Review

The Tour de France: a physiological review

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On 5 July 2003, the Tour de France (TDF) has celebrated 100th running. Instead of a chimney sweep competing during his free time (as in 1903), the recent winner is a highly trained, professional cyclist whose entire life-style has been dedicated to reach his pinnacle during this event. The TDF has been held successfully for 100 years, but the application of the physiologic sciences to the sport is a relatively recent phenomenon. Although some historical reports help to understand the unique physiological characteristics of this race, scientific studies were not available in Sports Science/Applied Physiology journals until the 1990s. The aim of this article is to review the history of the TDF. Special emphasis is placed on the last decade where classic physiology has been integrated into applied scientific cycling data.

On 1 July 1903, a group of amateur athletes came to the starting line of a new cycling competition. In a publicity stunt aimed at bolstering newspaper sales, Henri Desgranges organized near the city of Paris what many now consider the most grueling endurance event in the history of sport – The Tour de France (TDF). Known simply as “The Tour”, the first event began under the eaves of the Le réveil matin, where 60 “working class” riders, comprised mostly of farmers and blacksmiths, lined up to start the first stage of the TDF – a 467 km race along unpaved roads between Paris and Lyon. Little did they know they were embarking as pioneers for an event that would last a full century. Among them is a French chimney sweep, Maurice Garin who, some 17 h later, will win the inaugural stage at a speed of \( \sim 27 \text{ km h}^{-1} \). Eventually, six stages, 2428 km and 94 h: 33 min later, Garin will be declared the winner as only 21 cyclists manage to complete the race, which ends in Paris. The last place finisher will take \( \sim 65 \text{ h} \) longer.

One hundred years later, on 5 July 2003, the TDF also started in Paris. Instead of a professional chimney sweep and amateur rider competing in his free time, the recent winner is a highly trained, professional cyclist whose entire life-style is oriented to reach top endurance performance over a 3-week period. The aim of our paper is to recount the history of the TDF with scientific knowledge and application when possible. Inherent to this endeavor should be the understanding by the reader that the application of scientific principles will not occur in professional cycling until the end of the 20th century. We begin our paper with a quick historical overview of the race. We continue with the application of science to this historical event, which celebrated its 100th anniversary this July.

The TDF: a quick historical overview

From its first edition in 1903 to the year 2002, the average (±SD) distance of the TDF has been approximately 4339 ± 685 km. The shortest events on record were 2428 km (1903 and 1904), while the longest was 5745 km (1926). Although the total distance of the race has varied considerably over the years, a clear tendency towards a decrease began in the mid to late 1920s (Fig. 1). The TDF can be divided into several developmental periods lasting approximately one or two decades (Table 1).

(Information on the main characteristics and exercise volume of the TDF editions before the 1990s is available only in non-scientific sources, i.e., the official book of TDF’s history by Augendre (2001a) (see reference list) and the official website of the race, www.letour.fr).

The first Tours (first three decades of XX century) were the heroic Tours. Its participants were freelance professionals independent of trade teams. These
men, known as tourists-routiers, rode their own bicycles weighing \(\approx 20\, \text{kg}\). By comparison, modern bikes weigh less than 9 kg. Each rider was also responsible for his own repairs. This meant that riders had to carry the extra weight of spare inner tubes and tires around their necks during each stage (Fig. 2). Daily stages often began early in the morning and finished in the evening, leaving the participants little time to recover before the next grueling day of competition. The longest event in the history of the Tour occurred in 1926 (5745 km) and became known as *le Tour de la souffrance* (the Tour of suffering). Mountain stages crossing the Pyrenees (cols of Tourmalet (2115 m) and Aubisque (1709 m)) and the Alps were included since 1910–1911, whereas individual time trials (TT) were introduced in 1934.

