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A Simple Creatine Kinase Model to Predict Recovery and Efficiency of Weight Lifting Programs

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Abstract:
Background*: Creatine kinase (CK) is a blood marker used to assess muscle damage and overtraining. A simple model was developed to assess the effectiveness of various weight training programs. The model assumes that every weight training session has an additive effect on CK levels.*
Materials and Methods*: A subject trained the chest, and then measured the CK response over the baseline for a few days. To confirm the additive effect of training on CK levels, the CK levels were also measured after the back training following one to three days the chest training. The model was applied to typical weight training programs of two to four sessions per week.*
Results*: The results confirmed the validity of the model and its simplified assumptions. Application of the model showed that the CK levels can remain elevated depending on the training frequency. Thus, attention should be paid to the recovery days in order to keep CK within acceptable ranges.*
Conclusion: *The simplified CK model can be used to estimate the CK levels of weight training programs. Keeping the CK levels at appropriate levels will not only avoid overtraining, but may optimize recovery and improve performance.*
Keywords*: Creatine kinase; Resistance training; Bodybuilding; Recovery; Overtraining; Training frequency; Weight training.*

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I. Introduction

Nowadays weight training is a common activity to increase strength and muscle mass. One of the most important principles of weight training is the progressive overload. For best results every workout has to be more challenging than the previous one, but within the tolerance of the athlete, and the recovery must be completed before the next workout[1]. Challenging workouts can result in muscle tissue damage, accompanied by release of enzymes such as creatine kinase (CK)[2]. After damaging exercise, CK, from typical base levels below 200 U/L, peaks after three or more days at values >5,000 U/L[3,4]. CK returns to base levels after one week or even longer. CK monitoring is common is sports[5] as an indirect indicator of muscle damage and/or overtraining. Small increases of serum CK levels arising from normal physical exercise may be a consequence of normal metabolic activity rather than representative of physical damage to muscle[4,6]. So it has also been suggested that CK could be used as an index of proper recovery and even optimized training[7]. However, the research in this direction is limited. After (non-damaging) weight training, serum CK increases and peaks after one to three days at levels <1000 U/L for normal responders[2,7]. CK levels depend on age, gender, race, genetic characteristics, training status, and physical activity[2,4]. The CK response to exercise for high responders can exceed 2000 U/L[2]. A review of long term studies with trained subjects found that only CK levels <500 U/L were positively correlated with performance improvements, while decreased performance was noticed with CK levels >550 U/L[7].

Based on this background, one could assess a training program by monitoring the CK levels, before reaching the end of the program. Periodically checking the CK levels is a strategy being followed in sports, but mainly to avoid overtraining[8]. For weight lifting, avoiding overtraining is very important, but following an optimized program is the main objective. In addition to the regular strength increases[9,10], periodic CK measurements would help in this direction[11]. However, a more structured approach with less blood exams involved will have better results and will be more applicable to non-competitive trainees and athletes. Modeling of the CK response is limited today and is focused on horses[12] or heart attacks[13,14].

Objective of this study is to develop a simple model to estimate the CK levels of various non-damaging weight training programs. The weekly average, minimum and maximum estimated CK levels can be compared to lower and maximum CK levels found in the literature for overtraining or for improved performance respectively. This way one can predict the potential effectiveness of a training program.

II. Model

Figure 1 summarizes the model with an example. The model assumes that every weight training session increases the CK levels, they peak after one to three days and then they gradually return to baseline levels. The increases of the CK for each weight training session are additive, even if the CK levels have not returned to the baseline. The simplification of the model is that the CK response does not need to be fitted to complex equations, but the subject's measured data can be used as future responses of the training sessions. Another assumption is that each training session results in similar CK responses. This assumption is probably valid for trained individuals, but not for untrained or for unaccustomed exercise. Thus, application of this model to beginners requires at least one month of gradual progressive weight training in order to achieve repeatable CK responses. Typical weight training programs split the body in different parts, thus, the CK responses could be different for different body parts (and different training days). In this case, the simplification of similar CK responses may not be valid and CK measurements for each training day (body parts) would be needed.

Although the CK increase after weight lifting is well known, the influence of a second training session before CK levels restoration is not clear. Thus, the assumption that the effect of each weight training is additive, needs to be experimentally evaluated. The assumptions will be discussed in the "Discussion" section.

