Does medium chain triglyceride play an ergogenic role in endurance exercise performance?

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ABSTRACT
Because of the medium chain triglycerides (MCT) specific physical and chemical properties, they have been used over the last 40 years in enteral and parenteral nutrition. Results from clinical practice lead some researchers in the early 80’s to use them for ergogenics purposes. The hypothesis was based on the relationship between the oxidation rates of carbohydrate and fat. The increase in fat oxidation would promote glycogen sparing effect, and therefore, delay the time to exhaustion. The aim of the present paper is to review the effects of MCT supplementation upon endurance exercise performance. Most of the studies failed to prove the ergogenic effect of MCT. A few studies that showed the ergogenic effect of MCT administration used alternative experimental designs, such as high MCT dose (above from the previous established limit) or infusion. The chronic use of MCT by athletes is new and few studies have been done in this matter. These few studies showed controversial results. There is a strong tendency in the literature that MCT is not a viable strategy to increase performance during endurance exercise. The aim of this study is to discuss the effects of MCT use on endurance exercise.

Key words: Medium chain triglycerides. Endurance. Ergogenic effect.

INTRODUCTION
The progress of sports-related research over the past decades has added significantly to the increase of athletic performance. In regard to nutrition, research has typically focused on the relationship between the management of basic nutrients found in diet and performance enhancement¹.

From this assumption came the idea of providing the athlete with a load of carbohydrate before the competition, to delay exhaustion. Overcompensation diet has successfully increased both muscular glycogen storage and performance²,³. It was thus established a direct relationship between muscular glycogen content and ability to perform exercises.

Based on these findings, from the 60s, other nutritional strategies were developed to increase availability of free fatty acids (FFA) or fatty acids oxidation capability, both aiming to promote glycogen sparing effect and therefore delay exhaustion⁴.

Initially, studies by Rennie et al.⁵ and Hickson et al.⁶ used rats. In their studies, reduction of glycogen degradation rate and increased time for exhaustion after administration of corn oil were seen. These results encouraged the carrying out of tests on lipid supplementation in humans. Costill et al.⁷, Coyle et al.⁸, Dick et al.⁹ and Vukovich et al.¹⁰ showed that by increasing FFA concentration, it was possible for humans to reduce muscular glycogen utilization when performing endurance exercise. It has also been observed increase in exercise performance-maintenance capability.

It is important to mention that the techniques to raise FFA concentration employed in those studies include triglycerides intake followed by intravenous heparine infusion, but this is a too invasive procedure for a practical benefit of the athlete. Moreover, heparine is a powerful anti-coagulant, and could potentiate bleeding, in case of lesions.

Medium chain triglycerides – MCT
Due to their specific physical and chemical features, MCT have been used in enteral and parenteral diets for over 40 years¹¹,¹². They are made of fatty acids presenting 6 to 12 carbon atoms in their chain¹¹-¹⁴.
At room temperature, MCT is liquid; it is rapidly digested, and in the small intestine it splits into glycerol and 3 medium-chain fatty acid (MCFA) molecules\textsuperscript{13,14}. These compounds are submitted to lipase action at the gut and duodenum\textsuperscript{15}.

Gastric emptying rate of a MCT solution is similar to the one of a carbohydrate isotonic beverage at rest\textsuperscript{16}. MCFA absorption velocity is similar to the glucose one\textsuperscript{17}. MCFA are more polar and hydrophilic than long-chain fatty acids (LCFA), therefore, they are more rapidly absorbed by the epithelial intestinal cells\textsuperscript{16}.

Differently than LCFA, MCFA is not significantly incorporated in lipoproteins. MCFA is soluble in water\textsuperscript{13}, and is transported via hilus hepatis to the liver, bound to albumin\textsuperscript{14}.

MCT has a swift oxidation at rest and under exercise, differently than the long-chain triglycerides (LCT)\textsuperscript{18}. LCFA intramitochondrial transport depends on carnitine\textsuperscript{19}. MCFA, on the other hand, is transported through the mitochondrial membrane independently of the carnitine palmitoil-transferase (CPT) system\textsuperscript{20}. Because of its features, described earlier, MCT is a swift source of power. However, due to the huge number of carbon atoms already bound to oxygen, and thus cannot be oxidized, MCT provides approximately 8 Kcal per gram\textsuperscript{11}.

