

Magnesium-Creatine Supplementation Effects on Body Water

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This study evaluated magnesium-creatine (MgCre) supplementation on body water and quadriceps torque. Maltodextran (*P* placebo), Mg oxide plus Cre (MgO-Cre), and Mg-creatine chelate (MgC-Cre) at 800 mg Mg and 5 g Cre per day were used for 2 weeks in 35 subjects in a random assignment, blinded study. Pre-post measures were completed with bioimpedance to determine total body water (TBW), extracellular water (ECF), and intracellular water (ICF), and an isokinetic device at 180 degrees per second for knee extension peak torque (T), total work (W), and power (PWR). Body weights increased for both treatment groups, MgO-Cre Δ 0.75 kg ($P < .05$) and MgC-Cre Δ 0.4 kg ($P = .07$). Significant pre-post differences ($P < .05$) were noted only for MgC-Cre in ICW (26.29 ν 28.01 L) and ECW (15.75 ν 14.88 L). MgC-Cre had significant peak T (Nm) increase (124.5 ν 135.8, $P < .05$), while MgO-Cre (116.4 ν 124.9, $P = .06$) and placebo (119.8 ν 123.7, $P = .343$) did not. Both treatment groups had increased PWR ($P < .05$). MgC-Cre affects cellular fluid compartments. The peak torque changes were significant only in the MgC-Cre group, which had increases in ICW that may infer more muscular creatine due to its osmotic effect, and with increased cellular hydration, perhaps increased protein synthesis.

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THERE IS SOME scientific consensus that creatine (Cre) is an effective ergogenic aid for athletes engaging in repeated bouts of brief strenuous, high-intensity, maximal exercise.¹⁻⁵ Cre may enhance strength and power performances, leading to increased repetitions and power output. Cre supplementation at a rate of 2 to 5 g/d will increase muscle creatine and phosphocreatine. The general finding is that 20 g/d is the loading dose used for a period of 6 to 14 days, followed by a maintenance dose of 5 g/d continued throughout the training period.¹⁻⁵ A single dose of 5 g of Cre has raised creatine plasma levels to a peak in 1 hour, with a return to pre-supplement levels observed 5 hours after dosing. The serum half-life of Cre is probably approximately 2 hours.

Cre is more efficient with a low-fat, high carbohydrate diet. Carbohydrates (CHO) moderate differences in response to Cre supplementation.⁵ Magnesium (Mg) is ubiquitous in CHO and integral in insulin metabolism.⁶ A refinement of CHO influence would be to determine the role of Mg as an important contributor to creatine action.

Mg is intimately linked to the metabolic cycle of adenosine triphosphate (ATP) production and hydrolysis.⁶ High-intensity exercise relies on ATP from (1) ATP existing in muscle sarcoplasm, (2) myokinase reaction (ADP + inorganic phosphate), and (3) creatine kinase (CK) reaction. Both the myokinase and CK reactions require Mg. The effects of Cre and Mg overlap in muscle bioenergetics.^{6,7} With Mg deficiency, energy cannot be obtained from Cre. The diets of people engaged in exercise may be insufficient to meet their needs, which includes Mg.^{8,9}

A noted effect of Cre in the original clinical study that demonstrated its efficacy as an ergogenic aid in patients was an

increase in body weight.¹⁰ A side effect associated with Cre supplementation appears to be a small increase in body mass of approximately 0.4 to 2.1 kg, which is due to either water retention or increased protein synthesis.¹¹⁻¹³ A single study reported 55% of the body mass rise observed after 9 weeks of Cre intake was related to increased body water content.¹⁴ This finding suggests that the remaining 45% should be the consequence of a dry matter growth. A study using football players supplemented with a loading dose for 1 week and a maintenance dose for the subsequent 8 weeks showed an increase in total body water (TBW) without an increase in knee extension peak torque (T).¹⁵ It is still far from clear what proportion of weight gain during Cre supplementation is due to fluid retention and what proportion is due to an increase in lean body mass.¹ Recent methodology provides a noninvasive tool for determination of TBW and cellular fluid compartments with good reliability, with $r = 0.93$ to 0.96 ,^{16,17} and validity across ages, sex, and hydration status changes.¹⁸⁻²⁰

Information on evaluation of MgCre in 2 forms, with potentially different absorption properties with a "stacking" form and a chelate form, for effects on body water and quadriceps isokinetic torque would be of interest for physical performance and clinical relevance. The intent of this proposed study is to evaluate the effect of a 2-week supplementation period on outcomes. The study design attempts to discern the effects of different formulated MgCre supplementation compared to a placebo on TBW and cellular fluid compartments, plus T, total work (W), and power (PWR) in physically active, young subjects.

