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Original Research Article

Evaluation of Post-Exercise Blood Pressure Recovery Time as an Indicator of Cardiovascular Fitness and Metabolic Adaptation in Healthy Adults

Annu Ankita[1], Abhilasha[2], Purushottam Kumar[3], Mo Shaqib[4]

[1]Assistant Professor, Department of Physiology, Era Lucknow Medical College, Lucknow, UP, India

[2]Assistant Professor, Department of Biochemistry, Netaji Subhas Medical College & Hospital, Bihta, Bihar, India

[3]Assistant Professor, Department of Biochemistry, Mahabodhi Medical College & Hospital, Gaya, Bihar, India

[4]Post. Senior Resident, Department of Physiology, Dr B.S. Kushwah Institute of Medical Science, Kanpur, UP, India

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Corresponding author: Dr. Abhilasha
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Abstract

Cardiovascular fitness is an important determinant of overall health and physical performance. The recovery of cardiovascular parameters following exercise reflects autonomic regulation, cardiovascular efficiency, and underlying metabolic adaptation. Exercise induces several biochemical changes including increased glucose utilization, enhanced ATP turnover, lactate production, and oxidative stress responses, all of which contribute to physiological adaptation and recovery. The present study aimed to evaluate post-exercise blood pressure recovery time as a marker of cardiovascular fitness and metabolic adaptation in healthy adults. A cross-sectional study was conducted among 120 healthy adults aged 18–35 years. Participants performed a standardized three-minute step exercise test. Blood pressure was measured at baseline, immediately after exercise, and during recovery at 1, 2, 3, and 5 minutes. Recovery time was defined as the duration required for systolic blood pressure to return within 10 mmHg of baseline values. Participants were categorized into high-fitness, moderate-fitness, and low-fitness groups based on recovery time. The mean baseline systolic blood pressure and diastolic blood pressure were 118 ±8 mmHg and 76 ±6 mmHg, respectively. Immediately after exercise, systolic blood pressure increased significantly to 154 ±10 mmHg. Blood pressure gradually declined during the recovery period. Individuals with higher cardiovascular fitness demonstrated significantly faster blood pressure recovery compared with those with lower fitness levels ($p < 0.001$). The findings suggest that post-exercise blood pressure recovery time is strongly associated with cardiovascular fitness and may serve as a simple, non-invasive marker of cardiovascular function. Recovery characteristics may also reflect underlying metabolic adaptations associated with improved exercise tolerance and cardiovascular conditioning.

Keywords: Cardiovascular Fitness, Blood Pressure Recovery, Exercise Physiology, Autonomic Regulation, Step Test.

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Introduction

Cardiovascular fitness represents the capacity of the heart, lungs, and circulatory system to supply oxygen to working muscles during sustained physical activity. It is widely recognized as an important indicator of overall health and functional capacity. Individuals with higher cardiovascular fitness demonstrate better exercise tolerance, improved metabolic health, and reduced risk of cardiovascular disease. [1-4]

Cardiovascular fitness is closely linked with metabolic health. During exercise, increased energy demand stimulates coordinated activation of aerobic and anaerobic metabolic pathways, resulting in enhanced glucose uptake, glycogenolysis, fatty-acid oxidation, and ATP synthesis. Individuals with superior cardiovascular fitness exhibit greater metabolic flexibility and improved efficiency of energy utilization, enabling better exercise performance and faster recovery. [16,17]

Exercise is also accompanied by important biochemical responses. Accelerated glycolysis and oxidative phosphorylation increase ATP turnover, while lactate is produced during periods of increased metabolic demand. Simultaneously, reactive oxygen species are generated as by-products of mitochondrial respiration. Regular physical activity enhances antioxidant defense systems and mitochondrial efficiency, thereby improving the body's ability to recover following exercise. [18,19] Recovery following exercise represents restoration of both physiological and biochemical homeostasis. In addition to normalization of heart rate and blood pressure, recovery involves replenishment of energy stores, clearance of metabolic by-products, restoration of autonomic balance, and reduction of oxidative stress. Therefore, post-exercise blood pressure recovery may reflect not only cardiovascular efficiency but also underlying metabolic adaptation. [17,20]