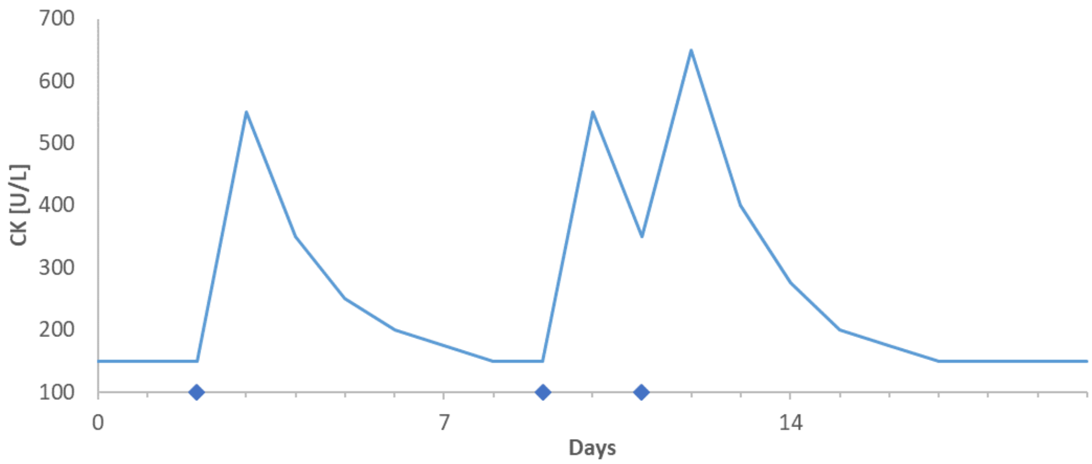

Figure 1: Explanation of the theoretical CK model. Diamonds indicate weight training sessions. Training (day 2) increases serum CK levels, which will restore to base levels after some days. A second training session (day 9) will have a similar CK response. A training session before CK restoration (day 11) will further increase the CK levels.

III. Materials and Methods

The model was validated with the author's CK data in the period 2019 to 2020. Only the data that followed similar training program were used. Then model was applied to assess the training program for the specific subject. Furthermore, data from the literature were used to assess the effectiveness of whole body programs (i.e. no body split). Details follow.

Single Subject Data

The subject followed for a few months a program that typically split the body in three parts: (1) chest and triceps; (2) back, biceps and side deltoids; (3) legs (**Table 1**). Each muscle group was trained with one exercise. The first two sets were done with a weight that resulted in muscular failure with approximately 6RM (repetitions maximum) and for the next three sets the weight was decreased to 12RM. The training frequency was five to seven days.

Table 1: Training program. Body was split in three parts. Number of sets to failure are also shown. Asterisk * indicates that the desired number of repetitions could not be achieved.

(1) Chest and triceps	(2) Back, biceps and deltoids	(3) Legs
Bench press x5: 6RM, 6RM*, 12RM, 12RM*, 12RM* *Triceps extensions x3:* 6RM, 12RM, 12RM*	*Barbell row x5:* 6RM, 6RM*, 12RM, 12RM*, 12RM* *Dumbbell curls x3:* 6RM, 12RM, 12RM* *Side raises x3:* 6RM, 12RM, 12RM*	*Squat x5:* 6RM, 6RM*, 12RM, 12RM*, 12RM* *Calf raises x5:* 6RM, 6RM*, 12RM, 12RM*, 12RM*

The CK values were based on blood exams one to six days after the last training session (usually chest or back). Depending on the training frequency the back training was done one to three days after the chest training and this could influence the CK levels measured after the back training. The blood was analyzed in various medical centers.

Literature Data

A recent literature review summarized the CK responses of trained and untrained subjects for different muscle groups[7]. For simplicity, only the average CK response after whole body exercising of trained subjects was used as input to the model[15–29] (**Figure 2**). The same review concluded that for trained subjects[30–43] the CK levels should be <550 U/L in order to ensure that the performance will not decrease.

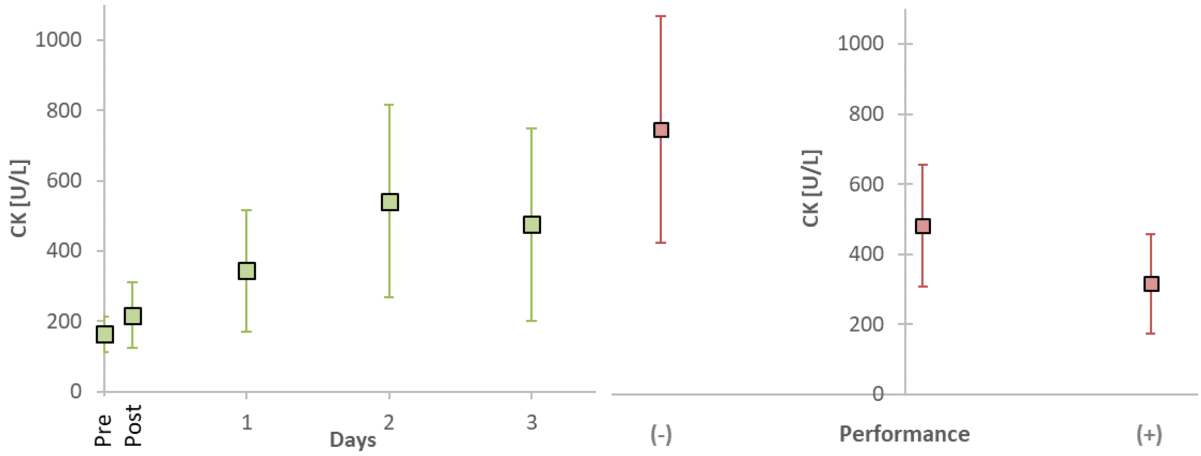

Figure 2: Left panel: CK values after exercising the whole body for trained subjects. Right panel: CK levels for long term studies that measured increase or decrease of performance. Data adapted from review study[7].

