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Original Research Article

The Metabolic Responses and EPOC of CAROL: an AI-Powered Exercise Bike

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ABSTRACT

Aim: This study sought (a) to quantify the acute metabolic responses to CAROL fat burn and intense rides and (b) to quantify excess post-exercise oxygen consumption (EPOC) following fat burn and intense rides. **Methods:** Participants completed trials to quantify resting metabolic rate and perform graded exercise testing (GXT) to determine maximal oxygen uptake (VO2max). Metabolic responses and EPOC were quantified for CAROL intense and fat burn rides, along with moderate-intensity and vigorous-intensity treadmill exercise. **Results:** There was a statistically significant increase ($p<0.05$) in post-exercise metabolism, as evidenced by a greater EPOC, when individuals exercised using either CAROL intense rides (87.7 calories) or fat burn rides (186.1 calories) when compared with either moderate-intensity treadmill exercise (45.2 calories) or vigorous-intensity treadmill exercise (72.1 calories). The duration of EPOC following CAROL fat burn rides was statistically significantly ($p<0.05$) longer when compared to CAROL intense rides. Indeed, the EPOC duration was more than 2-fold longer after CAROL fat burn rides (167.4 min) relative to CAROL intense rides (77.4 min). **Conclusion:** The most important findings of this project are two-fold: 1) it provides gold standard measures of the exercise energy expenditure to be expected during both fat burn and intense rides on CAROL, and 2) it provides scientific evidence to support the notion that personalized true REHIT performed on CAROL contributes to a significantly greater increased post-exercise metabolism (i.e., EPOC) when compared to more traditional moderate-intensity or vigorous-intensity exercise.

KEYWORDS: Caloric Expenditure, Energy Expenditure, Personalized Exercise, REHIT.

Introduction

Scientific research has demonstrated a general dose-response relationship between energy expenditure and multiple health outcomes, including cardiorespiratory fitness, risk of coronary artery disease and all-cause mortality, type 2 diabetes, and obesity[1-2]. The overall energy expenditure from exercise consists of both the energy expenditure during exercise itself and an increased caloric expenditure above resting metabolic rate that persists into the recovery period. The elevated post-exercise energy expenditure is a phenomenon known as excess post-exercise oxygen consumption (i.e., EPOC). Given EPOC contributes approximately 10% to overall exercise energy expenditure[3], it's an important parameter to account for when designing and evaluating the effectiveness of different exercise modalities and training paradigms. Numerous mechanisms are known to contribute to the magnitude of EPOC; however, research has reported that the intensity of an exercise bout has the greatest impact on EPOC[4-6].

CAROL (CARdiovascular Optimization Logic) is a stationary bike that incorporates a modified form of HIIT called reduced-exertion high-intensity training (REHIT). REHIT shortens the traditional HIIT workout by using fewer and shorter sprints, though those sprints are at a supra-maximal intensity. The metabolic responses and EPOC of CAROL are unknown. Therefore, the purpose of this study was (a) to quantify the acute metabolic responses to CAROL fat burn and intense rides and (b) to quantify excess post-exercise oxygen consumption (EPOC) following fat burn and intense rides.

Methods

Participants

20 participants between 25-75 years of age were recruited. Participant characteristics are presented in Table 1. One participant was unable to complete testing. The remaining nineteen participants completed all testing sessions. Exclusionary criteria included evidence of cardiovascular pulmonary, and/or metabolic disease. This study was approved by the Human Research Committee at Western State Colorado University in accordance with international standards and all participants gave their written informed consent[7].

Experimental design

Participants initially completed a trial to quantify resting metabolic rate and perform graded exercise testing (GXT) to determine maximal oxygen uptake (VO_2max). Next, participants performed five familiarization rides on the CAROL bike. Participants subsequently performed, in randomized order, four separate trials where gas exchange data was collected to quantify the acute metabolic responses and EPOC:

- <u>Intense ride</u>: consisted of a two-minute warm-up, a 20-second sprint, a three-minute recovery, a second 20-second sprint and finally a three-minute cool-down. Total workout time: 8 minutes and 40 seconds.
- <u>Fat burn ride</u>: consisted of a two-minute warm-up, 30 x 8-second sprints with 12 seconds of rest in between, and finally a three-minute cool-down. Total workout time: 15 minutes.
- <u>Moderate-intensity ride</u>: consisted of a 30-minute, moderate-intensity exercise (55-59% heart rate reserve – HRR) ride with no warm-up or cool-down.
- <u>Vigorous-intensity ride:</u> consisted of a 20-minute, vigorous-intensity exercise (75-80% HRR) ride with no warm-up or cool-down.