MATERIALS AND METHODS

Sample

Subjects (N = 35) were healthy, 19 to 24 years old, and recreationally active. Their primary mode of activities included a combination of jogging and/or cycling; some additionally participated in recreational sports such as soccer and basketball, among others. The frequency ranged from 3 to 6 days per week and the duration was typically 30 to 60 minutes. The subjects were asked to keep their exercise regimes consistent throughout the study. The institution's Human Subjects Committee, in accordance with the National Institutes of Health guidelines, approved the study. Subjects' informed consent and background medical history were obtained, then baseline testing was performed. Subjects were randomly assigned to 1 of 3 groups in a double-blind

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Table 1. Subject Characteristics

Group	Mean \pm SD				Weight Difference
	Age (yr)	Height (cm)	Weight Pre (kg)	Weight Post (kg)	
Placebo	22.27 \pm 2.05	171.52 \pm 7.81	71.84 \pm 11.32	71.88 \pm 10.62	0.04
MgO-Cre	22.83 \pm 4.30	169.83 \pm 8.01	67.28 \pm 11.33	68.03* \pm 10.96	0.75
MgC-Cre	21.92 \pm 2.31	173.44 \pm 12.25	71.48 \pm 16.86	71.88† \pm 17.15	0.4

NOTE. There are no between-group differences, $P > .05$. Pre-post differences within groups yielded * $P < .05$; † $P = .07$

manner with treatment order randomized: placebo, Mg oxide plus Cre (MgO-Cre), or Mg plus creatine chelate (MgC-Cre).

Diet and Supplementation

Two separate 3-day diet records were kept in each of the supplement weeks by the subjects and the records were analyzed using Nutritionist V (Silverton, OR) software. Dietary nutrient intakes were determined. Supplementation was given orally and the placebo, maltodextran, provided by the supplier appeared identical to the MgCre capsules. Subjects were given 5 g Cre and equivalent 800 mg Mg per day in 4 equal doses. The treatment period was 2 weeks. Compliance was monitored by interview as the subjects retrieved their daily doses.

Body Water

Since body weight changes may be partially related to the osmotic effect of Cre, body water was assessed with RJL Quantum X (RJL Systems, Clinton Twp, MI) body impedance spectroscopy (BIS). This tool has been used to assess TBW and volume of body water compartments, with good reliability and validity.¹⁶⁻²⁰ The subjects were instructed to maintain normal hydration and to avoid alcohol and caffeine 24 hours prior to the test. They refrained from exercise for at least 16 hours prior to testing. Tests were performed at baseline and at the completion of the treatment phase. All tests were complete at the same time of day, pre-post treatment.

Exercise Testing

The exercise protocol was maximal effort isokinetic knee extension following a reported protocol.²¹ Monitored maximal isokinetic knee extensions (speed = 180 deg \cdot s⁻¹) for 30 repetitions on a Biodex dynamometer (Biodex Medical Systems, Shirley, NY) were completed after a 10-minute warm up. All tests were complete at the same time of day, pre-post treatment.

Data Analysis

Means and standard deviations were calculated for all variables, with SPSS data analysis software (SPSS Inc, Chicago, IL). Data were

analyzed using a repeated-measures analysis of variance (ANOVA) plus Bonferroni *t*-test adjustments for multiple specific comparisons with an alpha level of 0.05.

RESULTS

Body Weights

There was a significant weight gain over the 2-weeks of 0.75 kg for the MgO-Cre group ($P < .05$), with a body weight difference of +0.4 kg in the MgC-Cre group ($P = .066$). Subject data for body weight are given in Table 1. From a 7-day activity log, the mean kilocalories expended weekly in physical activities during the study were 3,555 for placebo, 3,628 for MgO-Cre, and 3,695 for MgC-Cre, with no reported changes in activity patterns over the course of the study.

