# The 24-h Urinary Cortisol/Cortisone Ratio for Monitoring Training in Elite Swimmers

DJAMILA ATLAOUI[1], MARTINE DUCLOS[3], CAROLINE GOUARNE[3], LUCIEN LACOSTE[2], FREDERIC BARALE[2], and JEAN-CLAUDE CHATARD[1]

*[1]Laboratory of Physiology, GIP Exercise Sport and Health, Faculty of Medicine Jean Monnet, Saint-Etienne, FRANCE; [2]Toulouse Olympic Student Club, Toulouse, FRANCE; and [3]Laboratory of Neurogenetic and Stress, Bordeaux, FRANCE*

**ABSTRACT**

ATLAOUI, D., M. DUCLOS, C. GOUARNE, L. LACOSTE, F. BARALE, and J-C. CHATARD. The 24-h Urinary Cortisol/Cortisone Ratio for Monitoring Training in Elite Swimmers. *Med. Sci. Sports Exerc.*, Vol. 36, No. 2, pp. 218–224, 2004. **Purpose:** The effect of training variations on 24-h urinary cortisol/cortisone (C/Cn) ratio was investigated in highly trained swimmers to determine whether it could be a good marker of training stress and performance. **Methods:** Fourteen swimmers (five female and nine male) were tested after 4 wk of intense training (IT), 3 wk of reduced training (RT), and 5 wk of moderate training (MT). At the end of each period, the swimmers performed in their best event at an official competition. Individual performances were expressed as a percentage of the previous season's best performance. The fatigue state was evaluated with a questionnaire. **Results:** The C/Cn ratio was statistically different for the three periods (IT: 1.10 ± 0.7, RT: 0.64 ± 0.3, and MT: 0.57 ± 0.2). The differences in the C/Cn ratio between two consecutive performances were related to the differences in performance ($r = -0.52$, $P < 0.01$), and the C/Cn ratio was significantly related to the total training ($r = 0.32$, $P < 0.05$) and total score of fatigue (TSF) ($r = 0.35$, $P < 0.03$) over the follow-up period. Cn levels were related to the dryland training ($r = -0.46$; $P < 0.01$) and TSF ($r = -0.40$; $P < 0.02$). During IT, variations in the C/Cn ratio were related to the changes in the mean intensity ($r = -0.67$; $P < 0.02$) and to TSF ($r = 0.69$; $P < 0.01$). **Conclusion:** The 24-h C/Cn ratio was moderately related to both training and performance whereas Cn levels were only related to training. The C/Cn ratio could be a useful indicator for monitoring the overreaching state in elite swimmers. **Key Words:** HORMONE, OVERREACHING, OVERTRAINING, SWIMMING, PERFORMANCE

Elite swimmers undergo significant amounts of training at high intensity to improve their performance during competitions. To avoid the development of overtraining syndrome, they ensure a balance between intense training sessions and recovery time. As reviewed by Kuipers and Keizer (17), Urhausen et al. (28), and Fry and Kraemer (12), various hormonal parameters such as cortisol (C) have been suggested as indicators to monitor this balance and detect signs of maladaptations to training, leading to decrements in performance and accumulation of fatigue. However, data dealing with C responses to performance are conflicting. Significantly elevated resting plasma C levels have been detected in overtrained runners with impaired performance (2), whereas declines (18) or increases (16) in plasma C have been reported in athletes with stable performances. No differences in resting plasma C were observed between overreached swimmers exhibiting no performance gains and well-trained swimmers (15,20).

Address for correspondence: Djamila Atlaoui, Laboratory of Physiology, Pav. 12, St Jean Bonnefonds Hospital, 42 055 Saint-Etienne Cedex 2, France; E-mail: djamila.atlaoui@univ-st-etienne.fr.
Submitted for publication July 2003.
Accepted for publication October 2003.

0195-9131/04/3602-0218
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

DOI: 10.1249/01.MSS.0000113481.03944.06

Possible reasons for discrepancies between plasma and/or saliva C levels and performance or overreaching are probably due to the fact that plasma or saliva cortisol concentrations are not the unique determinants of the effect of cortisol on target tissues. Until a decade ago, it was thought that the main determinants of corticosteroid action were the levels of hormones in the blood, their binding with plasma proteins (corticosteroid binding globulin: CBG), and the varying densities of receptors in target tissues. However, it has now become apparent that an additional and important level of control is exerted by the prereceptor metabolism of cortisol by tissue-specific enzymes, in particular 11$\beta$-hydroxysteroid dehydrogenase (11$\beta$-HSD) (24). Two isoenzymes of 11 $\beta$-HSD interconvert hormonally active cortisol and inactive cortisone within target cells. They have been shown to modulate the action of the hormone at an autocrine level in several peripheral tissues (24). Therefore, the crucial physiological principle illustrated by the action of 11$\beta$-HSD is that cortisol action on target cells is determined by enzyme action within the cells rather than circulating cortisol levels alone (24). Such modulation of glucocorticoid action by local metabolism has not been explored until now in healthy trained individuals. Daily sessions of prolonged and/or intense exercise, such as in swim training, induce prolonged phases of endogenous hypercortisolism (8). Understanding the function of 11$\beta$-HSD may provide new insights into the adaptation of the hypothalamo-pituitary-adrenal (HPA) axis to endurance training. Therefore, quantitative assessment of enzyme activity may lead to the def-