From the observation of the results presented by MCT, particularly in the medical practice, MCT intake prior of exercise has been recommended, in order to increase total lipid oxidation. The idea is that, by providing an alternative energetic substratum for extended, aerobic endurance exercises, carbohydrate endogenous supply would be less required\textsuperscript{21-23}.

**MCT CLINICAL APPLICATION**

MCT has been broadly used in clinical nutrition, when lipid digestion and absorption are compromised. Its use is a possible alternative to ensure proper supply of lipids and energy.

Among the conditions in which MCT should be used, one can mention lipid digestion disorders, due to lack of pancreatic lipases, or biliary atresia, or obstruction of bile duct, pancreatectomy or cystic fibrosis\textsuperscript{14,24,25}, and absorptive disorders, such as Whipple disease, Crohn disease, and impaired neonatal absorption\textsuperscript{14,26,27}. Clinical application include problems in lipid transportation, such as impaired kilomicron synthesis and lymphatic system disorders\textsuperscript{13,14}.

Some clinical conditions, such as major burns and generalized infection, are marked by intense catabolism. Postoperative recovery patients also present increased protein catabolism. Lipidic emulsions with MCT are used in these cases to improve nitrogen balance and attenuate lean mass loss. Jiang et al.\textsuperscript{28} tested MCT and LCT supplementation in individuals under post-op recovery. In this study they observed higher nitrogen retention in the MCT supplement arm compared to the LCT arm. Such improvement in protein metabolism was related to an increase of serum ketonic bodies and insulin.

Some studies also related MCT intake to improvement of insulin-mediated glucose uptake. Eckel et al.\textsuperscript{29} submitted diabetic (non-insuline dependent) individuals to a diet rich in MCT, to observe its effect on glucose metabolism. In this study, the necessary amount of glucose to maintain serum glucose levels during constant insuline infusion was 30% higher in these individuals. It is also important to stress that Eckel et al.\textsuperscript{29} did not see changes in serum triglyceride concentration. These authors believe MCT intake is a promising strategy to treat type II diabetes, along with other conventional nutritional measures and administration of sulfonlyureas.

Other possible MCT application is the treatment of individuals who present impaired synthesis of the enzyme that takes part in LCFA intramitochondrial transport. According to Parini et al.\textsuperscript{30}, the use of MCT is a palliative strategy, to attenuate carnitine-acetylcarnitine translocase deficiency. MCT, however, cannot be considered an ideal source of power for patients with severe deficiency of this type of enzyme. Parini et al.\textsuperscript{30} further suggest that careful management of the diet can improve prognosis for this condition.

The appropriate diet during liver regeneration is still a puzzle. However, some investigations, such as the one by Blaha et al.\textsuperscript{31}, assessed MCT effect on hepatic regeneration. After LCT and MCT supplementation during regeneration process, these authors\textsuperscript{31} concluded that a balanced MCT and LCT supplementation (40% and 60%) is the most appropriate, as it preserves liver regeneration, which was not observed with the use of only one, MCT or LCT.

A number of studies related the use of ketogenic diet to suppression of seizures in epileptic individuals\textsuperscript{32}. MCT has also been studied in the treatment of convulsions, as partial MCFA oxidation in the liver favors the formation of ketonic bodies (aceto-acetate and beta-hydroxibutirate)\textsuperscript{33,34}. Outcomes from the studies are yet controversial, particularly from animal models\textsuperscript{32}. Thavendirathan et al.\textsuperscript{35} observed that rats fed with a ketogenic diet (rich in MCT) that were further submitted to experimental models that stimulated convulsion did not present anti-convulsivant effect. In spite of the high serum levels of ketogenic bodies those animals presented, Thavendirathan et al.\textsuperscript{35} suggest that this concentration does not necessarily suppress seizures.