Diet and Supplementation

There were no statistically significant ($P > .05$) dietary differences pre-post treatments, hence no significant changes in dietary parameters. There were significant baseline differences in energy between placebo and MgC-Cre ($P < .05$) that were not evident in the post-treatment energy levels, which were essentially the same: 2,446.6 versus 2,496.3 kcal. There were differences in grams of CHO between placebo and both MgO-Cre and MgC-Cre ($P < .05$), but not between MgO-Cre and MgC-Cre ($P > .05$), negating a possible confounding variable in dietary CHO effect on creatine availability to the muscle. Dietary energy and key nutrients are presented in Table 2. The amount of MgCre supplementation (800 mg Mg and 5 g creatine per day) has been used previously without untoward side effects reported in the literature. No untoward effects due to the treatments were reported.

Table 2. Dietary Energy and Key Nutrients From 3-Day Diet Records Pre-Post Treatments

Group	kcal Pre	kcal Post	Protein (g) Pre	Protein (g) Post	CHO (g) Pre	CHO (g) Post	Mg (mg) Pre	Mg (mg) Post
Placebo								
Mean	2,308.3	2,134.1	105.1	108.6	299.3	253.8†	349.4	284.5
SD	898.1	939.9	68.4	71.4	125.9	96.1	215.8	175.6
MgO-Cre								
Mean	2,177.7*†	2,446.6	96.5	95.7	322.7	377.8†	339.3	324.3
SD	584.4	958.0	26.5	24.0	97.4	163.2	107.6	130.5
MgC-Cre								
Mean	2,621.4*†	2,496.3	107.8	97.9	369.9	363.5*‡	377.0	360.6
SD	518.6	815.5	34.3	40.0	76.6	132.4	134.3	214.4

NOTE * $P < .05$.

†Significant baseline differences.

‡Placebo significantly different from MgO-Cre and MgC-Cre.

Body Water

Since body weight changes may be partially related to the osmotic effect of Cre, TBW, intracellular water (ICF), and extracellular water (ECF) were assessed. The MgC-Cre group gained 0.86 L in TBW ($P = .11$), but there was greater variability in this group. Liters of ICF increased from 26.29 to 28.0 L ($P = .04$) and liters of ECF decreased from 15.75 to 14.9 L ($P = .01$), reflecting the significant changes in relative body water compartments in MgC-Cre. The differences in TBW may account for some of the body weight changes noted pre-post supplementation. The statistically significant effects in compartmental water shifts in MgC-Cre, but not MgO-Cre, may indicate a greater availability of cellular creatine in the MgC-Cre-supplemented group. Data are presented in Table 3.

Isokinetic Torque

Monitored maximal effort isokinetic knee extensions (speed = $180 \text{ deg} \cdot \text{s}^{-1}$) for 30 repetitions were completed after a 10-minute warm-up. There were significant changes in peak T pre-post treatments ($P < .05$) for MgC-Cre with a trend towards an increase in MgO-Cre ($P = .06$), hence a positive effect of the active compounds versus any notable changes in the placebo group. There were no significant differences in total work done pre-post, although the MgCre groups tended to do more work (MgO-Cre, $P = .11$; MgC-Cre, $P = .08$). Both MgCre groups exhibited more PWR ($P < .05$) after treatment compared to baseline. Data are displayed in Table 4.

DISCUSSION

There were 36 subjects who began the study. One subject from the placebo group dropped out due to time factors. All of the remaining subjects completed the treatments and testing without complaints.

Creatine and phosphocreatine undergo irreversible cyclization and dehydration to form creatinine at a rate of approximately 2 g of creatinine per day. This amount of creatine must be obtained from dietary sources or endogenous synthesis is used to sustain the body supply of creatine and phosphocreatine on a daily basis. The endogenous synthesis of creatine takes place in the liver and kidney, and creatine is released into the bloodstream to be actively taken up by the muscle cells. Glycine, arginine, and methionine are the 3 amino acids used to

Table 3. Total Body Water and Fluid Compartment Water Using Bioelectrical Impedance Spectroscopy

	Pre			Post		
	ICF (L)	ECF (L)	TBW (L)	ICF (L)	ECF (L)	TBW (L)
Placebo						
Mean	25.56	16.09	41.67	26.81	15.31	42.08
SD	6.94	2.31	9.08	9.73	1.66	9.80
MgO-Cre						
Mean	24.23	14.90	39.14	24.77	14.88	39.65
SD	6.14	2.31	7.88	6.28	1.95	7.54
MgC-Cre						
Mean	26.29	15.75	42.06	28.01*	14.88*	42.92
SD	7.49	2.94	10.14	8.75	2.74	10.57

* $P < .05$, pre-post differences within groups.