The era of five-time winners started in the 1960s (Jacques Anquetil (1957, 1961–1964) and Eddie Merckx (1969–72, 1974)). Like today’s best competitors (Padilla et al., 2000a; Lucia et al., 2001b), Merckx was capable of sustaining a power output of more than 400 W for 1 h (Bassett et al., 1999). The age of the modern champions (Hinault, Lemond, Indurain, Armstrong) started in the 1980s. New bicycle equipment, especially clip-on pedals and aerodynamic components (e.g., compact wheels, triathlon bars or aerodynamic helmets), were introduced in the peloton. The introduction of such aerodynamic components and more aerodynamic

![Fig. 1. Total distance of each Tour de France’s edition throughout the history of this race (1903–2003, with two interruptions (1915–1918 and 1940–1946) due to World Wars I and II).](image)

<table>
<thead>
<tr>
<th>Period</th>
<th>Total distance (km)</th>
<th>Total time of winner (h)</th>
<th>No of stages</th>
<th>Speed (km h(^{-1}))</th>
<th>No of participants</th>
<th>Finishers (% of total)</th>
<th>Time difference between first and last (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1903–1909</td>
<td>3695 ± 1026</td>
<td>137 ± 36</td>
<td>11 ± 4</td>
<td>26.9 ± 1.8</td>
<td>91 ± 32</td>
<td>33 ± 7</td>
<td>84 ± 26</td>
</tr>
<tr>
<td><em>Inclusion of high mountain stages (Pyrenees (1910) and Alps (1911))</em></td>
<td>1910–1926</td>
<td>5381 ± 230</td>
<td>210 ± 21</td>
<td>25.6 ± 1.7</td>
<td>122 ± 24</td>
<td>30 ± 8</td>
<td>54 ± 23</td>
</tr>
<tr>
<td>Race total duration of ~3 weeks since 1927, as in nowadays</td>
<td>1927–1939</td>
<td>4723 ± 428</td>
<td>158 ± 22</td>
<td>29.8 ± 1.6</td>
<td>101 ± 32</td>
<td>49 ± 14</td>
<td>12 ± 11</td>
</tr>
<tr>
<td><em>World War II</em></td>
<td>1947–1965</td>
<td>4521 ± 242</td>
<td>130 ± 14</td>
<td>34.7 ± 1.9</td>
<td>122 ± 11</td>
<td>58 ± 9</td>
<td>5 ± 1</td>
</tr>
<tr>
<td><em>First anti-doping control in 1966</em></td>
<td>1966–1984</td>
<td>4016 ± 301</td>
<td>112 ± 12</td>
<td>35.8 ± 1.4</td>
<td>134 ± 18</td>
<td>68 ± 8</td>
<td>3 ± 1</td>
</tr>
<tr>
<td><em>Introduction of modern bicycle equipment (e.g., clip-on pedals, aerodynamic wheels, etc.)</em></td>
<td>1985–2002</td>
<td>3764 ± 297</td>
<td>97 ± 9</td>
<td>38.8 ± 1.2</td>
<td>192 ± 9</td>
<td>72 ± 8</td>
<td>4 ± 1</td>
</tr>
</tbody>
</table>

![Fig. 2. Photograph of one of the participants of the Tour de France of 1924, French Adelin Benoit. Reprinted with permission from The Sports Poster Warehouse, http://www.PureSportsArt.com.](image)
body positioning largely influenced TT performance (Jeukendrup & Martin, 2001). For instance, during the last TT of 1989s TDF (24.5 km-distance), race-winner Greg Lemond was able to sustain a mean speed of 54.55 km h⁻¹, unimaginable some decades ago. The aerodynamic helmet he used probably accounted for a 10-s reduction in his TT finishing time, i.e., it accounted for his overall win (since he defeated Laurent Fignon in the overall finishing time, i.e., it accounted for his overall win probably accounted for a 10-s reduction in his TT finishing time) (Faria, 1992). In 2000, Lance Armstrong set the record for classification by just 8 s over a total of 88 h (Faria, 2000). It was not until the late 1990s that scientific publications described the Tours intensity for the first time (Lucia et al., 1999, 2001c; Fernández-García et al., 2000; Padilla et al., 2000b, 2001) and reported the physiological characteristics of professional, world-class cyclists able to finish the TDF in top positions (Lucia et al., 1998, 2000, 2001d, 2002a,b; Padilla et al., 1999).

