Journal of Science in Sport and Exercise
https://doi.org/10.1007/s42978-022-00197-7

ORIGINAL ARTICLE

# Monitoring Training Load, Muscle Damage, and Body Composition Changes of Elite Indian Rowers During a Periodized Training Program

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Received: 5 November 2021 / Accepted: 9 September 2022


## Abstract

**Purpose** The purpose of this study was to monitor the Indian national rowing team's training regime and the changes that occur in the rowers' body composition, muscle cell damage, and training load markers during the phases of preparation for an international competition.

**Methods** Ten male and 9 female elite rowers from the national team underwent anthropometric assessment and blood tests during 17 weeks of training, at the end of general preparation (W4), preparation (W10), and pre-competition (W17) phase. Body fat% and somatotype were determined by Siri's equation and Heath-Carter manual, respectively. Assessments of blood biomarkers included measures of creatine phosphokinase (CPK), lactate dehydrogenase (LDH), urea, uric acid, testosterone, and cortisol concentration.

**Results** Changes in variables were estimated by repeated-measures ANOVA. Body fat% ($P<0.001$; male: $d=-2.03$; female: $d=-2.89$) and endomorph ($P<0.05$; male: $d=-2.05$; female: $d=-0.68$) decreased significantly at pre-competition, whereas weight, mesomorph, and ectomorph remained unchanged throughout training. Urea (male: $d=-1.47$; female: $d=-1.46$) and uric acid (male: $d=-0.74$; female: $d=-1.71$) showed a significant decrease at pre-competition phase in both groups. CPK concentration significantly ($P<0.05$) decreased at preparation ($d=-1.05$) and increased during pre-competition ($d=-1.28$) in male rowers. LDH showed significant increase ($P<0.01$) at preparation (male: $d=1.17$; female: $d=2.02$) and pre-competition (male: $d=1.28$; female: $d=2.09$) than base preparation. Whereas, no significant changes were observed in cortisol, testosterone, or $T/C$ ratio in subsequent measurements. Significant correlation ($P<0.05$) was found between LDH and T/C ratio with rowing timing in male rowers. The 2000 m rowing timing also showed a significant improvement at W17 compared to W4 (male: $d=-1.25$; female: $d=-0.94$).

**Conclusion** In conclusion, our results showed that rowers encounter more muscle damage and less protein catabolism during training season. Additionally, it is evidenced that rowing performance improved and biochemical markers—particularly enzymes—altered largely with altered training load rather than anabolic or catabolic hormone concentration in rowers.

**Keywords** Periodization · Creatine phosphokinase · Lactate dehydrogenase · Testosterone · Body fat percentage · Rowing

## Introduction

The aim of any physical training program is to stress the physiological systems of the body to bring about adaptation that in turn improves performance. An athlete's capacity for adaptation and their response to training is in part determined by their physical characteristics and genotype [6, 37]. However, an athlete will be able to fulfill their potential with appropriate training. Training for athletes consists of a well-programmed system of physical stress through regular training and sometimes even multiple daily workouts. Rowing is a power-endurance sport that is 70%–80% aerobic and 20%–30% anaerobic [23]. Understanding the demands of the

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Published online: 22 November 2022

rowing event and developing an appropriate training plan is crucial for improving fitness and performance of rowers.

Periodization is the systematic planning and variation of training methods intended to optimize decisive physiological adaptations and minimize injury [17]. A typical periodization plan involves cycles or phases of the different training techniques based on the goals and intended outcomes programmed across the preseason, early competition, late competition, and tapering phases. These outcomes could be that of strength, power, endurance, skills, and technique improvement. A purposeful change in training volume and intensity between training phases subsequently alters the physiological condition of the players. This phenomenon necessitates the regular monitoring of both external and internal training loads of the athletes [48]. In general, training volumes and intensities are inversely altered by phases. However, the profile of each cycle depends on the specific demands of a given sporting event and the level of competition. Coach or conditioning staff typically manipulate one or more training variables (e.g. training load, intensity, volume) to maximize performance across the training period. Studies have confirmed responses of different adaptive physiological systems and the outcomes are likely resulted from changes occurring at cellular and molecular levels [12, 16]. These data are important for appraising the efficacy of a training program and determining any adjustments necessary to optimize the training stimulus and adaptations.

Over the years, different sports have adopted different definitions and terminology to categorize the various types of training employed within a training program. The World Rowing Federation (FISA), the governing body for rowing, has adopted a widely accepted and implemented scheme that includes five different training zones largely based on the heart rate and blood lactate response to increasing exercise intensities [5]. As rowers progress toward competition, the training intensities are increased and volumes decreased. The evaluation of the trainability and overload state of an athlete is one of the most complicated tasks in sports science. To understand this more clearly, different enzymes, hormones, and blood biochemical biomarkers are used to monitor the state of an athlete during training [1, 21, 35, 47]. Surprisingly, little is known about the efficacy of the training program that the Indian elite rowers go through leading upto international competitions. The problem with studying training response in rowers is the complexity of training goals because different capacities like aerobic, anaerobic, power, strength, and tactical skills need to be optimized for maximal performance. To our knowledge, no studies have yet investigated the effects of the systematic training on elite Indian rowers.

The aim of the study was to examine 17 weeks of training stimulus imposed on Indian elite male and female rowers before the Asian Rowing Championship and the changes occurring in body composition, muscle cell damage markers, and training load markers from base preparation phase towards competition. It was hypothesized that the muscle cell damage markers and the training load markers of the participants would increase in line with increased training volume and intensity. Second, some physical and biochemical parameters may be associated with 2000 m rowing performance. In addition, it was expected that the periodized training program would lead to improve performance and positive performance leading to changes in body composition.