Participants completed the assigned trial while continuous gas exchange data was collected, from which exercise energy expenditure was quantified using the VO_2 data. Participants subsequently rested quietly while post-exercise VO_2 was calculated from gas exchange data. Participants remained seated until post-exercise VO_2 had returned to resting metabolic rate levels.

Table 1. Participant characteristics.

Participant	Age (yr)	Sex	Height (cm)	Weight (kg)	VO_2max (mL/kg/min)
1	30	F	170	73	52.4
2	25	M	188	69	59
3	33	F	175	58	45.8
4	29	M	170	72	61.3
5 *	37	F	163	64	47.5
7	44	F	163	50	33.2
8	39	M	175	94	54.7
9	52	F	165	62	36.6
10	49	M	191	98	50.4
11	47	F	173	71	41.9
12	50	M	185	64	44.5
13	55	F	158	58	29.1
14	57	M	191	87	34.8
15	61	F	177	72	25.3
16	63	M	180	81	30.1
17	66	F	165	67	34.1
18	69	M	178	75	28.5
19	72	F	167	79	29.2
20	76	M	187	95	28
Mean	**49.8**	**---**	**175.3**	**73.7**	**41.2**
SD	**15.1**	**---**	**10.1**	**13.1**	**11.7**
Range	**25–76**	**---**	**158–191**	**50–98**	**25.3–61.3**

*Participant 6 withdrew from the study before pilot testing was completed.

Procedures

Anthropometric and resting heart rate measurements

Participants were weighed to the nearest 0.1 kg on a medical grade scale and measured for height to the nearest 0.5 cm using a stadiometer. The procedures for assessment of resting heart rate outlined elsewhere were followed[1]. Briefly, participants were seated quietly for 5 min in a chair with a back support with feet on the floor and arm supported at heart level. Resting heart rate was obtained via manual palpation of radial artery in the left wrist and recording the number of beats for 60 s.

Resting metabolic rate and GXT

Initially, participants came into the laboratory in the early morning after an overnight fast and rested quietly for 30-

minutes in the supine position to establish resting metabolic rate. Participants were fitted to a mask, attached to the falconia tubing that was attached to the metabolic cart (TrueOne 2400, ParvoMedics, Sandy, UT). A 5-minute break was taken, and the participant was advised to hydrate with water as they wished.

After the 5-minute break, the participant was refitted to the mask, attached to the tube and metabolic cart. The subject was instructed to start a 2-minute warm up on a stationary bike at 50 Watts (Lode Excalibur Sport, Groningen, the Netherlands). After a proper warm-up, the participant began to pedal at a comfortable cadence between 70 to 90 rpm. The workload was increased by 10 watts every minute, and once participant cadence dropped below 40 rpm the test was terminated and a proper cool down commenced. The cool down lasted approximately 5 minutes.

Throughout the test the participant used a chest strap to record their heart rate (Polar Electro, Woodbury, NY, USA). Prior to each test the metabolic cart was calibrated per manufacturer guidelines with a calibration gas mixture (16.00 % O_2 and 4.00 % CO_2) and room air (20.93 % O_2 and 0.003 % CO_2). Gas exchange data were averaged 15 sec, and VO_2max was determined by averaging the final two 15-sec VO_2 average data during the maximal test. The highest achieved HR during the GXT was considered the maximal HR (HRmax).

Statistical Analyses

All analyses were performed using SPSS Version 26.0 (Chicago, IL) and GraphPad Prism 8.0. (San Diego, CA). Measures of centrality and spread are presented as mean $\pm$ SD. Repeated-measures ANOVA were used to examine differences in exercise energy expenditure and EPOC across intensity (moderate vs. vigorous) and CAROL rides (intense and fat burn). If a significant F-ratio was obtained, Tukey's post hoc test was used to identify differences between means. The probability of making a Type I error was set at $p < .05$ for all statistical analyses.

