



Original Article

Validity of anaerobic threshold measured in resistance exercise

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Abstract. [Purpose] Intensity for resistance exercise is estimated based on the maximum muscle strength. Exercise prescription without evaluating the biological response has a challenge. This study aimed to confirm whether anaerobic threshold measured using cardiopulmonary exercise test in resistance exercise is appropriate or not. [Participants and Methods] Resistance exercise adopted for the study was right-leg knee extension. The participants were 10 healthy young males. We investigated whether the oxygen uptake kinetics achieved a steady state within 3 min during the constant-load test with knee extension at 80% anaerobic threshold using cardiopulmonary exercise test with knee extension. If oxygen uptake kinetics achieved a steady state within 3 min, the exercise intensity measured using cardiopulmonary exercise test was considered appropriate. [Results] Anaerobic threshold was measured using the conventional approach in all participants. The steady state of oxygen uptake kinetics could be achieved within 3 min. In the constant-load test with knee extension at 80% anaerobic threshold, the oxygen uptake kinetics achieved a steady state within 3 min. [Conclusion] Based on the findings, the anaerobic threshold obtained using cardiopulmonary exercise test with resistance exercise was judged as appropriate. The results of this study contribute to the accurate setting of exercise load for resistance exercise and condition setting for the evaluation of skeletal muscle function.

Key words: Resistance exercise, Cardiopulmonary exercise test, Oxygen uptake kinetics

(This article was submitted Oct. 15, 2021, and was accepted Dec. 2, 2021)

INTRODUCTION

In patients with heart failure, chronic hypoperfusion of skeletal muscle and decreased physical activity result in skeletal muscle abnormalities^{1, 2)}, including decreased capillary density^{3–5)}, decreased oxidative enzyme activity and mitochondrial dysfunction^{1, 6, 7)}. Skeletal muscle abnormalities cause exercise intolerance⁸⁾.

In general, exercise training for patients with heart disease comprises aerobic and resistance exercise (RE). The prescribed aerobic exercise regimen is determined by evaluating the biological response to the exercise using cardiopulmonary exercise test (CPET). However, the RE regimen is determined based on maximum muscle strength. The biological response during RE must be evaluated before a physician can prescribe an exercise regimen. Therefore, the prescribed RE regimen should be based on the biological response during RE.

Evaluation of the biological response during RE requires CPET. Previous studies have determined the anaerobic threshold (AT) during RE using CPET^{9, 10)}. However, RE is not the standard exercise type of CPET. Usually, CPET is performed using

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bicycle ergometer or treadmill. Therefore, it is necessary to confirm that the AT during RE is appropriate. The purpose of this study was to confirm that the AT determined using RE for CPET is appropriate.

RE involves dynamic movement that repeats isotonic contraction 10–20 times in 2–3 min. Previous research has shown that during dynamic exercise with constant loading below AT, oxygen uptake kinetics achieved steady state within 3 min¹¹). In this study, we investigated whether the oxygen uptake kinetics achieved steady state within 3 min during the constant-load test with RE at 80% of AT (80% AT) using CPET. If oxygen uptake kinetics during the constant-load test with RE achieved steady state within 3 min, the exercise intensity measured using CPET was considered to be appropriate.

PARTICIPANTS AND METHODS

We included 10 healthy young male participants [age: 26 ± 4.9 years, height: 172 ± 6 cm, weight: 63 ± 5.8 kg, mean \pm standard deviation (SD)] with no history of respiratory or circulatory disease. The inclusion criteria were absence of smoking history and lack of exercise; the exclusion criteria were difficulty in knee movement because of orthopedic disease of the knee joint. The experimental protocol was approved by the Institutional Ethics Committee of the International University of Health and Welfare (approval number: 17S1109) and adhered to the tenets of the Declaration of Helsinki. Written informed consent was obtained from all the participants enrolled in this study.