Table 4. Means for Peak Torque, Total Work, and Power From the Isokinetic Strength Tests

	Pre	Post	P Value
Torque (Nm)			
Placebo	119.9	123.7	.34
MgO-Cre	116.5	125.0	.06
MgC-Cre	124.5	135.9	.04*
Work (Nm)			
Placebo	2,344.9	2,368.5	.40
MgO-Cre	2,246.2	2,419.7	.11
MgC-Cre	2,094.4	2,721.2	.08
Power (W)			
Placebo	151.3	159.2	.35
MgO-Cre	146.2	161.2	.04*
MgC-Cre	156.5	179.0	.04*

* $P < .05$ within groups pre-post; nonsignificant between groups.

synthesize of creatine. The body can produce from 1 to 2 g of creatine per day. In healthy athletes submitted daily to high-intensity strength- or sprint-training, the maximal oral Cre supplementation should be on the order of 2 times the daily turnover, ie, less than 5 to 6 g per day for less than 2 weeks.²² Thus, the dose used in this study is 5 g, which has previously been used as an identified low dose in other studies.²³

Mg has a recommended intake of approximately 4 mg per kg body weight per day, or 280 to 350 mg absolute levels per day. Previously, levels up to 8 mg per kg body weight per day were used without side effects if given in doses throughout the day.^{6,24} With adequate renal function, these doses are well tolerated.

Three-day diet records were analyzed during the first 3 and last 3 days of the treatments. There were significant baseline differences in energy between placebo and MgC-Cre ($P < .05$) that were not evident in the post-treatment energy levels, which were essentially the same: 2,446.6 versus 2,496.3 kcal. There were differences in grams of CHO between placebo and both MgO-Cre and MgC-Cre ($P < .05$), but not between MgO-Cre and MgC-Cre ($P > .05$), negating a possible confounding variable in dietary CHO effect on Cre availability to the muscle. Also, physical activity was unchanged over the course of the 2-week treatment phase. Thus, outcomes can be attributed to the interventions.

The key outcomes were typical gains in body weight for the treatment groups with stability in weight for the placebo, significantly greater ICF and lesser ECF in the MgC-Cre group. Additionally, there was an increase in peak knee extension T for the MgC-Cre group with improved leg power in both treatment groups. The PWR as well as T measures may have applicability to performance. Transference has not been well documented, but most competitive sports, especially team sports, have elements of strength and speed. Therefore, it is important to consider power. In this study, PWR improved. Total work performed may show a component of differences in ability to sustain forces for a period of time. Hence, both treatment groups demonstrated changes in body weight and leg power compared to the placebo, with the MgC-Cre group having specific responses in fluid compartment water levels and peak T that were not observed in placebo or MgO-Cre. The

MgO-Cre group did have a tendency towards increased peak T ($P = .06$).

A consistent finding with Cre supplementation is an increase in body mass of 0.4 to 2.1 kg. In the present study, the placebo group maintained weight with a 0.04-kg difference, while the MgCre group gained 0.75 kg ($P < .05$) and the Mg-Cre group gained 0.4 kg ($P = .07$). Both MgCre groups had body weight increases within the reported range from other studies.^{4,12,13} The small increase in body weight may be a detriment in activities where the body weight is supported such as running.

Because Cre may increase body water¹⁻⁵ and Mg may modify body water levels,⁶ this study evaluated body water pre-post treatment. In another study, the authors reported 55% of the body mass rise after Cre intake is related to increase in body water content.¹⁴ In the present study, TBW was assessed by BIS, as was done in the cited study, with statistically significant increases ($P < .05$) in absolute (liters) of ICF and ECF for MgC-Cre with a change of +0.86 L in TBW ($P = .11$). In contrast to the other report on body water and Cre,¹⁴ this study showed a greater contribution of water to the observed body weight gains. In the MgO-Cre group, the 0.51 L for 0.75 kg body weight gain can account for approximately 68% of the added weight. The Mg-Cre group had greater body water gains, 0.86 L, than body weight gains, 0.4 kg, and therefore potentially lost dry matter weight. Bembien et al¹⁵ reported a loss of body fat in their study on creatine monohydrate in football players over 9 weeks.