The physiological demands of the TDF in the recent years
Intensity estimated by actual heart rate data

Numerous historical, non-scientific reports are available attesting to the extremely high demands of the TDF over its history (Augendre, 2001). Unfortunately, little was known at that time about exercise intensity, so no comparison can be made between the different time periods as this variable is not linearly related to cycling speed (Jeukendrup & van Diemen, 1998). Many uncontrollable factors such as wind conditions, road surface and inclinations, aerodynamics of the rider and bicycle, drafting, bicycle mass, etc., can also significantly influence cycling speed. Other than environmental factors, most of these factors have significantly changed over the years (e.g., paved roads, larger pelotons, improved aerodynamics), thus partly accounting for the considerable increase in average cyclists’ velocity in recent years.

Until the late 1990s, the exercise intensity of the TDF was not reported in scientific journals as cyclists did not begin wearing heart rate (HR) monitors until this time. Since then, most riders in the peloton wear an HR telemeter during competition. A method that can be used for examining physical exertion under competition exercise conditions is obtained by dividing intensity into different phases (or “zones”) according to the reference HR values obtained during a previous ramp cycle-ergometer test until exhaustion. These would include: zone 1 (“light intensity”, below 70% VO₂max), zone 2 (“moderate intensity”, between 70% and 90% VO₂max) and zone 3 (“high intensity”, above 90% VO₂max). In round numbers, the general picture of the TDF during the last decade shows about 100 h of effort divided between 21 days of racing (with only 1–2 days of rest). Each daily effort lasts about 5 h. During the 1997 edition, the total percentage of time spent by 8 subjects (including two top-8 finishers and a stage winner) in zones 1, 2 and 3 was 70%, 23% and 7%, respectively (Lucia et al., 1999).

The high demands of 3-week tour races are reflected in recent research showing a certain state of hormonal exhaustion, i.e., decrease in basal (pre-stage) levels of testosterone and cortisol, in a group of riders by the end of the Vuelta a España (Lucia et al., 2001a). To date, there are no studies showing a significant decrease in the basal levels of both testosterone and cortisol after only three weeks of strenuous exercise, which suggests the uniqueness of 3-week races in terms of physiological demand. In fact, a total of 6 months was necessary to induce a similar decrease in basal testosterone and cortisol in trained runners (Wheeler et al., 1991).

Physiological demands of the TDF according to different types of stages

In terms of exercise intensity, the modern TDF usually includes three main competition requirements: flat mass-start stages (long parcours usually ridden at high speeds inside a large peloton), individual TT (40–60 km on an overall level terrain) and uphill cycling (high mountain passes interspersed along mass-start stages that are known as “high-mountain stages”) (Table 2).

In flat mass-start stages (~200 km or 4–5 h), cyclists ride most of the time inside a large group of ~200 competitors, pedaling at a cadence of ~90 rev min⁻¹ (Lucia et al., 2001c), which considerably reduces the primary force to be overcome in this type of terrain -that is, air resistance. As a result, the energy requirement of cycling is reduced by as much as 40% (McCole et al., 1990), which makes overall exercise intensity rather low to moderate. Nevertheless, a great mastery of technical skills (“drafting”
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Table 2. Main characteristics of the three main competition requirements of modern Tours: flat and high mountain stages (both mass-start), and flat individual time trials (TT)

