Article

Estimation of the Maximal Lactate Steady State Intensity by the Rating of Perceived Exertion

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Abstract
The maximal lactate steady state is the gold standard for evaluating aerobic capacity; however, it is time-consuming. The lactate minimum protocol is an easier alternative, but is not feasible and still expensive. This study investigated whether the rating of perceived exertion of 13 is an accurate predictor of lactate minimum and maximal lactate steady state intensities. Eleven physically active men performed three tests:

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(1) incremental exercise with workloads based on rating of perceived exertion of 10, 13, and 16 (experimental protocol – denominated RPE-13 test), (2) lactate minimum, and (3) maximal lactate steady state. No differences were observed among participants' workloads corresponding to rating of perceived exertion 13, lactate minimum, and maximal lactate steady state intensities. Thus, the workload associated with the rating of perceived exertion of 13 was equivalent to the other two protocols investigated.

Keywords
anaerobic threshold, aerobic capacity, lactate minimum

Introduction

The anaerobic threshold is a physiological concept defined as an exercise intensity that can be sustained by a large muscle group, while maintaining oxidative metabolism and without blood lactate accumulation (Svedahl & MacIntosh, 2003). The anaerobic threshold is used for exercise evaluation and prescription, besides being sensitive to training adaptations (Meyer, Lucía, Earnest, & Kindermann, 2005; Esteve-Lanao, Foster, Seiler, & Lucia, 2007). The gold standard to identify the anaerobic threshold is the maximal lactate steady state (MLSS) protocol (Svedahl & MacIntosh, 2003; Denadai, Figuera, Favaro & Gonçalves, 2004; Pardono, Sotero, Hiyane, Mota, Campbell, Nakamura et al., 2008). The MLSS method requires several 30-min exercise bouts on different days at constant workloads, with the MLSS being considered the highest exercise intensity in which the blood lactate steady state is still observed (Baron, Dekerle, Robin, Neviere, Dupon, Matran et al., 2003; Beneke, 2003; Billat, Sirvent, Py, Koralsztein & Mercier, 2003).

Due to the high cost and time-consuming procedures of the MLSS protocol, alternative methods have been proposed to identify the anaerobic threshold through the responses of heart rate variability (Sales, Campbell, Morais, Ernesto, Soares-Caldeira, Russo et al., 2011), ventilation (Neder & Stein, 2006; Aoike, Baria, Rocha, Kamimura, Mello, Tufik et al., 2012), blood glucose (Simões, Campbell, Kushnick, Nakamura, Katsanos, Baldissera et al., 2003; Sotero, Pardono, Landwehr, Campbell & Simões, 2009; Simões, Moreira, Hiyane, Benford, Madrid, Prada et al. 2010), blood lactate (Garcin, Mille-Hamard, Duhamel, Boudin, Reveillere, Billat et al., 2003; Johnson, Sharpe & Brown, 2009), and electromyography (Candotti, Loss, Melo, La Torre, Dutra, Oliveira et al., 2008). In addition, the rating of perceived exertion (RPE) is a feasible, non-invasive, low cost, and efficient procedure that has been applied during incremental exercise tests for aerobic evaluation and training prescription in a variety of populations (Hugget, Connely & Overend, 2005; Lima, Assis, Hiyane, Almeida, Arsa, Baldissera et al., 2008; Nakamura, Okuno, Perandini, Caldeira, Simões, Cardoso, et al., 2008, Nakamura, Okuno, Perandini, Oliveira, Buchheit & Simões 2009).

In theory, the RPE is considered a psychophysiological construct that is affected by physiological and psychological variables (Eston, 2012). For example, alterations in heart rate, oxygen uptake, muscle glycogen concentrations, and concentrations of centrally active metabolic compounds such as dopamine and glucose may affect RPE responses to exercise (Borg, 1982; Hampson, St Clair Gibson, Lambert & Noakes, 2001; Pires, Noakes, Lima-Silva, Bertuzzi, Ugrinowitsch, Lira et al., 2011). Furthermore, alterations in emotions seen in affective scores also influence both RPE and exercise performance (Baron, Moullan, Deruelle, & Noakes, 2011). Thus, it has been suggested that RPE is a robust variable indicating an individual's subjective tolerance of exercise at a given intensity (Hampson et al., 2001; Baron, Noakes, Dekerle, Moullan, Robin, Matran et al., 2008; Pires et al., 2011; Eston, 2012).