Exercise produces a series of physiological responses that involve the coordinated activity of the cardiovascular, respiratory, and nervous systems. During physical activity, there is an increase in heart rate, stroke volume, cardiac output, and systolic blood pressure. These changes occur primarily due to activation of the sympathetic nervous system and increased metabolic demands of skeletal muscles. [2,3,5]

Following cessation of exercise, cardiovascular parameters gradually return to baseline levels through a process known as recovery. Recovery is mediated mainly by parasympathetic reactivation and withdrawal of sympathetic stimulation. The rate at which cardiovascular parameters normalize after exercise reflects the efficiency of autonomic regulation and cardiovascular conditioning. [6-8]

Post-exercise cardiovascular recovery has gained increasing attention as an indicator of cardiovascular health. Delayed recovery may indicate impaired autonomic function, reduced cardiovascular fitness, or increased cardiovascular risk. Conversely, rapid recovery is generally associated with better cardiovascular conditioning and improved autonomic balance. [6,8,11,12]

Blood pressure response during exercise has been extensively studied in exercise physiology. However, the recovery phase following exercise has received comparatively less attention. Post-exercise blood pressure recovery reflects multiple physiological mechanisms, including vascular compliance, baroreceptor sensitivity, autonomic regulation, and cardiac efficiency. [5,9,10,12]

Measurement of post-exercise blood pressure recovery is simple, inexpensive, and feasible in most clinical and laboratory settings. Therefore, it has the potential to serve as a practical marker of cardiovascular fitness in healthy populations. [5,9,10]

The present study was undertaken to evaluate post-exercise blood pressure recovery time in healthy adults and to determine its association with cardiovascular fitness.

Materials and Methods

Study Design: This cross-sectional observational study was conducted in the Department of Physiology in collaboration with the Department of Biochemistry.

Study Population: The study included 120 healthy adults aged 18–35 years. Participants were recruited from students and staff volunteers.

Inclusion Criteria

- Healthy individuals aged 18–35 years
- Both males and females
- No history of chronic illness

Exclusion Criteria

- Hypertension
- Cardiovascular disease
- Diabetes mellitus
- Respiratory disorders
- Use of medications affecting cardiovascular function
- Recent illness or injury

Ethical Considerations: Informed consent was obtained from all participants before participation. The study protocol adhered to ethical principles for biomedical research involving human subjects.

Exercise Protocol: Participants performed a standardized three-minute step test using a 30-cm step bench. The stepping rate was maintained at 24 steps per minute using a metronome to ensure uniformity of exercise intensity.

Blood Pressure Measurement: Blood pressure was measured using a calibrated automated sphygmomanometer.

Measurements were recorded at the following intervals:

- Baseline (after 5 minutes of rest)
- Immediately after exercise
- 1 minute recovery
- 2 minutes recovery
- 3 minutes recovery
- 5 minutes recovery

Definition of Recovery Time: Blood pressure recovery time was defined as the time required for systolic blood pressure to return within 10 mmHg of baseline value.

Fitness Classification Participants were categorized into three groups based on recovery time:

Recovery Time	Fitness Category
≤ 2.5 minutes	High fitness
2.6–4 minutes	Moderate fitness
> 4 minutes	Low fitness

Biochemical Assessment: Fasting venous blood samples were collected from all participants following an overnight fast. Fasting blood glucose was estimated by the glucose oxidase-peroxidase method. In addition, serum lactate concentration was measured using an enzymatic colorimetric assay to assess exercise-related metabolic adaptation. Approximately 3 mL of fasting venous blood was collected under aseptic precautions from each participant. Samples were processed in the Department of Biochemistry and analyzed using standard laboratory methods.

Statistical Analysis Data were analyzed using descriptive and inferential statistics.