<table>
<thead>
<tr>
<th>Distance (km)</th>
<th>Flat stages</th>
<th>High mountain ascents</th>
<th>TT</th>
</tr>
</thead>
<tbody>
<tr>
<td>~200</td>
<td>~200</td>
<td>~20</td>
<td>40–60 (mostly flat)</td>
</tr>
<tr>
<td>4–5</td>
<td>5–6</td>
<td>Moderate to high (zones 2–3 during ascents)</td>
<td>~1</td>
</tr>
<tr>
<td>Mean velocity (km h⁻¹)</td>
<td>Low to moderate (zones 1–2)</td>
<td>~45 (during ascents)</td>
<td>High (zones 2 and 3)</td>
</tr>
<tr>
<td>Cycling position</td>
<td>Traditional (sitting)</td>
<td>Alternating (sitting and standing)</td>
<td>~50 (TT specialists)</td>
</tr>
<tr>
<td>Main requirements</td>
<td>Technical</td>
<td>Physiological</td>
<td>Aerodynamic (triathlon bars)</td>
</tr>
<tr>
<td>Specific concerns</td>
<td>Crashes</td>
<td>Moderate hypoxia (altitude &gt;1500 m)</td>
<td>Aerodynamics</td>
</tr>
<tr>
<td>Estimated mean power output</td>
<td>200–250 W</td>
<td>≥6 W kg⁻¹ in climbing specialists</td>
<td>350 W (~400 W in TT specialists)</td>
</tr>
</tbody>
</table>

Zone 1: <70% VO₂max; zone 2: 70–90% VO₂max and zone 3: >90% VO₂max.

or the ability to avoid crashes) appears most important in this type of stage, which is usually not a determinant in the final outcome of 3-week tour races, as the majority of riders are able to finish in the same time.

The TDF also includes three TT or solo rides against the clock that are held along overall flat terrains: a short, opening TT ("prologue") of 5–10 km, and two long TT (40–60 km) (Table 2). Occasionally, a mountain TT is added to the race as well. This phase of the competition is usually one of the primary determinants in the final outcome of tour races as air resistance accounts for more than 90% of the total resistance that the cyclist encounters in his forward movement at speeds above 30 km h⁻¹ (Kyle, 1991). Thus, aerodynamics factors (cyclist’s riding posture, size of frontal wheels, etc.) play a major role (Lucia et al., 2001c). Those specialists who seek top performances (average velocity ≥50 km h⁻¹ during long time periods) must tolerate high constant workloads (at or above ~90% VO₂max) during the entire TT, e.g., the winner of a 65-km flat TT in the 1997 TDF tolerated ~75 consecutive minutes in zone 3 (Lucia et al., 1999). Some authors have estimated that the mean absolute power output of an average rider during long TT averages ~350 W, although TT specialists probably generate much higher power outputs (>400 W) (Padilla et al., 2000b). For instance, the wattage of the best TT specialist in the TDF’s history, Miguel Indurain, averaged 509.5 W during his 1-h world record in a velodrome in 1994 (set at 53.04 km; Padilla et al., 2000a). During TT, the cycling cadence of most riders averages ~90 rev min⁻¹, but can approach 100 rev min⁻¹ in the best specialists (Lucia et al., 2001c).

One of the main features that distinguish the TDF from other professional races is that 4–6 high mountain, mass-start stages of ~200 km are raced in each modern event. These mountain stages include three or more long (>10 km) mountain passes of 5–10% mean gradient ("first" or "hors category" ascents) and thus require cycling uphill during several periods of a duration ≥45 min interspersed over a total time of 5–6 h (Table 2). When climbing at low speeds (~20 km h⁻¹ in hors category mountain passes), the cyclist must mainly overcome the force of gravity (Swain, 1994). Because each rider must overcome gravity-induced resistance, body mass has a major influence on climbing performance. Therefore, a high-power output:body mass ratio at maximal or near-to-maximal intensities (6 or more W kg⁻¹) is paramount for successful uphill performance. In addition, rolling resistance resulting from the interaction between the bicycle tires and the road surface considerably increases at these lower riding speeds and when riding on roughly road surfaces (Swain, 1994) such of those of many mountain cols in the Alps and Pyrenees. This last factor alone is partly responsible for the increase in climbing speeds of modern TDFs as compared to the old days in which several parts of now classic legendary ascents were still unpaved. A comparison of the performance of some “historical” ascents in TDF mountains is shown in Table 3.

In order to overcome the aforementioned forces, cyclists frequently switch from the conventional sitting position to a less economical standing posture. This allows the rider to exert more force on the pedals and possibly increases blood flow through the iliac artery – which is partly occluded over the ventral surface of the psoas muscle during hip flexions, especially when the rider adopts aerodynamic cycling positions (Schep et al., 1999). High mountain ascents are performed by climbing specialists at intensities ≥90% VO₂max (Lucia et al., 1999; Padilla et al., 1999; Fernández-García et al., 2000). Because of team requirements, however, some riders such as sprint specialists and domestiques with a predominant team role are not required to perform maximally.