MCT supplementation in some specific instances has been quite effective. These findings fostered a number of stud-
ies, carried out in the 80s, to test it in exercises \textsuperscript{21-23}. However, it is not possible to assume that success in medical practice ensures effectiveness for physical exercises.

**MCT SUPPLEMENTATION IN ENDURANCE EXERCISES**

**Acute MCT administration**

Pioneer studies using MCT to enhance performance were carried out in the 80s \textsuperscript{21-23}. In the first 3 studies, no advantage on the use of MCT over carbohydrate was found.

A single study by Sabatin et al. \textsuperscript{36} demonstrated a positive effect from MCT supplementation. After intake of 45 grams of MCT, there was a proven reduction of glycogen oxidation rate \textsuperscript{36}.

Massicotte et al. \textsuperscript{37} have, afterward, compared intake of an MCT solution (approximately 30 grams) with one of glucose in humans before an extended exercise session (120 minutes), performed at 65\% of \textit{VO}_\textit{max}, in an ergometric cycle. Once oxidation rate of those substrata was assessed, it was demonstrated that both provided similar contribution for power generation during exercise. Both carbohydrate and MCT intake prevented glucose serum levels to fall, which typically occurs in longer-lasting exercises. Sustained serum glucose levels attenuated insulin reduction and increase of its regulatory counterparts (adrenaline and glucagon). According to these authors \textsuperscript{37}, hormone adjustment would have made difficult the role of endogenous fatty acid in power generation, thus preventing glycogen sparing effect.

In Borghouts et al. \textsuperscript{38} study, a double-blind, crossed supplementation model was used to determine MCT effect on the utilization of muscle glycogen. It was noted that MCT supplementation did not differ from carbohydrate in glycogen content after 180 minutes of exercise at 61\% of \textit{VO}_\textit{max} in ergometric cycle.

Still in 1995, a study performed by Sidossis et al. \textsuperscript{39} achieved results that regarded interest on the use of MCT in exercise. These authors compared the effect of MCFA with LCFA infusion during an exercise of progressive intensity. This study showed that increase in intensity reduced LCFA and increased MCFA oxidation. In relation to MCFA metabolism, Jong-Yeon et al. \textsuperscript{40} observed that endurance training enhances their oxidation.

After the above mentioned studies, the main focus of investigation was to compare intake of MCT alone, MCT associated to carbohydrates, and carbohydrates alone. Jeukendrup et al. \textsuperscript{41} gave MCT supplement to athletes, in order to raise their serum concentration of fatty acids and, therefore, enhance their oxidation. Results showed that during exercise performed in ergometric cycle at 57\% of \textit{VO}_\textit{max} for 180 minutes, MCT oxidation rate, when associated to glucose, reached 72\% of the intake amount. It was thus shown that MCT is an alternative source of energy for exercising. Due to low gastrointestinal tolerance, however, energetic contribution from MCT oxidation was insignificant (3\% to 7\% of the energy used). Previous studies, such as that by Ivy et al. \textsuperscript{21}, also confirmed that the maximum tolerance to MCT is 30 grams. In 1996, Jeukendrup et al. \textsuperscript{42} induced glycogen depletion in humans and then administered MCT alone, MCT associated to carbohydrate or carbohydrate alone, prior to a 90-minute exercise session at 57\% of \textit{VO}_\textit{max} in ergometric cycle. It was then noted that reduction of stored glycogen exacerbated total fat oxidation \textsuperscript{42}. However, oxidation of the administered MCT was not significantly increased. Once more, energy from MCT oxidation was insignificant.

In another study carried out by Jeukendrup et al. \textsuperscript{12}, supplementation of 29 grams of MCT with carbohydrate during an exercise at 57\% of \textit{VO}_\textit{max} for 180 minutes in ergometric cycle did not promote increase in the concentration of serum fatty acids, neither influenced the utilization of endogenous carbohydrate.