## Materials and Methods

### Participants

Ten male and 9 female elite Indian rowers from the national rowing team participated in this study (Table 1). Elite status of the rowers were decided based on the criterion described by Swann et al. [45]. All the participants had more than 5 years of rowing experience. In our subjects, one male rower participated in Olympic Games earlier, 4 rowers secured bronze medal in Asian Rowing Championship, five male and two female rowers secured medals in Asian Junior Rowing championships, and others female rowers represented the country as well. The study was conducted according to the Declaration of Helsinki and Institutional ethics committee approved this study (Certificate number: IECH/OCH/01/CC). The rowers underwent routine health checkups and basic fitness tests conducted by the Department of Sports Science and Medicine of the Sports Authority of India, Bangalore. Any rowers who had suspect pathological findings

**Table 1** Physical traits of Indian rowers

| Variable | Male rowers ($n = 10$) | | | Female rowers ($n = 9$) | | |
|---|---|---|---|---|---|---|
| | Mean ± SD | Range | 95% CI | Mean ± SD | Range | 95% CI |
| Age (years) | 24.53 ± 1.86 | 21.3–27.3 | 23.1–25.8 | 20.89 ± 3.48 | 16.0–26.0 | 18.2–23.6 |
| Height (cm) | 183.4 ± 4.58 | 175–189 | 180.1–186.6 | 166.22 ± 4.15 | 160–174 | 163.0–169.4 |
| 2000 m timing (s) | 400.7 ± 7.23 | 390–411 | 395.5–405.8 | 507.7 ± 18.96 | 465–525 | 493.1–522.2 |
| Rowing years | 6.4 ± 0.97 | 5–8 | 5.7–7.1 | 5.6 ± 0.86 | 5–7 | 5.0–6.3 |

*CI* confidence interval

during the health checkup, a recent history of disease or injury, or altitude exposure, were excluded from the study. Participants were screened and written informed consent was obtained from the rowers or their parents who was under 18 years of age eligible for participating in the study.

## Design

To evaluate training stimulus induced changes in potential body composition and selected biochemical parameters of Indian elite rowers, a 17-week training plan designed to prepare rowers for Asian Rowing Championship, 2017 was monitored. The rowers lived near the boat house in their own dorm and were in balanced diet. Meals were served according to the menu prepared by a registered dietician. For measurement of training load and muscle damage markers, the rowers were asked to provide a total of 3 blood draws after 24 h adequate rest from training and also undergone anthropometric measurements at the end of three different training phases. The time points were last micro-cycle of each phase, i.e. 4th week of base preparation, 6th week of preparation, and 7th week of pre-competition phase. The assessments were completed in the morning to rule out the circadian rhythm influence on biochemical variables.

## Training Plan

A 17-week (approximately four months) long training periodization for national rowers before 2017 Asian Rowing Championship was made by the coaching staff members and certified strength and conditioning specialist and monitored in this study. The training periodization encompassed three phases: (1) general preparation, (2) preparation, and (3) pre-competition phase that consisted of 4, 6 and 7 micro-cycles, respectively, which aligns with the NSCA guidelines [3, 42]. The types of training were based on heart rate (HR) reserve, boat speed, stroke rate, and blood lactate response. The training employed for the rowers in this study included five different training zones as defined by the World Rowing Federation (FISA) [22, 32]: (1) basic oxygen utilization training (UT2) [HR reserve = 59%–67%; boat speed = 55%–65%; stroke rate = 20 to 22; lactate = 0–2 mmol/L], (2) oxygen utilization training (UT1) [HR reserve = 67%–75%; boat speed = 65%–75%; stroke rate = 22 to 24; lactate = 2–3.5 mmol/L], (3) anaerobic threshold training (AT) [HR reserve = 75%–85%; boat speed = 75%–85%; stroke rate = 24 to 26; lactate = 3.5–4.5 mmol/L], (4) oxygen transport training (TR) [HR reserve = 85%–100%; boat speed = 85%–95%; stroke rate = 26 to 30; lactate = 4.5–6 mmol/L], and (5) anaerobic capacity training (AN) [boat speed ≥ 95%; stroke rate ≥ 30; lactate ≥ 6 mmol/L]. Training plan and progression was predecided and no changes were made during training period (Fig. 1). In addition to on-water training, alternative training was also carried out, which included jogging, rowing ergometer training, and resistance training that included Olympic and powerlifting as a regular conditioning activity carefully designed by the certified strength and conditioning specialist. The training plan was implemented and HR reserve and blood lactate were monitored by the coaching staff and strength and conditioning specialist to meet the weekly training load.