Results

Individual power output and physiological responses to CAROL intense and fat burn rides are shown in Table 2. Individual resting oxygen consumption and metabolic responses to CAROL intense and fat burn rides are shown in Table 3.

Table 2. Power output and physiological responses to CAROL intense and fat burn rides.

Participant	Target HR (BPM)	CAROL Intense Ride			CAROL Fat Burn Ride		
		Peak Power (WATTS)	Total Power (WATT SECONDS)	Max HR (BPM)	Peak Power (WATTS)	Total Power (WATT SECONDS)	Max HR (BPM)
1	152-171	696	26,203	152	302	59,852	151
2	157-176	694	24,115	148	408	63,245	155
3	150-168	520	20,475	141	188	45,823	141
4	153-172	730	22,983	144	404	70,418	154
5 *	146-165	523	20,151	143	230	52,414	136
7	141-158	438	18,413	138	148	37,819	122
8	145-163	868	24,623	151	616	85,113	162
9	134-151	544	22,352	153	175	43,597	137
10	137-154	811	24,083	144	577	81,168	168
11	138-156	415	18,034	147	215	47,749	133
12	136-153	555	20,767	145	268	50,975	140
13	124-140	404	20,381	133	153	38,434	127
14	130-147	662	21,288	147	293	55,688	140
15	127-143	381	17,851	138	189	43,726	136
16	127-143	653	24,630	151	223	44,786	144
17	123-139	351	17,991	120	195	35,300	122
18	121-136	549	19,689	139	199	42,096	133
19	118-133	441	20,044	135	164	36,897	132
20	115-130	423	18,239	129	209	40,623	128
Mean	**---**	**560.9**	**21,174**	**142**	**271.4**	**51,354**	**140.1**
SD	**---**	**151.8**	**2625**	**8.5**	**136.6**	**14,622**	**12.9**
Range	**115–176**	**351–868**	**17,851–26,203**	**120–153**	**148–616**	**35,300–85,113**	**122–168**

*Participant 6 withdrew from the study before pilot testing was completed.

Table 3. Resting oxygen consumption and metabolic responses to CAROL intense and fat burn rides.

Participant	Resting VO_2 (mL/kg/min)	CAROL Intense Ride			CAROL Fat Burn Ride		
		Exercise (kcal)	EPOC (kcal)	EPOC duration (min)	Exercise (kcal)	EPOC (kcal)	EPOC duration (min)
1	3.45	38	98	95	84	204	210
2	3.82	52	104	90	105	212	185
3	3.34	42	87	70	88	183	160
4	3.86	55	96	100	116	201	235
5 *	3.36	43	82	60	89	167	115
7	3.38	37	69	65	79	161	145
8	4.13	59	137	110	133	295	225
9	3.55	40	78	70	92	163	155
10	3.87	61	121	95	146	262	220
11	3.48	36	83	85	83	171	185
12	3.69	46	86	75	98	183	170
13	3.39	30	77	105	69	161	220
14	3.63	51	90	80	111	195	165
15	3.35	32	70	50	73	153	105
16	3.81	47	98	70	101	211	145
17	3.75	29	61	55	67	144	135
18	4.13	43	79	60	95	164	120
19	3.71	34	67	65	75	139	145
20	4.37	49	84	70	103	167	140
Mean	**3.69**	**43.4**	**87.7**	**77.4**	**95.1**	**186.1**	**167.4**
SD	**0.3**	**9.5**	**18.6**	**17.6**	**21.0**	**39.4**	**39.6**
Range	**3.34–4.37**	**29–61**	**61–137**	**50–110**	**67–146**	**139–295**	**105–235**

*Participant 6 withdrew from the study before pilot testing was completed.

Magnitude of EPOC

The overall energy expenditure (exercise combined with EPOC) of CAROL intense and fat burn rides, along with 30min moderate-intensity (55-59% heart rate reserve) treadmill exercise and 20min vigorous-intensity (75-80% heart rate reserve) treadmill exercise are presented in **Figure 1**.