IV. Results

Initially the CK model is validated with experimental data: (i) CK response to a single weight training session; (ii) validity of the additive effect of each weight training session on CK levels. Then the model is applied to assess different weight training frequencies and training programs for the specific subject or for the average CK response found in the literature for whole body training (**Figure 2**).

CK Model Validation

Figure 3 (left panel) plots the measured CK values after one to six days of a chest and triceps training. After the first day the CK was elevated (330 U/L) and then gradually returned to base levels. This response can be approximated with logarithmic[14] or exponential[12,44] functions. Alternatively, the actual measurements can be considered for future responses to exercise, because more details (e.g. CK between days) are not needed.

The CK response was modeled for two cases (**Figure 3**, right panel): Back, biceps and deltoids training immediately after chest and triceps training (**Figure 3**, right panel, red line) or after three days (**Figure 3**, right panel, green line). The influence of the back, biceps and deltoids training was assumed to have the same magnitude on CK as the chest and triceps training and was added to the already elevated CK values (due to the previous chest and triceps training). The available CK data for the continuous (squares) and after three days (triangles) trainings fit nicely to the theoretical curves. These results confirm that, for the specific program and subject, the chest and triceps training had similar effect as the back, biceps and deltoids training. Even more importantly, they confirmed that the CK release from the subsequent training can be added to the actual (elevated) CK levels.

CK Model Application

At a next step the CK model was applied to estimate the CK levels of the specific subject with 3 times or 4 times per week training of the program of **Table 1** (i.e. training frequency every seven or five days respectively). **Figure 4** (upper panel) plots the CK results for three times per week training. The CK increases the day after training, then drops and further increases with the next training. During the week CK ranges between 260 and 473 U/L with a mean value of 363 U/L. It drops to 260 U/L only on the second rest day at the end of each week. With four times per week training **Figure 4** (lower panel) the CK levels range between 326 and 540 U/L with an average weekly value of 436 U/L.

The CK model was also applied to typical CK response of whole body exercising for trained subjects, based on the input of **Figure 2** (left panel). With two times per week training the weekly average CK levels are 456 U/L, ranging from 304 to 557 U/L (**Figure 5,** upper panel). With three times per week training the weekly average CK levels are 603 U/L, ranging from 484 to 682 U/L (**Figure 5,** lower panel).

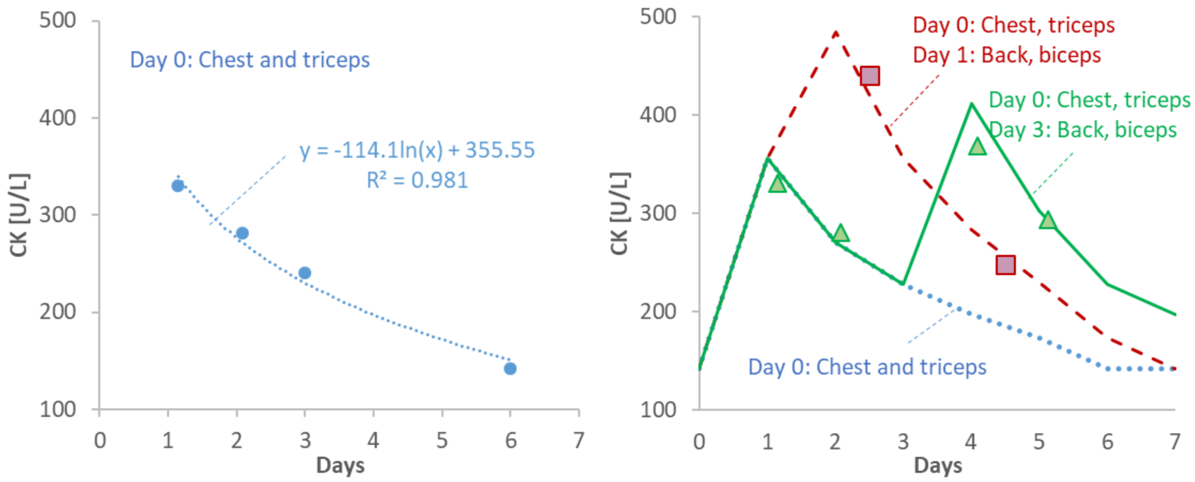

Figure 3: Left panel: CK value after chest and triceps training (circles). The dotted line shows the logarithmic fit. Right panel: Application of the model (i.e. using the CK response of the left panel) for every training: Back, biceps and deltoids training immediately after chest and triceps training or after three days. The squares are CK measured values after the back training following the chest training. Triangles are CK measured values after the back training following three days after the chest training.