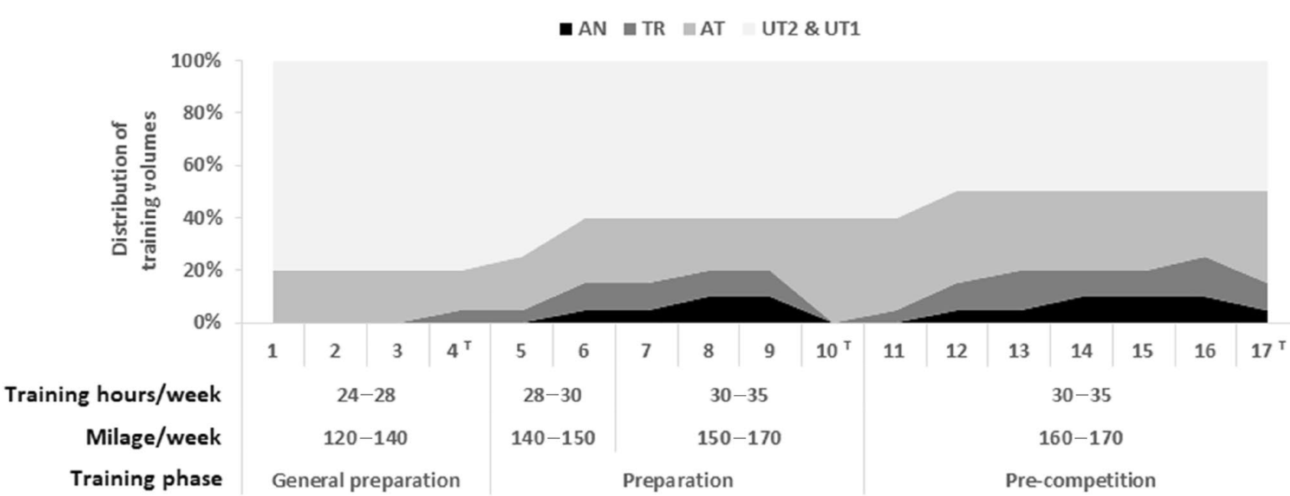


**Fig. 1** Training periodization of the rowers. UT2 = Basic oxygen utilization training [HR reserve = 59%–67%; boat speed = 55%–65%; stroke rate = 20 to 22; lactate = 0–2 mmol/L], UT1 = Oxygen utilization training [HR reserve = 67%–75%; boat speed = 65%–75%; stroke rate = 22 to 24; lactate = 2–3.5 mmol/L], AT = Anaerobic threshold training [HR reserve = 75%–85%; boat speed = 75%–85%; stroke rate = 24 to 26; lactate = 3.5–4.5 mmol/L], TR = Oxygen transport training [HR reserve = 85%–100%; boat speed = 85%–95%; stroke rate = 26 to 30; lactate = 4.5–6 mmol/L], AN = Anaerobic capacity training [boat speed ≥ 95%; stroke rate ≥ 30; lactate ≥ 6 mmol/L]. $^{T}$time point of anthropometric and biochemical assessment

## Procedure

All the rowers underwent anthropometric assessment and blood tests at three time points of the training program: (1) at the end of the general preparation phase that is considered as the baseline (4th micro-cycle or W4), (2) at the end of preparation phase (10th micro-cycle or W10), and (3) at the end of the pre-competition phase (17th micro-cycle or W17). The subjects abstained from strenuous physical training 24 h prior to blood sample collection, however, light exercise was allowed. The blood sample was collected under standard conditions between 7 to 8 am to eliminate influence of the circadian rhythm on biochemical variables and after a 12 h overnight fast. Anthropometric assessments were done on the same day as well.

## Anthropometric Measurements

Height and weight were measured using an anthropometric rod and portable weighing machine, respectively. Body mass index (BMI) was calculated by dividing their body weight with the square of the height. The skinfold thickness measurements were taken at biceps, triceps, sub-scapula, supra-spinale, and calf using a Harpenden skinfold caliper. Upper arm and calf circumferences and elbow and knee diameters were measured by anthropometric tape and sliding caliper, respectively. A minimum of two measurements were made at each site on the left side of the body. Body density was predicted from the log of the sum of four caliper skinfold thicknesses and then body fat percentage was calculated from body density using the Siri's equation for adolescents: Body fat% = (4.95/body density − 4.5) × 100 [38, 41]. Heath-Carter formulae were used for somatotype rating that includes calculation of ectomorph, mesomorph, and endomorph [11].

## Biochemical Analysis

Approximately 5 ml of venous blood was collected from the ante-cubital vein with minimal stasis into ethylene diamine tetra acetic acid (EDTA) containing tubes for plasma isolation and clot activator tubes for serum isolation. Samples were transported and stored in the laboratory where analyses were performed strictly following recommended international guidelines (Banfi and Dolci 2003). Hemoglobin (Hb) and hematocrit (Hct) were measured from whole blood collected in EDTA vials using Sysmex pocH-100i Automated Hematology Analyzer, USA. Creatine phosphokinase (CPK), lactate dehydrogenase (LDH), urea, and uric acid were estimated from serum samples. Urea concentration was estimated by the Berthelot method, and uric acid concentration by enzymatic method using a standard kit-Spinreact. CPK and LDH were estimated by the kinetic method of colorimetry using the same kit using Erba Chem-7 semi-automatic chemical analyzer, Germany. The plasma samples were analyzed to determine testosterone and cortisol concentration by ELISA method using CalBiotic assay kits and reading was taken by ELX800 BioTek absorbance microplate reader, USA. The testosterone/cortisol (*T*/*C*) ratio was calculated from the value of testosterone and cortisol.

## Rowing Performance Evaluation

Changes in weather and water conditions make it difficult to compare on-water testing data in rowing and derive valid conclusions. The ability to conduct a rowing activity in a controlled setting made the rowing ergometer an appealing instrument for monitoring performance and minimizing the effect of confounding circumstances. After a proper warm up, the 2000 m all-out rowing test was conducted on air resistance braked Concept II model D (USA) rowing ergometer and total time taken to finish 2000 m was recorded. A portable lactate analyzer (Lactate SCOUT, EKF Diagnostics, UK) was used to measure peak lactate on the 3rd min after finishing the rowing test.

## Statistical Analysis

The assumption of normal distribution was verified using the Shapiro–Wilk test. One-way repeated-measures ANOVA was done with Bonferroni confidence interval adjustment to determine pairwise changes in variables across the training period. Our intention was to see time-based changes in variables by sex rather a comparison of physiological responses between the sexes. Accordingly, no statistical comparison between the sexes were performed. Delta variations in percentage term (Δ%) were calculated from the pre-test value and post-test value of each individual. Test–retest reliability of biochemical and anthropometric measurements was calculated with the intraclass correlation coefficient and standard error of measurement [49]. Pearson correlation coefficient ($r$) was used to find the correlation of the measured parameters with the 2000 m all-out rowing performance of the examined rowers. All statistical analysis was performed using the IBM SPSS Version 23.0. Data are expressed as mean ± standard deviation (SD). The value of $P < 0.05$ was considered statistically significant. In addition to acquiring statistical significance ($P < 0.05$), Cohen's $d$ (small = 0.2, medium = 0.5, large = 0.8) effect size statistics were also used to measure the magnitude of difference.