In 1996, a study carried out by VanZyl et al. \textsuperscript{43} reported performance improvement from MCT intake. The subjects were submitted to submaximal exercise (60\% of \textit{VO}_\textit{max} for 120 minutes in ergometric cycle) followed by a an exercise test in cycloergometer in which one should traverse 40 kilometers in as short a time as possible. During exercise, athletes would receive, initially, 400 ml, followed by 100 ml at every 10 minutes of one of the following solutions: MCT at 4.3\% (MCT), MCT at 4.3\% associated to carbohydrate at 10\% (MCT + CHO), or carbohydrate at 10\% (CHO). Athletes who received MCT + CHO traversed the 40 kilometers in significantly less time than the others. There was no difference in serum glucose levels, glyceral and endogenous fatty acids between MCT + CHO group and CHO only group \textsuperscript{43}.

For the first two hours, total serum fatty acid concentration was unchanged. Only from the third hour of the test on, the MCT + CHO group presented increase in MCFA and ketonic bodies concentration. At the same time, this group presented reduced lactate production compared to CHO group. These results lead to the conclusion that reduced oxidation of endogenous carbohydrate in the MCT group was due to ketogenesis increase \textsuperscript{43}.

The amount of MCT used by VanZyl et al. \textsuperscript{43} (86 grams) was significantly higher than the amount given in prior studies. These authors propose that the reduced MCT amount, of approximately 30 grams (4 ml/kg in the beginning, and 2 ml/kg at every 20 minutes, of a solution at 5\%), used in prior studies \textsuperscript{12,41,42} was not effective in promoting increase
of serum fatty acids and, therefore, glycogen sparing effect.

The findings of VanZyl et al.⁴³ caused a lot of controversy among investigators of the field as, up to now, studies had respected the intake limit of 30 grams of MCT. Therefore, to corroborate these findings, Jeukendrup et al.⁴⁴ carried out a study similar to VanZyl’s et al.⁴³, supplementing subjects with 85 grams of MCT. Subjects exercised for 120 minutes at 60% of VO₂ max, immediately followed by a cycloergometer testing. Administration of solutions was done as follows: 8 ml/kg at the beginning of the exercise, and 2 ml/kg at every 15 minutes during exercise. There was no significant differences in the time taken to perform exercise between carbohydrate solution at 10% and MCT at 5% + carbohydrate at 10% solution. MCT at 5% solution not only cause gastrointestinal discomfort, but impaired performance, compared to placebo (water) and carbohydrate at 10% solution groups.

That controversy on the effect of the MCT amount on performance lead to a new study. Goedecke et al.⁴⁵ gave 9 cyclists one of three supplements: 10% glucose solution, 10% glucose solution + 1,72% MCT, or 10% glucose + 3.44% MCT. The investigators were also interested in studying the effects of progressive MCT intake on gastrointestinal tract and carbohydrate oxidation during cycloergometer exercise with 120-minute duration at 63% of VO₂ max.

FFA and ketonic bodies concentration raised, but this did not affect oxidation of this substrate nor cyclists performance. The high carbohydrate intake (approximately 140 grams) before the exercise, in that study, raised the level of serum insulin. According to Goedecke et al.⁴⁵, this facilitated carbohydrate, rather than fatty acid oxidation, in spite of the high concentration of the later after MCT intake.

In Van Zyl et al. study,³ the meal prior to the test included 85 grams of carbohydrate. The amount of carbohydrate intake resulted in serum insulin concentration close to 6-7 mU/L, whereas in Goedecke et al. study, serum insulin concentration ranged between 13-24 mU/L. To Goedecke et al.,⁴⁵ ergogenic benefit from MCT may be limited by the increase of serum insulin and its inhibition effect on lipolysis and fatty acid oxidation.

As to gastrointestinal discomfort, Goedecke et al.⁴⁵ observed that only 2 athletes were intolerant to MCT. Jeukendrup et al.⁴⁴, conversely, suggested that lack of performance improvement in their investigation could be partially due to gastrointestinal discomfort, also reported by Ivy et al.⁴¹ and Decombaz et al. ²². To Goedecke et al.,⁴⁵, MCT tolerance is an individual feature, and cannot be considered as the sole limiting factor to performance. Those results suggest that athletes should test their tolerance to MCT at training sessions, before using it at a competition.