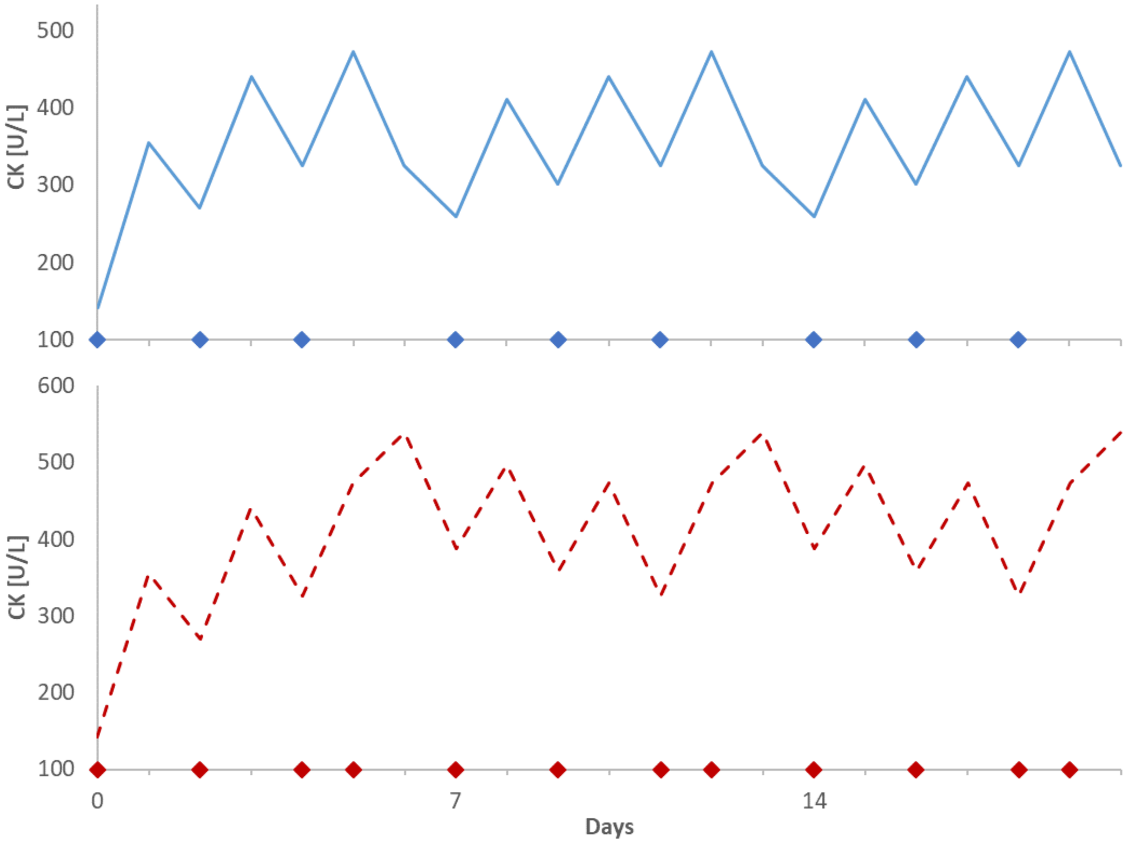

Figure 4:CK levels with three (upper panel) or four (lower panel) times per week training (**Table 1**) of the subject with CK response as in **Figure 3** (left panel). Diamonds indicate weight training days.