## Results

### Changes in Body Composition

Results showed both male ($n=10$) and female ($n=9$) rowers' body weight and BMI remained largely unchanged ($P>0.05$) throughout training. Body fat% and endomorph component showed a significant decrease progressing towards W17 compared to W4 in both groups (Table 2). Large effect size was observed in body fat percentage between W4 and W10 (male: $\Delta=-24.5\%$, $d=-1.51$; female: $\Delta=-10.4\%$, $d=-0.99$), W4 and W17 (male: $\Delta=-30.8\%$, $d=-2.03$; female: $\Delta=-33.4\%$, $d=-2.89$), and W10 and W17 (female: $\Delta=-25.7\%$, $d=-2.10$). Whereas a medium effect was observed between W10 and W17 ($\Delta=-8.3\%$, $d=-0.46$) in male rowers. Additionally, large effect size was also observed in endomorph between W4 and W10 (male: $\Delta=-30\%$, $d=-1.56$), W10 and W17 (female: $\Delta=-14.2\%$, $d=-0.64$), and W4 and W17 (male: $\Delta=-36.7\%$, $d=-2.05$; female: $\Delta=-16.4\%$, $d=-0.68$), and medium effect size was observed in W10 and W17 (male: $\Delta=-9.5\%$, $d=-0.47$). No significant changes ($P>0.05$) were observed in mesomorph and ectomorph in relation to their subsequent measurements. The percentage changes ($\Delta\%$) in variables during training are presented in Fig. 2.

### Changes in Muscle Damage Markers

CPK concentration decreased significantly in W10 ($\Delta=-33.4\%$, $d=-1.05$) and increased significantly in W17 ($\Delta=79.9\%$, $d=-1.28$) compare to W4 and W10, respectively, in male rowers (Table 3). Whereas in female rowers, no significant changes ($P>0.05$) were seen in the CPK concentration starting from pre-training to post-training across three sampling points taken. LDH concentration showed a significant rise in both groups as the training progressed. In particular, a large effect size was observed in between the measurements of W4 and W10 (male: $\Delta=26.9\%$, $d=1.17$; female: $\Delta=45.5\%$, $d=2.02$) and W4 and W17 (male: $\Delta=55.7\%$, $d=1.28$; female: $\Delta=56.4\%$, $d=2.09$). Urea ($\Delta=-19\%$, $d=-1.47$) and uric acid ($\Delta=-8.4\%$, $d=-0.74$) were significantly decreased in male rowers with a large effect size between the measurement of W10 and W17. Whereas in female rowers, a significant decrease was observed with a large effect size in urea ($\Delta=-19.1\%$, $d=-1.46$) and uric acid ($\Delta=-24.2$, $d=-1.71$) level between the measurement of W4 and W17.

### Changes in Training Load Monitoring Markers

No significant changes ($P>0.05$) were observed in Hb, Hct, cortisol, testosterone, and $T/C$ ratio in their subsequent measurements. However, an increasing trend was

**Table 2** Changes in body composition of elite Indian rowers

| Variable | | Male | | | | | | Female | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | W4 | W10 | W17 | $ICC_{(2,1)}$ | SEM | *P* value | W4 | W10 | W17 | $ICC_{(2,1)}$ | SEM | *P* value |
| Weight (kg) | | 74.65 ± 5.29 | 75.00 ± 4.78 | 74.39 ± 4.41 | 0.99 | 1.44 | 0.077 | 58.49 ± 4.85 | 59.12 ± 4.28 | 59.53 ± 3.39 | 0.960 | 2.44 | 0.307 |
| BMI ($kg/m^2$) | | 22.17 ± 0.94 | 22.29 ± 0.95 | 22.11 ± 0.87 | 0.967 | 0.48 | 0.139 | 21.16 ± 1.42 | 21.33 ± 1.21 | 21.60 ± 0.94 | 0.938 | 0.86 | 0.417 |
| Body fat% | | 13.31 ± 2.34 | 10.05 ± 1.98 $^{a\$}$ | 9.21 ± 1.64 $^{a\$\ b\#}$ | 0.646 | 3.35 | < 0.001 | 27.03 ± 2.99 | 24.23 ± 2.65 $^{a\$}$ | 18.01 ± 3.26 $^{ab\$}$ | 0.493 | 5.99 | < 0.001 |
| Somatotype | Endomorph | 2.35 ± 0.52 | 1.64 ± 0.37 $^{a\$}$ | 1.49 ± 0.28 $^{a*\ b\$}$ | 0.58 | 0.71 | < 0.001 | 4.04 ± 1.07 | 3.93 ± 0.87 | 3.38 ± 0.87 $^{a*\ b\#}$ | 0.906 | 0.82 | 0.001 |
| | Mesomorph | 3.76 ± 0.61 | 3.86 ± 0.58 | 3.90 ± 0.57 | 0.952 | 0.37 | 0.455 | 3.52 ± 0.70 | 3.51 ± 0.82 | 3.72 ± 0.82 | 0.968 | 0.41 | 0.124 |
| | Ectomorph | 3.32 ± 0.48 | 3.26 ± 0.51 | 3.36 ± 0.49 | 0.968 | 0.27 | 0.05 | 2.55 ± 0.56 | 2.80 ± 0.76 | 2.72 ± 0.64 | 0.946 | 0.44 | 0.249 |

Values are expressed as mean ± SD

*ICC* intraclass correlation coefficient, *SEM* standard error of measurement, *BMI* body mass index

$P<0.05$ was considered to be statistically significant. $^{*}P<0.05$; $^{\#}P<0.01$; $^{\$}P<0.001$; [a]Significantly different from W4; [b]Significantly different from W10

