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A 7-week follow-up study of the behaviour of testosterone and cortisol during the competition period in rowers*

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Summary. Nine rowers (six men of the regional and three women of the national top class) participated in the study. During 7 consecutive weeks of the competition period serum testosterone (T), SHBG, cortisol (C) and urea were determined at the same time every morning under fasting conditions. From the concentrations of T and SHBG the free testosterone fraction (T/SHBG) was calculated, and from the concentrations of T and C the ratio of T/C was derived. The object of the investigation was to gather information on a potentially altered anabolic-catabolic hormone relationship dependent upon the intensity of the individual training periods. All rowers showed a continuous decrease in T, T/SHBG and T/C during the observation period. A week of regenerative training halted the decrease. In two of the oarsmen who discontinued their training after 2 and 3 weeks respectively, T, T/SHBG and T/C showed a normalization in the following weeks. In all subjects the concentrations of urea increased during the first 2 weeks and decreased during the subsequent weeks of intense training and competition. The findings suggest an increase in catabolic activity in periods of intensive physical strain, including competitions. Regenerative phases of training seem to reduce the anabolic-catabolic imbalance.

Key words: Cortisol — Testosterone — Intense training — Regeneration — Overtraining

Introduction

The behaviour of the hormones testosterone (T) and cortisol (C) immediately after short-term or long-term maximal and submaximal physical exercise has repeatedly been investigated (Dessypris et al. 1976; Galbo et al. 1977; Guglielmini et al. 1984; Kindermann et al. 1986; Kindermann et al. 1982; Kuoppasalmi et al. 1980; Schmid et al. 1982; Schmitt et al. 1981). In contrast, little information is available on the further course of these hormones during periods of repeated and intensive physical exercise (Adlercreutz et al. 1986; Häkkinen et al. 1985; Remes et al. 1985). So far there have been no investigations into the hormonal balance among high-performance athletes during several weeks of intensive training including repeated competitive events. Since T has an anabolic and C a catabolic effect, the behaviour of T and C can shed light on the anabolic-catabolic balance over long periods of training.

The object of this study was to investigate the influence of a 7-week period of rowing training, including several competitions, upon the anabolic-catabolic balance by repeated determinations of T and C. In addition, the concentrations of urea in blood were determined, since this substrate increases after prolonged physical exercise, reflecting an increase in proteolysis, and therefore can be used to detect a possible state of overtraining (Haralambie and Berg 1976; Kindermann 1984).

Material and methods

Our sample consisted of six male rowers of regional top class standard and three female rowers of the national top class level, of whom two later qualified for the world rowing cham-

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Table 1. Physical characteristics and maximal oxygen uptake measured on a rowing ergometer of the 9 rowers participating in the study *(mean values ± SD)*

	n	Age (years)	Training (years)	Height (cm)	Weight (kg)	$\dot{V}_{O_2max}$ ($ml \cdot min^{-1}$)	$\dot{V}_{O_2max}$/kg ($ml \cdot min^{-1} \cdot kg^{-1}$)
Men	6	20.0 ±0.8	3.8 ±1.6	187 ±5	80 ±9	4830 ±370	60.6 ±3.4
Women	3	20.3 ±0.5	6.0 ±0.8	177 ±1	73 ±5	3730 ±240	50.8 ±0.9

pionship finals (anthropometric data Table 1). During 7 consecutive weeks of the competition period venous blood samples were drawn every Monday at the same time (between 6:00 and 8:00 am) under fasting conditions. All samples were taken from the subjects when supine before getting up in the morning. In the 2nd week of the study the rowers participated in the first regatta (Re). Because of a rise in the concentration of urea, regenerative training (endurance training of reduced intensity) was conducted during the 3rd weekend and throughout the following week. Starting in the 4th week of the study, either a training camp (Tr) or competitions were held at the end of each week (also see description of abscissa in Figs. 1–4).

