NUTRITIONAL STRATEGIES FOR THE TOUR DE FRANCE

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The Tour de France (TDF) is without doubt, one of the world's most well-recognised and popular endurance events[1]. Since its first outing in 1903, the Tour has evolved considerably and now consists of 21 stages that vary in terms of exercise intensity, duration and terrain. Such stages typically comprise a variety of flat terrain stages, medium mountains, high mountains (with summit finishes) and time trials (both individual and team). The 2016 TDF consisted of 198 riders (22 teams of nine riders) where a total of 3509 km was completed. An overview of the 2016 TDF stage profiles and estimated exercise intensities are presented in Table 1.

The TDF has only been won by Caucasians and those who possess exceptional physiological characteristics (e.g. VO_2 max > 80 ml/kg/min) and a body composition that maximises power to weight ratio, thereby promoting climbing performance (see Table 2 for a summary of the physiological profile of the 2015 TDF champion). While such winning performances are undoubtedly due to an accumulation of years of focused training, there is a growing appreciation of the role that nutrition can play in modulating the 'endurance' phenotype, achieving optimal body composition and of course, promoting race day performance and recovery.

The aim of this paper is to provide a contemporary review of nutritional strategies that can support a TDF-winning performance, by drawing on both scientific research and practical experience. To provide an appropriate framework for key discussion points, the reader is firstly introduced to classical nutritional-related causes of fatigue, before the presentation of separate sections on nutrition for training, racing and supplements/ergogenic aids.

OVERVIEW OF NUTRITIONAL CAUSES OF FATIGUE

It is noteworthy that although carbohydrates (CHO) supply the major energy source for moderate to high-intensity exercise such as > 70% VO_2 max[2], the absolute amount of CHO that can be stored is typically limited to around 500 g (approximately

100 g as liver glycogen and 400 g as muscle glycogen) and is effectively depleted by the end of 2 to 3 hours of exercise. In contrast, the supply of fat sources within the body is more plentiful (both from adipose tissue stores and intra-muscular triglycerides) but lipids are a more important energy source for low to moderate intensity exercise (i.e. < 60% VO_2 max). From a race performance point of view, it is therefore important to develop the muscles' capacity to use fat as a fuel (as achieved via endurance training) during moderate intensity exercise (e.g. flat stages/sections) and hence spare muscle glycogen utilisation so that sufficient CHO stores are available to support the latter stages of the race, where both intensity and altitude is likely to increase (e.g. >85%. VO_2 max). Moreover, time-trial stages are dependent on high-intensity efforts that are CHO-dependent. In addition to ensuring adequate pre-exercise muscle and liver glycogen stores, CHO feeding during exercise also increases endurance performance via multiple mechanisms including liver and muscle glycogen sparing and maintenance of plasma glucose levels, as well as having direct effects on the central nervous system and contractile apparatus of muscle fibres[3]. The CHO requirements during each stage of racing are also likely to be exacerbated during medium-to-high mountain stages and especially those undertaken in high ambient temperatures, where both hypoxia and elevated core and muscle temperatures increase CHO utilisation[4]. Furthermore, fluid intake during racing needs to be sufficient to prevent excessive dehydration that may also impair performance[5]. In addition to potential nutritional-related causes of fatigue, achieving optimal body composition can have a profound influence on race performance through optimising power to weight ratio[6].

TRAINING NUTRITION: 'READY TO RACE'

Training for the Tour de France typically begins 7 to 8 months in advance of the race when pre-season training commences in December of the preceding year. From a nutritional perspective, the use of nutrition for training can be aligned to three main goals of:

Table 1

	Flat stages	*Mountain stages*	*Time trial stages*
Stages (n=)	*9*	*10*	*2*
Mean distance (km)	*189 ± 35*	*175 ± 22*	*37 & 17*
Typical stage duration (h)	*4 - 5*	*4 - 5*	*< 1*
Typical exercise intensity	*Low to moderate*	*Moderate to high*	*High*
Typical meanvelocity (km/h)	*~40*	*~20 (during ascents)*	*~50*
Estimated mean power output (W)	*200 - 250 W*	*> 6 W/kg in climbers*	*350 W (> 400 W in time trialists)*

Table 1: An overview of stage profiles and estimated exercise intensity during the 2016 TDF. W=watts.