In the lactate minimum (LM) protocol, the participant exercises to exhaustion twice: the first time early on to induce hyperlactatemia and the second time in the final part of the protocol. Pardono et al. (2008) utilized the traditional LM protocol with several stages and selected three stages: the first stage of LM (fixed at 75 W) and the second and third stages with workloads corresponding to RPEs of 13 and 16, respectively. The authors used polynomial adjustment to analyze the lactate curve formed by these three points, identifying the minimum point. When this point was compared with the MLSS, they were not statistically different. Although the stages were selected at submaximal intensities, the participants performed the traditional LM to exhaustion twice. The RPE has not been used in submaximal exercise tests to predict MLSS intensity. Using the RPE method could reduce costs and be a useful tool for functional evaluation. Therefore, the purpose of this study was to investigate if a submaximal exercise protocol, with an associated workload corresponding to a rating of perceived exertion of 13 (RPE-13), could estimate the exercise intensity corresponding to MLSS and LM.

Hypothesis. The submaximal RPE-13 protocol would estimate the exercise intensity corresponding to both MLSS and LM.

Method

Participants were eleven physically active men (age = 24.6 ± 4.7 yr, body mass index = 23.9 ± 2.8 kg/m^2, body fat = 15.3 ± 5.2%) recruited at the University where the study was conducted. To take part in this study, the participants were neither smokers nor did they have cardiovascular, orthopedic, or neuromuscular diseases. The study was approved by the local ethical committee for human research. All volunteers signed a written informed consent after explanation of the study's procedures, risks, and benefits. Participation was voluntary, and any participant could leave the study at any time. The participants were advised to maintain their normal diet throughout the duration of the study and to refrain from strenuous exercise for the 24 hours prior to the tests.

All tests were performed on a cycle ergometer controlled by electromagnetic brakes (Excalibur, Lode, The Netherlands) with a 48-hr minimum interval between experimental sessions. In the first session, participants were directed to choose a comfortable pedal cadence (60–80 revolutions per minute) and to maintain this cadence on all tests. Heart rate was monitored during all tests (Polar® Sport Tester, Finland). In the final 30 sec of each stage, 25 µL of capillary blood were collected from the earlobe. The sample was mixed in 50 µL sodium fluoride (1%), and deposited into 1.5 mL tubes for posterior analysis. Lactate concentrations were analyzed with the Biochemistry Analyzer YSI 2700 Select (Yellow Springs, Ohio, USA) according to the manufacturer's instructions.

Procedure

The experiment consisted of several visits. In the first session, anthropometric variables were collected and a familiarization session was performed. In the second session, the participants performed the RPE-13 protocol followed by the LM test immediately afterward. The final part of experimental design consisted of at least two visits in which participants underwent the MLSS protocol. On the second visit, participants rested for five minutes before the experimental protocol was initiated.

The familiarization session was initiated at a workload of 75 W and increasing workload of 25 W every 3 min until exhaustion. In the final 30 sec of each stage, a blood sample was collected. The RPE was recorded at each minute. Heart rate was monitored during the entire test.

Measures

Rating of Perceived Exertion (RPE). Measures of RPE were obtained with the 15-point (6 to 20) Borg Scale (Borg, 1982) using the original verbal descriptors. The participants were asked to report their overall RPE based on breathlessness, cardiopulmonary work, and muscle discomfort. Category expressions such as "comfortable intensity level" were used as anchors. The use of RPE was based on several controlled trials and population studies that have observed that individuals can correctly categorize the RPE and accurately identify different exercise intensities based on RPE (Nakamura et al., 2008; Nakamura et al., 2009; Simões et al., 2010; Pires et al., 2011).

The RPE-13 protocol consists of three stages of 3 min each with intensities set according to the RPE Borg Scale. The first workload was set at the RPE corresponding to a Borg score of 10 (between "very light" and "fairly light"); the second workload was set at the RPE corresponding to a Borg score of 13 ("somewhat hard"); and the third workload was set at the RPE corresponding to a Borg score of 16 (between "hard" and "very hard"). The individualized workloads corresponding to each RPE were identified during the familiarization session according to the participants' RPE responses and adjusted during the first 30 sec of each stage. The designated workload during the second stage corresponded with the intensity of RPE-13 and was used to compare the relationship to MLSS and LM.