- Mean and standard deviation were calculated for all variables.
- Differences between fitness groups were analyzed using one-way ANOVA.
- A p value < 0.05 was considered statistically significant.
- Fasting blood glucose and serum lactate values were expressed as mean ±standard deviation.
- Correlation between biochemical parameters and blood pressure recovery time was assessed using Pearson correlation analysis.

Results

Baseline Characteristics: A total of 120 participants completed the study.

Table 1. Baseline Characteristics of Study Participants

Parameter	Mean ± SD
Age (years)	24.3 ± 3.2
Baseline SBP (mmHg)	118 ± 8
Baseline DBP (mmHg)	76 ± 6

Table 1 shows the baseline characteristics of the study participants. The mean age of participants was 24.3 ± 3.2 years, and the baseline blood pressure values were within the normal physiological range.

Table 1A. Baseline Biochemical Characteristics of Study Participants

Parameter	Mean ± SD
Fasting Blood Glucose (mg/dL)	89.6 ± 7.8
Serum Lactate (mmol/L)	1.9 ± 0.4

The baseline biochemical characteristics of participants are presented in Table 1A. Mean fasting blood glucose and serum lactate levels were within normal physiological limits, indicating normal metabolic status among the study population. These findings suggest adequate metabolic health and exercise adaptation in the enrolled participants. Participants with shorter recovery times tended to demonstrate more favorable biochemical profiles, suggesting a possible association between metabolic status and cardiovascular recovery. However, further studies are required to establish the strength of this relationship. No significant abnormalities were observed in the biochemical parameters, indicating that the study population was metabolically healthy and suitable for evaluation of exercise-induced cardiovascular responses.

Table 1B: Comparison of Biochemical Parameters Among Different Cardiovascular Fitness Groups

Parameter	High Fitness	Moderate Fitness	Low Fitness	p-value
Fasting Blood Glucose (mg/dL)	87.8 ± 7.2	89.5 ± 7.9	91.2 ± 8.1	0.08
Serum Lactate (mmol/L)	1.7 ± 0.3	1.9 ± 0.4	2.1 ± 0.5	0.03

A statistically significant difference in serum lactate concentration was observed among the fitness groups ($p = 0.03$), whereas fasting blood glucose levels did not differ significantly ($p = 0.08$). Lower lactate levels in the high-fitness group may indicate enhanced aerobic metabolism and superior exercise adaptation. Participants in the high-fitness group exhibited lower mean serum lactate levels compared with the low-fitness group. This finding suggests more efficient metabolic adaptation and enhanced aerobic capacity among individuals with better cardiovascular fitness.

Table 2. Blood Pressure Response during Exercise Recovery

Time Point	Mean SBP (mmHg)	Mean DBP (mmHg)
Baseline	118	76
Immediate post-exercise	154	84
1 minute recovery	140	82
2 minutes recovery	132	80
3 minutes recovery	125	78
5 minutes recovery	120	76

Table 2 demonstrates the changes in systolic and diastolic blood pressure following exercise. Systolic blood pressure increased markedly immediately after exercise as a physiological response to increased cardiac output and metabolic demand. During the recovery period, blood pressure gradually declined toward baseline levels, reflecting restoration of autonomic balance, normalization of peripheral vascular resistance, and recovery from exercise-induced metabolic stress. The observed pattern indicates effective cardiovascular adaptation and maintenance of physiological homeostasis following physical activity.

Table 3. Comparison of Blood Pressure Recovery Time among Fitness Groups

Fitness Group	Participants (n)	Mean Recovery Time (min)	SD
High fitness	40	2.1	0.6
Moderate fitness	38	3.4	0.7
Low fitness	42	4.8	0.9

Individuals with higher cardiovascular fitness showed significantly faster blood pressure recovery. Table 3 compares post-exercise blood pressure recovery time among participants with different levels of cardiovascular fitness. Individuals in the high-fitness group exhibited significantly shorter recovery times compared with moderate- and low-fitness groups, indicating superior cardiovascular conditioning. Faster recovery may also reflect enhanced metabolic efficiency, improved mitochondrial oxidative capacity, and more effective utilization of energy substrates during and after exercise. Conversely, prolonged recovery time in the low-fitness group may indicate comparatively reduced physiological and metabolic adaptation to exercise stress.