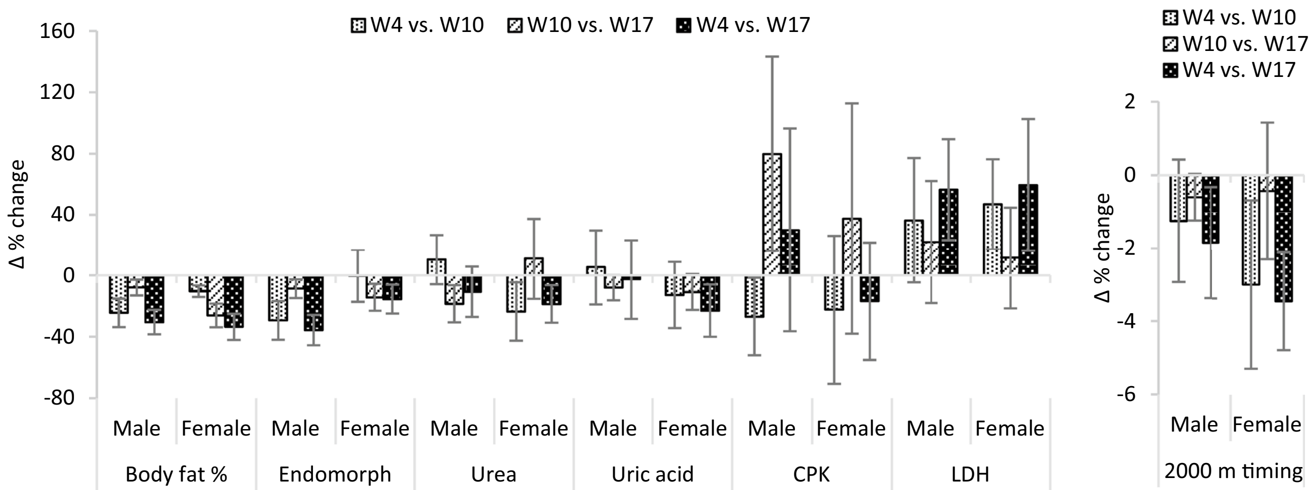


**Fig. 2** Percentage changes in body composition, muscle damage markers and 2000 m performance during training in male and female rowers. *W* week, *CPK* creatine phosphokinase, *LDH* lactate dehydrogenase

observed in testosterone and *T*/*C* ratio in both groups as training progressed.

### Changes in 2000 m Rowing Timing and Peak Lactate

Rowing performance as measured through 2000 m all-out rowing test showed a significant improvement after training. Male rowers took significantly less time ($P < 0.05$) to finish 2000 m rowing at W17 compared to W4 ($\Delta = -1.9\%$, $d = -1.25$) and W10 ($\Delta = -1.3\%$, $d = -0.8$). Medium effect size was observed in female rowers 2000 m timing in between W4 and W10 ($\Delta = -3\%$, $d = -0.93$) and W4 and W17 ($\Delta = -3.5\%$, $d = -0.94$). No significant changes ($P > 0.05$) were observed in peak lactate level throughout the training period.

### Correlation Between Physical and Biochemical Parameters with 2000 m Rowing Performance

2000 m rowing ergometer timing was significantly correlated with body weight ($r = -0.568$; $P < 0.01$), BMI ($r = -0.393$; $P < 0.05$), mesomorph ($r = -0.419$; $P < 0.05$), LDH ($r = -0.429$; $P < 0.05$), and *T*/*C* ratio ($r = 0.374$; $P < 0.05$) in male rowers (Table 4). Whereas body weight ($r = -0.747$; $P < 0.001$), BMI ($r = -0.465$; $P < 0.05$) and body fat% ($r = 0.411$; $P < 0.05$) were found significantly correlated with 2000 m timing in female rowers. No significant correlation was found between measured biochemical parameters and 2000 m rowing performance in female rowers.

## Discussion

Our study provides an insight into the training load and intensities imposed by a periodized training plan and its effects on biochemical components of national team rowers preparing for an international competition. This is the first study, to our knowledge, that examined different time points of training and reported the seasonal variations in rowers' body composition, well-being with respect to training demands, and rowing performance of elite Indian rowers. The training program involving general preparation, preparation and pre-competition phases lead to improve performance and positive performance leading changes in body composition.

### Changes in Body Composition

While monitoring training, we did not observe any significant changes in weight and BMI throughout training. However, percentage of body fat and its endomorph component significantly decreased in both male and female rowers as training progressed from general preparation towards competition phase (Fig. 3). Amount of fat percentage has a significant role in sports performance [11, 31]. A certain amount of fat is required to maintain body metabolism but excess adiposity adversely affects 2000 m rowing ergometer performance [23, 29]. Increase in anaerobic threshold training, oxygen transport training, and anaerobic capacity training towards pre-competition than general preparation phase may be responsible for this improvement. Along