The main purpose of Horowitz et al. study⁴⁶ was to investigate if a tolerable intake of medium-chain triglycerides (25 grams) actually decreases muscle glycogenolysis and muscular glycogen oxidation during intense exercise (84% of VO₂ max). Their subjects were 7 well-trained cyclists who should perform high-intensity exercise for 30 minutes on cycloergometer, being the first 2 minutes at 60% of VO₂ max and the ensuing 28 minutes at 84% of VO₂ max, 60 minutes after carbohydrate intake (0.72 grams of sucrose/kg) alone or associated to MCT (0.36 gram of MCT/kg + 0.72 gram of sucrose/kg).

Horowitz et al.⁴⁶ reported that serum FFA did not increase, but this does not mean that ingested MCT did not enter blood stream. As Massicotte et al.³⁷ previously showed, about 60% of a MCT meal was oxidated during exercise, without increase of serum FFA higher than in controls. In this study, MCT supplementation did not affect substratum oxidation during high-intensity exercise.

According to Angus et al.,⁴⁷ most studies assess MCT supplementation effects from exercises of constant and moderate intensity. For them, however, these experimental models do not replicate the conditions of an actual competition. In order to simulate a competition environment, a cycloergometer test was carried out, in which 100 kilometers should be traversed in as little time as possible. Three different solutions – carbohydrate (6%), carbohydrate (6%) + MCT (4.3%), and sweet placebo – were administered as follows: 250 ml of solution before the test and 250 ml during exercise, at 15-minute intervals until the end. Angus et al.⁴⁷ noted that athletes kept a similar level of work generation (watts) for the first 135 minutes, regardless of what they drank, which decreased close to the end of the exercise for the placebo group, only.

Angus et al.⁴⁷ also showed that CHO intake over 100 kilometers by well-trained athletes enhanced performance. The adding of MCT to CHO beverage did not change FFA serum concentration nor promoted further reduction in the stored CHO, compared to CHO alone. The suggested explanation was that high intense exercise decreases blood flow to the gastrointestinal tracts, affecting MCFA serum availability and thus limiting its energetic contribution.

As to acute MCT consumption to preserve muscular glycogen, most studies failed to show positive results. Among the few studies³⁶,³⁹,⁴³ that demonstrated MCT ergogenic effect, some aspects should be stressed. In Sidossis et al. study,⁴³, MCT was intravenous administered. After being absorbed, MCFA follow through the hilus hepatis directly to the liver, where they are rapidly metabolized. Intravenous administration is, therefore, a strategy to overcome the physiologic barrier that liver represents for these fatty
acids, and this would increase their availability to the muscle.

Both in Sabatin et al.36 and in VanZyl et al.43 studies, the amount of MCT administered is higher than the gastrointestinal tolerance limit proposed as safe by the literature. In VanZyl et al.43 study, carbohydrate intake prior to the exercise was lower than in other studies. This has influenced insulin concentration, adding to a higher FFA mobilization and oxidation. The amount of ingested carbohydrate may have also contributed for discrepant results. Such differences in experimental models prevent direct outcomes comparison.

As to acute MCT supplementation, the challenges one still has to face are establishing maximum MCT tolerance, and the confirmation of a dose-dependent relationship between MCT and glycogen sparing effect.

**Chronic MCT administration**

One of the pioneer studies to assess chronic use of MCT was Fushiki’s et al.48. Its aim was to investigate the effect of chronic MCT intake (6 weeks) in swimming endurance capability of sedentary and trained rats. Two diets were prepared, one with 80 grams of MCT + 20 grams of LCT, the other with 100 grams of LCT.

Swimming capability for groups receiving chronic MCT supplements was the same as for the LCT supplement group. However, two weeks after the beginning of training associated to supplementation, MCT group presented a significantly higher resistance to fatigue than the LCT group48. Resistance to fatigue of rats that received a single MCT dose (acute supplementation) was not affected48. These data confirmed most results from acute MCT intake studies.