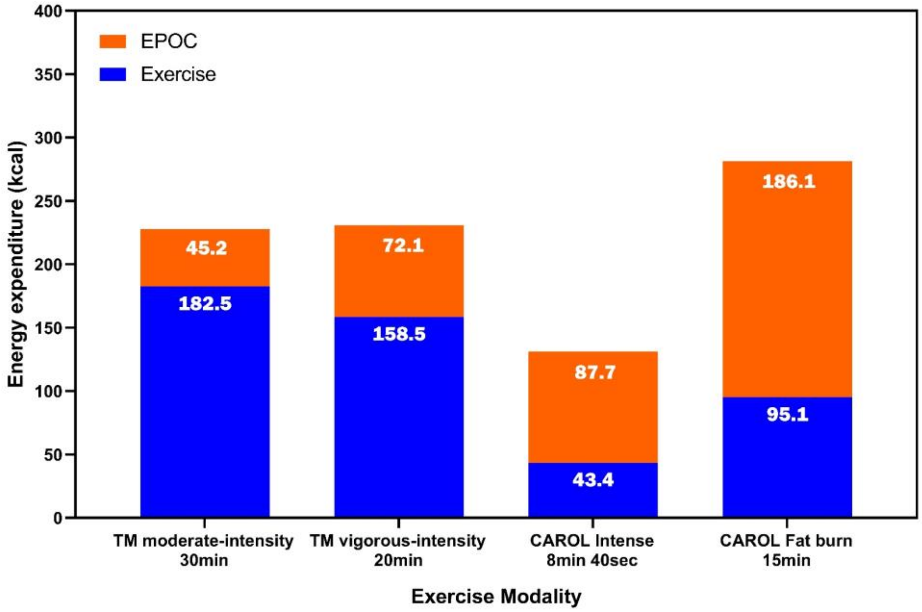

Figure 1. Energy expenditure of traditional moderate-intensity and vigorous-intensity treadmill exercise compared to CAROL intense and fat burn rides.

There was a statistically significant increase (p<0.05) in post-exercise metabolism, as evidenced by a greater EPOC (**Figure 2**), when individuals exercised using either CAROL intense rides (87.7 calories) or fat burn rides (186.1 calories) when compared with either moderate-intensity treadmill exercise (45.2 calories) or vigorous-intensity treadmill exercise (72.1 calories). Indeed, the magnitude of EPOC following fat burn rides was more than 2.5-fold greater than vigorous-intensity treadmill exercise. Similarly, the magnitude of EPOC following intense rides was 2-fold greater than moderate-intensity treadmill exercise.

