

Effect of Resistance- and Aerobic-Based Cardiac Rehabilitation on Resting Heart Rate and Cardiac Workload (Rate-Pressure Product) After Coronary Artery Bypass Grafting: A Randomized Controlled Trial

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Abstract

Resting heart rate is a modifiable marker of autonomic balance and cardiovascular prognosis, and with systolic blood pressure it determines the rate-pressure product (RPP), an index of myocardial oxygen demand. How resistance- and aerobic-based rehabilitation compare on these markers after coronary artery bypass grafting (CABG), especially in South Asian patients, is unclear. This trial examined their effects on resting heart rate, with derived RPP as an index of cardiac workload. Forty-five clinically stable patients recovering from CABG (40 men, 5 women; mean age $\approx$ 57 years) took part in a single-centre, parallel-group randomized controlled trial in Karachi, Pakistan, and were assigned in equal proportions to resistance-based rehabilitation, aerobic-based rehabilitation, or conventional care. A computer-generated sequence governed assignment, concealment used serially numbered sealed opaque envelopes, and assessors were masked. The two exercise arms trained under supervision thrice weekly for ten weeks. Resting heart rate and systolic blood pressure were recorded at entry and at ten weeks; heart rate was analysed by two-way repeated-measures analysis of variance (Group $\times$ Time), and RPP was derived as the product of systolic pressure and heart rate. The arms were balanced at entry for age, sex and resting heart rate. Heart rate fell in every arm but to differing degrees, yielding a significant Group $\times$ Time interaction ($F(2, 42) = 19.67$, $p < 0.001$, partial $\eta^2 = 0.484$). Both exercise arms reached a lower post-intervention heart rate (resistance $\approx$ 72.9 bpm; aerobic $\approx$ 72.3 bpm) than conventional care ($\approx$ 76.5 bpm), and the between-group difference at ten weeks was significant ($p = 0.024$). Derived RPP declined most after aerobic-based rehabilitation (-21.7%), followed by resistance-based rehabilitation (-18.5%) and conventional care (-10.5%). Both exercise-based rehabilitation modalities lowered resting heart rate after CABG more than conventional care, and the accompanying fall in derived cardiac workload was largest with aerobic-based training. Structured exercise, and an aerobic emphasis in particular, favourably modifies autonomic-related and workload markers after CABG, supporting its routine use in Pakistani and comparable settings.

Keywords: Cardiac Rehabilitation; Coronary Artery Bypass Grafting; Resting Heart Rate; Rate-Pressure Product; Myocardial Oxygen Demand; Aerobic Exercise; Resistance Training

Introduction

Coronary artery bypass grafting (CABG) relieves ischaemia and improves survival in advanced coronary artery disease, but the recovery that follows depends heavily on secondary prevention, of which exercise-based cardiac rehabilitation is a central element (Yuan et al., 2023). Rehabilitation improves cardiopulmonary function, functional capacity and quality of life and reduces recurrent events after coronary procedures (Shi et al., 2025; Subih et al., 2024). Among the physiological targets of rehabilitation, resting heart rate has attracted growing attention because it is easily measured, responsive to training, and prognostically important in its own right.

A higher resting heart rate reflects a shift in cardiac autonomic balance toward sympathetic predominance and reduced vagal tone, and large cohort studies have shown it to be an independent predictor of cardiovascular and all-cause mortality across general and cardiac populations (Archangelidi et al., 2018; Tadic et al., 2018). The prognostic signal persists after adjustment for conventional risk factors and extends to patients with established atherosclerotic disease, with each additional beat per minute conferring measurable incremental risk (Moraes et al., 2025; Patcheva et al., 2021). Because resting heart rate is modifiable, lowering it through non-pharmacological means such as exercise is a clinically meaningful goal after CABG. Resting heart rate also carries physiological importance beyond its role as a risk marker, because it is one of the two determinants, alongside systolic blood pressure, of the rate-pressure product (RPP), the product of the two, which serves as a widely used non-invasive index of myocardial oxygen demand and cardiac workload (Zeng et al., 2023). A lower RPP indicates that the heart is performing a given amount of work at a lower metabolic cost, which is advantageous in patients with compromised coronary perfusion. Exercise training has been shown to reduce RPP in a range of cardiac and hypertensive populations, and RPP is increasingly used to monitor cardiovascular efficiency during rehabilitation after cardiac surgery (Falz et al., 2023; Handirosiyanto et al., 2025; Obaseki et al., 2025). Although the general cardiovascular benefits of exercise-based rehabilitation are established, the comparative effects of its two principal modalities, resistance training and aerobic training, on resting heart rate and cardiac workload after CABG have received limited direct study, and evidence from South Asia, where rehabilitation services are scarce and under-researched, is particularly sparse (Mamataz et al., 2021; McAllister et al., 2025). The present randomized controlled trial therefore examined the effects of resistance-based and aerobic-based Phase II rehabilitation, against conventional care, on resting heart rate in patients recovering from CABG in Pakistan, and additionally reported the derived rate-pressure product as an index of cardiac workload. It was hypothesised that both exercise modalities would lower resting heart rate more than conventional care and that the modalities would differ in the magnitude of their effect.