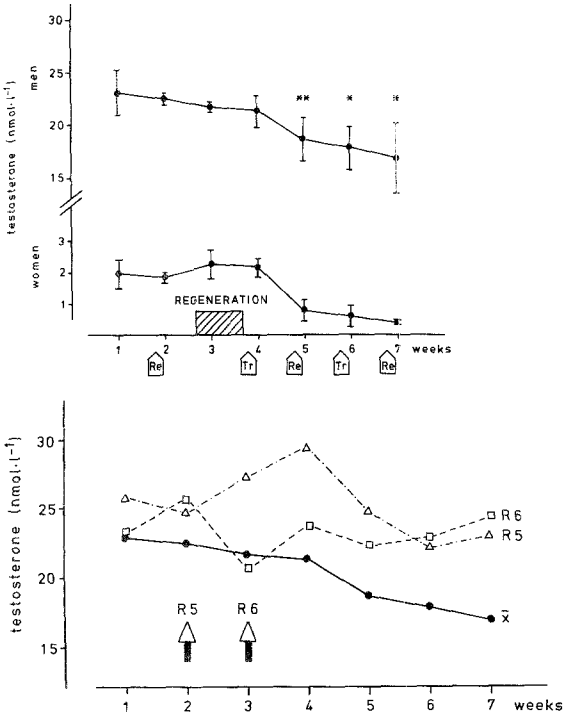

Fig. 1. a (top) Mean values ±SD for serum testosterone in 4 male and 3 female rowers during the 7-week training and competition period (Tr = training camp, Re = regatta). Asterisks denote significant changes compared to the respective initial values (* = $p < 0.05$, ** = $p < 0.01$) of the male rowers. **b** (bottom) Individual values for serum testosterone in 2 male rowers who stopped intensive training and competition after 2 (△- · -△; R5) and 3 weeks (□--□; R6) respectively, compared to the mean values (●—●; $\bar{X}$) of the training group

There were no essential qualitative differences between the training programms for the male and female group. Immediately after the 2nd and 3rd week of the study, two male rowers (R5, R6) discontinued training but continued to undergo blood sampling.

Serum concentrations of C (Rolleri et al. 1976) and T (Nieschlag 1975) were determined by radioimmuno-assay.

All hormone assays were carried out in duplicate. The samples from each subject were analysed in the same assay. Sexual-hormone-binding-globulin (SHBG) was determined by a immunoradiometric "sandwich type" assay, using monoclonal antibodies (Hammond et al. 1985). From the hormone concentrations determined, the T/C ratio was calculated as an expression of the anabolic-catabolic balance and the T/SHBG ratio was calculated as an expression of the biologically active free testosterone fraction (Anderson 1974, Mean et al. 1977). In the same blood samples the concentrations of urea were determined using a colorimetric method.

Data are expressed as means ±SD. Differences of means between the base line values of the 1st week and the subsequent samples were statistically tested using the *t*-test for paired data. Differences with $p \leq 0.05$ were considered statistically significant. Statistical tests were conducted only for the male group. In the female group only descriptive statistical procedures were used.

Results

The course of T (Table 2, Fig. 1a) showed a similar behaviour in male and female rowers. During the regenerative training period T among women tended to increase. Between the 5th and 7th week, during the phase of intensive training and competition, T in men as well in women showed a rapid and continuous decrease. In contrast, T in the two rowers who discontinued training after the 2nd and 3rd week increased over the following weeks (Fig. 1b).

SHBG showed only slight changes throughout the entire investigation (Table 2). T/SHBG, as a reflection of the free testosterone fraction (Fig. 2a), behaved similarly to T. This ratio showed the effect of 1 week of regeneration more clearly than total testosterone. In the two rowers (R5 and R6) who discontinued their training prematurely, both total testosterone and free testosterone increased over the following weeks (Fig. 2b).

Table 2. Mean values (±SD) for serum concentrations of testosterone, SHBG and cortisol in 4 male and 3 female rowers during the 7-week training and competition period. Asterisks denote significant changes compared to the respective initial values (* = $p < 0.05$, ** = $p < 0.01$) of the male rowers

		Weeks						
		1	2	3	4	5	6	7
Testosterone ($nmol \cdot l^{-1}$)	Men	23.0 ±2.2	22.1 ±0.3	21.5 ±0.5	21.2 ±1.5	18.6** ±2.1	17.9* ±2.1	16.8* ±3.3
	Women	1.93 ±0.47	1.83 ±0.11	2.23 ±0.47	2.11 ±0.28	0.76 ±0.32	0.58 ±0.33	0.37 ±0.01
SHBG ($nmol \cdot l^{-1}$)	Men	24.16 ±1.72	25.00 ±0.30	22.97 ±0.38	23.59 ±1.73	20.93 ±1.30	23.29 ±1.11	20.85 ±1.94
	Women	38.92 ±4.06	39.89 ±3.02	34.56 ±3.14	37.23 ±0.31	34.59 ±3.95	37.88 ±5.24	35.35 ±3.57
Cortisol ($\mu mol \cdot l^{-1}$)	Men	0.384 ±0.077	0.367 ±0.050	0.431 ±0.040	0.413 ±0.081	0.412 ±0.055	0.374 ±0.111	0.406 ±0.076
	Women	0.409 ±0.020	0.356 ±0.050	0.446 ±0.042	0.419 ±0.030	0.328 ±0.050	0.360 ±0.036	0.286 ±0.090