inition of new tools to monitor the delicate balance between exercise and recovery.

It has been shown that the 24 h urinary cortisol/cortisone (C/Cn) ratio is a good index for the measurement of renal 11$\beta$-HSD activity (3). Thus, this investigation was undertaken to examine whether the 24-h urinary C/Cn ratio could be a good marker for training stress and performance variations in highly trained swimmers.

## MATERIALS AND METHODS

**Subjects.** The subjects of this study were 14 French swimmers competing nationally and internationally, five female (21 ± 2 yr, 173 ± 5 cm, 60 ± 5 kg) and nine male (23 ± 4 yr, 186 ± 7 cm, 80 ± 7 kg). All were members of the same team and had a background in competitive swimming that averaged 15 ± 3 yr. They were either 50-, 100-, 200-, 400-, or 1500-m specialists in different strokes. All the swimmers trained 6 d·wk$^{-1}$, usually twice per day, with a rest on Sunday. They also practiced regular dryland training, 1 h·d$^{-1}$. Approval for the project was obtained from the Local Committee on Human Research. After being informed of the nature of the study, swimmers gave their written consent to participate in this study.

**Testing procedures.** Subjects were tested on three periods over 12 wk, between March 2001 and June 2001: the first period was a 4-wk intense training period (IT). The swimmers were tested at the end of the IT, week 31, week 1 being the beginning of the training season. The basal values (PreIT values) have been monitored at the end of the week 27. Indeed, PreIT training volume was 32.0 ± 16.1 km·wk$^{-1}$ versus 48.3 ± 12.5 km·wk$^{-1}$ during IT, mean intensity was 2.10 ± 0.3 arbitrary units·wk$^{-1}$ versus 2.14 ± 0.2 arbitrary units·wk$^{-1}$, and dryland training was 9.0 ± 7.6 km·wk$^{-1}$ versus 13.2 ± 7.6 km·wk$^{-1}$. During IT, the training volume increased by 72.2 ± 83.3%, mean intensity by 4.9 ± 15.5%, and dryland training by 59.9 ± 90.9%. The second period was a 3-wk reduced training period (RT), also called the taper period, just before the national championships, ending at week 34. The training volume was progressively decreased by 55.6 ± 22.1% (34.7 ± 7.2 km·wk$^{-1}$), mean intensity by 11.7 ± 6.9% (1.9 ± 0.1 arbitrary units·wk$^{-1}$), and dryland training by 69.2 ± 19.9% (4.1 ± 2.5 km·wk$^{-1}$). The third period was a 5-wk moderate training period (MT) starting after the taper period and ending at week 39. From the RT to MT periods, training volume and dryland training decreased by 38.1 ± 34.2% (22.3 ± 17.6 km·wk$^{-1}$) and 26.9 ± 40.6% (3.1 ± 2.9 km·wk$^{-1}$), respectively, whereas mean intensity increased by 1.6 ± 6.1% (1.9 ± 0.2 arbitrary units·wk$^{-1}$). At the end of each period, swimmers performed a competition (Fig. 1) and answered an eight-item questionnaire on fatigue (1) the day of the competition (Table 1).

**Fatigue questionnaire.** The eight questions focused on the perception of training, sleep, leg pain, infection, concentration, efficacy, anxiety, irritability, and general stress and were assessed on a 7-point scale from very very good (1 point) to very very bad (7 points). The responses to the questions were collated to obtain the total score of fatigue (TSF). All the questions played an important part in the TSF. The TSF was weighted and calculated according to the relative importance of each question in the score (1). The lower the score the better the perception of well-being, the higher the score the higher the perception of fatigue. Intrasubject variability of the TSF, assessed in 20 swimmers from coefficient of variation of difference between double measurements within half a day was 2.3%.