Lactate Minimum (LM). Immediately after completion of the RPE-13 protocol, without intermission, participants underwent the LM test. For the LM test the workload was first adjusted to the RPE corresponding to a Borg score of 17 ("very hard") to 20 (above "very very hard"), at which they cycled until exhaustion to elevate blood lactate. This intensity was chosen to elicit hyperlactatemia and was collected in the 7th minute of post-exhaustion recovery. The incremental test of the LM was initiated in the 8th minute of recovery. The previous high-intensity exercise induced the blood lactate to increase was important to promote the "U-shape" on the blood lactate curve during the incremental test. The first workload of incremental test was set at 75 W and was increased by 25 W every three minutes until exhaustion. This adaptation of the LM protocol initiated immediately after the incremental test based on RPE responses conforms with a previous study by our group, where this methodology showed good reliability (Madrid, Sotero, Campbell, Sousa, Carvalho, Vieira et al., 2012). Blood samples were collected during the last 30 sec of each stage without interrupting the exercise. Polynomial adjustment, using a derivation of the quadratic formula (Figure 1), was used to determine the LM intensity.

Maximal Lactate Steady State (MLSS). Participants underwent the MLSS protocol, which consisted of different constant workloads lasting 30 min each. The objective of this protocol was to find the maximal exercise workload corresponding to the MLSS or the maximal workload that elicited an increase of no more than 1 mmol.L^{-1} in the blood lactate concentration between the 10th and 30th minutes of exercise. Blood samples were collected at rest and in the10th, 20th, and 30th minutes of exercise. The first workload was set at the LM intensity, and the workloads performed in each subsequent session were adjusted to be 6% more or less intense according to the lactate responses observed. This procedure followed recommendations as reported by Beneke (2003).

Data Analysis

Data were reported as means and standard deviations (SD). The Shapiro-Wilks test was used to ensure normal distribution. Mauchly's test was used to check the sphericity of the data, and the data were corrected with the Greenhouse-Geisser adjustment in the case of sphericity violation. One-way ANOVA with repeated measures with *post hoc* Bonferroni comparisons were used to evaluate the means. The effect size was calculated by Cohen's f^2. The Pearson product-

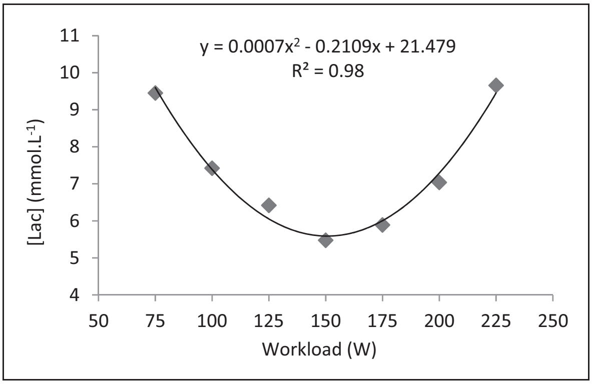

Figure 1. Example of the lactate minimum intensity identified by polynomial adjustment. The lactate minimum intensity was obtained through a derivation of the quadratic equation (LM = −b/2a). The R^2 mean = .98 and SD = .13.

Table 1. Descriptive Statistics for workload, lactate, and heart rate responses at three stages of the RPE-13 protocol.

	Rest		RPE 10		RPE 13		RPE 16	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Workload (watts)*	–	114	23	148	18	187	24	
Lactate (mmol.L^{-1})*	1.17	0.18	2.57	0.77	3.80	0.75	6.35	0.98
Heart Rate (bpm)*	68	7	125	14	145	14	168	14

Note. RPE: rating of perceived exertion. *Significant difference ($p < .001$) between all measurement times for the same variable.

moment correlation coefficient was used to determine the relationship among the workloads from the different protocols. The agreement between variables was analyzed with the Bland-Altman technique. Statistical significance was set at $p < .05$. The analyses were performed with SPSS 20.0 (IBM, Inc., Chicago, IL, United States) with the exception of the Bland-Altman test, which was analyzed using Medcalc 12.4.0 (Ostend, Belgium).

