

UNIVERSITY OF WISCONSIN-LA CROSSE

Graduate Studies

ACUTE METABOLIC EFFECTS OF BULLETPROOF COFFEE

A Manuscript Style Thesis Submitted in Partial Fulfillment of the Requirements for the
Degree of Master of Science

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Clinical Exercise Physiology

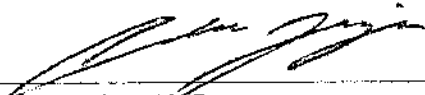
December, 2016

ACUTE METABOLIC EFFECTS OF BULLETPROOF COFFEE

By Joshua Fritchen

We recommend acceptance of this thesis in partial fulfillment of the candidate's requirements for the degree of Master of Science in Clinical Exercise Physiology


The candidate has completed the oral defense of the thesis.



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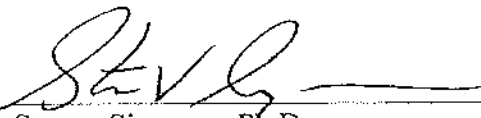


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ABSTRACT

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Bulletproof Coffee, a modified coffee, is rapidly gaining popularity due to its purported metabolic claims. The coffee is marketed as a fat burning ergogenic aid, containing medium chain triglyceride (MCT) Oil and grass fed butter. **Purpose:** This study compares the acute effects of Bulletproof Coffee on resting energy expenditure (REE) and fat oxidation (RQ) compared to standard black coffee. **Methods:** Twelve healthy subjects performed two double blind experimental metabolic tests. Subjects performed a baseline metabolic test. Subjects then completed a second test measuring changes in REE and RQ after consuming the two coffees. Satiety, alertness and gastrointestinal were assessed pre and post ingestion of both tests. **Results:** Significant increases in REE were seen from baseline to 30 minutes and 60 minutes post ingestion. Increases in REE were 207 ± 76 kcal/day and 224 ± 77 kcal/day 30 minutes and 60 minutes post ingestion, respectively. Significant decreases in RQ were 0.077 ± 0.015 and 0.068 ± 0.015 30 minutes and 60 minutes post ingestion respectively for Bulletproof Coffee. **Conclusion:** The results suggest the addition of MCT oil and butter to standard coffee appears results in acute increases in REE and fat oxidations rates.

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INTRODUCTION

Recent statistics estimate that over half of United States population consumes coffee (Greenberg, Boozer and Geliebter, 2006). The primary active ingredient found in coffee is caffeine, which is a stimulant whose effects have been widely researched. Through its influence on the sympathetic nervous system, caffeine has been shown to increase metabolic activity. For example, Acheson et al. (1980) examined the effects of coffee consumption on metabolic rate and substrate utilization. Acheson et al. (1980) found that coffee increased the mean metabolic rate by $12 \pm 3\%$ for the lean group and $10 \pm 2\%$ for the obese group after coffee consumption of 4 mg caffeine/kg bodyweight. Increases in rates of fat oxidation were apparent but not significant as well (Acheson et al., 1980). In a similar study, Braco et al. (1995) investigated coffee's influence on metabolism in lean and obese women (Bracco et al., 1995). They observed a significant increase in energy expenditure and fat oxidation following ingestion of coffee. Specifically, lipid oxidation increasing by 29 and 10% in lean and obese women, respectively. Research suggests a relationship between coffee consumption (4 mg caffeine/kg of bodyweight) and an increase in metabolic and fat oxidation rates.

Dulloo et al. (1989) examined the influence of caffeine consumption at commonly consumed dosages of 100-450 mg of caffeine can increase energy expenditure (Dulloo et al., 1989). Similarly, Acheson et al. (2004) investigated whether the lipolytic effect of caffeine was associated with increased lipid oxidation or futile cycling between

triacylglycerol and free fatty acids. They examined that caffeine consumption was associated with increases in both lipid oxidation rates and fatty acid turnover (Acheson et al., 2004). Over time these acute increases in energy expenditure and lipolysis may have a positive influence on body weight management. As evidenced, Lopez-Garcia et al. (2006) assessed the relationship between caffeine use and weight gain over 12 years and increases in caffeine intake may lead to small reduction in long-term weight gain (Lopez-Garcia et al., 2006).

