]
20. Chaumont M, Forton K, Gillet A, et al. How does the method used to measure the VE/VCO2 slope affect its value? A cross-sectional and retrospective cohort study. Healthcare (Basel). 2023;11:1292. [PubMed] [PMC]
21. Coeckelberghs E, Buys R, Goetschalckx K, et al. Test-retest reliability of maximal and submaximal gas exchange variables in patients with coronary artery disease. J Cardiopulm Rehabil Prev. 2016;36:263-9. [Crossref] [PubMed]
22. Popovic D, Kumar N, Chaudhry S, et al. Improvements in key cardiopulmonary exercise testing variables following cardiac rehabilitation in patients with coronary artery disease. J Cardiopulm Rehabil Prev. 2018;38:E5-8. [PubMed]
23. Van de Veire NR, Van Laethem C, Philippé J, et al. VE/VCO2 slope and oxygen uptake efficiency slope in patients with coronary artery disease and intermediate peakVO2. Eur J Cardiovasc Prev Rehabil. 2006;13:916-23. [Crossref] [PubMed]
24. El Missiri A, Amin SA, Tawfik IR, et al. Effect of a 6-week and 12-week cardiac rehabilitation program on heart rate recovery. Egypt Heart J. 2020;72:69. [Crossref] [PubMed] [PMC]
25. 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. [PubMed]
26. Myers J, Gademan M, Brunner K, et al. Effects of high-intensity training on indices of ventilatory efficiency in chronic heart failure. J Cardiopulm Rehabil Prev. 2012;32:9-16. [Crossref] [PubMed]