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Weight Training and Creatine Kinase (CK) Levels: A Literature Review

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Abstract: ***The Creatine Kinase (CK) is a blood marker commonly used to assess exercise induced muscle damage. However, little attention has been given for its use as an index of recovery and adaptation after weight training sessions. In this review, studies that measured the CK after single bouts of typical gym and fitness studios exercises were summarized, while eccentric actions or aerobic (endurance) studies were excluded. At a second step long term studies (>four weeks duration, or 1-2 weeks for overreaching) were used to estimate CK levels that could result in increase or decrease of performance (strength or hypertrophy). The analysis of this review showed that CK levels peaked after one to three days at mean levels of 2.5 (quads), 3.5 (whole body) or 4.5 (biceps) times the pre-exercise (base) levels. The variability though was very high and one more standard deviation brought these numbers to 5.5 times the base levels or 900 U/L. The long term studies showed that at CK levels >550 U/L (3.5 times the base levels), the performance tended to be stable or decrease. The main message of this review is that CK levels should be measured two to three days after the last training session and should be kept <550 U/L in order to avoid performance decrease and possibly to optimize improvements.***

Keywords: Creatine kinase (CK), bodybuilding, blood exams, recovery

1. Introduction

Weight training is a type of (resistance) training to increase the strength and size of skeletal muscles primarily using bars, dumbbells and/or other equipment. Weight training induces an increase of strength and muscle mass (muscular hypertrophy) through mechanical, metabolic, hormonal, and neurological stimuli and the respective adaptations [1]. Damage is typically observed following physical activity of greater than normal duration or tension and is heightened from the performance of lengthening (eccentric) or isometric contractions at long muscle lengths [2]. Some muscle damage indicators include delayed-onset muscle soreness (DOMS), decreased force production, or increased muscle proteins in the blood (creatine kinase and myoglobin) [3].

Creatine kinase (CK), also known as creatine phosphokinase, is an enzyme that plays a role in energy production. Higher amounts of this enzyme are found in tissues that use a lot of energy, such as the muscles (including the heart) and the brain. Base levels of serum enzyme CK vary from 20-35 to 200-400 U/L [4], [5]. Creatine kinase will leak into the blood when the skeletal muscle cell structure at the level of sarcolemma and Z-disks are damaged [6]. Measured serum CK will reflect relative amounts of CK released, degree of enzyme activity of released CK, and the rate of clearance of CK from the serum [7]. It has also been hypothesized that under critical metabolic conditions, adenosine triphosphate (ATP) consuming enzymes like CK are 'volitionally' expulsed by muscle cells in order to prevent cell death [8]. Some researchers have moved from associating CK with 'muscle damage' to 'membrane damage' or 'membrane permeability'.
Elevated plasma CK activity has been proposed as one of the qualitative indicator of muscle damage, especially in the case of resistance exercise [9]. Serum CK levels greater than 5000 U/L are generally considered to indicate serious disturbance to muscles [7]. CK has also been proposed as an indicator of recovery, but due to the high variability at base levels or at the exercise responses there is no general consensus.

The literature on eccentric exercise induced muscle damage has been widely studied [10]. However, the number of studies on CK with concentric actions and typical free weight protocols commonly used in fitness studios is smaller.

Objective of this study is to summarize the studies that measured the CK response after single bouts of (concentric) exercises with typical protocols used in gyms and fitness studios. At a second step, long term studies (i.e. with duration >4 weeks or 1-2 weeks for overreaching) with CK measurements were analyzed to find a possible correlation of CK levels and increase or decrease of performance (strength or hypertrophy).

2. Methods

The literature survey included only studies published until the end of 2019 in English. The participants had to be healthy with ages between 18 and 36 years old. The training equipment and training protocol had to be those typically used in gyms and fitness studios. Training with eccentric actions to induce muscle damage were excluded from the analysis. Studies with CK values higher than 5000 U/L were also excluded as they indicate muscle damage.

For the evaluation of the CK response after a single bout of exercise, only studies that included CK measurements at least pre-exercise and after one day or longer were included. When the study included evaluation of a medicine, supplemental or a treatment, only the control or placebo values were included in the analysis. Due to the wide range of pre-exercise base values, the reported CK increases after exercise were normalized to the base levels. Means and standard deviations of the CK in function of time (days of recovery) were calculated only if at least 5 studies were available.