Results

The results of the three stages of the RPE-13 protocol are presented in Table 1. The workload, F_{workload} (1.14, 11.39) = 85.99, $p < .001$, lactate concentration, F_{lactate} (3, 30) = 188.12, $p < .001$, and heart rate $F_{\text{Heart Rate}}$ (3,30) = 245.00, $p < .001$, were significantly different among the three stages evaluated in the RPE-13 protocol.

Table 2. Descriptive statistics for workload (Watts) in the three studied protocols.

Variable	*M*	*SD*	*Min*	*Max*
RPE-13	148	18	120	175
LM	156	11	142	174
MLSS	153	17	125	177

Note. RPE-13: rating of perceived exertion of 13. LM: lactate minimum. MLSS: maximal lactate steady state. $F(2,20) = 1.75$, $p = .20$, Power $= 0.32$.

As shown in Table 2, data from the RPE-13, the LM, and the MLSS protocols were not significantly different from each other ($ps > .05$). Medium effect sizes were observed between the protocols RPE-13 and MLSS (0.18), RPE-13 and LM (0.26), and LM and MLSS (0.15). Furthermore, the RPE-13 protocol showed a stronger correlation with MLSS ($r = .78$) than LM with MLSS ($r = .45$) (Figure 2). The Bland-Altman plot revealed agreement between intensities of the RPE-13, LM, and MLSS (Figure 3).

Discussion

The present study proposed a new methodology (the RPE-13 protocol) to predict the MLSS intensity through a submaximal test with workloads being identified by RPE scores. This test was composed of three stages with workloads defined at RPE of 10, 13, and 16, respectively. The initial hypothesis was that the RPE-13 would identify the exercise intensity corresponding to the MLSS and LM. In fact, workloads across the three investigated protocols were not significantly different from each other. The Pearson coefficients demonstrated a stronger correlation between RPE-13 and MLSS, when compared to the relationship between LM and MLSS. Moreover, the RPE-13 intensity (second stage) showed acceptable agreement with LM and MLSS according to the Bland-Altman analysis.

In the RPE-13 protocol, the workload corresponding to RPE of 13 produced a mean $3.8\,\text{mmol.L}^{-1}$ of blood lactate concentration, which was close to the $4.0\,\text{mmol.L}^{-1}$ that is considered the onset of blood lactate accumulation (OBLA). In the classic study by Heck, Mader, Hess, Műcke, Műller, and Hollmann (1985), the OBLA was not different from MLSS intensity, and the correlation between them was significant. Accordingly, it was observed that RPE-13 intensity was not different from MLSS and were strongly correlated. The similarity between blood lactate concentration obtained in the RPE-13 protocol from the present study and OBLA, together with no differences and strongly correlated RPE-13, MLSS, and LM intensities, are relevant indicators that the RPE-13 workload is a valid measure of MLSS, LM, and consequently the anaerobic threshold.

