

social and financial ties. This does not release us from normal professional responsibility.

Child abuse is addressed in a recent leaflet entitled "Protecting children from abuse",<sup>1</sup> the result of a project that was initiated by Amateur Swimming Federation, developed by the National Society for the Protection (NSPCC) and National Coaching Foundation, and supported by the Sports Council and Childline. It is a difficult time for those involved in sport for children and in this context we must welcome the leaflet and its timely guidance. The leaflet provides a useful guide to all those involved in sport on what to do in case of suspected child abuse.

The National Coaching Foundation is also organising a nationwide series of workshops to raise awareness following on from the publication of this leaflet. We can only hope that a frank and open discussion, and setting out the steps necessary to protect children and officials, will help prevent the problem in the future.

DOMHNALL MACAULEY

<sup>1</sup> The Sports Council, Childline, The National Coaching Foundation, Amateur Swimming Federation of Great Britain, NSPCC. *Protecting children from abuse. A guide for everyone involved in children's sport*, 1996. Cretine supplementation: recent developments

## Leaders

### Creatine supplementation: recent developments

It is generally accepted that the development of fatigue during short lasting maximal exercise in man is at least partly the result of the inability of phosphocreatine (PCr) hydrolysis to maintain a high adenosine triphosphate:adenosine diphosphate (ATP:ADP) ratio, due to PCr depletion. Evidence in support of this line of thought comes from animal studies showing that complete pharmacological depletion of PCr can substantially impair muscle force production<sup>1</sup> and from human studies showing that the extent of PCr resynthesis during recovery following a bout of maximal exercise is positively correlated with exercise performance during a subsequent bout of exercise.<sup>2</sup>

The general idea that fatigue during maximal exercise may be related to the failure of skeletal muscle to maintain an adequate rate of ATP resynthesis as a result of PCr depletion led to the idea that oral creatine supplementation may be an effective strategy to increase muscle PCr and creatine (total creatine) concentrations and, thereby, exercise performance during single and repeated bouts of maximal exercise in man.<sup>3</sup> This idea is not new; studies earlier this century reported that the development of fatigue during exercise in man could be delayed by the addition of large amounts of glycine to the diet. It was hypothesised that, since glycine is a creatine precursor, glycine ingestion would stimulate creatine biosynthesis and as a result increase muscle creatine concentration and thereby improve exercise performance. However, it has also been known for some time that creatine is present in the diet of meat eaters and that oral ingestion of creatine per se can substantially increase the whole body creatine pool, the majority of which is "trapped" in skeletal muscle.<sup>4</sup>

In 1981, Sipila *et al*<sup>5</sup> reported that in patients receiving 1.5 g of creatine/day as a treatment for gyrate atrophy there was a subjective increase in strength and a reversal of the type II muscle fibre atrophy associated with this disease following a 1 year period of supplementation. More recently, creatine supplementation has been shown by several laboratories to have a positive effect on short lasting maximal exercise performance.<sup>3</sup> In accordance with this, recent work indicates that creatine supplementation mediates its performance enhancing effect by increasing PCr availability principally in fast twitch muscle fibres.<sup>6</sup> This finding is in agreement with published work suggesting the depletion of PCr specifically in fast muscle fibres limits exercise performance during maxi-

mal exercise,<sup>2</sup> and with the hypothesis that PCr acts as a temporal buffer of cytosolic ADP accumulation in this fibre type during exercise.

In the majority of exercise performance studies to date, subjects have ingesting a dose of 20 g of creatine on a daily basis for five to six days. This regimen was based on the work of Harris *et al*<sup>7</sup> which was shown to result in a ~25 mmol kg<sup>-1</sup> dry mass (dm) increase in muscle total creatine concentration with the between subject variation, however, being rather large (range 2-40 mmol kg<sup>-1</sup> dm). Since this initial study, data have been published concerning the most appropriate procedures to maximise muscle creatine uptake in man.<sup>8</sup> Indeed, in agreement with Harris *et al*,<sup>7</sup> it would appear that a rapid way to "creatine load" skeletal muscle in man is to ingest 20 g of creatine for five to six days. The increase in tissue creatine concentration achieved can then be maintained by ingesting 2 g per day thereafter. Alternatively, the ingestion of 3 g of creatine per day over a minimum period of four weeks is likely to be as effective at raising tissue levels as the higher dose regime, albeit at a slower rate.

As already mentioned, the extent of muscle creatine retention during supplementation is variable between subjects. The combination of results from several studies undertaken in our laboratory over recent years has revealed that ~20-30% of individuals "do not respond" to creatine supplementation, that is, they show less than a 10 mmol kg<sup>-1</sup> dm (8%) increase in muscle total creatine following five days of 20 g per day oral creatine supplementation (4 × 5 g doses dissolved in ~250 ml). Furthermore, it would appear that the positive effect of creatine supplementation on postexercise PCr resynthesis is not apparent if the magnitude of muscle creatine accumulation is less than 20 mmol kg<sup>-1</sup> dm. Obviously, these findings have important implications for athletes wishing to gain benefits from creatine supplementation. Indeed, more recent work has revealed that the magnitude of improvement in exercise performance following creatine supplementation is also closely related to the extent of muscle creatine accumulation during supplementation.<sup>6</sup> Hopefully, these findings will provide some insight to those athletes who have "unexplainably" gained no benefit from creatine supplementation.