RE adopted right-leg knee extension exercise (KE). KE were performed using a Leg Extension device (WTS-02, Minato Medical Science Co., Ltd., Osaka, Japan). Gas exchange data were measured using the breath-by-breath method with an Aero Monitor device (AE-310S, Minato Medical Science Co., Ltd.).

Right-leg KE was performed in the range of 90° – 0° of knee flexion. KE consisted of 3 s for extension, 3 s for return to the original position, and 3 s for rest. To limit compensatory movement during the exercise, we instructed the participants to place their arms on the abdomen and maintain their back flush against the back mat.

The protocol 1 comprised 3 min of rest and 3 min of warm-up exercise followed by KE, which was maintained until the participant found it difficult to continue (Fig. 1). Warm-up exercises were performed using a non-resistance load. Following the warm-up exercises, KE was initiated from 20 N, and the workload was increased by 20 N every 90 s (after 10 cycles of KE).

The protocol 2 comprised 3 min of rest and 3 min of warm-up exercise followed by 6 min of constant-load KE (Fig. 2). Warm-up exercises were performed with a non-resistance load. Constant-load KE was performed at 80% AT determined using Protocol 1.

In Protocol 1, AT was determined according to the conventional AT determination method. The conventional AT determination method is the rising point of pulmonary carbon dioxide output (VCO_2) for oxygen uptake (VO_2), the point at which minute ventilation (VE) / VO_2 increases without any increase in VE/VCO_2 ; the rising point of the respiratory quotient for VO_2 ; and the rising point of VE for VO_2 , the point at which partial pressure of end-tidal oxygen ($PETO_2$) increases without any increase in partial pressure of end-tidal carbon dioxide ($PETCO_2$).

Under Protocol 2, in order to investigate trends among whole participants, the data were calculated as averages value for one minute. In addition, to investigate the tendency of each participant, the data for each breath was extracted. Data were calculated from 3 min 00 s to 3 min 59 s and 5 min 00 s to 5 min 59 s after initiating constant-load KE. If the VO_2 data is equal at the 3 min 00 s to 3 min 59 s and 5 min 00 s to 5 min 59 s, it is determined that VO_2 has reached a steady state within 3 min.

Statistical analysis was performed using SPSS Statistics version 25.0 (IBM, Armonk, NY, USA). The level of significance was set at $p < 0.05$. Mean VO_2 was compared among whole participants using a paired t-test. To confirm the trend in each participant, each breath VO_2 was compared among the participants using an unpaired t-test.

We set the error range to verify whether VO_2 achieved steady state. The error range was determined based on a previous study¹²), which examined the SD of VO_2 in steady state using various intervals. The SD of 1-min mean VO_2 was reported to be 0.8 mL/min/kg and each breath VO_2 was 4.5 mL/min/kg.

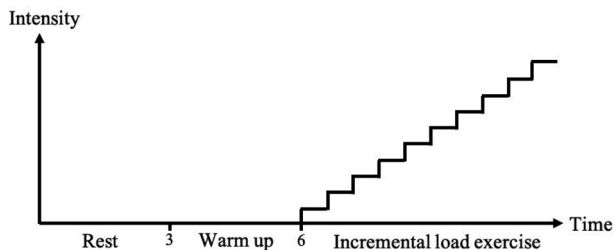


Fig. 1. Protocol 1: Cardiopulmonary exercise test during resistance exercise.

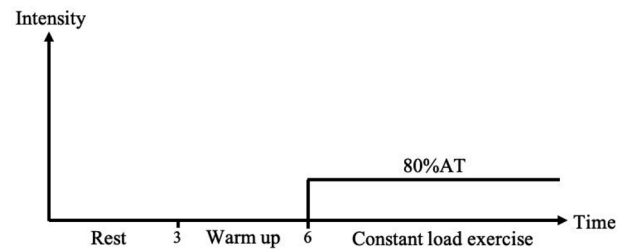


Fig. 2. Constant-load test with resistance exercise.