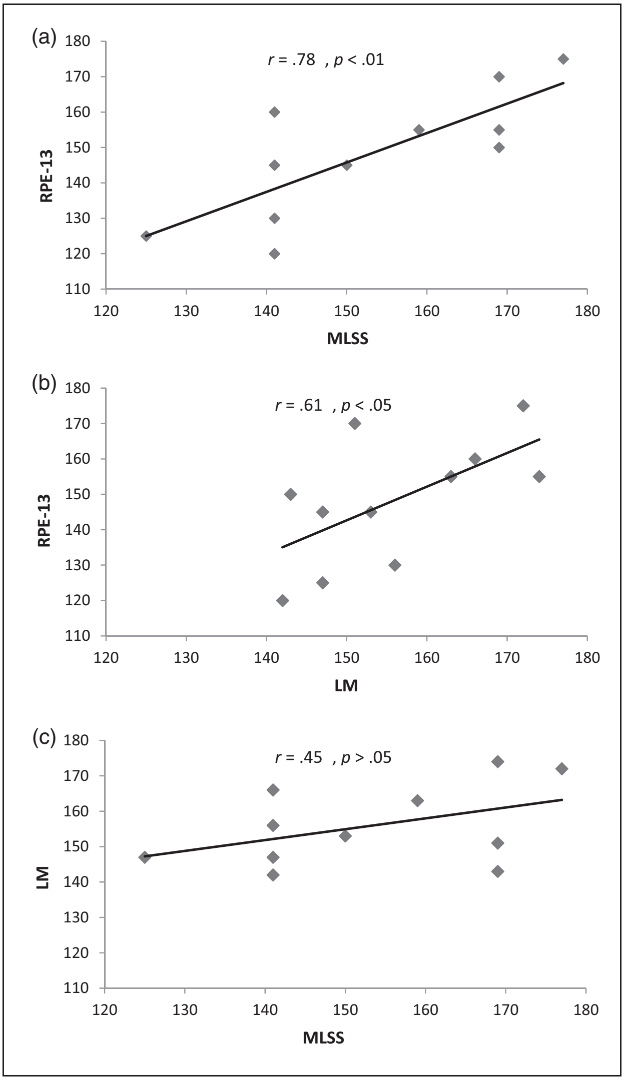

Figure 2. Relationships between RPE-13 and MLSS (a), RPE-13 and LM (b), and LM and MLSS (c). RPE-13: rating of perceived exertion 13 protocol (experimental protocol); LM: lactate minimum; and MLSS: maximal lactate steady state.

In another study, Pardono et al. (2008) selected three stages of a complete LM test (the first stage, RPE 13, and RPE 16) and applied a polynomial adjustment obtaining 192 W ($SD = 27$) at LM three points. This workload did not differ from the exercise intensity corresponding to MLSS 204 W ($SD = 16$) with moderate correlation ($r = .65$, $p = .03$). These findings were the fundamental basis for

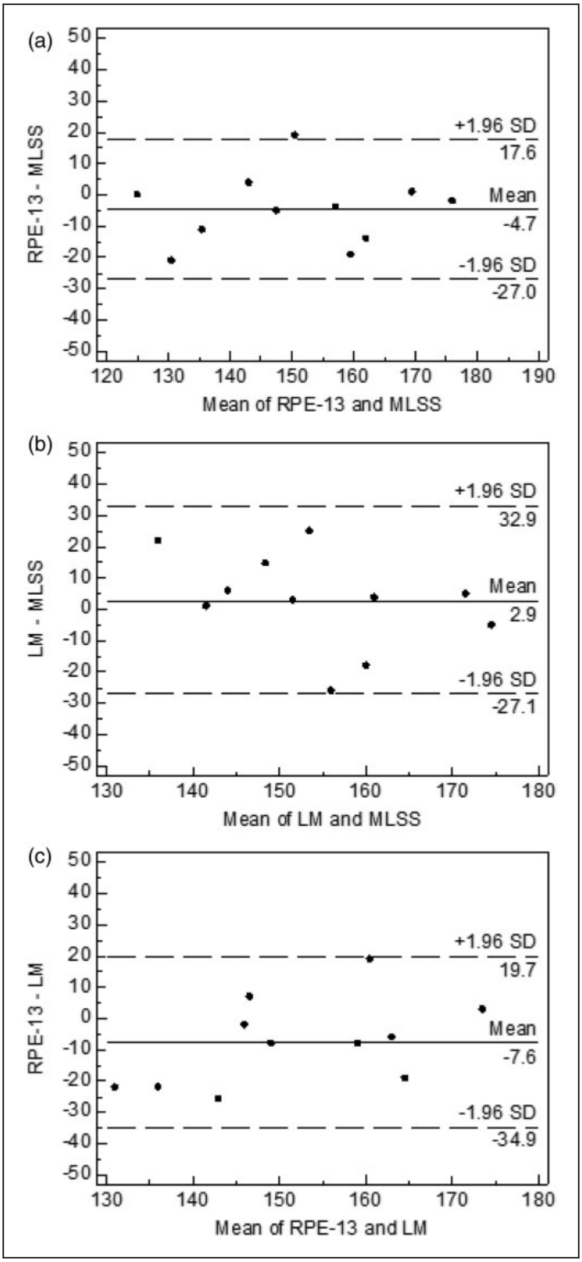

Figure 3. Bland-Altman Plots with workloads in Watts. (a) RPE-13 vs MLSS [-4.7 ± 22.3]. (b) LM vs MLSS [2.9 ± 30.0]. (c) RPE-13 LM [-7.6 ± 27.3]. RPE: rating of perceived exertion. LM: lactate minimum. MLSS: maximal lactate steady state.