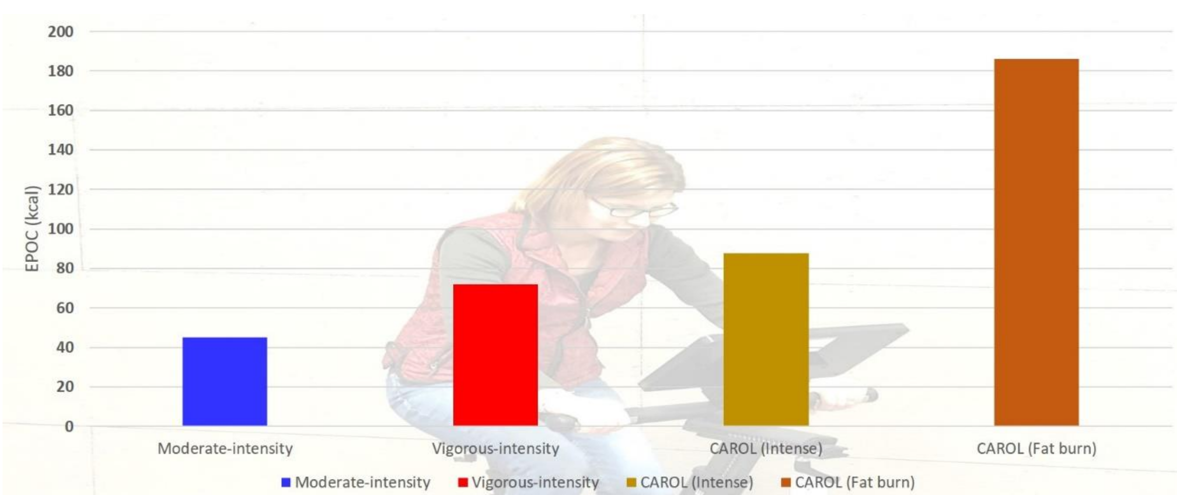

Figure 2. The EPOC following moderate-intensity treadmill exercise (**blue**), vigorous-intensity treadmill exercise (**red**), CAROL intense rides (**gold**), and CAROL fat burn rides (**orange**).

Duration of EPOC

The duration of EPOC following CAROL fat burn rides was statistically significantly ($p<0.05$) longer when compared to CAROL intense rides. Indeed, the EPOC duration (**Figure 2**) was more than 2-fold longer after CAROL fat burn rides (167.4 min) relative to CAROL intense rides (77.4 min).