Table 4: One-Way ANOVA Showing Comparison of Blood Pressure Recovery Time Among Fitness Groups

Source of Variation	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	F value	p value
Between Groups	42.6	2	21.3	21.1	<0.001
Within Groups	118.4	117	1.01	—	—
Total	161.0	119	—	—	—

The statistically significant difference in recovery time among the three fitness groups suggests marked variation in cardiovascular and metabolic adaptation among participants.

Individuals demonstrating rapid recovery are likely to possess better autonomic regulation, improved vascular responsiveness, and enhanced cellular energy metabolism, all of which contribute to efficient restoration of homeostasis following exercise.

A one-way ANOVA demonstrated a statistically significant difference in blood pressure recovery time among the three fitness groups ($F = 21.1$, $p < 0.001$).

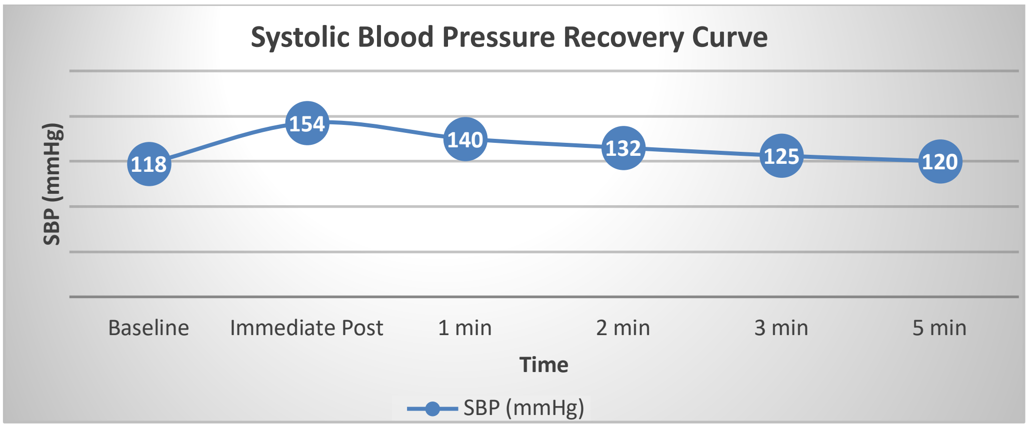

Figure 1: Changes in systolic blood pressure (SBP) measured at baseline, immediately after exercise, and during recovery at 1, 2, 3, and 5 minutes following a standardized step test in healthy adults.

The graph demonstrates a marked increase in systolic blood pressure immediately after exercise followed by a gradual decline during the recovery period. The return of systolic blood pressure toward baseline values reflects efficient cardiovascular regulation and recovery from increased metabolic demand. Faster normalization of systolic blood pressure may indicate superior cardiovascular fitness and greater physiological adaptability.