Pedal frequency, on the other hand, averages ~70 rev min⁻¹, ranging from ~60 to ~80 rev min⁻¹ in the slowest and fastest ascenders, respectively.
Compared to slow pedal rates (cadence on the efficiency of professional riders. A study has assessed the effects of changes in pedal rate on efficiency, and although this pattern is theoretically less efficient than lower cadences, to date no data are available concerning the age or other demographic characteristics (height, mass) of all-time participants. Anthropometric variables might greatly differ depending on each rider specialty. For example, TT or flat terrain specialists are usually taller and heavier (180–185 cm, 70–75 kg, BMI of 25) than those who excel in uphill climbing (175–180 cm, 60–66 kg, BMI of 19–20) (Padilla et al., 1999; Lucia et al., 2001d). The morphometric characteristics of most modern champions and TDF winners, able to excel in both type of terrains, are, however, close to those of time trialists (Padilla et al., 1999, e.g., 183 cm and 73 kg for Jan Ullrich and 179 cm and 71 kg for Lance Armstrong. Mean values of VO2max reported in TDF participants (including several top-10 finishers) range between 5.0 and 5.5 L min⁻¹ or between 70 and 80 mL kg⁻¹ min⁻¹ (Lucia et al., 2001b). Although there are exceptions, the highest relative values (~80 mL kg⁻¹ min⁻¹) are comparable to those of elite distance runners such as Kenyans, and are shown by uphill climbing specialists. Lower values (~70 mL kg⁻¹ min⁻¹) usually correspond to TT specialists.

Demographic/anthropometric and physiological variables in TDF participants

Besides certain exceptions (e.g., eight North-African participants in the 1940s), the majority of TDF participants have been Caucasian. The average age of all TDF winners is 28 ± 3 (SD) years [range: 20 years (H. Cornet, 1904)–36 years (F. Lambot (1922))] (Augendre, 2001). The oldest participant in the history of the race was H. Paret (50 years old, 11th overall in 1920). Although some data from pre-race mandatory medical check-ups have been made available to the general press in the last few years, to the best of our knowledge, no reliable data are available concerning the age or other demographic characteristics (height, mass) of all-time participants.

Cycling performance in each of competition terrains (i.e., level vs. uphill roads) is partly determined by individual morphological characteristics (body mass, height, body surface and frontal areas, body mass index or BMI) (Padilla et al., 1999). Therefore, anthropometric variables might greatly differ depending on each rider specialty. For example, TT or flat terrain specialists are usually taller and heavier (180–185 cm, 70–75 kg, BMI = 22) than those who excel in uphill climbing (175–180 cm, 60–66 kg, BMI of 19–20) (Padilla et al., 1999; Lucia et al., 2001d). The morphometric characteristics of most modern champions and TDF winners, able to excel in both type of terrains, are, however, close to those of time trialists (Padilla et al., 1999, e.g., 183 cm and 73 kg for Jan Ullrich and 179 cm and 71 kg for Lance Armstrong. Mean values of VO2max reported in TDF participants (including several top-10 finishers) range between 5.0 and 5.5 L min⁻¹ or between 70 and 80 mL kg⁻¹ min⁻¹ (Lucia et al., 2001b). Although there are exceptions, the highest relative values (~80 mL kg⁻¹ min⁻¹) are comparable to those of elite distance runners such as Kenyans, and are shown by uphill climbing specialists. Lower values (~70 mL kg⁻¹ min⁻¹) usually correspond to TT specialists.
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It seems that very high VO\textsubscript{2}max values (≥6 L min\textsuperscript{-1} and/or ≥80 mL kg\textsuperscript{-1} min\textsuperscript{-1}) are necessary to win this race. For instance, the VO\textsubscript{2}max of the last five-time TDF winner Miguel Indurain was reported to be of 6.4 L min\textsuperscript{-1} (equaling 79 mL kg\textsuperscript{-1} min\textsuperscript{-1} for his 81-kg mass) (Padilla et al., 2000a). Although high VO\textsubscript{2}max values (usually ≥70 mL kg\textsuperscript{-1} min\textsuperscript{-1}) are required for cycling performance at a professional level, other physiological variables (discussed below and that relate to the ability to perform at high but submaximal intensities) are far more important. For instance, similar VO\textsubscript{2}max and GE/CE, however, would distinguish the potential TDF winner.