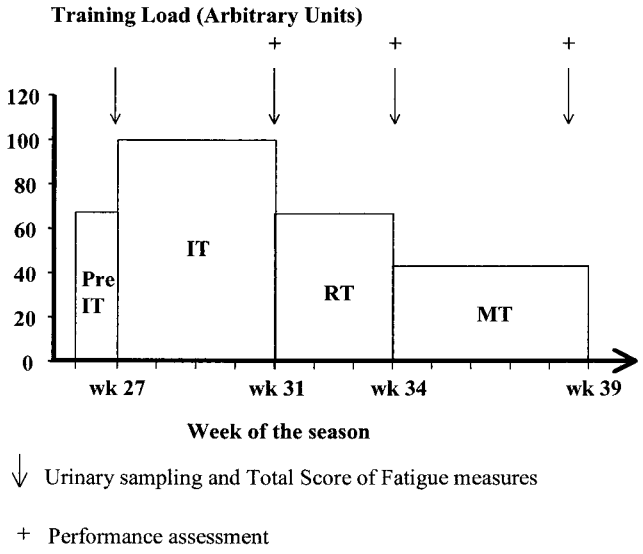


**FIGURE 1—Study design: training load and timing of performance assessment, TSF measures, and urinary sampling.**

**Performance assessment.** At the end of each period, the swimmers performed in their best event at an official competition as planned in their normal training season program (Fig. 1). Individual performances were expressed as a percentage of the previous season's best performance. A decrease in the performance time corresponded to an improvement in the performance percentage. During the follow-up period, they were asked to avoid any medication and maintain their usual diet.

**Training program.** The swimmers followed the training program set by their two coaches. The training volume, intensity, and dryland work times were recorded by the coaches each day for each swimmer and then averaged per week and period. The different swimming intensities ranged from 1 to 5 and were evaluated after lactate testing as described by Mujika et al. (22). Dryland training was composed of 50% warm-up and stretching exercise empirically considered as close to intensity 1, 25% of submaximal strength exercise, considered as close to the intensity 4, and 25% of maximal strength exercise, considered as close to intensity 5. The mean intensity of the three training periods (MI) was calculated as the sum of the distance covered at intensities 1, 2, 3, 4, and 5 multiplied by the stress indices 1, 2, 3, 5, and 8, respectively, divided by the total training volume. The calculated equivalent of dryland training, expressed in kilometers as previously described (22), was added to the figure

$$MI = \frac{(1km1 + 2km2 + 3km3 + 5km4 + 8km5 + \text{dry land equivalent})}{\text{Training volume}}$$

TABLE 1. Description of the eight items of the questionnaire of fatigue.

| No. | Item | Rating Scale | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Very Very Good | | | Average | | | Very Very Bad |
| 1 | I found training more difficult than usual | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 2 | I slept more | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 3 | My legs felt heavy | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 4 | I caught cold/infection/flu | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 5 | My concentration was poorer than usual | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 6 | I worked less efficiently than usual | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 7 | I felt more anxious or irritable than usual | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 8 | I had more stress at home, school, training, work | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

The total training load (TT) corresponds to the sum of the distance covered and the dryland training, and was averaged for each period.

For each period, the training volume (km), MI (arbitrary units), and TT (arbitrary units) were expressed as a weekly average (Fig. 2).

**Urinary sampling.** During each competition day, all urinary samples were collected over a 24-h period, the diuresis was noted, and 100 mL samples were frozen at −80°C until analysis. Concentrations of the urinary unconjugated cortisol and cortisone were determined by high-performance liquid chromatography (HPLC) with ultraviolet absorbance detection based on the Hay and Mormède (14) method with the following adaptations. Urine was centrifuged for 15 min at 4°C at 4000 × *g* and filtered (1/20). The urine (300 $\mu$L) was adjusted according to its dilution (i.e., according to creatinine concentration). Creatinine levels were determined using spectrophotometry. This method is based on the destruction of the color derived from the reaction between creatinine and alkaline picrate. Thus, the differences in color intensity measured at 500 nm before and after acidification of the mixture is proportional to creatinine concentration. The urine was eluted from a column with absolute ethanol. Eluates were then evaporated during 4 h at 50°C. After complete evaporation, dried residues were dissolved in mobile phase and were injected into the HPLC system. Quantification was achieved with UV absorption detection, as previously described (14). Both cortisol and cortisone concentrations were expressed in nanograms per milogram of creatinine per 24-h period and determined in duplicate. The intra- and interassay coefficients of variations were <1%.

**Statistical analysis.** Means and standard deviations were calculated for all variables. One-way, repeated ANOVA tests were performed to analyze the mean differences between the three training periods. When the differences were significant, the *F*-test was followed by *post hoc* procedures (Fisher's PLSD test). Correlations between hormone values, performance, training, and TSF were calculated from linear regression. Correlations were retained only when the significances were reconfirmed using a Spearman nonparametric test. The StatView program (Brain Power Inc., Calabasas, CA) was used in all statistical analyses. A probability level of 0.05 was selected as a criterion for statistical significance.