Only the Mg-Cre group showed significant increases in liters of water in the ICF and decreases in the ECF compartments. The compartmental fluids may correspond to the osmotic effect of intracellular creatine due to supplementation effects. The statistically significant effects in MgC-Cre, but not MgO-Cre, may infer a greater availability of cellular creatine in the MgC-Cre-supplemented group. Speculation may be made between cellular hydration and protein metabolism. Clinically, cellular hydration is a determinant of protein metabolism.²⁵ Cellular hydration state is an important factor controlling cellular protein turnover, protein synthesis, and protein degradation. An increase in cellular hydration (swelling) acts as an anabolic proliferative signal. Cell shrinkage is catabolic and antiproliferative. Cell swelling favors the synthesis and inhibits the degradation of protein and glycogen. Thus, cell swelling can be considered an anabolic signal. Cell swelling has an antiproteolytic effect. The cellular hydration state is mainly determined by the activity of ion and substrate transport systems in the plasma membrane. Hormones, substrates, and oxidative stress can change the cellular hydration states within minutes, thereby affecting protein turnover. A possible mechanism for the findings of increased muscle performance may be the cellular hydration state effects of the supplement.

Mg has specific reported effects on cell volume.²⁵ The K-Cl cotransporter is a major determinant of sickle cell dehydration and is inhibited by increasing erythrocyte Mg content. Oral Mg supplementation reduces the number of dense erythrocytes and improves the erythrocyte membrane transport abnormalities of patients with sickle cell disease. An increase of intracellular Mg activity stimulates Na^+/H^+ exchange and $\text{Na}^+-\text{K}^+-2\text{Cl}^-$ cotransport and thus participates in regulatory cell volume increase.

Athletes consuming 20 g of Cre daily may incur water retention, and it may be that some reported muscle cramping and heat intolerance result from this effect.^{1,4,5} In addition, there are anecdotal reports of muscle strains and diarrhea with oral Cre.⁵ A recent report on anterior compartment syndrome has been associated with Cre supplementation.²⁶ Abnormal increases in anterior compartment pressure were noted in the lower leg at rest and following 20 minutes of level running at 80% of maximal aerobic power post Cre supplementation. A caveat may be that increased Cre would increase water and possibly result in such findings. However, the subjects in the present study did not report lower leg discomfort nor was anterior compartment pressure assessed.

The ICF increases may be related greater intracellular creatine and thus to the significantly increased T noted in the Mg-Cre group versus the positive, nonsignificant trend ($P = .06$) in the MgO-Cre group. Both MgCre groups had increased power over the set of repetitions. These findings are consistent with a recent report on these variables and response to low-dose Cre supplementation, without the added Mg.²³ Cell swelling enhances contractility in cardiac and vascular smooth muscle cells.²⁵ It is unknown whether this mechanism also works in skeletal muscle, thus contributing to reported effects of creatine-enhanced muscle power.

Cre and Mg effects have overlaps in muscle bioenergetics. The CK and the myokinase reactions provide the majority of energy required for high intensity, anaerobic activity. Both reactions require Mg.⁶ In addition, the CK reaction requires a creatine substrate. Further research is required to determine the bioavailability of the 2 different Mg and Cre formulations, stacking versus chelate.

These factors may have a positive effect on physical performance. This nascent study on effects of Mg-Cre supplementation during high-intensity exercise is limited by sample selection and being an initial comparison of the compounds on human physical performance outcomes. Further studies may discern effects in discrete populations of athletes. Studies on additional workload intensities and modes may add further information to the putative effects of such compounds on physical performance.