Fushiki et al.48 further observed that sedentary and trained rats fed with MCT for 6 weeks took longer for exhaustion. For these authors, increase in concentration of ketonic bodies and fatty acids from the chronic MCT intake may have partially added to performance improvement.

In a study we carried out 49, chronic supplementation (8 weeks) with palmiste oil (rich in medium-chain fatty acids – C12:0) muscle glycogen sparing effect was evident, compared to the control group. However, at the end of the treadmill workout, carried out for 60 minutes at 65% of maximum oxygen uptake (VO2max), liver glycogen levels were decreased, compared to controls49. It is to be stressed that, in rodents, hypoglycemia-related liver glycogen depletion precedes muscular glycogen reduction49. Therefore, for rats, liver glycogen is a limiting factor for exercise performance. In spite of time for exhaustion not having been assessed, we believe reduction of the liver glycogen storage is deleterious for exercise maintenance capability49.

Studies in humans, such as Goedecke’s et al.51 and Missel’s et al.52, as well as those in rodents, present controversial outcomes. Goedecke et al.51 investigated the effect of an isocaloric diet, rich in MCT, for 15 days. Each experiment included 150 minutes on cycloergometer at 70% of VO2peak immediately followed by a test in which 40 kilometers should be traversed in as little time as possible. Before the experiment, athletes ingested an emulsion of orange flavored 10% carbohydrate and 3.44% of MCT. In this study, chronic intake associated to acute ingestion of MCT was assessed.

Goedecke et al.51 reported that exposure to a hyperlipidic diet for a short period of time, such as 5 to 10 days, leads to an increase in fat oxidation and, at the same time, spares muscular glycogen during exercise, compared to the control diet. This change in the metabolism of the substratum may occur due to increase of the CPT enzyme complex in the muscle and to the low muscular glycogen stored. However, no reduction in the time to traverse 40 kilometers was seen.

In Missel et al.52 study, the aim was to determine the effect of chronic MCT intake on endurance exercise performance of runners. Participants ingested 56 grams of LCT and 60 grams of MCT per solution, daily, for two weeks. This recommendation was followed until the day before the test, keeping total fat intake of approximately 30% of the total power. The test was performed on a treadmill, at 85% of VO2max for 30 minutes, after which intensity was reduced to 75% of VO2max until voluntary exhaustion. MCT supplementation did not cause time to exhaustion to increase, compared to LCT. Initially, MCT intake caused discomfort in all participants; however, after 2 weeks, most participants reported symptom decrease. Missel et al.52 believe chronic MCT intake increases tolerance to its acute ingestion, and that safety limit of 30 grams, previously suggested, may be changed.

In spite of some promising results from the chronic use of MCT, it is to be stressed that there are few studies that assessed side effects from this practice. We noted that chronic and high intake of palmiste oil (rich in lauric acid C12:0) in sedentary rats triggered deleterious adaptations, such as GI index reduction (glucose and insulin ratio, broadly used to assess peripheral resistance to insulin), increase of serum triglycerides and proportion of fat53-55. In trained rats, however, such deleterious effects from chronic MCT use were attenuated55.

Chronic MCT administration to humans, to enhance physical performance, is recent and little explored. Some issues are still open, such as the ideal duration of supplementation period, and the proportion of lipids in relation to the overall calories ingested. Only after solving these
issues, it will be possible to conclude if MCT provides ergogenic benefit with no health hazards.

**CONCLUSIONS**

Over the past 20 years, MCT use for endurance exercises was the focus of a number of investigations. However, some issues are yet to be solved in regard to MCT supplementation, such as assessing if glycogen sparing effect has a dose-dependent relationship with MCT administration, and to determine if gastrointestinal tolerance is an individual feature. As to the safe limit for intake, more evidences are necessary to confirm this can be changed by chronic MCT use.

**REFERENCES**


As to the question posed in the title of this review, one may conclude that there are some controversies about MCT-induced performance. Currently, however, there is a strong tendency in the literature not to associate MCT supplementation to glycogen sparing effect and performance enhancement. Except for some few studies that suggested ergogenic benefit from MCT intake, most results show this diet strategy is poorly effective, and is not superior to carbohydrate supplementation.

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