One subject (one female) of the 14 swimmers was considered to be overtrained. Indeed, she suffered a decline in her performance (increase in competition times) throughout the follow-up period. She was also tired, reporting high fatigue scores owing to sleeping disorders, infection, and general stress (as assessed by questions 2, 4, and 8 of the questionnaire). She was thus excluded from the study group statistical analyses. Statistical analyses were then conducted with the remaining 13 subjects.

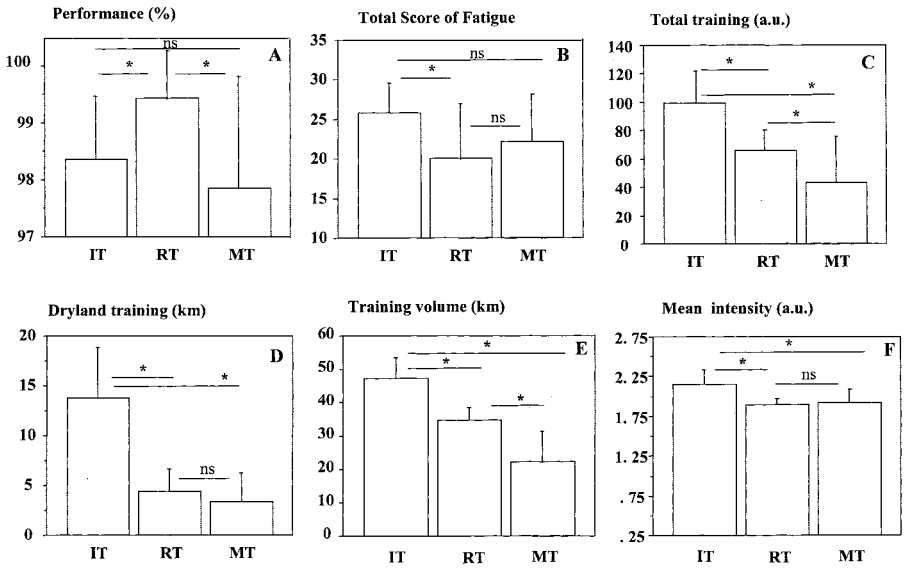


**FIGURE 2—Mean (SD) of (A) performance, (B) total score of fatigue (TSF), (C) total training (TT), (D) dryland training, (E) training volume, and (F) mean intensity (MI) for the three periods (IT; intense training, RT; reduced training; MT moderate training).**

TABLE 2. Twenty-four hour Urinary cortisol (C), cortisone (Cn) (ng·mg$^{-1}$ of creatinine) and C/Cn ratio concentrations for the three studied periods; subject 14 ($N$ = 1) was considered as overtrained.

| Subject ($N$) | | Week of the Season | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Week 27 Baseline Values | | | Week 31 Intensified Training | | | Week 34 Reduced Training | | | Week 39 Moderate Training | | |
| | | C | Cn | C/Cn | C | Cn | C/Cn | C | Cn | C/Cn | C | Cn | C/Cn |
| 13 | Means | 16.9 | 24.2 | 0.65 | 18.5 | 17.3 | 1.10 | 21.4 | 32.7* | 0.64* | 16.3 | 33.6* | 0.57* |
| | SD | 12.9 | 9.8 | 0.38 | 16.9 | 13.4 | 0.7 | 15.6 | 20.9 | 0.3 | 8.6 | 21.8 | 0.2 |
| 1 | | 12.7 | 9.9 | 0.74 | 24.5 | 56.6 | 0.43 | 56.4 | 94.3 | 0.60 | 31.6 | 42.7 | 0.74 |

C concentrations were not significantly different over the three periods.
* $P < 0.05$ from IT.

## RESULTS

For the three studied periods, 24-h urinary cortisol (C) and cortisone (Cn) concentrations did not differ significantly between male and female swimmers, and data were pooled for analysis (Table 2). The C/Cn ratio, Cn levels, performance, total score of fatigue (TSF), total training (TT), dryland training, training volume, and mean intensity (MI) were significantly different for the three periods ($P < 0.03$, Fig. 2). From IT to RT, the C/Cn ratio, TSF, TT, dryland training, training volume, and MI decreased significantly, whereas Cn levels and performance increased significantly. From IT to MT, the C/Cn ratio, TT, dryland training, training volume, and MI decreased significantly, whereas Cn levels increased significantly. From RT to MT only the performance, TT and training volume showed a significant decrease.

**Relationship with performance.** Over the three studied periods, the differences in C/Cn ratio between two consecutive performances were correlated to the differences in performance ($r = -0.52$, $P < 0.01$; Fig. 3A). After the 3 wk of reduced training, percentage changes in C/Cn ratio were related to the percentage changes in performance ($r = -0.69$, $P < 0.02$; Fig. 3B). However, no relationship was found between changes in C and Cn levels and performance changes.