Methods

Trial design, ethics and shared protocol

The data reported here were collected within a single-centre, three-arm, parallel-group randomized controlled trial carried out at a tertiary cardiac facility in Karachi, Pakistan, over a ten-week intervention window. Conduct followed the principles of the Declaration of Helsinki; the institutional review board granted ethical approval, and every participant provided written informed consent prior to enrolment. Because this analysis and its companion reports draw on the same trial, the design, allocation procedures and intervention protocols summarised below have been described in the companion publications from this study, and are presented here in sufficient detail for the present report to stand alone. The analysis reported in this paper focuses on resting heart rate and the derived rate-pressure product.

Participants and eligibility

Adults were considered eligible if they had undergone CABG, were haemodynamically stable, and had been cleared for exercise by the supervising cardiologist during the early outpatient (Phase II) period. Individuals were not enrolled if they had unstable angina, decompensated heart failure, clinically significant arrhythmia, uncontrolled hypertension, or any neurological or musculoskeletal disorder that would make supervised exercise unsafe. Application of these criteria yielded a final sample of 45 participants, all of whom completed both assessment points.

Allocation and masking

A computer-generated random-number sequence was used to distribute the 45 participants evenly across the three arms, fifteen to each. To keep the upcoming assignment hidden from those enrolling participants, the sequence was held in serially numbered, sealed, opaque envelopes that were opened only after consent and baseline measurement had been completed. Given the physical nature of the interventions, blinding of participants and of the therapists delivering the programmes was not achievable; nonetheless, the assessors who recorded the outcomes and the analyst who handled the data were kept unaware of group membership, limiting measurement and analytical bias.

Intervention arms

Participants in the two active arms trained under direct supervision three times each week for ten weeks. Those in the resistance arm undertook progressive strengthening of the principal upper- and lower-limb muscle groups, with attention to controlled movement and continuous breathing, and with load advanced as tolerance allowed. Those in the aerobic arm performed continuous and interval aerobic work at a moderate intensity that was progressed in duration and intensity across the programme. Every training session opened with a warm-up and closed with a cool-down, and heart rate, blood pressure and symptoms were observed throughout each session. The third arm received conventional post-operative care — routine medical management together with general advice on activity — without a supervised exercise programme.

Measurements and derived index

Resting heart rate (in beats per minute) and resting systolic blood pressure (in mmHg) were measured after the participant had been seated quietly, at baseline and again at the end of the ten-week programme, following standardised procedures used routinely in post-cardiac-surgery assessment (Radi et al., 2021). The rate-pressure product was then derived for each assessment as the arithmetic product of resting systolic blood pressure and resting heart rate, and is presented divided by 1,000 in accordance with common convention; RPP was treated as a non-invasive index of myocardial oxygen demand and cardiac workload (Zeng et al., 2023).

Data analysis

Analyses were performed with significance set at $p < 0.05$. Baseline equivalence across arms was examined with one-way analysis of variance. The primary outcome, resting heart rate, was modelled using a two-way repeated-measures analysis of variance with Time (baseline versus ten weeks) as the within-participant factor and Group as the between-participant factor; the Group $\times$ Time interaction was the term of principal interest, because it tests whether the three arms changed by different amounts, and the effect size was expressed as partial eta-squared. The rate-pressure product is reported descriptively at the group level, as the product of the corresponding group mean systolic pressure and group mean heart rate, and is presented as an index of the direction and relative magnitude of change in cardiac workload rather than as a separately modelled inferential outcome.