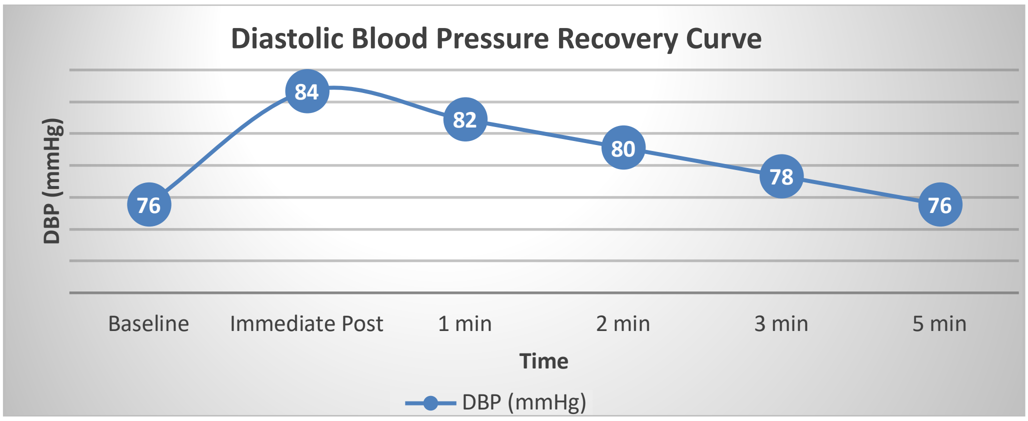

Figure 2: Changes in diastolic blood pressure (DBP) measured at baseline, immediately after exercise, and during recovery at 1, 2, 3, and 5 minutes after the step exercise test.

Diastolic blood pressure showed a mild increase immediately after exercise followed by gradual normalization during the recovery period. This pattern reflects restoration of peripheral vascular function, autonomic balance, and metabolic equilibrium following cessation of physical activity.

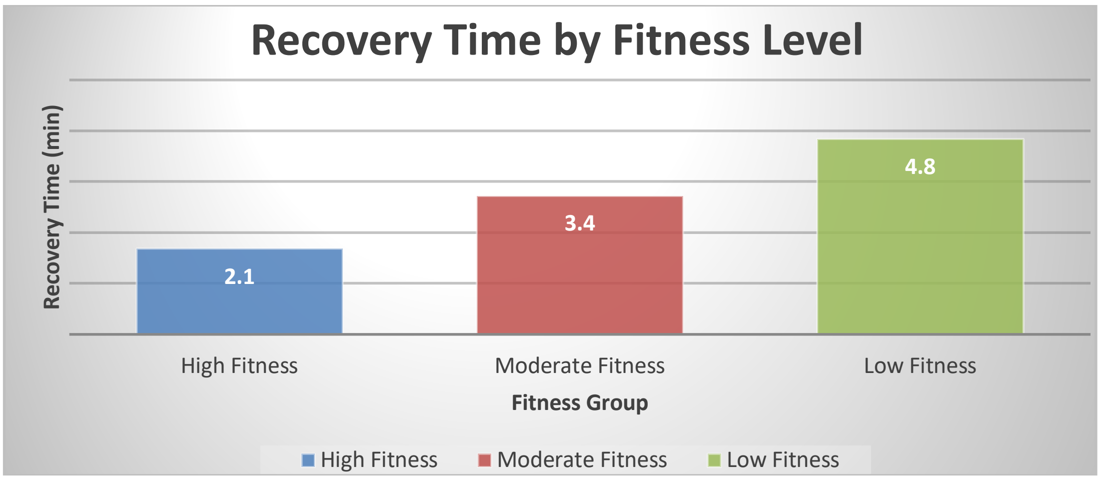

Figure 3: Comparison of mean blood pressure recovery time among participants categorized into high, moderate, and low cardiovascular fitness groups.

Participants in the high-fitness group demonstrated significantly shorter recovery times compared with moderate- and low-fitness groups. These findings suggest that individuals with better cardiovascular fitness possess more efficient physiological mechanisms for recovery and may exhibit enhanced metabolic adaptation to exercise

Metabolic Interpretation of Recovery Findings: The differences observed in blood pressure recovery among fitness groups may be explained not only by cardiovascular factors but also by variations in metabolic adaptation. Exercise imposes increased energy demands that require coordinated cardiovascular and biochemical responses. Individuals with superior fitness are likely to exhibit enhanced mitochondrial function, efficient ATP production, improved substrate utilization, and greater resistance to exercise-induced physiological stress. These adaptations may contribute to the rapid recovery of cardiovascular parameters observed in the present study.