**Relationship with training and TSF.** Over the three studied periods, the C/Cn ratio was significantly related to the total training ($r = 0.32$, $P < 0.05$, Fig. 4A) and TSF ($r = 0.35$, $P < 0.03$), whereas Cn levels were related to the dryland training ($r = -0.46$; $P < 0.01$, Fig. 4B) and TSF ($r = -0.40$; $P < 0.02$, Fig. 5A). The differences in the C/Cn ratio between two competitions were correlated with the difference in TSF ($r = 0.51$; $P < 0.01$; Fig. 5B). The changes in C/Cn ratio after 4 wk of IT were related to changes in MI ($r = -0.67$; $P < 0.02$; Fig. 4C) and TSF ($r = 0.69$; $P < 0.01$; Fig. 5C).

**Results of the case swimmer.** The C/Cn ratio of the swimmer that showed decrease in performance (from 97.6% to 96.7%) and increase in TSF scores (from 19 points to 28 points) throughout the study increased gradually from IT to MT as opposed to the remaining swimmers (Table 2). C and Cn concentrations were also higher than those of the 13 other swimmers.

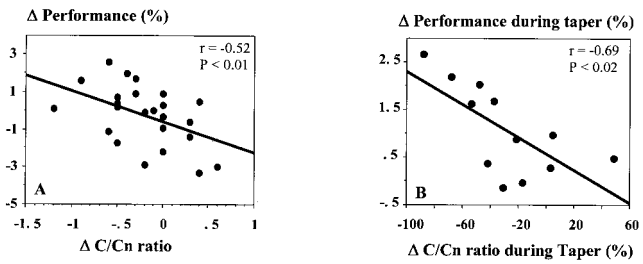


**FIGURE 3—Relationships between (A) differences in performances between two competitions and differences in cortisol/cortisone (C/Cn) ratio over the three studied periods and (B) variations in performance and C/Cn ratio, expressed in percent before and after the 3 wk of taper.**

## DISCUSSION

The main findings of the present study indicated that the variations in the 24-h C/Cn ratio were related to the performance and to the training program variations. Indeed, the ratio increased during IT and decreased during RT, whereas Cn levels decreased during IT and increased during RT. The 24-h C/Cn ratio and Cn levels were also related to the TSF over the three studied periods.

Urine sampling methods, as opposed to plasma, are noninvasive, nonstressful, reliable, and practical methods to assess HPA axis responses when athletes are performing large amounts of training and competitions, without any disturbances of their training conditions. Plasma cortisol levels are modulated by variations of its binding protein (CBG) and poorly correlated with cortisol production rates unless differences in CBG are corrected. Conversely, urinary free cortisol concentrations are independent of CBG concentrations and thus closely reflect the 24-h free active plasma cortisol production (5).

The results of the present study show a large interindividual variability in 24-h free urinary cortisol (C) concentrations in response to the different training periods. This suggests that C levels are not relevant in predicting performance and/or diagnosing of overreaching. In contrast, both Cn concentrations and the C/Cn ratio changed throughout the program during intense training and taper periods in line with the swimming performance and TSF.

**C/Cn ratio relationships with performance.** As HPA axis is involved in the response to acute exercise, and in the adaptation to endurance training (9,11,13,19), salivary and plasma C levels have been suggested as possible tools for predicting performance. However, literature demonstrates conflicting reports on the response of salivary and

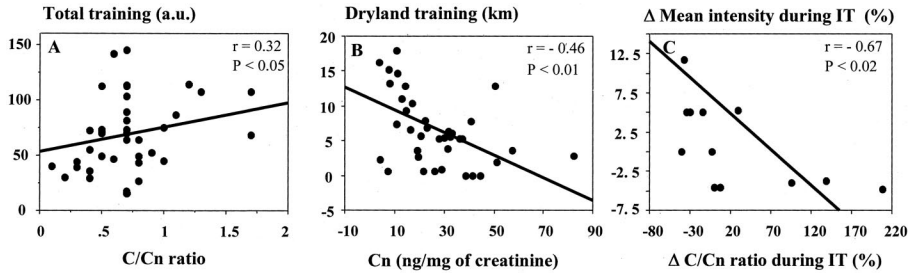


**FIGURE 4—Relationships between (A) the cortisol/cortisone ratio (C/Cn), and total training over the three studied periods, (B) cortisone levels and dryland training over the three periods studied, and (C) percentage variations in the C/Cn ratio and variations in mean intensity during intense training (IT).**