Results

Baseline characteristics

All 45 randomised participants completed the trial. The sample was largely male (40 men, 5 women), with a mean age of about 57 years, reflecting the usual profile of patients undergoing CABG at this centre. The three arms were statistically similar at baseline in age (resistance 57.33 ± 7.87 years; aerobic 57.13 ± 4.05 ; conventional 56.20 ± 3.67 ; $p = 0.836$) and, importantly for the present analysis, in resting heart rate (resistance 81.67 ± 3.54 bpm; aerobic 80.13 ± 4.39 ; conventional 79.80 ± 4.18 ; $p = 0.410$), confirming that randomisation produced comparable starting values. Body mass index was lower in the resistance arm than in the aerobic and conventional arms (24.71 ± 4.28 versus 31.50 ± 5.56 and 30.23 ± 5.85 kg/m²; $p = 0.002$), a difference taken into account when interpreting the findings. Baseline characteristics are shown in Table 1.

Table 1. Baseline characteristics of the three study arms (mean $\pm$ SD)

Characteristic	Resistance (n = 15)	Aerobic (n = 15)	Conventional (n = 15)	p
Age (years)	57.33 ± 7.87	57.13 ± 4.05	56.20 ± 3.67	0.836
Body mass index (kg/m ²)	24.71 ± 4.28	31.50 ± 5.56	30.23 ± 5.85	0.002
Resting heart rate (bpm)	81.67 ± 3.54	80.13 ± 4.39	79.80 ± 4.18	0.410
Systolic blood pressure (mmHg)	147.13 ± 3.98	146.80 ± 4.92	148.13 ± 4.55	0.703

SD, standard deviation. p-values from one-way analysis of variance. The overall cohort comprised 40 men and 5 women; the per-group sex distribution should be inserted from the trial records.

Resting heart rate

Resting heart rate decreased from baseline to ten weeks in all three arms, but the extent of the decrease depended on the programme received, producing a large and statistically significant Group $\times$ Time interaction ($F(2, 42) = 19.67$, $p < 0.001$, partial $\eta^2 = 0.484$). In the two exercise arms the reduction was pronounced: resting heart rate fell to 72.87 ± 3.02 bpm after resistance-based rehabilitation (a decrease of about 8.8 bpm) and to 72.27 ± 3.79 bpm after aerobic-based rehabilitation (about 7.9 bpm), whereas conventional care produced a smaller decline, to 76.53 ± 5.95 bpm (about 3.3 bpm). The three arms had been indistinguishable at baseline ($p = 0.410$) but differed significantly at ten weeks ($p = 0.024$), confirming that the divergence emerged over the course of the intervention and favoured the two exercise programmes. The resting heart rate data and analysis are summarised in Table 2 and illustrated in Figure 1.

Table 2. Resting heart rate (bpm) by arm and time, and repeated-measures analysis of variance

Arm	Baseline	10 weeks	Change	–
Resistance (n = 15)	81.67 ± 3.54	72.87 ± 3.02	–8.8	–
Aerobic (n = 15)	80.13 ± 4.39	72.27 ± 3.79	–7.9	–
Conventional (n = 15)	79.80 ± 4.18	76.53 ± 5.95	–3.3	–
Between-group p	0.410	0.024	–	–

Values are mean $\pm$ SD. Between-group p-values from one-way analysis of variance at each time point. Group $\times$ Time interaction (two-way repeated-measures ANOVA): $F(2, 42) = 19.67$, $p < 0.001$, partial $\eta^2 = 0.484$, indicating a large effect.