Throughout the study no significant changes in C could be discerned (Table 2). During the training and competition period, especially between the 5th and 7th week, the T/C ratio (Fig. 3a) fell lower than the initial values both among men and women. In the 6th and 7th week the decline among men was statistically significant. Rowers R5 and R6 also showed an initial decline. However, after discontinuation of training their T/C ratio markedly increased and reached the initial range at the end of the study (Fig. 3b).

The concentrations of urea among all the men and women are depicted in Figs. 4a and 4b: The pronounced increase by 69% during the first 2 weeks was halted by the phase of regenerative training. During the following weeks urea fell continuously but at the end of the observation period was still found to be significantly elevated. In spite of the discontinuation of training, rowers R5 and R6 showed the same behaviour (Fig. 4b).

In one of the male rowers who nearly collapsed during the last regatta, the highest C and the lowest T/C values of all subjects had been observed 4 days earlier. One day after this event he showed the lowest values for T, T/SHBG and C. During the first 5 weeks the hormone levels in this rower were similar to those among the other rowers. Throughout the study, both before and after his radical decrease in performance, this rower's concentration of urea behaved similarly to that of the other subjects.

Discussion

The subjects examined in this study represent two relatively homogeneous groups of male and female rowers, all with comparable age and training condition, so as to exclude any unwanted influence upon hormonal behaviour (Dessypris et al. 1976; Nieschlag et al. 1973; Schmid et al. 1982). All blood samples were taken from the subjects under fasting conditions when supine and at the same time of day, in order to eliminate changes caused by diet, stress and circardian rhythm (Faiman and Winter 1971).

In confirmation of previous findings (Schmitt et al. 1981), the behaviour of anabolic and catabolic hormones showed no essential qualitative sex-related differences after comparable training and competitive strain. The SHBG concentrations were within the normal range reported in the literature (Hammond et al. 1985) and remained unchanged during the 7 weeks of observation, which corresponds to the findings of earlier investigations carried out during training periods of several weeks (Häkkinen et al. 1985).

Both total testosterone and the biologically active free testosterone fraction (Anderson 1974; Gillespie and Edgerton 1970) showed a behaviour which corresponded to the intensity of physical strain. After intense physical exercise, testosterone and T/SHBG decreased, whereas after phases of reduced intensity (regenerative training), they remained unchanged or even tended to