plasma C levels in overtrained athletes exhibiting performance decrements (6,15,20). Significantly elevated resting C levels have been observed in overtrained runners with impaired performance (2), whereas Kirwan et al. (16). reported high resting salivary C levels in swimmers despite unaltered performance. Decreases in plasma C levels were seen to be associated with an improvement in swimming performance (4). No differences in resting plasma C were observed between overreached swimmers exhibiting performance decrements and well-trained swimmers (15,20). Several factors such as sampling method, circadian rhythms, and cortisol metabolism could explain these disparities. Indeed, cortisol secretion follows a nycthemeral rhythm with significant fluctuations of its plasma concentrations between awakening (peak of cortisol concentrations) and its evening nadir. One of the major benefits of 24-h urinary collection is that 24-h C levels represent a nonstressful integrated measure of 24-h cortisol secretion (5). Finally, an additional and high level of control of the effect of cortisol on target cells is exerted by prereceptor metabolism of cortisol by the tissue-specific enzymes 11$\beta$-hydroxysteroid dehydrogenase (11$\beta$-HSD) (24). Two isoenzymes of 11 $\beta$-HSD interconvert hormonally active cortisol and inactive cortisone and have been shown to modulate cortisol hormone action in several peripheral tissues (24). 11$\beta$-HSD2 inactivates cortisol to cortisone, and is mainly expressed in the kidney in which it protects the mineralocorticoid receptor from cortisol excess (25). By contrast, 11$\beta$-HSD1 is expressed in numerous tissues where it converts the inactive cortisone to the active cortisol (24). The crucial physiological principle illuminated by the action of 11$\beta$-HSD is that cortisol action on target cells is determined by enzyme activity within the cells rather than circulating cortisol levels alone. Therefore, one major cause of discrepancy between the different studies may be due to this intracellular cortisol metabolism. It has been shown that the peripheral metabolism of cortisol can be assessed accurately from the urinary free C/Cn ratio, which is a good index of the measurement of renal 11$\beta$-HSD activity (3). In the present study, isolated C or Cn changes were not good predictors of the swimming performances. On the contrary, changes in the C/Cn ratio were related to performance changes. Indeed, a decreased C/Cn ratio was associated with an increase in performance. The decrease in C/Cn ratio was mainly due to increased Cn concentrations, suggesting a greater inactivation of cortisol to cortisone. Given the antagonistic action of glucocorticoids on anabolic processes in muscle, this increased inactivation could protect the organism against the deleterious effect of prolonged hypercortisolism (23). These results are in accordance with previous findings, reporting decreased tissue sensitivity to glucocorticoids in endurance-trained men 24 h after the last bout of exercise, compared to sedentary men, i.e., another mechanism to protect tissues against excessive cortisol concentrations (10,11).

One swimmer displayed performance decrement concomitant with high scores of fatigue throughout the follow-up period. This swimmer showed a gradual increase in the C/Cn ratio from IT to MT in contrast with the significant decreases reported in the other swimmers. However, after the period of reduced training (i.e., taper), the performance decrement observed in this swimmer was concomitant with elevated C and Cn levels compared with the remaining swimmers, whereas the C/Cn ratio of the two groups was very similar. These results also suggest that it was not the value of the C/Cn ratio which was important but rather its evolution during the training and competitive season. This point has been found in another situation where increased cortisol secretion is observed, for example, major depression (29). In this situation the C/Cn ratio has been reported to remain similar with controls (29).

**C/Cn relationships with training and TSF.** In the present study, the C/Cn ratio and Cn levels changed significantly along the training. The C/Cn ratio was positively and moderately correlated to the total training over the three

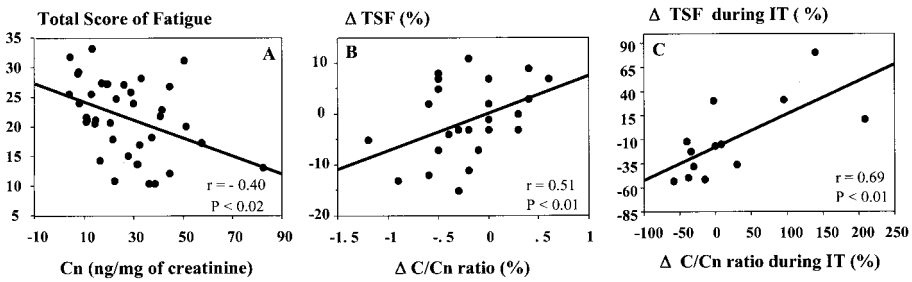


**FIGURE 5—Relationships between (A) total score of fatigue (TSF) and cortisone (Cn) levels and (B) differences in TSF between two competitions and differences in the cortisol/cortisone ratio (C/Cn) and (C) variations in C/Cn ratio and percentage variations in TSF during intense training (IT).**