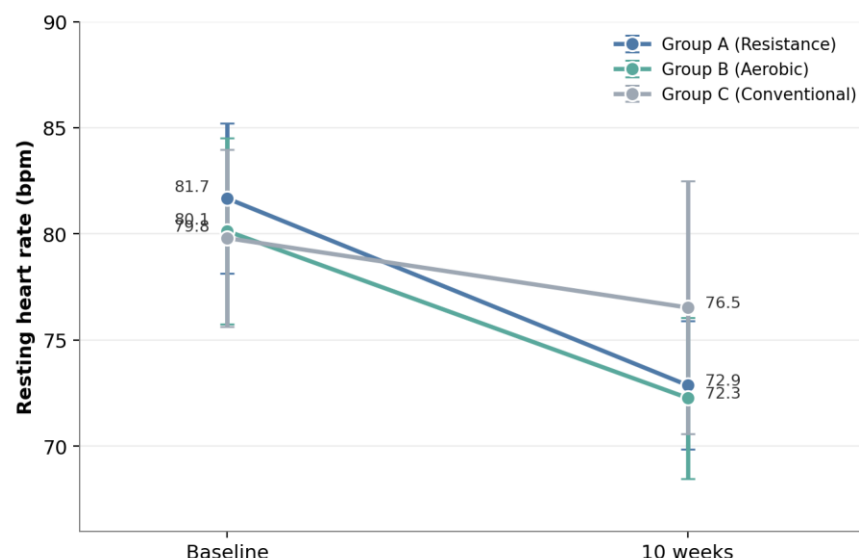


Figure 1. Resting heart rate at baseline and after the 10-week intervention in the three arms. Points are group means and error bars represent standard deviations. The Group $\times$ Time interaction was significant ($F(2, 42) = 19.67$, $p < 0.001$), and the arms differed significantly at 10 weeks ($p = 0.024$). Both exercise arms reached a lower resting heart rate than conventional care.

Derived rate-pressure product

The derived rate-pressure product, computed at the group level as an index of cardiac workload, decreased in all three arms in parallel with the heart-rate and systolic-pressure changes, and decreased most in the exercise arms. Expressed in conventional units ($\times 1,000$), group RPP fell from approximately 12.02 to 9.79 after resistance-based rehabilitation (a reduction of about 18.5%), from approximately 11.76 to 9.21 after aerobic-based rehabilitation (about 21.7%), and from approximately 11.82 to 10.58 with conventional care (about 10.5%). The aerobic programme therefore produced the largest relative reduction in derived cardiac workload, the resistance programme an intermediate reduction, and conventional care the smallest, mirroring the pattern seen for resting heart rate. Because these RPP values were derived from group means rather than from participant-level data, they are reported descriptively, to indicate the direction and relative magnitude of change, and were not subjected to separate inferential testing. The derived values are presented in Table 3.

Table 3. Derived rate-pressure product by arm (group-level, descriptive)

Arm	Baseline RPP ($\times 1,000$)	10-week RPP ($\times 1,000$)	Relative change
Resistance	12.02	9.79	−18.5%
Aerobic	11.76	9.21	−21.7%
Conventional	11.82	10.58	−10.5%

RPP, rate-pressure product = systolic blood pressure $\times$ heart rate, divided by 1,000. Values were derived from the corresponding group mean systolic blood pressure and group mean resting heart rate; they are presented descriptively to show the direction and relative magnitude of change and were not analysed inferentially, as participant-level data were not available.

Discussion

In this randomized comparison of rehabilitation modalities after CABG, both resistance-based and aerobic-based programmes lowered resting heart rate significantly more than conventional care

over ten weeks, and the derived rate-pressure product — an index of myocardial oxygen demand — declined most after aerobic training. The large interaction effect for resting heart rate, together with the significant between-group separation at follow-up despite equivalent baseline values, indicates a genuine training effect rather than the natural course of postoperative recovery alone.

The reduction in resting heart rate with exercise is best understood as a manifestation of improved cardiac autonomic regulation. Coronary artery disease is characterised by heightened sympathetic activity and diminished vagal tone, and exercise training shifts this balance in a favourable direction, increasing vagal modulation and reducing sympathetic outflow (Badrov et al., 2019; Souza et al., 2021). A meta-analysis specific to CABG patients has shown that exercise training improves indices of heart-rate variability that reflect both overall and vagally mediated autonomic control (Kushwaha et al., 2022), and broader syntheses confirm that training enhances vagal-related autonomic function and lowers resting heart rate across cardiac and general populations (Amekran et al., 2024; Yilmaz et al., 2024). The coordinated reductions in resting heart rate observed in both exercise arms are consistent with this autonomic mechanism; although the present study did not measure heart-rate variability directly, resting heart rate is a simple, accessible surrogate of autonomic status, and its improvement here aligns with the mechanistic evidence.

The clinical relevance of lowering resting heart rate is considerable, because a higher resting heart rate is an established, independent predictor of cardiovascular and all-cause mortality, with risk rising incrementally across the range seen in these patients (Archangelidi et al., 2018; Tadic et al., 2018). Reductions of the magnitude achieved by the exercise programmes — moving patients from the high-70s/low-80s to around 72 bpm — are therefore likely to carry prognostic value in addition to reflecting improved autonomic health, and the persistence of the prognostic signal even at heart rates once regarded as normal underscores the value of pushing resting heart rate lower through training (Moraes et al., 2025). That both exercise modalities achieved this reduction, whereas conventional care did so only modestly, reinforces the argument that structured exercise adds materially to usual postoperative care.