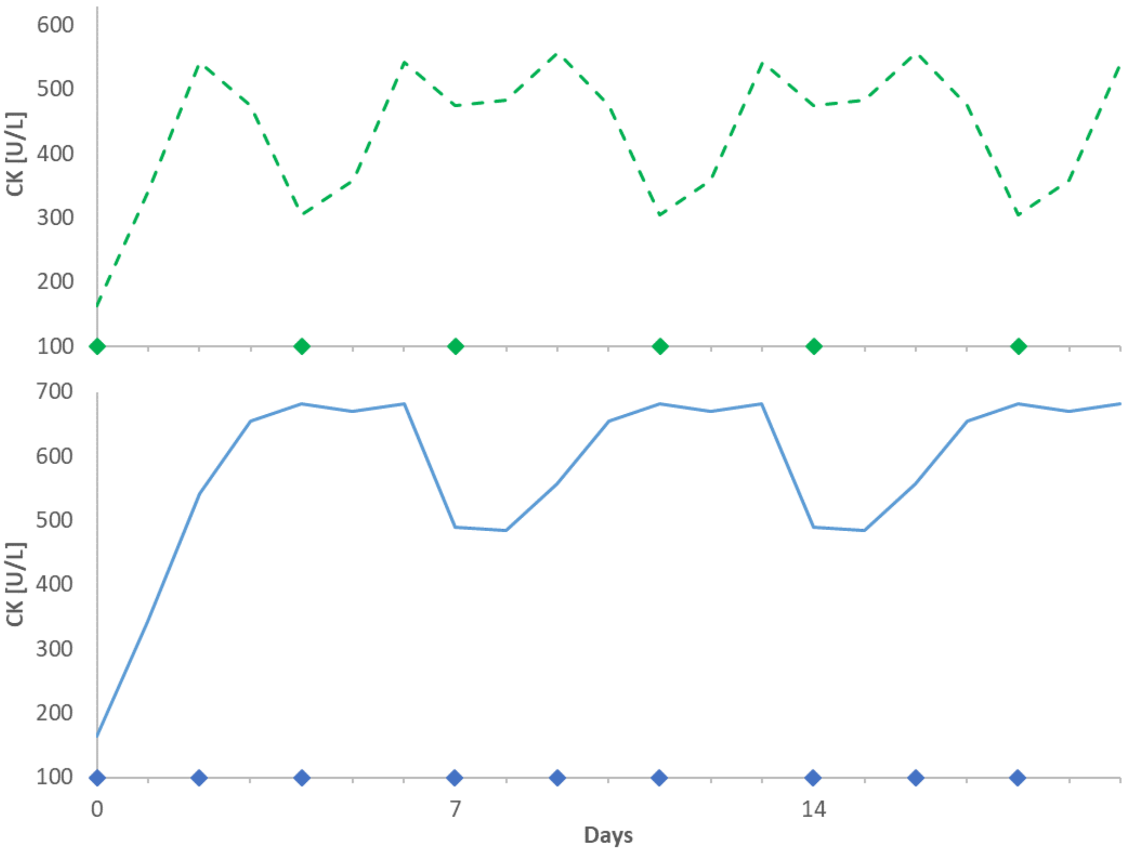

Figure 5:CK levels with two (upper panel) or three (lower panel) times per week whole body training for trained individuals based on **Figure 2** (left panel). Diamonds indicate weight training days.

V. Discussion

This study presented a CK model to assess the effectiveness of weight training programs. The main assumptions were:

1. Each weight training session increases the serum CK levels for a few days.
2. The increases are similar for subsequent training sessions of the same or other muscle groups.
3. The increases are additive, even if the CK levels are still elevated from a previous training.

Regarding the first assumption, it is well known that weight lifting can increase the serum CK levels[2,7]. Typically, CK peaks after one to three days and then returns to base levels in less than one week. The curve is highly variable and big differences can be seen between different subjects, even for the same program[2,45]. Thus, for the application of this model it is necessary to take CK measurements daily for at least three days after a weight training session. This way an accurate CK response curve can be determined. The CK increases (i.e. CK levels minus base levels) do not need to be modelled: the specific measured values can be used for the model application. This is one of the model simplifications. Another one is that the same CK increases can be assumed for subsequent training sessions. This is reasonable for trained subjects. It is not valid for unaccustomed exercise or untrained subjects. The initial CK response is very high and it diminishes at subsequent bouts of exercise (repeated bout effect)[46]. Thus, before the blood exams, at least one month of the specific weight training program should have been followed. Split programs need special attention. The CK response after a chest day may not be the same after back or legs training, especially for sedentary subjects[47,48]. Nevertheless, in order to minimize the necessary blood exams, it can be assumed that the response will be the same[49]. This can be valid if the body is split in “equal” parts and the intensity and volume of training is similar for each training day[50,51]. If there are doubts, separate CK measurements should be conducted after each training split.

The last simplification (i.e. that CK response is additive) deserves more discussion. Many studies showed that after damaging eccentric exercise protocols any subsequent training had no effect on the CK response curve during the recovery period[52–56]. In this study it was shown that for a second (non-damaging) training of another muscle group the CK levels are additive and thus the assumption is valid. There are a few studies that their findings indirectly support this assumption[57,58].

The model can be used to estimate easily CK levels over weeks of a training program. This information is useful in order to understand the CK values of blood exams during a training program. It was shown that the weekly range can be wide and consequently, the day of the blood sample is important. The model can also be used to estimate the optimal training frequency. Even the first blood exams give an indication of the recovery rate, different training frequencies will result in different weekly CK levels. Application of the model can show whether the CK levels remain elevated or not and for how long.

The interpretation of the CK values is challenging. Although there are guidelines for muscle damage (i.e. CK >5000)[4], acceptable values for overtraining have not been established. For some sports there are some limits which could indicate overtraining or higher risk of injury[5,8]. Limits for optimum weight training are not existent. Based on a recent review CK values >550 U/L may result in decreased performance[7]. Based on the studies of that review improved performance is expected for CK levels around 350 U/L (**Figure 2**).

Table 2 summarizes the findings of that review[7] and how the CK levels (measured or estimated from the model) of this study could be interpreted. The 3-way split with three or four times per week training sessions would probably result in improvements as the max values are below 550 U/L. However, the mean CK value of the four times per week program is on the high end, and periods of rest may be useful every few months. The whole body training twice per week seems also to result in acceptable CK levels. The three times per week whole body training seems quite taxing and might result in stagnation after a few weeks of training. It should be emphasized that these values are first average approximations and individual responses vary. It is very important that the actual progress is monitored. In combination with actual CK values, it will be also possible to assess future programs, i.e. how one responds to specific CK levels.

Table2: Mean, min and max CK values as estimated for various training programs.