Table 2

Physiological profile		
Age		*31*
Body mass (kg)		*67**
Height (cm)		*185.7*
Lactate threshold (2 mmol/L)		
	Power output (W)	*380*
	W/kg	*5.7*
	Heart rate (bpm)	*127*
Maximal aerobic power		
	VO_2 peak (ml/kg/min)	*88.2*
	Peak power output (W)	*525*
	W/kg	*7.5*

** Denotes known racing weight, all performance/physiological data are expressed relative to the athlete's known race weight.*

Table 2: Physiolgical profile of the 2013, 2015 and 2016 TDF Champion, Chris Froome. Data were independently collected in August 2015 at the GlaxoSmithKline Human Performance Laboratory. A full laboratory report and testing procedures is provided at www.gskhpl.com/dyn/_assets/_pdfs/chris-froome-bodycompaerophys.pdf.

1. Fuelling training and promoting recovery.
2. Maximising training adaptations of key physiological systems (especially muscle ultra-structure and metabolism).
3. Achieving optimal body composition.

During this time, riders are likely to train 6 to 7 days per week in a periodised plan that may accumulate 500 to 1000 km and 20 to 35 hours of cycling per week. Additionally, riders prioritising the TDF may also compete in 30 to 50 prior race days (consisting of short 4 to 8 day stage races and one-day classics) as well as a number of dedicated training camps that may also be aligned to aspects of acclimatisation such as altitude and heat training. Ultimately, the training (inclusive of nutritional strategy) and racing schedule is individualised to each rider, so that they may achieve their optimal physiological profile to promote peak performance during the Tour itself.

Nutrition strategies for endurance training have traditionally adopted a 'performance and energy focus' in order to fuel and recover from the high training volume and intensities that are habitually undertaken by elite endurance athletes. However, with the increased utilisation of molecular biology techniques in the last decade of research, it has now become apparent that altering the energy status of the muscle fibre before, during and after training sessions can play a potent role in modulating many of the adaptations inherent to endurance training[7]. For example, data from our laboratory and others have collectively shown that strategically training in carefully chosen conditions of reduced CHO availability (as opposed to classic CHO loading approaches) can actually increase mitochondrial biogenesis, increase fat metabolism and can improve exercise capacity and performance. This innovative approach to training has been referred to as the train-low (or smart),compete high approach to training and racing, surmising that certain training sessions are completed with reduced CHO availability (so as to promote training adaptation), yet competition is always performed with high CHO availability so as to promote performance and recovery.

There are multiple practical approaches to training low that have been studied in the literature and typically consist of fasted training, omission of energy consumption during exercise (i.e. no sports drinks, gels or foods), consuming protein only before and during training and finally, reducing CHO and energy intake in the post-training period. However, despite the emergence of such approaches in the research literature, the optimal approach to practically apply this with elite riders is not currently known. Such limitations are most well-recognised for the potential reductions in absolute training intensity associated with reduced CHO availability, perturbations to immune function and associated increases in muscle protein breakdown, all of which could be detrimental to long-term training and athletic performance. Nonetheless, perhaps a suitable approach to training smart is to periodise both CHO and energy availability according to the structure and aims of each training session, so as to simultaneously promote training intensity and recovery but yet, also achieve periods of CHO and energy deficit that are intended to drive training adaptation and body fat loss. In essence, the theme that emerges appears to be the concept of both 'day-to-day' and 'meal-by-meal' CHO periodisation in accordance with the upcoming training workloads that have been prescribed. In practice, this approach of forward planning could represent an

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amalgamation of train-low paradigms and is perhaps best communicated by the principle of 'fuel for the work required'[8]. Careful day-to-day periodisation (as opposed to chronic periods of CHO restriction) is likely to maintain metabolic flexibility (i.e. retain the muscle's capacity to switch between both fat and CHO as a fuel) and still allow for the completion of high-intensity and prolonged duration workloads on heavy training days e.g. interval-type workouts undertaken above lactate threshold. Intuitively, train-low sessions may be best left to those training sessions that are not CHO-dependent and in which the intensity and duration of the session is not likely to be compromised by reduced CHO availability e.g. steady-state-type training sessions performed at intensities below the lactate threshold. Although it is not possible to provide definitive CHO guidelines, owing to individual differences in rider goals, a 'traffic light system' to categorise feeding patterns and meals as high (green), medium (amber) or low (red) CHO availability can provide a simple visual cue to educate riders. It is crucial, however, that sport nutritionists work alongside both the coach and rider to understand the energy demands and requirements of each training session, so as to develop a periodised plan that does not compromise the ability to fuel high-intensity training sessions. In the authors' experience, the absolute CHO intake per day during training may fall in ranges described as low (<3 g/kg body mass), moderate (4 to 6 g/kg body mass) and high (7 to 10 g/kg body mass) dependent on the training goals of that particular day.