Another possible distinguishing factor is the degree of cardiac hypertrophy exhibited by chronically training professional riders, e.g., 95% confidence intervals for mean ventricular mass index of 100.9 to 187 g m\textsuperscript{-2} in all the participants of the 1995 TDF (Abergel et al., 1998). Mean values of ~152 and 116 g m\textsuperscript{-2} have been reported by other research groups (Rodríguez Reguero et al., 1995; Lucia et al., 2001b). This adaptation is compatible with the cardiac profile, i.e., predominantly eccentric left ventricular hypertrophy (enlarged left ventricular end-diastolic internal diameter and proportional increase in wall thickness), expected of endurance sportsmen in general – the so-called “athlete’s heart” (Fagard, 1996).

**Nutrition and hydration in TDF’s history**

During the stages of the first two TDF decades, cyclists often obtained their food in bars and drank from fountains (Fig. 3). In the 1930s, Christensen & Hansen (1939) first reported the beneficial effects of consuming carbohydrates (CHO) during endurance exercise. However, TDF riders were neither aware of these pioneer findings nor of the need for replenishing pre-exercise glycogen levels. Thus it not surprising that exercise-induced hypoglycaemia (the so-called “bonk”) due to depletion of liver glycogen – first reported in the scientific literature in marathon runners (Levine et al., 1924) - and its accompanying neurological symptoms has been experienced by numerous cyclists throughout the history of the TDF. Carbohydrate intake on the bicycle during 3-week races is rather low nowadays (average 25 g h\textsuperscript{-1}) (García-Rovés et al., 1998), and below the recommendations (30–60 g h\textsuperscript{-1}) for maintenance of a high rate of CHO oxidation during prolonged strenuous exercise (Coyle et al., 1986).

Since the 1980s, nevertheless, the total daily nutritional intake of TDF cyclists has been shown to be high enough (23–25 MJ day\textsuperscript{-1}) to match energy expenditure (Saris et al., 1989). Particularly, CHO intake (>12–13 g kg\textsuperscript{-1} day\textsuperscript{-1}) appears sufficient.

**Fig. 3.** Nutrition during stages in the 1920s: French Robert Jacquinot, participant in six editions of the Tour de France (1919–24) photographed with spare tyres looped round his shoulders, at a table in a small estaminet, eating a bowl of soup, glass of wine and some bread. Reprinted with permission from The Sports Poster Warehouse, http://www.PureSportsArt.com.
to replenish riders’ glycogen stores within the 18 h that elapses from the end of each daily stage, at ~17:00 p.m., to the beginning of the next one, at ~12:00 p.m., throughout the entire 3-week period. Another report from the mid-1990s examining the Vuelta a España confirms the adequacy of riders’ diet during modern 3-week races (Garcia-Rovés et al., 1998). In the second half of the 1990s, mean daily food intake during this type of competition was ~840 g of CHO, 200 g of protein and 158 g of fat corresponding to some 23.5 MJ. A novel feature from the 1990s is the addition of proteins (0.35 g kg⁻¹) to CHO during the first hour after each daily stage (mixture of cereals, dairy products and fruits), which probably accounts for a faster replenishment of muscle glycogen stores (Garcia-Rovés et al., 1998).

Few scientific reports are available dealing with the hydration status of TDF participants during the race. Saris et al. (1989) reported a mean fluid intake of 6.7 L per 24 h. Beginning in the 1980s, fluid bottles were supplied to riders during each stage by team cars and TDF organization. In earlier years, each rider was responsible for providing his own fluid in the absence of water supplies by the organizers.