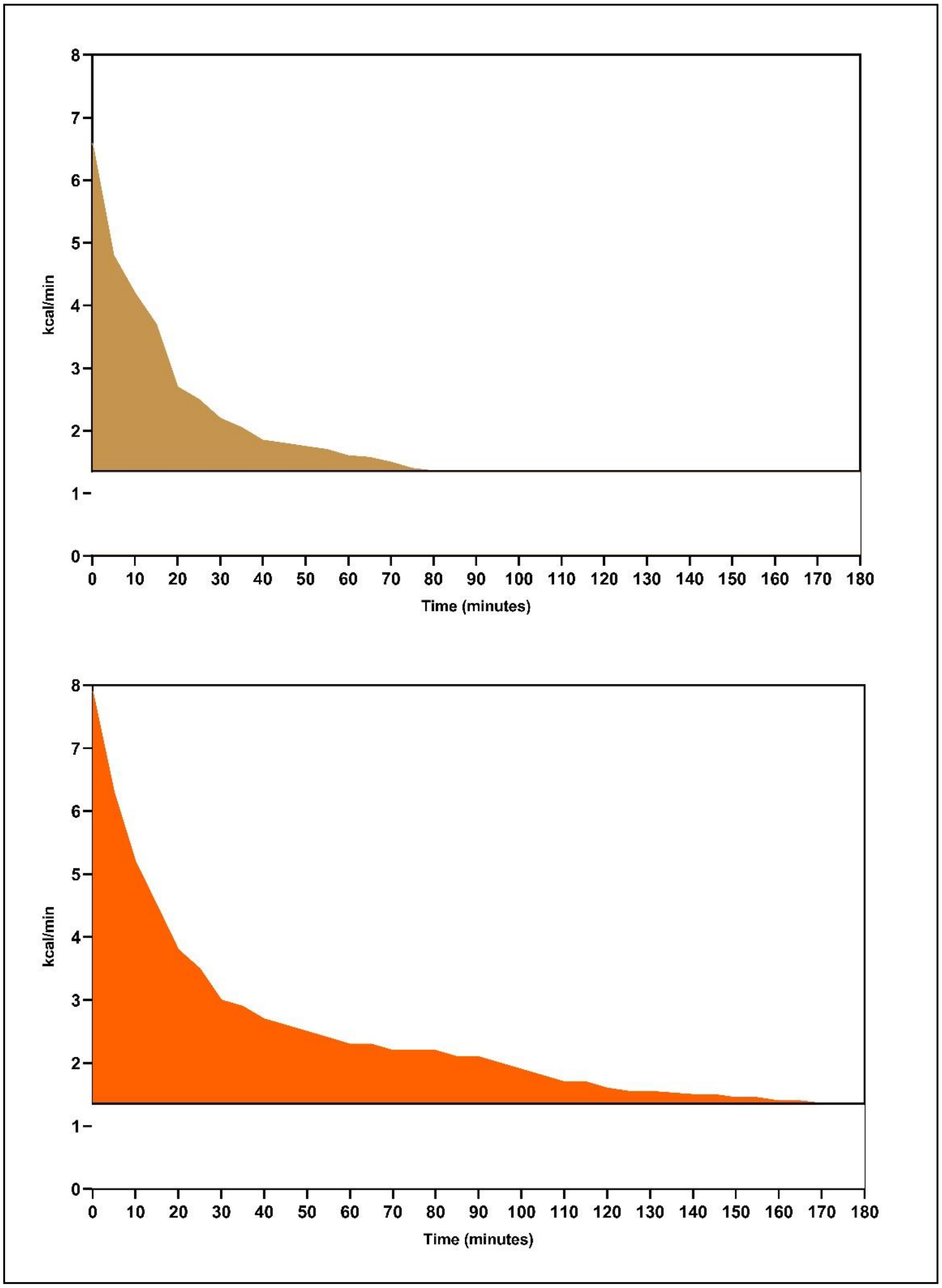

Figure 3. Duration of EPOC following intense CAROL rides (upper panel – **gold**) and fat burn CAROL rides (lower panel – **orange**).

Discussion

The most important findings of this project are two-fold: 1) it provides gold standard measures of the exercise energy expenditure to be expected during both fat burn and intense rides on CAROL, and 2) it provides scientific evidence to support the notion that personalized true REHIT performed on CAROL contributes to a significantly greater increased post-exercise metabolism (i.e., EPOC) when compared to more traditional moderate-intensity or vigorous-intensity exercise.

Post-exercise oxygen consumption (VO_2) gradually returns toward baseline levels in an exponential manner, demonstrating an initial rapid component followed by a slow, longer component. The overall VO_2 that is consumed above resting values during this phase is referred to as EPOC. It was originally proposed in 1923 that the elevated VO_2 following exercise was an oxygen debt; this interpretation was based on the understanding that there would be an oxygen cost involved with replenishing creatine phosphate and also oxidation of lactate produced from glycolysis (i.e., the oxygen deficit)[8]. More recently, it has been acknowledged that additional factors beyond those recognized by Hill and Lupton contribute to post-exercise VO_2. In reality, elevated post-exercise metabolism is a product of widespread homeostatic perturbation of which the settlement of the oxygen deficit is only a fractional contribution. Accordingly, in 1984 the term EPOC was coined to better represent the multiple factors that contribute to elevated post-exercise metabolism[9].

The rapid phase of EPOC generally lasts approximately two to three minutes but may continue as long as 30 to 60 minutes. The physiological mechanisms responsible for the rapid phase of EPOC include:

- Phosphagen resynthesis
- Removal and oxidation of lactate
- Reloading hemoglobin/myoglobin with oxygen

The slow phase of EPOC lasts considerably longer than the rapid phase of EPOC, and may persist for several hours, depending on exercise modality, intensity, duration and environmental factors[3]. Accordingly, the slow phase of EPOC, in particular, has the potential to make a significant impact on overall energy expenditure. The physiological mechanisms responsible for the slow phase of EPOC include:

- Thermoregulation
- Increased heart rate and ventilation
- Increased metabolism due to tissue repair, protein synthesis and glycogen resynthesis
- Residual effects of circulating hormones (e.g., catecholamines)

Overall, EPOC generates approximately 10 percent of the total energy expenditure of exercise[3]. Further, an increase in post-exercise metabolism of 80 to 100 calories is generally considered to be a meaningful

EPOC. It is important to appreciate the long-term benefits accrued from modest increases to overall exercise energy expenditure stemming from an elevated EPOC. For example, the cumulative effect of EPOC over a one-year period could be the energy expenditure equivalent of 3 to 6 pounds of fat. Moreover, it has recently been reported that over the last 50 years in the United States (U.S.) that daily occupation-related energy expenditure has decreased by approximately 140 calories, and this reduction in energy expenditure accounts for a significant portion of the increase in mean U.S. body weights for both women and men[10].

Conclusion

Our findings provide a research-substantiated estimate for the caloric expenditure from EPOC to be expected based on the peak power output performance during fat burn and intense ride sprint bouts on CAROL. Critically, a better understanding of the acute metabolic responses and EPOC to fat burn and intense rides provides CAROL consumers with evidence-based and personalized exercise feedback.

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