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Recommended Citation

Gullum, Trevor L.; Dumke, Charles; and Ruby, Brent, "Muscle Glycogenolysis and Resynthesis in Response to a Half Ironman Triathlon: A Case Study" (2006). *Integrative Physiology and Athletic Training Faculty Publications*. 4.

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CASE STUDIES

International Journal of Sports Physiology and Performance, 2006;1:408-413
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Muscle Glycogenolysis and Resynthesis in Response to a Half Ironman Triathlon: A Case Study

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Purpose: To describe the degrees of muscle-glycogen depletion and resynthesis in response to a half Ironman triathlon. **Methods:** One male subject (38 years of age) completed the Grand Columbian half Ironman triathlon (1.9-km swim, 90-km bike, 21.1-km run, Coulee City, Wash). Three muscle biopsies were obtained from his right vastus lateralis (prerace, immediately postrace, and 4 hours postrace). Prerace and postrace body weight were recorded, in addition to macronutrient consumption before, during, and after the race. Energy expenditure and whole-body substrate oxidation were estimated from linear regression established from laboratory trials (watts and run pace relative to VO_2 and VCO_2). **Results:** Body weight decreased 3.8 kg from prerace to postrace. Estimated CHO energy expenditure was 10,003 kJ for the bike segment and 5759 kJ for the run segment of the race. The athlete consumed 308 g of exogenous CHO (liquid and gel; 1.21 g CHO/min) during the race. Muscle glycogen decreased from 227.1 prerace to 38.6 mmol · kg wet weight⁻¹ · h⁻¹ postrace. During the 4 hours postrace, the athlete consumed a mixed diet (471 g CHO, 15 g fat, 64 g protein), which included liquid CHO sources and a meal. The calculated rate of muscle-glycogen resynthesis was 4.1 mmol · kg wet weight⁻¹ · h⁻¹. **Conclusion:** Completing a half Ironman triathlon depends on a high rate of muscle glycogenolysis, which demonstrates the importance of exogenous carbohydrate intake during the race. In addition, rates of muscle-glycogen resynthesis might be dampened by the eccentric damage resulting from the run portion of the race.

Key Words: endurance training, physical performance, nutrition, metabolism, exercise physiology, exercise performance, hydration, carbohydrate feedings, glycogen resynthesis

The triathlon is a distinct sporting event combining 3 disciplines (swimming, cycling, and running) that impose unique metabolic and nutritional concerns for working muscles, depending on the duration of the event. Kimber et al¹ have

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reported a mean energy intake of 16,500 kJ and an estimated energy expenditure of 42,050 kJ for male triathletes during a full Ironman triathlon. The half Ironman triathlon consists of a 1.9-km swim followed by a 90-km cycle and 21.1-km run.

Fatigue during prolonged, intense exercise is associated with glycogen depletion in working skeletal muscles.² Moreover, muscle glycogen is the most important substrate for contracting muscle during moderate to heavy exercise.² Although endogenous glycogen stores are limited, prerace diet can increase these stores, proper training can attenuate their use, and feeding during the race might decrease the rate of muscle-glycogen depletion. The purpose of this study was to describe the degrees of muscle-glycogen depletion and resynthesis in response to a half Ironman triathlon.

Methodology

One experienced, recreationally competitive, 38-year-old male subject completed a half Ironman triathlon (1.9-km swim, 90-km bike, and 21.1-km run, Grand Columbian, Coulee City, Wash). The subject's recent training history included a mean volume of 20 h/wk (including a mean 6000 m/wk swimming, 298 to 402 km/wk cycling, 64 to 80 km/wk running for the last 3 months leading up to the race). Before the race, the subject, in a carbohydrate-fed state similar to prerace conditions but not ingesting supplements during the laboratory tests, underwent descriptive laboratory testing to determine peak oxygen uptake ($\text{VO}_{2\text{peak}}$) and ventilatory threshold (VT) on an electronically braked cycle ergometer (initiated at 50 W and progressed at a rate of 30 W/min in ramp protocol; Velotron, Seattle, Wash) and motorized treadmill (initiated at a speed of 3.6 m/s, 1% grade, and progressed at a rate of 0.22 m/s each minute until 4.7 m/s, after which the grade was increased 1% every 30 seconds until volitional exhaustion (Quinton treadmill, Seattle, Wash). In addition to the maximal exercise testing, on a separate day the subject completed 4 steady-state exercise stages (7- to 10-minute stages) on the cycle and treadmill. Using these steady-state data, linear-regression equations were established for cycle watts and treadmill running pace relative to submaximal, steady-state measures of VO_2 , VCO_2 , and heart rate. Despite not accounting for alterations in substrate oxidation over time (because of the duration of exercise and changes in core temperature), these regression equations were used to estimate rates of whole-body substrate oxidation and total energy expenditure during the cycle and run portions of the race. Descriptive characteristics of the subject are shown in Table 1.