Despite the rationale for training-low, it is advised that riders habitually consume a daily diet that is considered high in protein e.g. 2 to 2.5 g/kg body mass. For a 70 kg cyclist, this therefore equates to 140 to 175 g protein per day and it is suggested that protein is consumed at regular intervals and doses throughout the day e.g. 20 to 30 g doses every 3 hours[9]. Indeed, this regular feeding of protein induces superior rates of muscle protein synthesis compared with skewed protein doses (i.e. smaller portions at breakfast and bigger portions in evening) or fewer but larger protein doses (e.g. 2 x 40 g versus 4 x 20 g). In addition to the obvious requirement of protein feeding to promote protein synthesis in recovery from training sessions, there is also the requirement to consume increased dietary protein in an attempt to offset any potential reductions in lean muscle mass that occurs through any chronic periods of energy deficit. Indeed, consuming three times the recommended dietary allowance of protein attenuates lean muscle mass loss during energy restricted diets[10]. Additionally, recent research has also shown the importance of consuming protein prior to sleep so as to maintain a positive protein balance in the overnight period and hence facilitate long-term training adaptations.

"In the context of race-day performance, it is clear that carbohydrate (but not fat) remains king and that carefully chosen ergogenic aids can promote performance in the correct setting"

Despite the increased popularity of high-fat diets (especially in social media circles), the evidence supporting their efficacy for elite endurance athletes is equivocal[11]. Indeed, although chronic periods of high-fat feeding can increase intramuscular fat stores and increase fat use during steady state exercise (hence sparing glycogen use), high-fat feeding also impairs the ability to use CHO as a fuel through attenuating key enzymes regulating CHO oxidation. As such, high-intensity performance is impaired and this may result in reduced climbing or time trial performance when riders are racing at intensities that are dependent on CHO metabolism. In addition, emerging evidence also suggests that high-fat feeding in the post-exercise period may impair muscle protein synthesis, this in itself a vital component of training adaptations[12].

When taken together, it is clear that nutritional strategies for training are much more important that simply providing adequate fuel for training and recovery. Rather, it is now thought that strategic periodisation of CHO intake alongside consistent high daily protein intake may allow long-term development of training adaptation and body fat loss while also promoting training intensity on those days and periods when high training intensities and volumes are required. As such, nutrition strategies for training should be used to promote an endurance phenotype and body composition that is aligned to the goal of promoting riders who are 'ready to race' on race day.

RACE DAY NUTRITION: 'RACE TO WIN'

In contrast to training nutrition, nutritional strategies for the race itself are more aligned to the traditional textbook approach, where the goals are to promote race-day performance and recovery, as well as reducing illness. In this regard, the main aim is to ensure sufficient CHO intake in the pre-race meal (i.e. breakfast), on the bike itself, post-stage recovery, evening meal and snacks. When taken together, daily CHO intakes typically range from 8 to 12 g/kg body mass. Furthermore, due to the sheer volume of food that riders consume each day, as well as strategic use of certain

Table 3

Time	*Location*	*Nutritional aims*	*Example foods*
Breakfast (~8.00 am)	*Hotel/kitchen truck*	*Promote liver and muscle glycogen storage, protein synthesis and hydration*	*Porridge, museli, rice, pasta, quinoa, pancakes, breads, jams, nut butters, eggs, smoothies, fruit & vegetable juices, avocado, mixed berries/fruits, Greek yoghurt*
Pre-race snack (~10.30 am)	*Bus*	*Final pre-race energy intake*	*Rice cakes, energy bars, bananas, protein bars, yoghurts, sports drinks*
On-bike (~12 - 5.00 pm)	*Bike*	*Spare muscle/liver glycogen utilisation, maintain plasma glucose, hydration and prevent fatigue, 60-90 g CHO per hour*	*Rice cakes, isotonic energy gels, energy bars, paninis, cakes, caffeine, sports drinks, water*
Post-race (~5 - 6.30 pm)	*Bus*	*Muscle and liver glycogen resynthesis, protein synthesis and rehydration*	*Rice, pasta, quinoa, sweet potato, salad, whey protein, fruit smoothie, chicken, tuna, salmon, Greek yoghurt, avocado, mixed berries/fruits*
Evening meal (~8 - 9.00pm)	*Hotel/kitchen truck*	*Muscle and liver glycogen resynthesis, protein synthesis and rehydration*	*Rice, pasta, quinoa, sweet potatoes, potatoes, fish, beef, poultry, vegetables, salad, yoghurts, fruit & vegetable juices*