Because 95% of the data is present within 2SD, the error range of mean VO₂ was set at 1.6 mL/min/kg, whereas the error range of each breath VO₂ was set at 9.0 mL/min/kg. Using the error range, we defined the steady state of VO₂. The definition of steady state was when the 95% confidence interval (CI) for the difference between the two points of VO₂ included 0 and was within the set error range (Fig. 3).

RESULTS

AT was determined using the conventional approach in all participants (Table 1). The VO₂ at AT (VO_{2AT}) was 7.0 ± 1.0 mL/kg/min, and the load required for 80% AT was 119 ± 33 N (mean ± SD).

The mean VO₂ at two points was calculated for each participant and compared among whole participants using the paired t-test. No significant difference of mean VO₂ was observed between the two points. Figure 4 shows the association between the 95% CI of the difference and error range. The 95% CI of the difference was within the error range that included 0.

Each breath VO₂ was extracted from two points and compared among each participants using the unpaired t-test. There was no significant difference in each breath VO₂ between the two points. Figure 5 shows the association between the 95% CI of the difference and error range. In all participants, the 95% CI of the difference was within the error range that included 0.

DISCUSSION

In this study, we investigated that the AT using CPET with RE is appropriate. The results of Protocol 1 determined the exercise load (80% AT) that was used in Protocol 2. To confirm the validity of AT, we investigated whether oxygen uptake kinetics achieved steady state within 3 min.

The time required for oxygen uptake kinetics to achieve steady state depends on the exercise intensity. For intensities below AT, the oxygen uptake kinetics achieved steady state within 3 min¹¹). Therefore, if the oxygen uptake kinetics achieve steady state within 3 min under Protocol 2, the exercise load setting of Protocol 1 is accurate as exercise load below AT. We

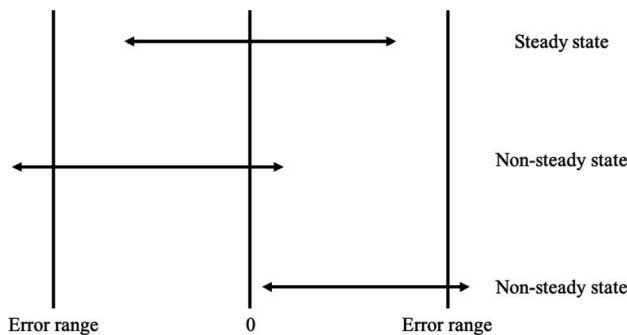


Fig. 3. Steady state defined by the 95% confidence interval (CI) for the difference and error range.

Table 1. Cardiopulmonary exercise test during resistance exercise

Participants	VO _{2AT} (mL/kg/min)	80% AT (N)
1	7.4	160
2	6.6	130
3	5.9	100
4	7.9	160
5	6.7	60
6	5.7	130
7	7.1	130
8	9.1	80
9	6.5	140
10	7.5	100
Mean ± SD	7.0 ± 1.0	119 ± 33

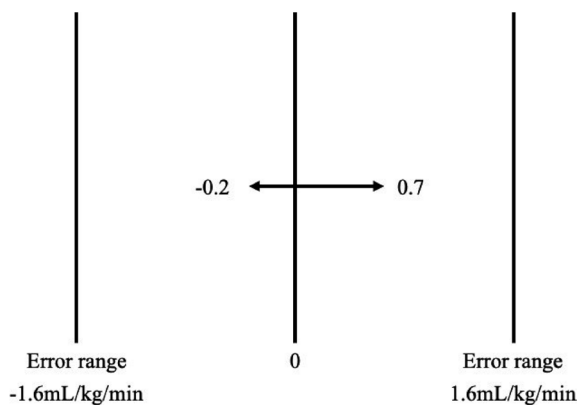


Fig. 4. Association between the 95% confidence interval (CI) and the error range in all participants.