studied periods, whereas Cn levels were negatively related to the training intensity. The present investigation is the first report indicating changes in 24-h C/Cn ratio in healthy trained subjects during IT. Such increases have been reported in patients suffering from endogenous and permanent hypercortisolism (Cushing's syndrome) (7,21,26,27). In these patients, the activity of the 11$\beta$-HSD2 enzyme, which protects mineralocorticoid target tissues by inactivating cortisol into cortisone, is overloaded (i.e., reduced). In the present study, the poor inactivation of cortisol into Cn (twofold less than during RT and MT) argues against overloading of 11$\beta$-HSD2 but, instead, suggests an inhibition of this enzyme during IT. The mechanisms responsible for this inhibition remain to be determined. The elevated C/Cn ratio observed during IT was reversed after a recovery period (i.e., tapering) due to increased Cn concentrations. The reduced training load of the taper resulted in a reduction in physical stress that was not reflected by decreased C levels but rather by increased Cn levels. This increase in Cn levels observed in RT and MT periods may act to compensate for the relative hypercortisolism of the IT period.

In the present study, the C/Cn ratio was also positively and significantly, but only moderately, related to the TSF over the three studied periods. Cn levels were negatively related to the TSF. The TSF (e.g., self-report of the perception of training, sleep, leg pain, infection, concentration, efficacy, anxiety, irritability, and general stress) has been shown to increase during a period of intense training and to decrease during taper (1). TSF has been suggested as a good marker of the training stress in swimmers. Thus, both the 24-h Cn levels, the 24-h C/Cn ratio, as well as TSF could be useful indicators for monitoring the training stress and recovery.

In summary, the results of the present study together with data from the literature suggest that punctual plasma or salivary cortisol or 24-h urinary cortisol levels (present study) are poor markers of overreaching and/or overtraining syndromes. On the other hand, the 24-h Cn levels were moderately related to the increase or decrease of training, whereas the C/Cn ratio was related to both training and performance. Thus, the 24-h Cn levels and 24-h C/Cn ratio may provide useful markers for monitoring the overreaching state in elite swimmers.

The authors gratefully acknowledge the French Swimming Federation, coaches, and athletes of the Toulouse Olympic Student Club who supported this study. The authors also thank Professor Thierry Busso, Dr. Mohamed Rehalia, Professor Jean-René Lacour, and Desmond Carey for their valuable assistance.