The history of doping in the TDF

Several historical, non-scientific reports are available showing TDF participants’ reliance on pharmacological aids that have traditionally been viewed as an unavoidable method to cope with the high physical demands of the race. During the first few decades, cyclists used wine laced with strychnine, ether-soaked handkerchiefs or rubbing chloroform into the gums to release pain and decrease the feeling of fatigue (Fiè, 2000). Others have been rumoured to use cocaine or sympathomimetic drugs in order to attenuate the feeling of fatigue associated with such a prolonged exercise effort. On July 13th 1967, under extreme environmental conditions (>40°C) a 29-year-old British, Tom Simpson, died shortly after falling off his bike and losing consciousness some 3 km from the top of Mont Ventoux (~1700 m altitude) (Augendre, 2001). The autopsy showed that he had consumed a mixture of alcohol (cognac) and amphetamines during the stage.

In the last two decades, sports haematology and blood doping have become a contentious topic in professional cycling (Lasne & de Ceaurriz, 2000; Parisotto et al., 2000). Since recombinant human erythropoietin (r-HuEPO) is demonstrably effective in increasing haemoglobin concentration, VO₂max and physical work capacity (Ekblom & Berglund, 1991), the lack of a reliable test (until most recently) to confirm its use may have presumably induced many TDF participants to experiment with this drug over the last 15 years. In fact, the possible health risks of hyperviscosity and thrombogenicity associated with the misuse of this drug could have caused the mysterious deaths of some European riders between 1987 and 1990 (Eichner, 1992). The suspected association between elite cycling and blood doping with r-HuEPO was confirmed by both the discovery of vials of this drug (among other drugs such as growth hormone and anabolic steroids) on a car of a professional cycling team during the 1998 TDF and the recent finding of abnormally high EPO levels in several frozen urine samples collected during this race (Lasne & de Ceaurriz, 2000). To dissuade the use of r-HuEPO and to minimize the health risks associated with the abuse of this drug, the International Cycling Union (ICU) has imposed an upper limit of 50% on haematocrit levels since 1997’s TDF. Some professional cyclists (including former TDF winner Marco Pantani in May 1999) have surpassed the 50% limit, suggesting the possible use of this drug to increase blood oxygen transport capacity artificially. Indeed, although a subset of endurance athletes including elite cyclists (i.e., 2–8% of total) might naturally surpass the 50% threshold (Marx & Vergouwen, 1998; O’Toole et al., 1999), haematocrit levels consistently below 50% (mean of 43.0 ± 0.02%; range 0.39–0.48) were reported in 353 blood samples collected during 1980–1986 TDFs, i.e., before r-HuEPO was commercially available (Saris et al., 1998). Fortunately, both indirect (based on markers of altered erythropoiesis (Parisotto et al., 2000) and the aforementioned 50% limit) and direct methods based on urine samples (Lasne & de Ceaurriz, 2000) have been used in the TDF since 2001. The aforementioned methods have probably accounted for a consistent decrease in the mean haematocrit levels of professional cyclists in the recent years towards a healthy, dilutional pseudoanaemia secondary to plasma volume expansion as expected in non-doped endurance athletes, e.g., levels of haemoglobin and haematocrit of 13.8 ± 0.7 g dL⁻¹ and 41.9 ± 2.4%, respectively, in a group of Spanish riders by the end of the 1998 Vuelta a España (Chicharro et al., 2001).

Perspective

Scientists from many countries have discovered and elucidated those factors that help the human machine to function better. Although the Tour de France celebrated its centenary in July of 2003, much remains to be learned of the demands associated with such prolonged and continuous bouts of physical exertion. To date, some descriptive studies (mostly published in the late 1990s) have
analysed the physiological responses and adaptations to such an extreme endurance event. As a result, the body of knowledge concerning cycling physiology has increased considerably. The next century presents itself as a new opportunity to expand on our knowledge surrounding this event and of the human body’s ability to adapt and cope.

Key words: professional cycling, physiology, endurance exercise.

References