While it is clear that there is considerable variation between subjects in the extent of muscle creatine accumulation during supplementation, it has also be-

come apparent that a concentration of 160 mmol kg<sup>-1</sup> dm appears to be the maximum total creatine concentration achievable as a result of creatine supplementation and occurs in about 20% of subjects. Harris *et al*<sup>7</sup> showed that the initial presupplementation muscle total creatine concentration appears to be an important determinant of creatine accumulation during supplementation, and that accumulation can be augmented by a further 10% when exercise was performed in conjunction with creatine ingestion. However, the magnitude of this response was again somewhat variable. Recent work from our laboratory<sup>9</sup> has revealed that muscle total creatine accumulation can be increased by a further 60% on average when creatine is ingested in solution (five days of creatine at 20 g per day) in combination with simple carbohydrates (370 g of carbohydrate per day), raising muscle creatine concentration in *all* subjects closer to, and in one case above, the upper limit of 160 mmol kg<sup>-1</sup> dm. As might be expected, urinary creatine excretion and plasma creatine concentration were reduced in parallel with the increase in muscle total creatine. Evidence was also presented to indicate that this augmentation of muscle creatine accumulation as a result of carbohydrate ingestion occurred because of a stimulatory effect of insulin on muscle creatine transport and this outweighed any effect that exercise had on muscle creatine accumulation.

The individual increases in muscle total creatine concentration from the study of Green *et al*<sup>9</sup> highlight the major difference between ingesting creatine in combination with carbohydrate compared with ingesting creatine alone. Fifty per cent of the subjects who ingested creatine alone (4 × 5 g per day for five days) experienced an increase in muscle total creatine concentration of less than 20 mmol kg<sup>-1</sup> dm. This contrasts with the subjects who ingested creatine in combination with carbohydrate (4 × 5 g creatine + 93 g of simple sugars for five days), all of whom experienced more than a 20 mmol kg<sup>-1</sup> dm increase. In agreement with the work of Harris *et al*,<sup>7</sup> there was a significant inverse relation between the initial muscle total creatine concentration and the magnitude of accumulation seen following creatine supplementation alone ( $r = -0.579$ ,  $n = 12$ ;  $P < 0.05$ ). However, this was not the case for those subjects who ingested creatine in combination with carbohydrate ( $r = 0.058$ ,  $n = 9$ ;  $P > 0.05$ ); therefore, the initial muscle creatine concentration was found to have no significant effect on the extent of muscle creatine accumulation when creatine was ingested in combination with carbohydrate. Given the functional relations between muscle creatine accumulation, postexercise PCr resynthesis, and maximum exercise performance outlined above, these findings will be of interest to athletes who ingest creatine in an attempt to increase exercise performance.

Of further interest, it has recently been shown that caffeine (5 mg kg<sup>-1</sup> body mass d<sup>-1</sup>, single dose) ingested in combination with creatine (0.5 g kg<sup>-1</sup> body mass d<sup>-1</sup>, eight equal doses per day) can counteract the positive effect of creatine supplementation on performance during repeated bouts of high intensity exercise.<sup>10</sup> The authors hypothesised that caffeine ingestion would augment muscle creatine accumulation through a direct and indirect (catecholamine mediated) stimulation of sodium dependent muscle creatine transport and thereby may enhance exercise performance further. However, caffeine appeared to have no stimulatory effect on muscle creatine accumulation as the authors showed a 4–6 % increase in resting muscle PCr concentration irrespective of whether caffeine was ingested or not (muscle total creatine was

not assessed directly but PCr was determined using phosphorus magnetic resonance spectroscopy). Surprisingly, therefore, the ergolytic effect of caffeine ingestion was not attributable to caffeine inhibiting muscle creatine accumulation during supplementation. The authors offered no clear alternative explanation for their performance findings but did point out that it was unlikely to be attributable to an effect of caffeine on “muscle energetics” as the final caffeine dose preceded the post-supplementation exercise test by at least 20 hours, which is easily sufficient time for caffeine elimination to have occurred. They did conclude, however, that caffeine-containing beverages are an inappropriate vehicle for ingestion of creatine supplements. This conclusion seems rather harsh given the very high single dose of caffeine given in this study. Indeed, the first reports of creatine supplementation increasing muscle creatine accumulation, maximum exercise performance, and PCr postexercise resynthesis involved subjects dissolving creatine in everyday caffeine-containing beverages immediately before consumption.

There have been recent press reports that creatine supplementation is linked to kidney damage in healthy individuals. However, at the time of writing I am aware of no data to support this conclusion. Creatine supplementation does cause an increase in urinary creatinine excretion, which is often used as an indicator of kidney function, but this increase correlates well with the increase in muscle creatine observed during supplementation and reflects the increased rate of muscle creatine degradation to creatinine rather than any abnormality of renal function.<sup>8</sup> It should be stressed, nevertheless, that the long term health risks of chronic ingestion of large amounts of creatine are presently unknown. However, with respect to the more common short term loading procedure of 20 g per day for five to six days, full haematological and clinical chemistry screening has been carried out before and after supplementation, and no adverse effects have been recorded. Equally, the 2 g per day “maintenance dose” of creatine ingestion currently advocated to maintain muscle creatine concentration during chronic periods of creatine supplementation after five to six days of creatine loading<sup>8</sup> is perhaps no greater a quantity of creatine than that found in a meat eaters diet.

PAUL L GREENHAFF

Department of Physiology and Pharmacology, University Medical School, Queens Medical Centre, Nottingham NG7 2UH.

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