CK values	Overtraining	Improved performance	3-way split 3 times per week	3-way split 3 times per week	Whole body 2 times per week	Whole body 3 times per week
	Figure 2	**Figure 2**	**Figure 4** (upper)	**Figure 4** (lower)	**Figure 5** (upper)	**Figure 5** (lower)
Mean	756	317	363	436	456	603
Min	542	-	260	326	304	484
Max	-	507	473	540	557	682

VI. Conclusions

A simple creatine kinase (CK) model was developed to assess weight training programs. The model increases the CK levels after each weight training session. The increases are additive for each subsequent session. The response curve is based on measured data (data from the literature can also be used). Experimental data confirmed the main assumptions that (i) the responses are similar for each training session, and (ii) the responses are additive for non-damaging exercise. Application of the model for split or whole body programs estimated CK levels with weekly average values between 260 and 484 U/L, and peak concentrations between 473 and 682 U/L. Comparison of these values with average and peak CK levels of studies that resulted in performance improvements (317 and 507 U/L respectively) or overtraining (>542 U/L) may be used to assess the potential effectiveness (or not) of the programs.

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References

[1]. Giechaskiel B. Recovery and adaptation after weight training sessions with different number of sets to failure. Am J Sports Sci Med. 2018;6(3):89–98.
[2]. Koch AJ, Pereira R, Machado M. The creatine kinase response to resistance exercise. J Musculoskelet Neurolo Interact. 2014;14(1):68–77.
[3]. Kim J, Lee J, Kim S, Ryu HY, Cha KS, Sung DJ. Exercise-induced rhabdomyolysis mechanisms and prevention: a literature review. J Sport Health Sci. 2016 Sep;5(3):324–33.
[4]. Baird MF, Graham SM, Baker JS, Bickerstaff GF. Creatine-kinase- and exercise-related muscle damage implications for muscle performance and recovery. J Nutr Metab. 2012;2012:1–13.
[5]. Mougios V. Reference intervals for serum creatine kinase in athletes. Br J Sports Med. 2007 Oct 1;41(10):674–8.
[6]. Brancaccio P, Maffulli N, Limongelli FM. Creatine kinase monitoring in sport medicine. Br Med Bull. 2007 Feb 6;81–82(1):209–30.
[7]. Giechaskiel B. Weight training and creatine kinase (CK) levels: a literature review. Int J Sci Res IJSR. 2020;9(1):303–11.
[8]. Lazarim FL, Antunes-Neto JMF, da Silva FOC, Nunes LAS, Bassini-Cameron A, Cameron L-C, et al. The upper values of plasma creatine kinase of professional soccer players during the Brazilian national championship. J Sci Med Sport. 2009 Jan;12(1):85–90.
[9]. Giechaskiel B. Implementation of a personalized weight training protocol and influence of sleep duration. J Sports Res. 2018;5(1):40–8.
[10]. Warren GL, Lowe DA, Armstrong RB. Measurement tools used in the study of eccentric contraction-induced injury. Sports Med. 1999;27(1):43–59.
[11]. Hartmann U, Mester J. Training and overtraining markers in selected sport events: Med Sci Sports Exerc. 2000 Jan;209.
[12]. Volfinger L, Lassourd V, Michaux JM, Braun JP, Toutain PL. Kinetic evaluation of muscle damage during exercise by calculation of amount of creatine kinase released. Am J Physiol-Regul Integr Comp Physiol. 1994 Feb 1;266(2):R434–41.
[13]. Apple FS, Rhodes M. Enzymatic estimation of skeletal muscle damage by analysis of changes in serum creatine kinase. J Appl Physiol. 1988 Dec 1;65(6):2598–600.