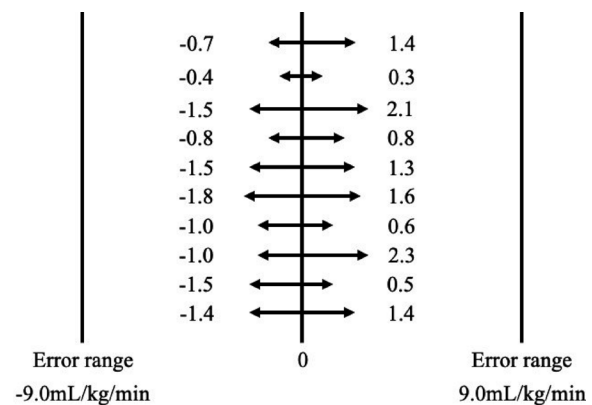


Fig. 5. Association between the 95% confidence interval (CI) and the error range in each participant.

defined the steady state of oxygen uptake kinetics as the case where the 95% CI of the difference in VO_2 between two values compared using paired and unpaired t-tests included 0 within the error range (Fig. 3). In this study, 95% CI of the difference in mean VO_2 and each breath VO_2 between two points was within the error range that included 0 (Fig. 4 and Fig. 5). Therefore, the steady state of oxygen uptake kinetics could be achieved within 3 min under Protocol 2. Furthermore, because oxygen uptake kinetics achieved steady state within 3 min at 80% AT, Protocol 1 was considered to be appropriate at any exercise intensity below AT. In previous studies, the validity of CPET was not verified using exercise other than a bicycle ergometer and/or treadmill^{9, 10}. Our study results suggest that using CPET-based exercise load settings for KE is appropriate.

In addition, this study contributed to the evaluation of τVO_2 during KE. τVO_2 is the index of oxygen uptake kinetics and was measured using bicycle ergometer or treadmill. τVO_2 measured using bicycle ergometer or treadmill reflects the ability to supply and use oxygen^{13–16}. Conversely, oxygen uptake kinetics during KE does not reflect the ability to supply oxygen^{17–19}. Therefore, τVO_2 measured during KE may be a new index of the ability to use oxygen. In this study, we confirmed that the oxygen uptake kinetics during KE achieved steady state. This result contributes to the evaluation of τVO_2 during KE.

One limitation of this study is that the participants were young, healthy males, and the baseline data had to be collected to develop CPET during KE. There is no evidence for CPET during KE. Therefore, we recruited healthy males as participants in order to establish basic data. New research is necessary for indications for disease groups and whether τVO_2 reflects oxygen uptake in skeletal muscles during KE.

Oxygen uptake kinetics achieved steady state within 3 min during the constant-load test with KE. Therefore, the exercise load settings based on CPET with RE can be considered to be appropriate. The results of this study elucidate the appropriate exercise load for RE and clarify the optimal conditions for skeletal muscle evaluation.

Funding

This work was supported by the Japan Society for the Promotion of Science KAKENHI (grant number: JP19K20006, JP17K13226).

Conflict of interest

None.

ACKNOWLEDGMENT

The authors would like to thank Enago (www.enago.jp) for the English language review.