For the evaluation of the CK levels after long term training studies that lasted at least 4 weeks and reported strength or muscle mass results (in addition to the CK levels) were included. Furthermore, studies of overreaching and overtraining of 1-2 weeks duration were also considered. Subjects were divided in untrained (no weight training experience for the last >6 months) or trained.

3. Results

3.1 General

The studies that measured CK after single bouts of exercise focused mainly on the biceps, quadriceps femoris (quads) or whole body (Table 1). The studies that examined calves, two body parts or chest were not enough to be assessed separately. Two studies for the whole body were excluded due to high CK levels (>5000 U/L) [11], [12]. The number of sets were on average 5 for biceps, 7 for quads and >15 for the whole body. The main exercises that were used were biceps curls for biceps, squats or leg presses for quads. The long term studies lasted on average 6 weeks (range 4-14 weeks). In most studies the quads were trained and in some studies the whole body (Table 2).

The mean age of the subjects in all studies was 23 years old. The majority of the studies included only males and there were a few studies with both males and females (see Table 1 and Table 2).

Table 1: Studies of single bouts of (concentric) exercise. M=Male, F=Female, T=Trained, U=Untrained

Muscle	*M / M+F / F*	*T / U*	*Studies*
Biceps	5 / 2 / 1	4 / 4	[13]–[20]
Quads	18 / 3 / 1	T	[21]–[42]
Quads	9 / 1 / 0	U	[42]–[52]
Rest	12 / 1 / 0	T & U	[27], [53]–[64]
Whole body	12 / 2 / 2	T	[65]–[79]
Whole body	8 / 1/ 0	U	[72], [80]–[87]

Table 2: Long-term studies (duration >4 weeks or 1-2 for overreaching and overtraining). M=Male, F=Female, T=Trained, U=Untrained

Muscle	*M / M+F / F*	*T / U*	*Studies*
Quads [1]	4 / 2 / 1	U	[88]–[94]
Whole body [2]	7 / 1 / 0	T	[23], [31], [95]–[100]

[1] one study biceps
[2] three studies quads

3.2 CK after Single Bouts of Exercise

Figure 1 plots the CK increase over time after quads training for trained, untrained and all subjects. The mean CK almost doubled post-exercise, peaked after one (trained) to two (untrained, all) days and returned close to the pre-exercise levels after 4 days approximately. As the error bars show, the range of CK responses was wide, with one standard deviation (i.e. 65% of the population) peaking at 4.5 times the base levels. With one exception, all CK values were <1000 U/L.

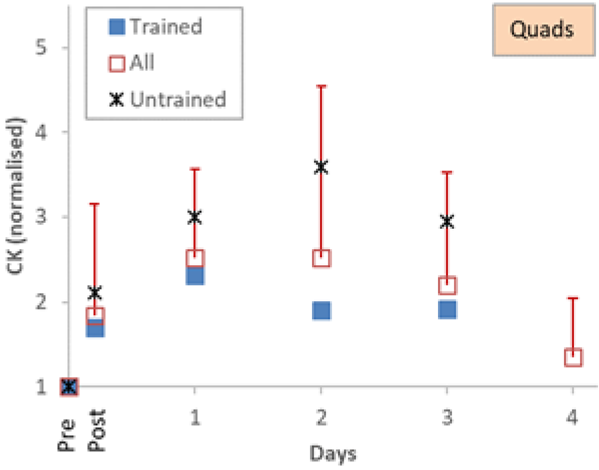

Figure 1: Normalized CK response after weight training of the quads. Only positive error bars (one standard deviation) are shown for the all subjects case for better clarity. Pre-exercise mean CK levels 140 U/L.

Figure 2 plots the CK increases over time after training the whole body for trained, untrained and all subjects. The mean CK peaked after one (untrained) to two (trained, all) days and it is not clear when it returned to base levels. As the error bars show, the range of CK responses was wide, with one standard deviation (i.e. 65% of the population) peaking at 5.5 times the base levels. All CK values were <1000 U/L.