Discussion

The present study evaluated post-exercise blood pressure recovery as a marker of cardiovascular fitness in healthy adults. The results demonstrated a significant relationship between cardiovascular fitness level and the rate of blood pressure recovery following exercise. [9,10,12]

Exercise causes activation of the sympathetic nervous system, resulting in increased heart rate, stroke volume, and systolic blood pressure. These physiological adjustments allow the body to meet the increased metabolic demands during physical activity. After cessation of exercise, cardiovascular parameters gradually return to resting levels through parasympathetic reactivation and reduced sympathetic activity. [2,3,5]

The speed of recovery reflects the functional status of autonomic regulation and cardiovascular conditioning. Individuals with higher cardiovascular fitness tend to demonstrate more rapid recovery due to improved cardiac efficiency, enhanced vascular compliance, and stronger parasympathetic tone. [6-8,12]

In addition to autonomic mechanisms, biochemical adaptations may contribute significantly to post-exercise recovery. Individuals with superior cardiovascular fitness generally possess enhanced mitochondrial density, greater oxidative enzyme activity, and improved metabolic efficiency. These adaptations facilitate more effective ATP production during exercise and promote rapid restoration of physiological homeostasis during the recovery period. [16,17] The normal fasting blood glucose and serum lactate values observed in the present study further support the presence of adequate metabolic regulation among participants. Efficient glucose utilization and maintenance of normal lactate concentrations are important indicators of metabolic fitness and may contribute to effective cardiovascular recovery following exercise [16,17,18].

Lower serum lactate concentrations observed among participants with faster blood pressure recovery may indicate enhanced oxidative metabolism and improved aerobic efficiency. Lactate is an important marker of exercise-related metabolic stress, and efficient lactate handling is often associated with superior cardiovascular conditioning [16,17].

The findings of this study showed that systolic blood pressure increased significantly immediately after exercise and gradually declined during the recovery period. Participants with higher fitness levels exhibited significantly shorter recovery times compared with individuals with lower fitness levels. [9,11,12]

These results are consistent with previous studies that have reported an association between faster cardiovascular recovery and better physical fitness. Improved vascular elasticity and enhanced autonomic regulation may contribute to more rapid normalization of blood pressure in physically fit individuals. [6,9,12,14]

Exercise-induced cardiovascular responses are closely associated with cellular energy metabolism. Increased oxygen utilization, enhanced glucose uptake, and efficient oxidative phosphorylation contribute to improved exercise performance and recovery. Regular physical activity also improves antioxidant defense mechanisms, which help reduce exercise-induced oxidative stress and maintain vascular function. These biochemical adaptations may further support faster cardiovascular recovery in physically fit individuals. [18,19]

The relationship between cardiovascular recovery and metabolic adaptation highlights the integrated nature of physiological and biochemical responses to exercise. Faster recovery of blood pressure may indirectly reflect enhanced metabolic flexibility, improved substrate utilization, and efficient regulation of energy balance. Therefore, assessment of post-exercise recovery may provide insight not only into cardiovascular fitness but also into underlying metabolic health. [17,20] Post-exercise recovery indices have been increasingly recognized as useful indicators of cardiovascular health. Delayed recovery has been associated with reduced autonomic function and increased cardiovascular risk. [6,11,12] Because blood pressure measurement is simple and widely available, assessment of post-exercise blood pressure recovery could serve as a practical tool for evaluating cardiovascular fitness in both clinical and community settings. [5,9,10]

Conclusion

Post-exercise blood pressure recovery time was found to be significantly associated with cardiovascular fitness in healthy adults. Individuals with higher fitness levels demonstrated more rapid normalization of blood pressure following exercise, indicating superior cardiovascular conditioning and autonomic regulation. In addition to physiological mechanisms, exercise recovery is influenced by metabolic and biochemical adaptations, including efficient energy utilization, enhanced mitochondrial function, improved oxidative metabolism, and effective regulation of oxidative stress. These integrated physiological and biochemical responses contribute to improved exercise tolerance and recovery capacity. Therefore, assessment of post-exercise blood pressure recovery provides a simple, non-invasive, and cost-effective method for evaluating cardiovascular fitness and may also serve as an indirect indicator of underlying metabolic adaptation. Incorporation of biochemical markers in future studies may further enhance the understanding of mechanisms linking cardiovascular recovery and overall metabolic health.