REFERENCES

- 1) Kinugawa S, Takada S, Matsushima S, et al.: Skeletal muscle abnormalities in heart failure. *Int Heart J*, 2015, 56: 475–484. [[Medline](#)] [[CrossRef](#)]
- 2) Mainguy V, Maltais F, Saey D, et al.: Peripheral muscle dysfunction in idiopathic pulmonary arterial hypertension. *Thorax*, 2010, 65: 113–117. [[Medline](#)] [[CrossRef](#)]
- 3) Ingjer F: Effects of endurance training on muscle fibre ATP-ase activity, capillary supply and mitochondrial content in man. *J Physiol*, 1979, 294: 419–432. [[Medline](#)] [[CrossRef](#)]
- 4) Mancini DM, Coyle E, Coggan A, et al.: Contribution of intrinsic skeletal muscle changes to ³¹P NMR skeletal muscle metabolic abnormalities in patients with chronic heart failure. *Circulation*, 1989, 80: 1338–1346. [[Medline](#)] [[CrossRef](#)]
- 5) Sullivan MJ, Green HJ, Cobb FR: Skeletal muscle biochemistry and histology in ambulatory patients with long-term heart failure. *Circulation*, 1990, 81: 518–527. [[Medline](#)] [[CrossRef](#)]
- 6) Clark AL, Poole-Wilson PA, Coats AJ: Exercise limitation in chronic heart failure: central role of the periphery. *J Am Coll Cardiol*, 1996, 28: 1092–1102. [[Medline](#)] [[CrossRef](#)]
- 7) Duscha BD, Schulze PC, Robbins JL, et al.: Implications of chronic heart failure on peripheral vasculature and skeletal muscle before and after exercise training. *Heart Fail Rev*, 2008, 13: 21–37. [[Medline](#)] [[CrossRef](#)]
- 8) Dalla Libera L, Vescovo G, Volterrani M: Physiological basis for contractile dysfunction in heart failure. *Curr Pharm Des*, 2008, 14: 2572–2581. [[Medline](#)] [[CrossRef](#)]
- 9) de Sousa NM, Magosso RF, Pereira GB, et al.: The measurement of lactate threshold in resistance exercise: a comparison of methods. *Clin Physiol Funct Imag*, 2011, 31: 376–381. [[Medline](#)] [[CrossRef](#)]
- 10) de Sousa NM, Magosso RF, Pereira GB, et al.: Acute cardiorespiratory and metabolic responses during resistance exercise in the lactate threshold intensity. *Int J Sports Med*, 2012, 33: 108–113. [[Medline](#)] [[CrossRef](#)]
- 11) Armstrong N, Welsman JR: Aerobic fitness: what are we measuring? *Med Sport Sci*, 2007, 50: 5–25. [[Medline](#)] [[CrossRef](#)]
- 12) Myers J, Walsh D, Sullivan M, et al.: Effect of sampling on variability and plateau in oxygen uptake. *J Appl Physiol* 1985, 1990, 68: 404–410. [[Medline](#)]
- 13) Burnley M, Jones AM, Carter H, et al.: Effects of prior heavy exercise on phase II pulmonary oxygen uptake kinetics during heavy exercise. *J Appl Physiol* 1985, 2000, 89: 1387–1396. [[Medline](#)]
- 14) Poole DC, Barstow TJ, McDonough P, et al.: Control of oxygen uptake during exercise. *Med Sci Sports Exerc*, 2008, 40: 462–474. [[Medline](#)] [[CrossRef](#)]
- 15) Murias JM, Spencer MD, Delorey DS, et al.: Speeding of VO_2 kinetics during moderate-intensity exercise subsequent to heavy-intensity exercise is associated

- with improved local O₂ distribution. *J Appl Physiol* 1985, 2011, 111: 1410–1415. [[Medline](#)]
- 16) Murias JM, Spencer MD, Kowalchuk JM, et al.: Muscle deoxygenation to VO₂ relationship differs in young subjects with varying τVO₂. *Eur J Appl Physiol*, 2011, 111: 3107–3118. [[Medline](#)] [[CrossRef](#)]
 - 17) Koga S, Poole DC, Shiojiri T, et al.: Comparison of oxygen uptake kinetics during knee extension and cycle exercise. *Am J Physiol Regul Integr Comp Physiol*, 2005, 288: R212–R220. [[Medline](#)] [[CrossRef](#)]
 - 18) duManoir GR, DeLorey DS, Kowalchuk JM, et al.: Kinetics of VO₂ limb blood flow and regional muscle deoxygenation in young adults during moderate intensity, knee-extension exercise. *Eur J Appl Physiol*, 2010, 108: 607–617. [[Medline](#)] [[CrossRef](#)]
 - 19) Jones AM, Krstrup P, Wilkerson DP, et al.: Influence of exercise intensity on skeletal muscle blood flow, O₂ extraction and O₂ uptake on-kinetics. *J Physiol*, 2012, 590: 4363–4376. [[Medline](#)] [[CrossRef](#)]