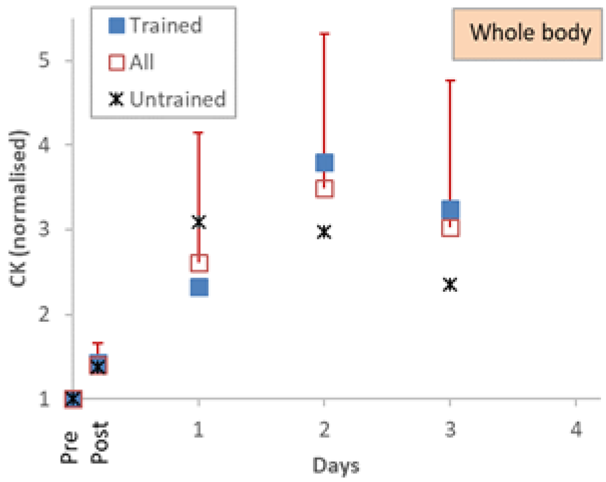

Figure 2: Normalized CK response after weight training of whole body. Only positive error bars (one standard deviation) are shown for the all subjects case for better clarity. Pre-exercise mean CK levels 160 U/L.

Figure 3 plots the mean CK increase over time after training biceps, quads, and whole body for all subjects. While the mean CK peaked after one to two days for quads and whole body training, it peaked after three days for biceps. After four days the mean CK values did not return to pre-exercise levels for biceps.

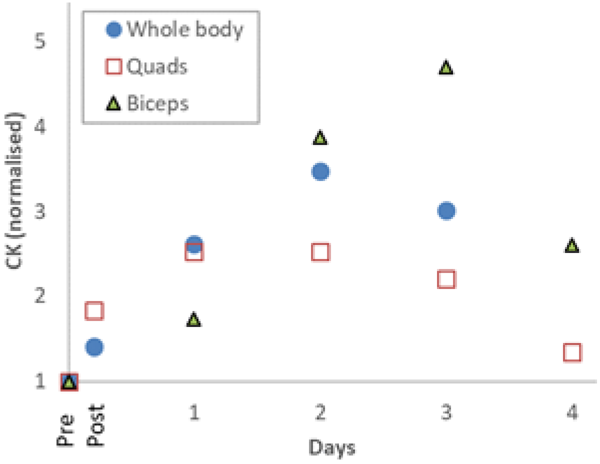

Figure 3: Normalized CK response after weight training of biceps, quads, or the whole body. Both trained and untrained subjects are included. Pre-exercise CK levels 140-180 U/L

3.3 CK at Long Term Studies

Figure 4 plots the CK levels measured one to three days after the last training session at long term studies (duration up to fourteen weeks). The CK levels are plotted in function of the performance (mainly strength, but sometimes hypertrophy) (negative, neutral, positive). In general, values higher than 550 U/L result in negative to neutral (no) results, while values <550 U/L result in positive to no results. The 550 U/L value corresponds to approximately 3.5 times the pre-exercise levels.

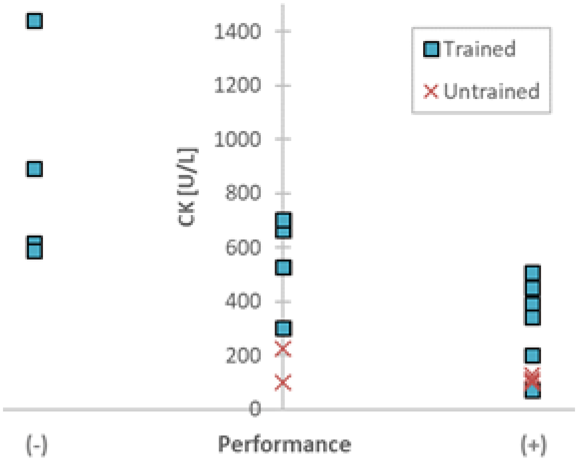

Figure 4: CK levels of trained and untrained subjects after weight training of four to fourteen weeks of training or one to two weeks of overreaching. The CK levels were measured one to three days after the last training session.

4. Discussion

Weight training is a very common free time activity for health, increase of strength and/or muscle mass [101]. However, in extreme cases (high intensity, volume, duration and eccentric actions), exercise-induced muscle damage can result in rhabdomyolysis, a potentially serious condition that may lead to acute renal failure [102]–[104]. CK values exceeding 50000 U/L have been reported. In general, though, the majority of the cases with high CK levels from exercise do not result in renal failure [105]–[107]. Although high CK levels are not desirable, some damage and consequently CK leakage in the blood might be important for optimal results. This review tried to quantify the typical and necessary CK levels after exercise. The novelty of this review compared to other older reviews on the topic [6], [7], [9], [108] is the focus on CK levels from typical weight training protocols and their quantification after single training sessions. In addition, this is the first study that tried to quantify levels with negative and positive impacts on performance.