**Table 3** Changes in training load monitoring markers and 2000 m performance of elite Indian rowers

| Varible | Male | | | | | | Female | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | W4 | W10 | W17 | $ICC_{(2,1)}$ | SEM | *P* value | W4 | W10 | W17 | $ICC_{(2,1)}$ | SEM | *P* value |
| Hb (gm/dL) | 16.34 ± 0.98 | 16.14 ± 0.83 | 16.01 ± 0.90 | 0.828 | 0.97 | 0.505 | 12.7 ± 1.15 | 12.5 ± 1.09 | 12.9 ± 1.25 | 0.942 | 0.80 | 0.096 |
| Hct (%) | 49.9 ± 3.22 | 49.8 ± 2.94 | 50.4 ± 4.20 | 0.917 | 2.78 | 0.684 | 43.7 ± 2.72 | 43.4 ± 2.78 | 43.9 ± 2.73 | 0.940 | 1.90 | 0.534 |
| CPK (IU/L) | 215.89 ± 90.30 | 143.76 ± 36.88 $^{a*}$ | 258.56 ± 120.93 $^{b*}$ | 0.568 | 138.07 | 0.01 | 157.72 ± 62.38 | 114.18 ± 85.02 | 120.45 ± 39.05 | 0.380 | 103.00 | 0.242 |
| LDH (IU/L) | 299.43 ± 85.76 | 379.86 ± 44.93 $^{a\#}$ | 466.07 ± 162.34 $^{a\#}$ | 0.581 | 171.70 | < 0.001 | 352.56 ± 46.52 | 512.88 ± 102.21 $^{a\#}$ | 551.24 ± 126.00 $^{a\#}$ | 0.069 | 170.79 | 0.004 |
| Urea (mg/dL) | 29.17 ± 4.37 | 31.82 ± 4.17 | 25.77 ± 4.05 $^{b\#}$ | 0.573 | 6.56 | 0.007 | 32.62 ± 4.27 | 24.84 ± 6.22 $^{a*}$ | 26.39 ± 4.25 $^{a\#}$ | 0.523 | 8.17 | 0.009 |
| Uric acid (mg/dL) | 5.14 ± 1.19 | 5.19 ± 0.62 | 4.76 ± 0.55 $^{b*}$ | 0.372 | 1.32 | 0.039 | 5.11 ± 0.71 | 4.36 ± 0.77 | 3.87 ± 0.74 $^{a*}$ | 0.342 | 1.27 | 0.008 |
| Cortisol (ng/mL) | 125.41 ± 34.81 | 129.00 ± 34.12 | 114.09 ± 37.59 | 0.728 | 44.71 | 0.287 | 150.88 ± 51.39 | 119.29 ± 51.07 | 139.83 ± 42.15 | 0.442 | 74.78 | 0.408 |
| Testosterone (ng/mL) | 8.17 ± 3.56 | 8.95 ± 3.20 | 9.21 ± 2.21 | 0.844 | 3.14 | 0.426 | 0.86 ± 0.59 | 1.45 ± 0.93 | 1.66 ± 1.24 | 0.114 | 1.50 | 0.324 |
| *T/C* ratio | 0.065 ± 0.02 | 0.073 ± 0.03 | 0.086 ± 0.02 | 0.505 | 0.04 | 0.146 | 0.007 ± 0.006 | 0.017 ± 0.014 | 0.015 ± 0.014 | 0.104 | 0.02 | 0.120 |
| Peak lactate $_{2000\ m}$ (mmol/L) | 15.62 ± 1.49 | 16.66 ± 2.09 | 16.87 ± 2.40 | 0.698 | 2.68 | 0.240 | 13.7 ± 3.35 | 14.8 ± 3.23 | 15.4 ± 3.56 | 0.823 | 3.69 | 0.057 |
| 2000 m timing (s) | 400.7 ± 7.23 | 395.6 ± 5.44 | 393.2 ± 4.39 $^{ab*}$ | 0.809 | 6.58 | 0.005 | 507.7 ± 18.96 | 492.2 ± 13.94 $^{a*}$ | 490.1 ± 18.33 $^{a\$}$ | 0.849 | 19.00 | < 0.001 |

Data are presented as mean ± SD

*ICC* intraclass correlation coefficient, *SEM* standard error of measurement, *Hb* hemoglobin, *Hct* hematocrit, *CPK* creatine phosphor kinase, *LDH* lactate dehydrogenase, *T/C ratio* testosterone/cortisol ratio.

$P < 0.05$ was considered to be statistically significant. $^{*}P < 0.05$; $^{\#}P < 0.01$; $^{\$}P < 0.001$; $^{a}$Significantly different from W4; $^{b}$Significantly different from W10

**Table 4** Correlation of body composition, training load, and muscle damage markers with 2000 m rowing performance

| Parameters | 2000 m timing | |
|---|---|---|
| | Male | Female |
| Weight | −0.568[#] | −0.747 [$] |
| BMI | −0.393* | −0.465 * |
| Body fat% | 0.075 | 0.411 * |
| Endomorph | 0.123 | 0.354 |
| Mesomorph | −0.419 * | −0.286 |
| Ectomorph | 0.115 | 0.077 |
| Hb | −0.256 | 0.013 |
| Hct | 0.127 | 0.108 |
| Urea | 0.016 | 0.334 |
| Uric acid | 0.080 | 0.075 |
| CPK | −0.163 | −0.006 |
| LDH | −0.429* | −0.131 |
| Cortisol | 0.260 | 0.057 |
| Testosterone | −0.238 | −0.182 |
| T/C ratio | −0.374* | −0.172 |
| Peak lactate $_{2000\ m}$ | −0.005 | −0.322 |

$P<0.05$ was considered to be statistically significant. $^{*}P<0.05$; $^{\#}P<0.01$; $^{\$}P<0.001$

*BMI* body mass index, *Hb* hemoglobin, *Hct* hematocrit, *UA* uric acid, *CPK* creatine phosphokinase, *LDH* lactate dehydrogenase, *T/C ratio* testosterone/cortisol ratio

with optimum body fat%, having a greater bodyweight and height are also an advantage in rowing [27]. Literature suggests that there is no significant effect of regular training on statural growth (i.e. height) and the trait is highly genetic [30]. Hence, we have not considered the changes in rowers' height in the analysis of training response monitoring. However, the data were used in calculating BMI.

Muscle mass has a significant role as rowing requires endurance, strength, and power. In this study, we have not observed any significant changes in the mesomorph component, which represents muscularity, nor in ectomorph, which represents leanness, in both the group. However, an increasing trend was observed in these variable may be due to significant decrease in body fat percentage. Literature suggests, individuals with a high lean body mass possess a larger muscle mass are able to produce a greater force during the stroke [13]. The implications of these changes are that rowers should increase their lean body mass and where appropriate reduce their body fat%.