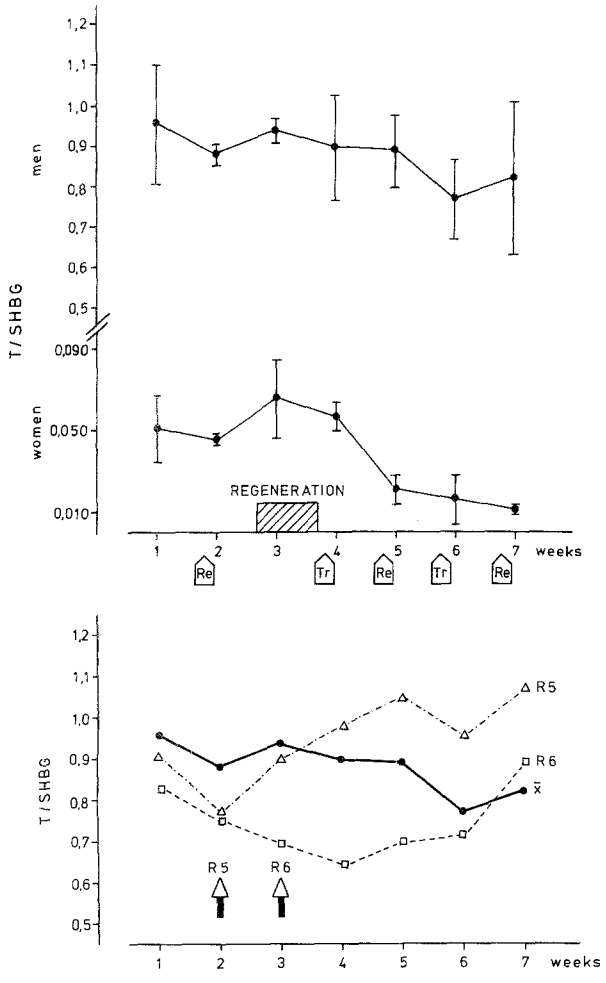

Fig. 2. a (top) Mean values ±SD for the testosterone/SHBG ratio in 4 male and 3 female rowers during the 7-week training and competition period (Tr = training camp, Re = regatta). **b** (bottom) Individual values for testosterone/SHBG ratio in 2 male rowers who stopped intensive training and competition after 2 (△- · -△; R5) and 3 weeks (□- -□; R6) respectively, compared to the mean values (●—●; X̄) of the training group

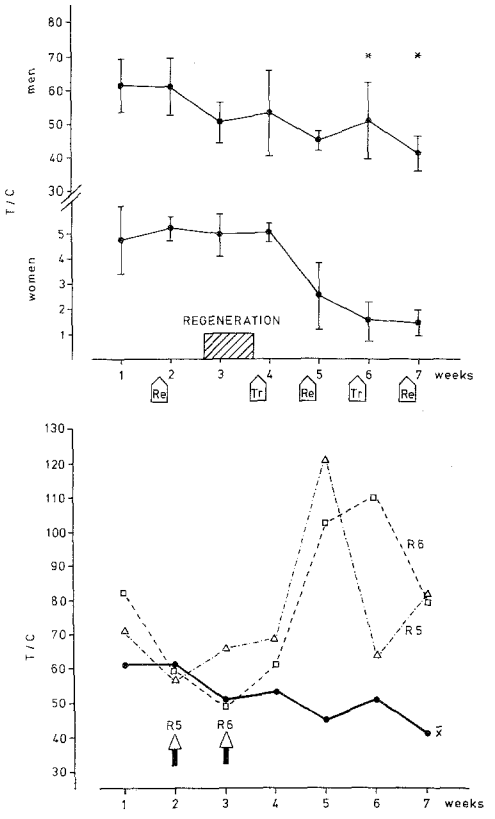

Fig. 3. a (top) Mean values (±SD) for the testosterone/cortisol ratio in 4 male and 3 female rowers during the 7-week training and competition period *(Tr = training camp, Re = Regatta)*. Asterisks denote significant changes compared to the respective initial values (* = $p < 0.05$) of the male rowers. **b** (bottom) Individual values for the testosterone/cortisol ratio in 2 male rowers who stopped intensive training and competition after 2 (△- · -△; R5) and 3 weeks (□- -□; R6) respectively, compared to the mean values (●—●; X̄) of the training group

rise. The particularly intense period of physical activity at the end of the study, resulting from frequent training camps and competitions, lead to a marked decrease in testosterone. Among the female rowers the last samples showed values below the normal range reported in the literature (Ismail 1976). Earlier studies occasionally hinted that a decrease in the free testosterone fraction might reflect insufficient regeneration during periods of repeated intensive physical exercise (Kuoppasalmi 1980; Remes et al. 1985). This claim is supported by the renewed increase in testosterone after discontinued training (see rowers R5 and R6).

The cortisol concentrations did not show any significant changes, which can be attributed either to an overly short observation period or to the relatively small sample. On the other hand, the T/C ratio continuously decreased after hard training or competition, suggesting an increase in catabolic activity (Adlercreutz et al. 1986). The increase in T/C ratio after regenerative training and the difference in its behaviour between athletes who discontinued training and those who continued, suggest a beneficial influence of adequate regeneration upon the anabolic-catabolic balance. In a previous investigation a parallel behaviour of the T/SHBG and the T/C ratio with the increase in strength during a 6-month strength-training period was noted. Although the training was continued and even intensified, a stagnation of performance set in, comparable to a state of overtraining with no detectable simultaneous increase in T/SHBG and T/C. The authors therefore concluded that an appropriate relationship between