Table 3: Overview of timing and types of foods prescribed on race-days. CHO=carbohydrate.

supplements (e.g. whey protein), both daily protein and fat intake are habitually 2 to 3 and 1.5 to 2 g/kg body mass, respectively. Such volumes of macronutrient intakes are commensurate with earlier published accounts[13] and certainly equate to absolute energy intakes >5000 kcal per day, though riders are encouraged to consume additional energy intake during those stages with higher energy demands e.g. long duration and/or mountain stages. In the authors' experience, such absolute energy intakes are considered appropriate to prevent any loss in body mass over the course of the 3 weeks of racing. An overview of timing, type and quantity of food choices is also shown in Table 3.

Pre-race

In order to commence each stage with sufficient muscle and liver glycogen stores, the pre-race nutrition strategy should commence the day before, through the post-stage nutrition of the previous stage, as well as the evening meal. Additionally, breakfast on race-day serves as the pre-race meal and is essentially focusing on topping up both storage pools of glycogen. The absolute CHO intake of both the evening meal and breakfast itself usually equates to 3 g/kg body mass and is achieved through a combination of both high and low glycaemic index sources such as rice, pasta, potatoes, breads, quinoa, porridge, fruit juices/smoothies and yoghurts etc.

In-race

The conventional approach to CHO fuelling during exercise is to consume CHO beverages, although relying solely on this approach does not allow for flexibility in terms of individual variations in body mass or actual fluid requirements, given variations in ambient conditions. As such, many riders rely on a CHO fuelling approach that is based on a combination of solids (e.g. rice cakes, bars), semi-solids (e.g. gels) and fluids (e.g. sports drinks) so as to collectively meet their personalised exogenous CHO targets, typically in the region of 30 to 90 g/hour depending on exercise duration and intensity. Nevertheless, although there is little difference in exogenous CHO oxidation rates (albeit in fluid matched conditions) between the aforementioned sources, it is noteworthy that many athletes experience gastrointestinal discomfort when attempting to hit these targets, possibly related to extreme differences in osmolality between commercially available CHO gels as well as the presence of fibre, fat and protein in energy bars. It is therefore advised that riders should clearly practice their approach to in-competition fuelling during those training sessions of similar intensity and duration as competition. In the authors' experience, riders typically consume between 30 to 60 g/hour of CHO during flat stages and between 60 to 90 g/hour on longer duration and/or high mountain stages (Figure 1). In-race fuelling strategies typically comprise solid choices for the first half of the race when intensity is considered low-to-moderate, before switching to CHO gels for the latter part of the race when exercise intensity increases. Riders are also advised to adopt a 'drink to thirst' approach to hydration, where absolute fluid intake (a mixture of both water and electrolyte solutions) can vary between 350 to 800 ml per hour depending on ambient conditions. Such an approach to fuelling and hy-dration limits exercise-induced dehydration to <3 to 4%.

Post-race

Whereas the emphasis on pre- and during-stage fuelling is simply providing adequate energy, the purpose of post-stage nutrition is to promote muscle and liver glycogen re-synthesis, muscle protein synthesis and rehydration. In this regard, the timing, type and quantity of food choices all play an integrative role in supporting recovery. Emphasis is given to fuelling high-glycaemic CHO sources within 30 minutes post-exercise so as to maximise muscle glycogen storage at a rate of 1.2 g CHO per kg body mass per hour (for at least 3 hours) alongside rapidly digestible protein sources to promote muscle protein synthesis (at least 40 g)[14]. Such feeding protocols are typically delivered 'on the road' while completing the transfer from stage finish to the hotel and are usually achieved through a combination of recovery drinks, rice/pasta/potatoes, fish/chicken and fruit smoothies (where fructose can support liver glycogen re-synthesis). A larger evening