REFERENCES

1. Jacobs I: Dietary creatine monohydrate supplementation. *Can J Appl Physiol* 24:503-514, 1999
2. Kraemer WL, Volek JS: Creatine supplementation. *Clin Sports Med* 18:651-666, 1999
3. Kreider RB, Feffreira M, Wilson M, et al: Effects of creatine supplementation on body composition, strength, and sprint performance. *Med Sci Sport Exerc* 30:73-82, 1998
4. Sillber ML: Scientific facts behind creatine monohydrate as sport nutrition supplement. *J Sports Med Phys Fit* 39:179-178, 1999
5. Terjung RL, Clarkson P, Eichner ER, et al: American College of Sports Medicine roundtable. The physiological and health effects of oral creatine supplementation. *Med Sci Sports Exerc* 32:706-717, 2000
6. Brilla LR, Lombardi VP: Magnesium in exercise and sport, in Wolinsky I, Driskell JA (eds): *Macromolecules, Electrolytes and Mac-*

roelements in Sports Nutrition. Boca Raton, FL, CRC Press, 1999, pp 47-90

7. Balsom P, Soderhund K, Sjodin B, et al: Skeletal muscle metabolism during short duration high-intensity exercise: Influence of creatine supplementation. *Acta Physiol Scand* 154:303-310, 1995

8. Bazzarre TL, Scarpino A, Sigmon R, et al: Vitamin-mineral supplement use and nutritional status of athletes. *J Am Coll Nutr* 12:162-169, 1993

9. Worme JD, Doubt TJ, Singh A, et al: Dietary patterns, gastrointestinal complaints, and nutrition knowledge of recreational triathletes. *Am J Clin Nutr* 51:690-697, 1990

10. Siplä I, Rapola J, Simell O, et al: Supplementary creatine as a treatment for gyrate atrophy of the choroid and retina. *N Engl J Med* 304:867-870, 1981

11. Clarkson PM, Rawson ES: Nutritional supplements to increase muscle mass. *Crit Rev Food Sci Nutr* 39:317-328, 1999

12. Demant TW, Rhodes EC: Effects of creatine supplementation on exercise performance. *Sports Med* 28:49-60, 1999

13. Juhn MS, Tarnopolsky M: Potential side effects of oral creatine supplementation: A critical review. *Clin J Sport Med* 8:298-304, 1998

14. Francaux M, Poortmans JR: Effects of training and creatine supplement on muscle strength and body mass. *Eur J Appl Physiol Occup Physiol* 80:165-168, 1999

15. Bembien MG, Bembien DA, Loftiss DD, et al: Creatine supplementation during resistance training in college football athletes. *Med Sci Sport Exerc* 33:1667-1673, 2001

16. Armstrong LE, Kenefick RW, Castellani JW, et al: Bioimpedance spectroscopy technique: Intra-, extracellular, and total body water. *Med Sci Sport Exerc* 29:1657-1663, 1997

17. Berger VA, Rousset P, MacCormack C, et al: Reproducibility of

body composition and body water spaces measurements in healthy elderly individuals. *J Nutr Health Aging* 4:243-245, 2000

18. Ellis KJ, Wong WW: Human hydrometry: Comparison of multifrequency bioelectrical impedance and $^2\text{H}_2\text{O}$ and bromine dilution. *J Appl Physiol* 85:1056-1062, 1998

19. Koulmann N, Jimenez C, Regal D, et al: Use of bioelectrical impedance analysis to estimate body fluid compartments after acute variations of the body hydration level. *Med Sci Sport Exerc* 32:857-864, 2000

20. Ritz P: Bioelectrical impedance analysis estimation of water compartments in elderly diseased patients: The source study. *J Gerontol A Biol Sci Med Sci* 56:M344-M348, 2001

21. Greenhaff PL, Casey A, Short AH, et al: Influence of oral creatine supplementation of muscle torque during repeated bouts of maximal voluntary exercise in man. *Clin Sci* 84:565-571, 1993

22. Benzi G: Is there a rationale for the use of creatine either as nutritional supplementation or drug administration in humans participating in a sport? *Pharmacol Res* 41:255-264, 2000

23. Burke DG, Silver S, Holt LE, et al: The effect of continuous low dose creatine supplementation on force, power, and total work. *Int J Sport Nutr Exerc Metab* 10:235-244, 2000

24. Brilla LR, Haley TF: Effect of magnesium supplementation on novel strength training in humans. *J Am Coll Nutr* 11:326-329, 1992

25. Lang F, Busch GL, Ritter M, et al: Functional significance of cell volume regulatory mechanisms. *Physiol Rev* 78:247-306, 1998

26. Schroeder C, Pottenger J, Randall J, et al: The effects of creatine dietary supplementation on anterior compartment pressure in the lower leg during rest and following exercise. *Clin J Sport Med* 11:87-95, 2001