Table 1 Subject Descriptive Data

Age	Height (cm)	Weight (kg)	Peak VO_2 , bike (L/min)	Peak VO_2 , run (L/min)	Ventilatory threshold, bike (L/min)	Ventilatory threshold, run (L/min)
38	185.4	78.8	4.83	4.92	3.01	3.42

Prerace

During the 48 hours before the race, the subject was prescribed a nutritional intake that provided no less than 10 g/kg body weight each day. On race day, approximately 90 minutes before the start of the race, after the athlete had eaten breakfast, a prerace muscle biopsy was obtained from the right vastus lateralis.³ Muscle samples were immediately frozen in liquid nitrogen and stored at -85°C for later analyses. After the muscle biopsy, a measure of body weight was obtained. The macronutrient content of the subject's breakfast was quantified from a detailed food-intake inventory and analyzed using Food Processor Pro software.

Race

During the race, carbohydrate-consumption patterns were recorded from a preestablished intake plan amounting to approximately 1.2 g/min. Deviations from the intake plan were recorded from the subject's dietary recall during the race. Energy intake prerace, postrace, and 4 hours postrace is shown in Table 2. In addition, cycle power output (SRM power systems, Colorado Springs, Col) and heart rate (Polar S810i, Finland) were continually measured. Running pace was monitored by the subject using a digital running watch and mile-lap-split recordings. The run leg was performed on a flat, groomed bike path with good footing.

Postrace

Immediately after the race, a postrace measure of body weight was obtained with the athlete wearing the same clothing as prerace. A postrace biopsy was then obtained (from a second incision 2 cm proximal to the preexercise incision), after which the subject consumed a standardized diet (total = 471 g CHO, 15 g fat, 64 g protein) that included hourly liquid CHO sources (Gatorade® energy drink, 0.22 g CHO/mL) and a meal provided by the race organizers. Total carbohydrate intake during this 4-hour refeeding period was 6.3 g/kg ($1.6 \text{ g} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$). Four hours postrace, a third biopsy was obtained (from a third incision 2 cm proximal to the postexercise incision). Muscle glycogen was analyzed in triplicate using an enzymatic spectrophotometric method as has been previously described.⁴

Table 2 Self-Selected Energy Intake Before, During, and After the Race

	Prerace	During race	4 h postrace
Energy intake (kJ)	2386	4861	9546
CHO (g)	110 g	307.91 g	471 g

Results

Overall finish time for the race was 4:48:53 (33:33 swim, 2:43:11 bike, 1:28:40 run). The subject averaged 230 W (110% VT, 68% $\text{VO}_{2\text{peak}}$) for the cycle portion of the race and 14.24 km/h (101% VT, 70% $\text{VO}_{2\text{peak}}$) for the running portion. Body weight decreased 3.8 kg from prerace to postrace (4.9% weight loss). The ambient air temperature fluctuated throughout the race and was 13.9°C at the 09:30 start, 22.2°C at 12:00, and 23.9°C at the finish. Estimated CHO energy expenditure (EE) was 10,003 kJ (641 g CHO, 88% of total cycle EE) for the bike segment and 5,759 kJ (369 g CHO, 86% of total run EE) for the run segment of the race. During the race, the athlete consumed 308 g CHO (sports drink and gel products), averaging 1.2 g/min during the run and bike portions of the race. Total run and bike CHO EE was estimated at 15,762 kJ (1010 g), and energy intake during the race was estimated at 4,895 kJ (418 g), or 31% of the total CHO EE.

Muscle glycogen demonstrated an 83% decrease from 227.1 prerace to 38.6 mmol/kg wet weight postrace. During the 4 hours postrace, muscle glycogen demonstrated an increase to 54.90 mmol/kg wet weight, 24% of prerace values, with a calculated rate of resynthesis of $4.1 \text{ mmol} \cdot \text{kg wet weight}^{-1} \cdot \text{h}^{-1}$.

Discussion

The main findings from this case study indicate that completing a half Ironman triathlon is associated with a high rate of whole-body CHO oxidation and muscle glycogenolysis. Furthermore, this demonstrates the importance of prerace nutritional strategies to maximize glycogen storage, coupled with an aggressive exogenous CHO intake schedule during the race to maintain CHO oxidation and exercise intensity.