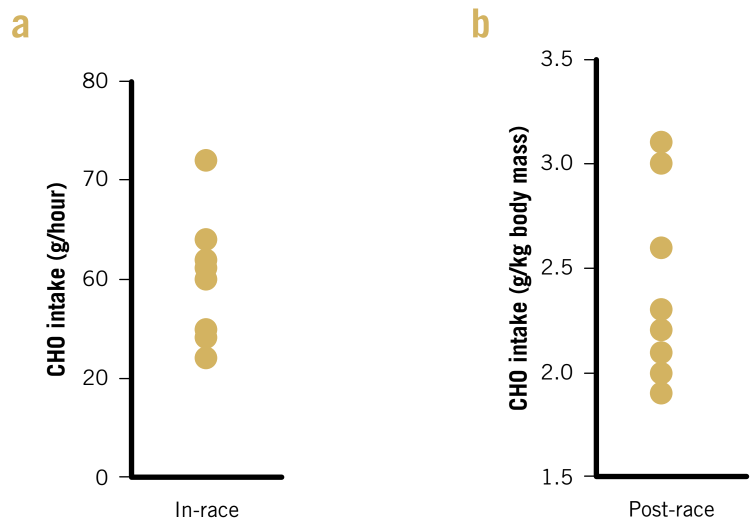

Figure 1: CHO intake (a) during and (b) in the first 1.5 hours of recovery after Stage 19 in the 2015 TDF. Each data point represents an individual rider.

Table 4

What?	*When?*	*Why?*
Carbohydrate drinks/ gels/bars	*60-90 g/hour during races*	*Can reduce liver and muscle glycogen utilisation, maintain plasma glucose, promote high CHO oxidation rates and improve cognitive function.*
Caffeine	*2-3 mg/kg body mass 30-60 minutes prior to time trials or consumed in-race prior to when performance benefit is desired*	*Acts directly on the central nervous system to reduce perception of effort. Can also improve high-intensity performance by reducing muscle metabolic stress. Usually consumed in coffee, sports drinks, gels or tablets.*
β-alanine	*3-6 g daily for 4 weeks to elevate muscle carnosine stores followed by 3 g per day thereafter*	*Maintains the capacity to perform high-intensity efforts by reducing muscle metabolic stress and the negative effects of acidosis caused by very high-intensity exercise. Acts as an intracellular buffer.*
Sodium bicarbonate	*0.3 g/kg body mass 90 minutes prior to time trials or consumed in-race prior to when performance benefit is desired*	*Maintains the capacity to perform high-intensity efforts by reducing the negative effects of acidosis caused by very high-intensity exercise. Acts as an extracellular buffer.*
Whey protein	*30 g post-training or racing*	*Increases muscle protein synthesis which helps promote recovery from racing and training*
Vitamin D	*Dose dependent on clinical assessment*	*May be required in winter months to maintain immune function and bone health as well as promote muscle protein synthesis in recovery from racing and training. Riders should have their vitamin D levels appropriately assessed prior to supplementing.*

Table 4: Potential sports supplements that are considered research-proven and ergogenic for race day performance and recovery.

meal is also consumed approximately 3 to 4 hours post-stage, where the aim is both recovery from the stage just completed and preparation for the upcoming stage on the subsequent day.

SUPPLEMENTS AND ERGOGENIC AIDS

Alongside a daily diet sufficient in both macro- and micronutrients, riders may also consume a number of sports supplements that are considered ergogenic to performance and facilitate recovery[15]. Due to space constraints, it is not possible to review in detail the scientific literature in support of such supplements, although an overview is provided in Table 4. It is, of course, important that all supplements are safe, legal and free of any contaminated/prohibited substances and therefore adhere to World Anti-Doping Association (WADA) code of conduct.

CONCLUSION

The Tour de France continues to grow in popularity and remains the world's most popular bike race. However, despite over a century of racing, the physiological demands continue to vary and remain to be fully documented in the scientific literature. Nonetheless, our understanding of the role of nutrition in promoting race-day performance and facilitating training adaptations continues to grow at a rapid rate. To this end, many World Tour teams now employ nutritionists on a full-time or consultancy basis in an attempt to achieve the desired physiological profile of riders who are considered 'ready to race' as well as developing a race-day performance strategy that is aligned to 'racing to win'. In the context of race-day performance, it is clear that carbohydrate (but not fat) still remains king and that carefully chosen ergogenic aids (e.g. caffeine, sodium bicarbonate, beta-alanine) can all promote performance in the correct setting. In relation to endurance training, it is now thought that strategic carbohydrate periodisation and elevated dietary protein intake may enhance training adaptations and facilitate power-to-weight ratio. As such, the nutrition strategy to fuel winning performances should be periodised throughout the annual racing and training cycle (according to the principle of 'fuel for the work required') so as to promote race-day performances, training adaptations and optimal body composition.

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