Limitations

- The study sample size was relatively small.
- Only healthy young adults were included.
- Long-term cardiovascular outcomes were not assessed.
- Biochemical parameters were assessed only at baseline; dynamic post-exercise biochemical changes were not evaluated.

Future Implications

Future studies may evaluate dynamic changes in serum lactate, glucose metabolism, and oxidative stress biomarkers before and after exercise to further elucidate the biochemical mechanisms underlying cardiovascular recovery. Integration of physiological and biochemical markers may improve assessment of cardiovascular fitness and exercise adaptation. [16–20]

References

1. American College of Sports Medicine. ACSM's guidelines for exercise testing and prescription. 10th ed. Philadelphia: Wolters Kluwer; 2018.
2. Guyton AC, Hall JE. Textbook of medical physiology. 13th ed. Philadelphia: Elsevier; 2016.
3. McArdle WD, Katch FI, Katch VL. Exercise physiology: nutrition, energy, and human performance. 8th ed. Philadelphia: Wolters Kluwer; 2015.
4. Wilmore JH, Costill DL, Kenney WL. Physiology of sport and exercise. 6th ed. Champaign: Human Kinetics; 2015.
5. Fletcher GF, Ades PA, Kligfield P, Arena R, Balady GJ, Bittner VA, et al. Exercise standards for testing and training: a scientific statement from the American Heart Asso ciation. Circulation. 2013;128(8):873–934.
6. Cole CR, Blackstone EH, Pashkow FJ, Snader CE, Lauer MS. Heart-rate recovery immediately after exercise as a predictor of mortality. N Engl J Med. 1999;341(18):1351–7.
7. Imai K, Sato H, Hori M, Kusuoka H, Ozaki H, Yokoyama H, et al. Vagally mediated heart rate recovery after exercise is accelerated in athletes but blunted in patients with chronic heart failure. J Am Coll Cardiol. 1994;24(6):1529–35.
8. Pierpont GL, Stolpman DR, Gornick CC. Heart rate recovery post-exercise as an index of parasympathetic activity. J Auton Nerv Syst. 2000;80(3):169–74.
9. Buchheit M. Monitoring training status with heart rate measures: do all roads lead to Rome? Front Physiol. 2014;5:73.
10. Arena R, Myers J, Guazzi M. Cardiopulmonary exercise testing: clinical and research applications. Circulation. 2007;116(3):329–43.
11. Watanabe J, Thamilarasan M, Blackstone EH, Thomas JD, Lauer MS. Heart rate recovery immediately after treadmill exercise and left ventricular systolic dysfunction as predictors of mortality. Circulation. 2001;104(16):1911–6.
12. Peçanha T, Silva-Junior ND, Forjaz CL. Heart rate recovery: autonomic determinants, methods of assessment and association with mortality and cardiovascular diseases. Clin Physiol Funct Imaging. 2014;34(5):327–39.
13. Carter R, Watenpaugh DE, Wasmund WL, Wasmund SL, Smith ML. Muscle pump and central command during recovery from exercise in humans. J Appl Physiol. 1999;87(4):1463–9.
14. Joyner MJ, Green DJ. Exercise protects the cardiovascular system: effects beyond traditional risk factors. J Physiol. 2009;587(23):5551–8.
15. Shephard RJ. Exercise physiology and human performance. 2nd ed. London: Croom Helm; 1982.
16. Brooks GA. Lactate as a fulcrum of metabolism. Redox Biol. 2020;35:101454.
17. Hawley JA, Hargreaves M, Joyner MJ, Zierath JR. Integrative biology of exercise. Cell. 2014;159(4):738-49.

18. Egan B, Zierath JR. Exercise metabolism and the molecular regulation of skeletal muscle adaptation. Cell Metab. 2013;17(2):162-84.
19. Powers SK, Jackson MJ. Exercise-induced oxidative stress: cellular mechanisms and impact on muscle force production. Physiol Rev. 2008;88(4):1243-76.
20. Lundby C, Montero D, Joyner M. Biology of VO_2max: looking under the physiology lamp. Acta Physiol. 2017;220(2):218-28.