The literature survey showed that common training protocols of 5-15 sets with 6-15 repetitions result in CK increases on the order of 400 to 700 U/L after 2-3 days for trained and untrained subjects. The CK returned to base levels after 4 or more days. Recovery after 3 or more days is in agreement with the literature. Full-body workouts need 2-3 days for 80% of the participants to recover [109]. Strength trained trainees need 4-5 days to recover from typical weight training protocols as fiber histochemical analysis and strength recovery tests have shown [110]–[112]. However, this recovery time is different to the recovery time needed with eccentric exercise. CK serum levels with eccentric resistance training peak typically between 3-4 days and need more than one week to return to the base levels. Furthermore, the absolute CK values are much higher [7]. It is possible that the appearance of CK in serum following low-moderate intensity exercise with levels <500 U/L represents a disturbance to muscle energy processes and is not representative of the type of muscle cell damage observed [7].

In order to get some insight on whether the CK levels found are optimal for performance improvements, strength or hypertrophy studies that lasted more than four weeks or overreaching studies of 1-2 weeks with CK measurements were summarized. Then the CK levels were correlated with the increase or decrease of the performance at the end of the duration of the relevant studies. Studies with CK levels below 550 U/L showed improvement of the performance. CK levels of >550 U/L were found to result in decrease or no improvement of the performance (typically strength). Excessive damage has a negative effect on exercise performance and recovery. Studies indicate that regeneration of muscle tissues in those with severe muscle damage needs more than one week [113], [114] The 550 U/L value is close to the 300-500 U/L break point of CK release that has been suggested for endurance exercise [115]. Interestingly, a study with soccer players found that CK values higher than 975 U/L could result in overtraining or injury [116].

These results indicate that excess muscle damage is counterproductive. They also show that some damage does not hinder the increase of the performance, but they do not clarify whether the results with low CK release are optimum or not. Improvements were found with both no CK release and with some CK release. Some studies argue that muscle damage is not required, while others argue that it might be important. Overall, muscle damage does not seem to be needed to increase muscle hypertrophy [92], [117]. Weight training should provide the least amount of damage. More damage will not result in more growth.

This review focused on males between 18 and 36 years old. CK levels may depend on age [118], gender [65], race [5], [119], [120], genetic characteristics [121], [122], training status [63], and physical activity [108], [123], [124]. For this reason, the values were normalized to the base levels in order to minimize the contribution of the above mentioned parameters. Nevertheless, special attention should be paid by persons not included in the studied populations. It is the author's opinion that the CK increases should be kept to the low levels of the reviewed values.

In this review some studies with high CK levels (>5000 U/L) were not taken into account for the estimations of the mean values. It is known though that some persons are high responders, i.e. typical protocols result in more than double CK levels [70]. Even though these high values return to normal levels after some days of rest and there is no particular health risk, it is the opinion of the author that such high values should be avoided and other training protocols or more gradual introduction should be applied to those subjects. It is known that the response after a second bout of exercise is lower and the recovery faster (repeated bout effect) [125]. In addition to the possible adverse health effects, currently there is no evidence that long term performance increases with high CK values.

5. Conclusions

A literature review was conducted for CK levels after weight training sessions. The search focused on typically used gym and fitness studios equipment and concentric training (i.e. eccentric training was excluded). The results showed that after acute bouts of exercise (i.e. one training session) levels increased and peaked after 1-3 days. The mean peak CK levels (400-700 U/L) were 2.5, 3.5 or 4.5 times the pre-exercise (base) levels for quads, whole body, and biceps respectively. However, the reported peaks were up to 1000 U/L (with few exceptions).

At a next step, long term studies that reported CK levels were evaluated. The CK levels were generally decreasing over the duration of the studies. Comparing the CK levels with the increase or decrease of the performance at the end of the evaluation period (typically six weeks) showed that CK levels above 550 U/L were correlating with decrease of performance, while below that level with improvements.

Concluding, based on the literature review, typical weight training protocols should result in CK levels below 550 U/L when measured one to three days after the training session.

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