## Biochemical Alterations

Assessment of biochemical markers of muscle damage and training load during prolonged physical stress has received considerable attention. It is due to the role of endocrine function in general adaptive mechanisms, including physical training responses and adaptations. In our study, we observed significantly decreased urea and uric acid at the pre-competition phase (W17) than base preparation (W4) in both male and female rowers with different magnitude

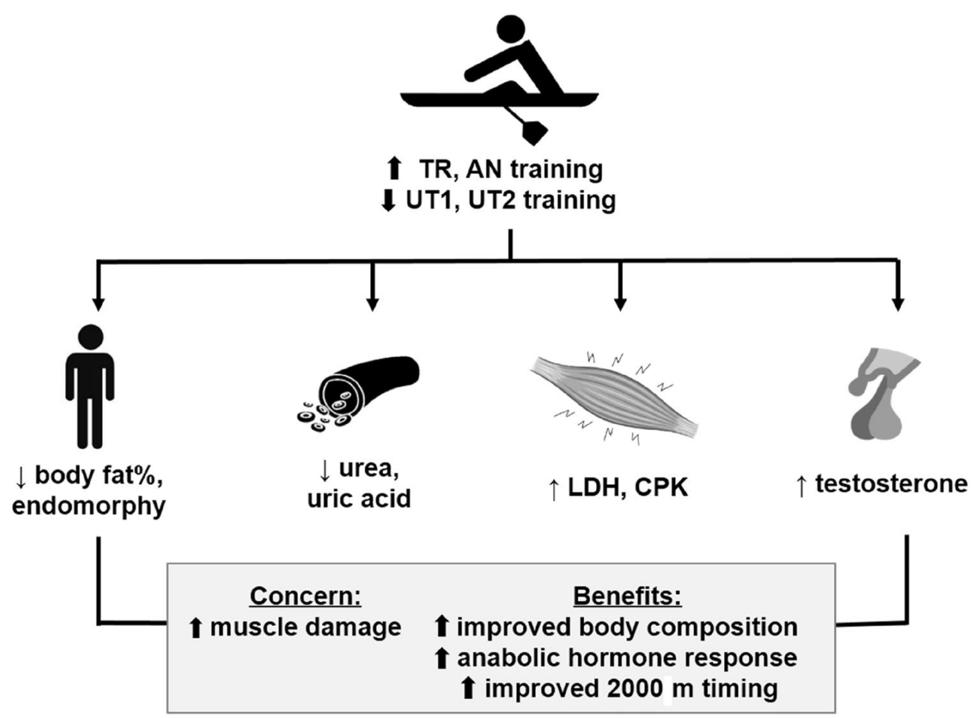


**Fig. 3** Changes in body composition, training load, and muscle damage markers of elite Indian rowers after training. *UT2* basic oxygen utilization training, *UT1* oxygen utilization training, *TR* oxygen transport training, *AN* anaerobic capacity training, *LDH* lactate dehydrogenase, *CPK* creatine phosphokinase

(Fig. 2). A large increase in blood urea (above 8.3 mmol/L or 49.8 mg/dL) is used as a marker of protein catabolism and amino acid utilization during exercise [36]. However, we observed urea concentration below the value, which does not support increased protein catabolism due to training in both the groups. The blood sample collection was carried out at the same time in the morning under similar conditions at the end of the phases and not after exercise. This was done to standardize the testing procedure to avoid the effect of plasma volume changes after exercise, circadian rhythms, and environmental influences that could cause biochemical change. Changes in urea or uric acid concentration due to exogenous factors like insufficient fluid intake or improper diet could be excluded in this study. To avoid training load intolerance in elite rowers, it has been suggested to monitor protein concentration changes during exercise at least every 3 days in standardized conditions [18].

## Increased Muscle Damage

We observed significantly higher LDH level at preparation (W10) and pre-competition phase (W17) than base preparation (W4) in both the group of rowers (Table 3). CPK and LDH concentration in blood are used as markers of exercise induced muscle damage as it varies with the exercise intensity and muscular strain [8, 24]. Kobayashi et al. demonstrated that aerobic exercise might promote increased LDH activity [26]. Resistance exercise has also been associated with an increase in muscle damage biomarker LDH [2, 4]. Our data also corroborate with these findings. Increased LDH is an evidence of prolonged muscle damage throughout the training course. This finding may be due to the complex nature of rowing training throughout the course of the study where the rowers underwent both aerobic (UT1 and UT2) and anaerobic training (TR and AN).

Another important finding of our study is related to creatine phosphokinase response. CPK had a different response profile from that of LDH. In our study, no significant changes were observed in CPK level in female rowers. However, in male rowers, CPK significantly decreased in preparation and increased in pre-competition phase (Table 3). CPK increases following a high muscular strain exercise because of muscle cell damage or leakage and also during technical training related to overload in single muscles [43]. The gender difference in CPK level was also reported in previous studies. Elevated CPK level in males are mainly due to greater skeletal muscle mass and higher testosterone level compared to females of the same age [50]. Neal et al. reported age-dependent decrease in CPK levels among men, but no such trend was seen among women, which corroborate with the findings of our study [34]. Large increases in creatine kinase activity have been reported in combination with reduced muscular adaptation to training and exercise tolerance [43, 44]. In our study, a possible decrease in weekly anaerobic training load (AN and TR) without altering total load at the end of preparation phase (W10) may have contributed to decrease skeletal muscle damage and/or lesion as seen in CPK concentration in the middle of the course. However, this response is not seen in LDH, which may be due to LDH clearance is much slower than CPK. In line with our observations, studies with professional soccer players have shown ups and downs in creatine kinase during the season [40]. Furthermore, enzymes released from muscle cells might not always reveal the degree of muscle damage. The change in CPK levels could possibly be a result of both damage and transient changes in membrane permeability caused by the efflux of intracellular proteins [9]. Our result also suggests that CPK responses are very subjective (i.e. gender wise high and low responds) (Fig. 2). Therefore, CPK changes need to be analyzed carefully [19]. It should also be noted that the CPK values we have observed during the course are within the reference ranges defined for athletes [21].