the experimental design of the present study. A protocol was similarly proposed with workloads determined by RPE 10, 13, and 16, but with submaximal characteristics and without previous effort. Results revealed that the stage corresponding to RPE 13, 148 W ($SD = 17$), was accurate in identifying the MLSS intensity, 153 W ($SD = 16$), demonstrating good agreement (-4.7 ± 22.3) and strong correlation ($r = .78$; $p < .01$) between them.

Simões et al. (2003) applied a maximal incremental test, with and without previous effort, utilizing variables such as blood lactate, blood glucose, and ventilation. They found that anaerobic threshold occurs between RPE of 13–15 in healthy individuals. While applying a maximal incremental test in type 2 diabetic patients, Simões et al. (2010) observed, through a linear regression between workloads and RPE, that the workload associated with the RPE of 13 (73.2 W) did not differ from the workload corresponding to the lactate threshold (75 W) as identified with the blood lactate breakpoint. In the present study, the workload was identified solely through RPE without any mathematical approach. It is noteworthy that the RPE-13 protocol is a simple, short test performed at submaximal intensity without previous effort or complicated mathematical procedures.

However, exercise performed at the LM intensity scored an average RPE value of 14.2. This greater RPE at LM intensity as compared with RPE-13 can be explained, at least in part, by the initial effort to induce hyperlactatemia prior to the LM test. Although the methods are slightly different, this approach corroborates with the findings of Eston, Faulkner, St Clair Gibson, Noakes, and Parfitt (2007), who verified an increase in RPE for the same absolute workload, when compared to a session with previous effort and a session starting from rest. The authors demonstrated that the RPE could modulate internal mechanisms and was not necessarily a reflection of physiological responses to an exact workload.

The MLSS has been used as a gold standard for aerobic evaluation and as a reference to validate other protocols. However, the workload corresponding to the MLSS in endurance cyclists was 282 W ($SD = 24$), in untrained cyclists 180 W ($SD = 25$) (Denadai et al., 2004), in recreational cyclists 204 W ($SD = 16.0$; Pardono et al., 2008), and in junior rowers 205 W ($SD = 21$; Beneke, Leithäuser, & Hütler et al., 2001), which demonstrated greater aerobic fitness in those participants as compared to the physically active participants of the present study 153 W ($SD = 17$). This lower workload of MLSS of the sample analyzed in the present study was expected and confirmed the efficiency of the present protocol to identify aerobic capacity.

The results of this study showed that the RPE-13 protocol is a practical method to identify anaerobic threshold intensity. The first stage of RPE 10 was exercise intensity below anaerobic threshold. The second stage, RPE 13, has been shown to effectively identify the exercise intensity corresponding to MLSS, LM, and consequently, the anaerobic threshold. The third stage of exercise, RPE 16, was above anaerobic threshold. Finally, the intensity of exercise corresponding to the RPE of 17 to 20 produced hyperlactatemia in LM and was supramaximal exercise intensity. Therefore, the use of RPE-13 provided a good estimate of the MLSS and could reduce the costs and complexity found in other protocols.

In the present study, LM intensity was used as an initial workload for the MLSS protocol. This would be a limitation, once could to induce for a better relationship of LM with MLSS. However, this did not occur in the present study. Actually the RPE-13 was a better predictor of the MLSS than LM. Although the general findings showed good results from the protocol, one participant's RPE-13 underestimated the MLSS by 21 W. Therefore, caution must be taken while explaining the Borg Scale to participants, mainly to those experiencing this protocol by the first time, since this particular underestimation can be attributed to such a misunderstanding. Future studies should be done, preferably with larger sample, to establish the reliability and sensitivity of the protocol in measuring physiological gains arising from training.

Finally, once the workload corresponding to the RPE of 13 was equivalent and associated with the other two protocols investigated, it was concluded that the proposed RPE-13 protocol is a good predictor of the MLSS intensity for the participants of present study.

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Declaration of Conflicting Interests

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