The behaviour of the derived rate-pressure product extends this interpretation from autonomic status to cardiac energetics. Because RPP is the product of systolic pressure and heart rate, and both fell in the exercise arms, the resulting decline in RPP indicates a reduction in myocardial oxygen demand at rest, meaning the heart performs its work more efficiently — a desirable adaptation after CABG, when the balance between myocardial oxygen supply and demand is central to recovery and to graft longevity (Zeng et al., 2023). The larger reduction in derived RPP after aerobic training reflects its combined effect on both determinants of the product, and is consistent with evidence that aerobic and endurance-type training reduce RPP and myocardial workload in cardiac and hypertensive populations (Falz et al., 2023; Obaseki et al., 2025). It also aligns with data specific to post-cardiac-surgery rehabilitation, in which RPP is used to characterise cardiovascular efficiency during Phase II programmes (Handirosiyanto et al., 2025). These findings should, however, be read in light of the descriptive, group-level nature of the RPP values reported here.

The comparative pattern — both modalities effective, aerobic somewhat more so for workload — is physiologically coherent. Aerobic training imposes a sustained cardiovascular stimulus that drives central and autonomic adaptations lowering both heart rate and systolic pressure, whereas resistance training, though it also improves autonomic function and lowers heart rate, exerts a comparatively smaller effect on systolic pressure and thus on the composite workload index (Königstein et al., 2023; Schneider et al., 2023). This is consistent with the broader trial and meta-analytic literature indicating that both modalities benefit cardiovascular markers after coronary events, with aerobic or combined approaches tending to produce the greatest haemodynamic gains, including larger reductions in resting blood pressure (Dwiputra et al., 2023; Edwards et al., 2023; Moneruzzaman et al., 2023). Notably, a recent post-CABG trial comparing resistance-type

modalities likewise found meaningful reductions in RPP with both, without clear superiority of one over the other, underscoring that resistance training is a legitimate and effective option where an aerobic emphasis is not feasible (Sharma & Kaur, 2026). Taken together, the results support offering structured exercise routinely after CABG and, where the aim is to reduce cardiac workload and resting heart rate, favouring an aerobic emphasis while retaining resistance training as a valuable component — a message of particular relevance to resource-limited South Asian settings where accessible, low-technology rehabilitation is most needed (Mamataz et al., 2021; McAllister et al., 2025; Subih et al., 2024).

Several limitations qualify these findings. The single-centre design and modest sample of 45 patients limit generalisability, even though the primary heart-rate analysis was strongly powered. Participants and therapists could not be blinded, as is inherent to exercise trials, although assessor and analyst masking reduced bias. The most important limitation specific to this report concerns the rate-pressure product: because the participant-level dataset was not available, RPP could be derived only from group means and is therefore presented descriptively, without standard deviations or inferential testing; its values should be interpreted as indicating the direction and relative magnitude of change rather than as a formally analysed outcome, and future work with participant-level data should confirm them. Baseline body mass index differed across arms, the follow-up was limited to ten weeks, and the predominantly male, single-country cohort further constrains generalisability. Larger, multi-centre, prospectively registered trials that measure autonomic function directly and analyse RPP at the participant level would strengthen and extend these observations.

Conclusion

Among patients recovering from coronary artery bypass grafting, both resistance-based and aerobic-based Phase II cardiac rehabilitation lowered resting heart rate significantly more than conventional care, and the derived rate-pressure product, an index of cardiac workload, fell most after aerobic-based training. These findings indicate that structured exercise favourably modifies autonomic-related and myocardial-workload markers after CABG, and that an aerobic emphasis offers the greatest reduction in cardiac workload, while resistance training remains a beneficial alternative. The results support the routine incorporation of supervised exercise-based rehabilitation into post-CABG care in Pakistan and comparable settings, with modality selection guided by the patient's clinical priorities. The rate-pressure product findings, derived at the group level, warrant confirmation in future studies using participant-level data.

Declarations

Ethics approval and consent to participate: The study was approved by the institutional review board and conducted in accordance with the Declaration of Helsinki; all participants provided written informed consent. **Consent for publication:** Not applicable. **Competing interests:** The authors declare no competing interests. **Funding:** This research received no specific grant from any funding agency. **Data availability:** The summary data supporting the findings are available from the corresponding author on reasonable request; the participant-level dataset was not available for the present analysis.

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