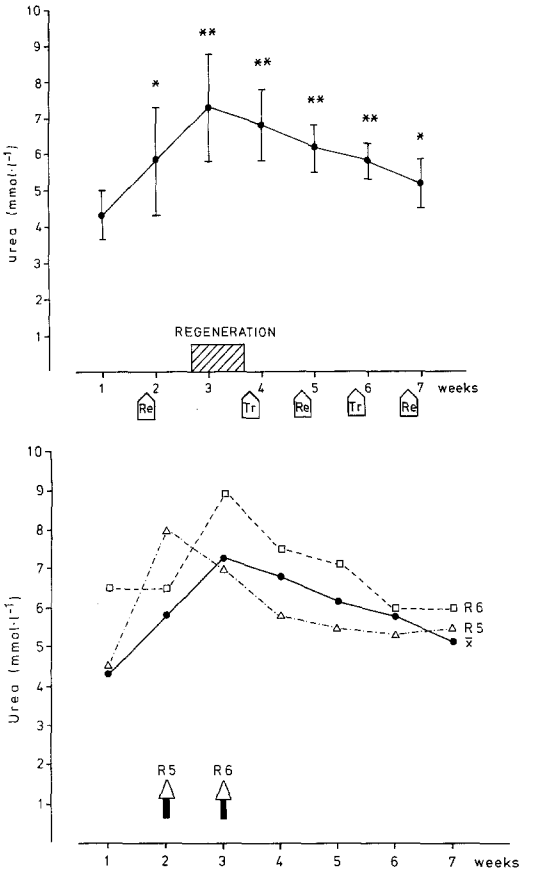

Fig. 4. a (top) Mean values (±SD) for serum urea in 4 male and 3 female rowers during the training and competition period *(Tr= training camp, Re= regatta)*. Asterisks denote significant changes compared to the respective initial values (*$=p<0.05$, **$=p<0.01$). **b** (bottom) Individual values for serum urea in 2 male rowers who stopped intensive training and competition after 2 (△- · -△; R5) and 3 weeks (□- -□; R6) respectively, compared to the mean values (●—●; $\bar{X}$) of the training group

anabolic and catabolic hormones was necessary for a gain in strength (Häkkinen et al. 1985). The one male rower who collapsed provides an interesting parallel to the case of a collapsed runner described in the literature (Dessypris et al. 1976). In the rower a remarkably low T/C ratio measured shortly before the incident indicated an unfavourable anabolic-catabolic balance. The markedly lower concentrations of free testosterone and cortisol in comparison with the other subjects, measured 1 day after the relevant regatta, could be interpreted as an expression of central fatigue (Dessypris et al. 1976).

The question remains open as to whether a lowered level of testosterone influences the energy providing metabolism, for instance by means of reduced glycogen storage (Gillespie and Edgerton 1970) or a decrease in the availability of creatine phosphate (Sutton et al. 1973). A chronic deficit in the free testosterone fraction could result in an increase in the catabolic effect of cortisol on the receptor level (Mayer and Rosen 1975). Our results offer no guidelines, however, for drawing a line between those levels of training and competitive strain which are necessary to achieve superior performance and those which accompany a state of overtraining. However, the majority of the rowers examined were able to yield top competitive performances in spite of their change in hormonal balance towards greater catabolic activity.

At present the cause of the decrease in testosterone concentration is still unclear. On the one hand, an influence on the central nervous system such as a possibly lowered secretion of LH or prolactine should be discussed (Aakvaag et al. 1978; Guezennec et al. 1982). On the other, a direct influence upon the testicular secretion of testosterone, such as inhibition of an enzymatic step or a decreased sensitivity of the Leydig cells to stimulating hormones might play a rôle (Guezennec et al. 1982).

In contrast to the marked differences in hormonal behaviour between those athletes who discontinued training and those who continued, the corresponding concentrations of urea proved to be similar in both groups. The one rower who was forced to abandon a race showed no dissimilarities in urea values. These findings could be considered as an indication that the observation of carefully selected hormonal parameters might be a more sensitive method for guiding and planning highly intense training programmes than methods previously applied. The increase in serum urea might therefore be an expression of an acute reaction to physical effort, whereas a decrease in the free testosterone fraction and the T/C ratio could be an indicator of chronic overstrain.

In conclusion, the behaviour of testosterone and cortisol detected in the present study suggests an increase in catabolic activity in periods of repeated intensive training or competition. Regenerative training measures might be able to curb the unfavourable changes in hormone balance.

For physical high performance training it seems necessary to develop appropriate guidelines for those hormone concentrations which would signal overtraining. Consequently it would be possible to guide the training in terms of intensity and duration. At present, however, the still relatively complicated methods for the determination of hormones and the inevitable delay before the results can be obtained are major obstacles to any hormonal monitoring or guiding of training programs.

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