Past research has suggested a feeding schedule amounting to 60 to 70 g/h of CHO during prolonged exercise because maximal rates of exogenous CHO oxidation average 1.0 to 1.1 g/min.⁵ If the CHO solution includes a mixture of 3 parts glucose, 1 part fructose, however, a higher rate of exogenous CHO oxidation is possible (20% to 50% increase in oxidation to approximately 1.50 g/min) than with the ingestion of an isocaloric glucose solution.⁶ It appears that glucose and fructose are absorbed by different intestinal transport mechanisms, which might lead to faster transport and subsequent oxidation of exogenous CHO sources by the active skeletal muscle.⁶ This type of strategy to maximize the rates of exogenous CHO oxidation might be crucial during this type of exercise. Although the importance of exogenous CHO is clear, we cannot conclude from these descriptive data whether the intake of exogenous CHO decreased the rate of muscle glycogenolysis. Although the consumption of exogenous CHO (1.21 g/min glucose and fructose mixture, 3:1) might have maximized the rate of exogenous CHO oxidation during the race, there was a noticeable decrement in running performance. Average split times were 6:17, 6:44, and 7:10 min/mile for miles 1 to 3, 6 to 8, and 10 to 13, respectively. This fatigue might be associated with but not limited to the combination of dehydration, central-nervous-system fatigue, diminished muscle glycogen, or elevated core body temperature. Fatigue was not likely related, however, to

inadequate exogenous CHO intake as it approached the reported maximal rates previously recommended.⁶

Total CHO availability (g) was supplemented by a combination of a prerace meal (110 g CHO) and feedings during the race (308 g CHO), which represented 41% of the total CHO oxidized during the cycle and run portions of the race, not accounting for additional CHO oxidation during the swim. This is in agreement with previous findings reporting that high rates of CHO oxidation can be maintained during the latter stages of prolonged continuous exercise when muscle glycogen stores are very low.⁷ CHO supplementation during prolonged exercise can partially compensate for the reduction of endogenous CHO stores and delay fatigue by maintaining plasma-glucose availability. It appears, however, that consuming exogenous CHO at a rate of approximately 1.2 g/min might not fully compensate for the negative effects of glycogen depletion, which might have, in part, caused impaired running performance late in the race. Nonetheless, it is important to consider the other possible contributors to this late-race fatigue; the possibility of an endogenous CHO-sparing effect caused by consuming exogenous CHO appears unlikely under competitive racing conditions.⁷

In addition, researchers have shown that the effects of eccentric muscle damage might dampen the rates of muscle-glycogen resynthesis.⁸ The calculated rate of muscle-glycogen resynthesis was $4.1 \text{ mmol} \cdot \text{kg wet weight}^{-1} \cdot \text{h}^{-1}$. The prolonged eccentric contractions during the run portion of the race could account for the lower rate of muscle-glycogen resynthesis reported than in some of our earlier work with a high-intensity cycling protocol, which demonstrated a much higher rate of muscle-glycogen resynthesis ($10.6 \text{ mmol} \cdot \text{kg wet weight}^{-1} \cdot \text{h}^{-1}$).⁴ Similar results have suggested that eccentric contractions dampen the rate of muscle-glycogen resynthesis when the traumatized muscle is penetrated with inflammatory cells, which oxidize glucose. Eccentric damage presents a competition between the inflammatory cells and the glycogen-depleted muscle fibers for blood glucose, reducing the amount of available glucose for muscle-glycogen storage.⁸ Researchers have also shown that CHO intake during prolonged exercise might diminish the rates of postexercise muscle-glycogen resynthesis, compared with prolonged exercise in a fasted state. The mean rate of muscle-glycogen resynthesis during the initial 4-hour recovery period after the fasting exercise bout was found to be ≈ 3 -fold higher than after exercise combined with carbohydrate ingestion, perhaps as a result of enhanced insulin action.⁹

Practical Applications and Conclusions

Completing a half Ironman triathlon requires a high rate of whole-body CHO oxidation and muscle glycogenolysis. This case study, data demonstrate the importance of prerace and race nutritional strategies to maximize prerace glycogen concentrations and the availability of exogenous CHO. The dampened rate of postrace muscle-glycogen resynthesis might result in part from the eccentric muscle damage or exogenous intake during the triathlon.

Acknowledgments

This research was funded in part by a grant from the Gatorade Sports Science Institute. Special thanks to Scott USA for the CR1 Plasma LTD time-trial bicycle used for this study.

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