[14]. Lopes RD, Lokhnygina Y, Hasselblad V, Newby KL, Yow E, Granger CB, et al. Methods of creatine kinase-MB analysis to predict mortality in patients with myocardial infarction treated with reperfusion therapy. Trials. 2013;14(1):123.
[15]. Amorim MZ, Machado M, Hackney AC, de Oliveira W, Luz CPN, Pereira R. Sex differences in serum CK activity but not in glomerular filtration rate after resistance exercise: is there a sex dependent renal adaptative response? J Physiol Sci. 2014 Jan;64(1):31–6.
[16]. Arazi H, Azizi M. Effect of consecutive aerobic and resistance exercise on cortisol, immunoglobulin a, and creatine kinase responses in male students. Biomed Hum Kinet. 2011 Jan 1;3:115–9.
[17]. de Castro A, Vianna JM, Damasceno VO, Matos DG, Filho MM, Machado Reis VM. Muscle recovery after a session of resistance training monitored through serum creatine kinase. J Exerc Physiol Online. 2011;14(5):1–8.
[18]. Deminice R, Sicchieri T, Mialich MS, Milani F, Ovidio PP, Jordao AA. Oxidative stress biomarker responses to an acute session of hypertrophy-resistance traditional interval training and circuit training: J Strength Cond Res. 2011 Mar;25(3):798–804.
[19]. Fatouros IG. Cell-free plasma DNA as a novel marker of aseptic inflammation severity related to exercise overtraining. Clin Chem. 2006 Sep 1;52(9):1820–4.
[20]. Machado M, Willardson JM. Short recovery augments magnitude of muscle damage in high responders: Med Sci Sports Exerc. 2010 Jul;42(7):1370–4.
[21]. Machado M, Koch AJ, Willardson JM, Pereira LS, Cardoso MI, Motta MKS, et al. Effect of varying rest intervals between sets of assistance exercises on creatine kinase and lactate dehydrogenase responses: J Strength Cond Res. 2011 May;25(5):1339–45.
[22]. Paul GL, DeLany JP, Snook JT, Seifert JG, Kirby TE. Serum and urinary markers of skeletal muscle tissue damage after weight lifting exercise. Eur J Appl Physiol. 1989;58(7):786–90.
[23]. Callegari GA, Novaes JS, Neto GR, Dias I, Garrido ND, Dani C. Creatine kinase and lactate dehydrogenase responses after different resistance and aerobic exercise protocols. J Hum Kinet. 2017 Aug 1;58(1):65–72.
[24]. Heavens KR, Szivak TK, Hooper DR, Dunn-Lewis C, Comstock BA, Flanagan SD, et al. The effects of high intensity short rest resistance exercise on muscle damage markers in men and women: J Strength Cond Res. 2014 Apr;28(4):1041–9.
[25]. Roberts J, Zinchenko A, Suckling C, Smith L, Johnstone J, Henselmans M. The short-term effect of high versus moderate protein intake on recovery after strength training in resistance-trained individuals. J Int Soc Sports Nutr. 2017 Dec;14(1):44.
[26]. Fátima-Ribeiro V de, Pereira R, Machado M. Resistance exercise-induced microinjuries do not depend on 1or 3 minutes rest time interval between series. RICYDE Rev Int Cienc Deporte. 2008 Oct 1;4(13):44–53.
[27]. Sikorski EM, Wilson JM, Lowery RP, Joy JM, Laurent CM, Wilson SM-C, et al. Changes in perceived recovery status scale following high-volume muscle damaging resistance exercise: J Strength Cond Res. 2013 Aug;27(8):2079–85.
[28]. Wilson JM, Lowery RP, Joy JM, Walters JA, Baier SM, Fuller JC, et al. Β-hydroxy-β-methylbutyrate free acid reduces markers of exercise-induced muscle damage and improves recovery in resistance-trained men. Br J Nutr. 2013 Aug 14;110(3):538–44.
[29]. Weakley JJS, Till K, Read DB, Roe GAB, Darrall-Jones J, Phibbs PJ, et al. The effects of traditional, superset, and tri-set resistance training structures on perceived intensity and physiological responses. Eur J Appl Physiol. 2017 Sep;117(9):1877–89.
[30]. da Silva DP, Curty VV, Areas JM, Souza SC, Hackney AC, Machado M. Comparison of Delorme with Oxford resistance training techniques: effects of training on muscle damage markers. Biol Sport. 2010;27:77–81.
[31]. Fry A, Kraemer WJ, van Borselen F, Lynch J, Marsit J, Roy P, et al. Performance decrements with high-intensity resistance exercise overtraining. Med Sci Sports Exerc. 1994;26(9):1165–73.
[32]. Wang C-C, Fang C-C, Lee Y-H, Yang M-T, Chan K-H. Effects of 4-week creatine supplementation combined with complex training on muscle damage and sport performance. Nutrients. 2018 Nov 2;10(11):1640.
[33]. Coutts AJ, Reaburn P, Piva TJ, Rowsell GJ. Monitoring for overreaching in rugby league players. Eur J Appl Physiol. 2007 Jan 25;99(3):313–24.
[34]. Kraemer WJ, Ratamess NA, Volek JS, Häkkinen K, Rubin MR, French DN, et al. The effects of amino acid supplementation on hormonal responses to resistance training overreaching. Metabolism. 2006 Mar;55(3):282–91.
[35]. Wilson JM, Lowery RP, Joy JM, Andersen JC, Wilson SMC, Stout JR, et al. The effects of 12 weeks of beta-hydroxy-beta-methylbutyrate free acid supplementation on muscle mass, strength, and power in resistance-trained individuals: a randomized, double-blind, placebo-controlled study. Eur J Appl Physiol. 2014 Jun;114(6):1217–27.
[36]. Tesch P, Komi P, Häkkinen K. Enzymatic adaptations consequent to long-term strength training. Int J Sports Med. 1987 Mar;08(S 1):S66–9.
[37]. Raeder C, Wiewelhove T, Simola RÁDP, Kellmann M, Meyer T, Pfeiffer M, et al. Assessment of fatigue and recovery in male and female athletes after 6 days of intensified strength training. J Strength Cond Res. 2016 Dec;30(12):3412–27.
[38]. Wilborn CD, Taylor LW, Campbell BI, Kerksick C, Rasmussen CJ, Greenwood M, et al. Effects of methoxyisoflavone, ecdysterone, and sulfo-polysaccharide supplementation on training adaptations in resistance-trained males. J Int Soc Sports Nutr. 2006 Dec;3(2):19.
[39]. Cadegiani FA, Kater CE. Basal hormones and biochemical markers as predictors of overtraining syndrome in male athletes: the EROS-BASAL study. J Athl Train. 2019 Aug;54(8):906–14.
[40]. Schimpchen J, Wagner M, Ferrauti A, Kellmann M, Pfeiffer M, Meyer T. Can cold water immersion enhance recovery in elite Olympic weightlifters? An individualized perspective: J Strength Cond Res. 2017 Jun;31(6):1569–76.
[41]. Khlif R, Marrakchi R, Jamoussi K, Sahnoun Z, Chtourou H, Souissi N. Plasma iron status in elite weightlifters after four weeks of intensive training. Sci Sports. 2019 Oct;34(5):328.e1-328.e8.
[42]. Wang X, Eungpinichpong W, Yang J, Chatchawan U, Nakmareong S, Wang Y, et al. Effect of scraping therapy on weightlifting ability. J Tradit Chin Med. 2014 Feb;34(1):52–6.
[43]. Eryılmaz SK, Aslankeser Z, Özdemir Ç, Özgünen K, Kurdak S. Effects of training load changes on physical performance and exercise-induced muscle damage. Rev Bras Med Esporte. 2019 Dec;25(6):509–14.
[44]. Carlson CJ, Meister W, Emilson B, Sheiner LB, Rapaport E, Bible L, et al. Clearance of serum creatine kinase activity. Cardiovasc Res. 1982 Feb 1;16(2):66–70.
[45]. Chen TC. Variability in muscle damage after eccentric exercise and the repeated bout effect. Res Q Exerc Sport. 2006 Sep;77(3):362–71.
[46]. Meneghel A, Crisp A, Verlengia R, Lopes C. Review the repeated bout effect in resistance. Int J Sports Sci. 2013;3(4):107–14.
[47]. Jamurtas AZ, Theocharis V, Tofas T, Tsiokanos A, Yfanti C, Paschalis V, et al. Comparison between leg and arm eccentric exercises of the same relative intensity on indices of muscle damage. Eur J Appl Physiol. 2005 Oct;95(2–3):179–85.
[48]. Graves JE, Clarkson PM, Litchfield P, Kirwan JP, Norton JP. Serum creatine kinase activity following repeated bouts of isometric exercise with different muscle groups. Eur J Appl Physiol. 1987 Sep;56(6):657–61.
[49]. Machado M, Brown LE, Augusto-Silva P, Pereira R. Is exercise-induced muscle damage susceptibility body segment dependent? Evidence for whole body susceptibility. J Musculoskelet Neuronal Interact. 2013;13(1):105–10.