## Changes in Catabolic and Anabolic Hormone Level

Steroid hormones regulate the catabolic and anabolic process of the body. Interestingly, how the biomarker enzymes of muscle damage (CPK and LDH) changed throughout the training course are not evident in *T* and *C* response. In this study, we did not observe any significant difference in testosterone, cortisol or testosterone–cortisol (*T*/*C*) ratio after training in either group. This result is consistent with the findings of previous studies [14, 35]. Testosterone is considered as the main anabolic hormone because it mainly stimulates protein synthesis in muscles and skeletal tissues, accounting for more than half of the body's mass. Whereas cortisol is a common catabolic hormone. Numerous investigations have studied the effects of prolonged physical stress on resting anabolic and catabolic hormone concentrations [28, 43, 47]. Some researchers, for instance, demonstrated that changes in plasma cortisol and testosterone were not correlated with the changes in training load in the monitored athletes of basketball and rugby similar to our observation in rowing [14, 35]. Other studies recommended the use of testosterone concentration as a key indicator of explosive performance rather than intermittent endurance performance [15, 33]. Maestu et al. suggested that the first sign of reduced adaptability in rowers is an impaired response of testosterone followed by impaired cortisol response [28]. Since the mean testosterone and cortisol value of the rowers over the course of the training was within the normal reference range, our data suggest that male and female rowers may have not experienced overreaching nor overtraining at preparation and pre-competition phase as indicated in biomarker analysis.

### Improved 2000 m Rowing Timing

Male and female rowers took significantly less time to finish 2000 m rowing at the end of pre-competition phase compared to baseline, which may be influenced by high training volume and increased percentage of anaerobic training (TR and AN) during pre-competition phase. Literature suggests, improvement in training status have been associated with decreases in maximal and sub-maximal blood lactate concentration [25]. Literature also suggests, exercising with damaged muscles causes an increase in lactate levels [46]. However, in this study, no significant changes were observed in 2000 m peak lactate in either the male or female rowers after training. The blood lactate level of rowers has proved to be of particular interest, both as a guide to an appropriate training intensity and as a measure of the peak intensity of effort that is achieved under aerobic, anaerobic or race conditions.

### Physical and Biochemical Parameters as Determinant of 2000 m Rowing Performance

Sports demand a specific physique together with other physiological, biochemical variables and skills, are important components in any sport performance. Physical characteristics are undoubtedly performance related factor in rowing [7]. In our study, weight and BMI were significantly negatively correlated with 2000 m timing in both groups. Literature suggests that elite rowers are heavier than the less successful rowers [39]. Previous work by Cosgrove et al. found high correlation between lean body mass and velocity in the 2000 m time-trial, which shows that muscle mass is an important variable in rowing performance. The implications of this are that less heavy individuals should increase their lean body mass and, where appropriate, reduce their body fat to allow them to maximize their muscle mass while remaining within their weight category [13]. A positive correlation was also found between rowing performance and body fat%. It is well established that high body fat% adversely affects 2000 m rowing ergometer performance [23, 29]. Therefore, low body fat% can be an advantage for success in rowing. We also found a significant negative correlation of 2000 m rowing timing only with LDH and *T*/*C* ratio in male rowers. Whereas, no significant correlation was found between urea, uric acid, CPK, LDH, testosterone and cortisol with 2000 m performance in female rowers. As basal hormone and enzyme levels and responses to training stimulations are highly sex-specific and muscle mass specific [10, 20], we suggest to monitor longer training period and additional biochemical parameters on larger population in further studies to find strong biochemical determinants of rowing performance and develop performance prediction models based on biochemical parameters.

We consider the small sample size as one of limitations of our study. Sample size in our study consisted of 19 elite rowers from the National rowing team and it is virtually impossible to monitor more rowers considering the team's intake capacity. Therefore, the findings in this study can't be generalized because few participants are based on national-level athletes. Another point that needs to be indicated is that we could not monitor the rowers during competition and tapering phase due to the team's unavailability. It would be interesting in future studies to investigate more time points and the effects of different training modalities as well on different population (i.e. college rowers, club-level rowers, elite rowers). Since reaction to fatigue differs between men and women, there is a need to examine this issue separately for men and women in the future as well. Regardless, the study results are unique in that the rowers of highest level were monitored, the training procedures were not modified in any way to aid this investigation, and the monitoring period was extremely relevant to the study population (i.e. before a major international competition Asian Rowing Championship).

In conclusion, the results of this study clearly show that biochemical markers particularly enzymes fluctuate more compared to anabolic or catabolic hormone concentration with the changes in intensity and volume of training in male and female rowers. As different types of training like basic athletic training, endurance training, power based training, and on-water training are employed in a rowing training season, the hormonal markers may not be a good indicator to monitor training load in either male or female rowers. Additionally, our results suggest that rowers experienced significant decrease in percentage of body fat, endomorphic component, urea, and uric acid at pre-competition compared to preparation phase.

### Practical Applications

This study is the first to examine the muscle damage and training load biomarkers in Indian rowers over the course of the preparation and pre-competitive season while simultaneously obtaining body composition and training load metrics. Body composition assessment on a regularly interval can help monitor a team's overall fitness that coach can use to tailor their athletes' development and training programs. Specific information of the training load (Fig. 1) can be used by coaches or trainers to guide their training and management practices before competition. Monitoring body composition and biomarkers response during training period can ensure coaches that training periodization goals are being met without any detrimental effect or related positive training adaptations are being elicited. We believe that the feasible model of concurrent training monitored in this study provide an important practical use to those involved in designing training programs for their athletes to optimize performance. These results will be used in the future to create more effective training plan and to promote more effective training adaptation. In addition, this study provides normative data of Indian elite rowers, so that conditioning coaches can use this information to determine standards of body composition and biochemical profile during the season.

**Acknowledgements** We thank Ismail Baig, Chief Coach of National rowing team, his entire coaching and support staff for assistance in testing and all the rowers who participated in this study. Rowing Federation of India and Sports Authority of India are also thanked for the administrative support.

**Funding** We have not received any funding to conduct this study.

**Data availability** Data will be made available on reasonable request.

## Declarations

**Conflict of interest** The authors do not have any conflicts of interest to declare.

**Ethical approval** Institutional ethics committee approved this study (Certificate number: IECH/OCH/01/CC).

**Consent to participate** Consent to participation was obtained from all participants.

**Consent for publication** All authors have read and agreed to the published version of the manuscript.

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