## REFERENCES


1. Atlaoui, D., L. Lacoste, F. Barale, M. Duclos, and J. C. Chatard. Relationships between well-being state, performance and training in elite swimmers. In: *IXth Word Symposium Biomechanics and Medicine in Swimming. Saint Etienne, France: Book of Abstracts*, 2002, p. 25.
2. Barron, J. L., T. D. Noakes, W. Levy, C. Smith, and R. P. Millar. Hypothalamic dysfunction in overtrained athletes. *J. Clin. Endocrinol. Metab.* 60:803–806, 1985.
3. Best, R., and B. R. Walker. Additional value of measurement of urinary cortisone and unconjugated cortisol metabolites in assessing the activity of 11 beta-hydroxysteroid dehydrogenase in vivo. *Clin. Endocrinol.* 47:231–236, 1997.
4. Bonifazi, M., F. Sardella, and C. Lupo. Preparatory versus main competitions: differences in performances, lactate responses and pre-competition plasma cortisol concentrations in elite male swimmers. *Eur. J. Appl. Physiol.* 82:368–373, 2000.
5. Bright, G. M. Corticosteroid-binding globulin influences kinetic parameters of plasma cortisol transport and clearance. *J. Clin. Endocrinol. Metab.* 80:770–775, 1995.
6. Chatard, J. C., D. Atlaoui, G. Lac, M. Duclos, S. Hooper, and L. Mackinnon. Cortisol, DHEA, performance and training in elite swimmers. *Int. J. Sports. Med.* 23:510–515, 2002.
7. Dotsch, J., H. G. Dorr, G. K. Stalla, and W. G. Sippell. Effect of glucocorticoid excess on the cortisol/cortisone ratio. *Steroids* 66:817–820, 2001.
8. Duclos, M., J. B. Corcuff, L. Arsac, et al. Corticotroph axis sensitivity after exercise in endurance-trained athletes. *Clin. Endocrinol.* 48:493–501, 1998.
9. Duclos, M., J. B. Corcuff, M. Rashedi, V. Fougere, and G. Manier. Trained versus untrained men: different immediate post-exercise responses of pituitary adrenal axis. A preliminary study. *Eur. J. Appl. Physiol. Occup. Physiol.* 75:343–350, 1997.
10. Duclos, M., C. Gouarne, and D. Bonnemaison. Acute and chronic effects of exercise on tissue sensitivity to glucocorticoids. *J. Appl. Physiol.* 94:869–875, 2003.
11. Duclos, M., M. Minkhar, A. Sarrieau, D. Bonnemaison, G. Manier, and P. Mormede. Reversibility of endurance training-induced changes on glucocorticoid sensitivity of monocytes by an acute exercise. *Clin. Endocrinol. (Oxf.)* 51:749–756, 1999.
12. Fry, A. C., and W. J. Kraemer. Resistance exercise overtraining and overreaching: neuroendocrine responses. *Sports Med.* 23:106–129, 1997.
13. Galbo, H. *Hormonal and Metabolic Adaptation to Exercise*. Stuttgart: Georg Thieme-Verlag, 1983, pp. 40–57.
14. Hay, M. and P. Mormède. Improved determination of urinary cortisol and cortisone, or corticosterone and 11-dehydrocorticosterone by high-performance liquid chromatography with ultraviolet absorbance detection. *J. Chromatogr. B. Biomed. Sci. Appl.* 702:33–39, 1997.
15. Hooper, S. L., L. T. Mackinnon, R. D. Gordon, and A. W. Bachmann. Hormonal responses of elite swimmers to overtraining. *Med. Sci. Sports Exerc.* 25:741–747, 1993.
16. Kirwan, J. P., D. L. Costill, M. G. Flynn, et al. Physiological responses to successive days of intense training in competitive swimmers. *Med. Sci. Sports Exerc.* 20:255–259, 1988.
17. Kuipers, H., and H. A. Keizer. Overtraining in elite athletes: review and directions for the future. *Sports Med.* 6:79–92, 1988.
18. Lehmann, M., U. Gastmann, K. G. Petersen, et al. Training-overtraining: performance, and hormone levels, after a defined increase in training volume versus intensity in experienced middle- and long-distance runners. *Br. J. Sports Med.* 26:233–242, 1992.
19. Luger, A., P. A. Deuster, S. B. Kyle, et al. Acute hypothalamic-pituitary-adrenal responses to the stress of treadmill exercise. Physiologic adaptations to physical training. *N. Engl. J. Med.* 316:1309–1315, 1987.
20. Mackinnon, L. T., S. L. Hooper, S. Jones, R. D. Gordon, and A. W. Bachmann. Hormonal, immunological, and hematological responses to intensified training in elite swimmers. *Med. Sci. Sports Exerc.* 29:1637–1645, 1997.
21. Morineau, G., A. Boudi, A. Barka, et al. Radioimmunoassay of cortisone in serum, urine, and saliva to assess the status of the cortisol-cortisone shuttle. *Clin. Chem.* 43:1397–1407, 1997.
22. Mujika, I., J. C. Chatard, T. Busso, A. Geyssant, F. Barale, and L. Lacoste. Effects of training on performance in competitive swimming. *Can. J. Appl. Physiol.* 20:395–406, 1995.
23. Sapolsky, R. M. Glucocorticoids and hippocampal atrophy in neuropsychiatric disorders. *Arch. Gen. Psychiatry* 57:925–935, 2000.

24. SECKL, J. R., and B. R. WALKER. Minireview: 11beta-hydroxysteroid dehydrogenase type 1- a tissue-specific amplifier of glucocorticoid action. *Endocrinology* 142:1371–1376, 2001.
25. STEWART, P. M., B. A. MURRY, and J. I. MASON. Type 2 11 beta-hydroxysteroid dehydrogenase in human fetal tissues. *J. Clin. Endocrinol. Metab.* 78:1529–1532, 1994.
26. STEWART, P. M., B. R. WALKER, G. HOLDER, D. O'HALLORAN, and C. H. SHACKLETON. 11 beta-Hydroxysteroid dehydrogenase activity in Cushing's syndrome: explaining the mineralocorticoid excess state of the ectopic adrenocorticotropin syndrome. *J. Clin. Endocrinol. Metab.* 80:3617–3620, 1995.
27. ULICK, S., J. Z. WANG, J. D. BLUMENFELD, and T. G. PICKERING. Cortisol inactivation overload: a mechanism of mineralocorticoid hypertension in the ectopic adrenocorticotropin syndrome. *J. Clin. Endocrinol. Metab.* 74:963–967, 1992.
28. URHAUSEN, A., H. GABRIEL, and W. KINDERMANN. Blood hormones as markers of training stress and overtraining. *Sports Med.* 20: 251–276, 1995.
29. WEBER, B., S. LEWICKA, M. DEUSCHLE, M. COLLA, P. VECSEI, and I. HEUSER. Increased diurnal plasma concentrations of cortisone in depressed patients. *J. Clin. Endocrinol. Metab.* 85:1133–1136, 2000.