[50]. Belcher DJ, Sousa CA, Carzoli JP, Johnson TK, Helms ER, Visavadiya NP, et al. Time course of recovery is similar for the back squat, bench press, and deadlift in well-trained males. Appl Physiol Nutr Metab. 2019 Oct;44(10):1033–42.
[51]. Bartolomei S, Sadres E, Church DD, Arroyo E, Iii JAG, Varanoske AN, et al. Comparison of the recovery response from high-intensity and high-volume resistance exercise in trained men. Eur J Appl Physiol. 2017 Jul;117(7):1287–98.
[52]. Smith LL, Fulmer MG, Holbert D, McCammon MR, Houmard JA, Frazer DD, et al. The impact of a repeated bout of eccentric exercise on muscular strength, muscle soreness and creatine kinase. Br J Sports Med. 1994 Dec 1;28(4):267–71.
[53]. Paddon-Jones D, Muthalib M, Jenkins D. The effects of a repeated bout of eccentric exercise on indices of muscle damage and delayed onset muscle soreness. J Sci Med Sport. 2000 Mar;3(1):35–43.
[54]. Chen TC, Hsieh SS. The effects of repeated maximal voluntary isokinetic eccentric exercise on recovery from muscle damage. Res Q Exerc Sport. 2000 Sep;71(3):260–6.
[55]. Chen TC, Nosaka K. Responses of elbow flexors to two strenuous eccentric exercise bouts separated by three days. J Strength Cond Res. 2006;20(1):108.
[56]. Sakamoto A, Maruyama T, Naito H, Sinclair PJ. Effects of exhaustive dumbbell exercise after isokinetic eccentric damage: recovery of static and dynamic muscle performance: J Strength Cond Res. 2009 Dec;23(9):2467–76.
[57]. Hyatt J-PK, Clarkson PM. Creatine kinase release and clearance using MM variants following repeated bouts of eccentric exercise: Med Sci Sports Exerc. 1998 Jul;30(7):1059–65.
[58]. Kang M-S, Kim J, Lee J. Effect of different muscle contraction interventions using an isokinetic dynamometer on muscle recovery following muscle injury. J Exerc Rehabil. 2018;14(6):1080–4.

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