Recently, a modified form of coffee, known as Bulletproof Coffee is rapidly gaining popularity due to its purported metabolic claims. The coffee is marketed as a fat-burning ergogenic aid and based upon manufacture recommendations, is to include coffee, grass-fed butter and medium chain triglyceride (MCT) oil. MCT oil is the key ingredient found in Bulletproof Coffee that is purported to enhance fat utilization. A meta analysis of MCT studies concluded that MCTs could be absorbed and oxidized quicker than normal long chain triglycerides (LCT) (Bach & Babayan, 1982). The quicker absorption and oxidation of MCTs led to further investigation for it's potential uses regarding weight loss. Previous research has suggested that diets high in MCTs compared to LCTs yielded higher rates of energy expenditure, fat oxidation and lower amounts of adipose tissue (Scalfi et al., 1991; St-Onge et al., 2003). By substituting breakfast with the blended coffee drink, Bulletproof Coffee claims individuals will see an increase in fat utilization and potentially enhance weight loss over time.

While Lopez-Garcia et al. (2006) and St-Onge et al. (2003) have shown caffeine and MCT, respectively, can aid in weight management over time, the current study intended to determine the acute metabolic effects of combining the two, common to that

of Bulletproof Coffee. Therefore, the purpose of this study was to compare the acute effects of Bulletproof Coffee on resting energy expenditure (REE) and fat oxidation, compared to standard black coffee. A secondary aim was to examine the influence of Bulletproof Coffee on satiety and gastrointestinal discomfort. We hypothesized that Bulletproof Coffee will elicit greater acute REE and fat oxidation rates.

METHODS

Subjects

The subjects for this study included twelve healthy, young adult volunteers from the University of Wisconsin-La Crosse. The subjects of the study were habitual coffee drinkers, consuming approximately 326.0 ± 99.67 mg of caffeine per day. The UW-La Crosse Institutional Review Board for Protection of Human Subjects (IRB) reviewed and approved this study. Prior to testing, the subjects provided written informed consent and completed a Physical Activity Readiness Questionnaire (PAR-Q) to determine health status. Subjects also filled out a coffee consumption questionnaire to avoid any caffeine intolerances during testing and ensure that entrance criteria had been met. The descriptive statistics of the subjects are included in Table 1.

Table 1. Descriptive Characteristics of Subjects (mean \pm SD)

	Male (n=3)	Female (n=9)
Age (yrs)	21.3 \pm 1.09	23.2 \pm 1.53
Height (cm)	178.3 \pm 92.52	165.1 \pm 5.67
Weight (kg)	92.5 \pm 18.21	66.5 \pm 10.70
Daily Caffeine Consumption (mg)	346.7 \pm 37.53	319.2 \pm 114.43

Testing Procedure

Experimental Design: The study utilized a double-blind cross-over design. Subjects completed two experimental testing conditions and were randomly assigned to ingest either Bulletproof or standard black coffee. Subjects' height and weight were recorded before their first test. In an attempt to limit the influence of different food consumption, subjects were instructed to fast 12 hours prior to testing and consume a standardized meal 12 hours prior to testing. The standardized meal consisted of 2 slices of wheat bread, 2 tablespoons of peanut butter, 1 banana and 12 ounces of orange juice which equated to 600 calories, 95 g of carbohydrates, 19 g of protein and 19 g of fat. Prior to testing, subjects first completed a questionnaire assessing their baseline levels of satiety, gastrointestinal (GI) tolerance and alertness on a five point Likert scale. Heart rate (HR) blood pressure (BP), REE and respiratory quotient (RQ) were also measured prior to ingestion of the drink. The REE was measure in kcal/minute. The RQ was used as an indicator of fat oxidation rates. Following baseline measurements, subjects were given 20 minutes to ingest their dosage of coffee. Immediately following ingestion of the coffee, subjects completed a second REE assessment. HR, REE and RQ were recorded at 30 and 60 minutes post ingestion. Blood pressure was assessed at 30 and 60 minutes post ingestion. Following both tests, subjects completed the questionnaire assessing their satiety, alertness and GI tolerance. Subjects repeated the testing protocol within 7 days on the initial testing session consuming the opposite coffee beverage.

Hemodynamics: Subjects wore a Polar heart rate monitor (Polar Electro Inc., Lake Success, NY) to record changes in heart rate during testing.

Metabolic Testing: Resting energy expenditure and RQ were assessed using indirect calorimetry. For these tests, subjects remained in a supine position for 20 minutes underneath a metabolic hood (Parvo Medics TrueOne 2400 Canopy System Parvo Medics, Sandy, UT) Data were collected over the final 10 minutes when changes in VO₂ varied by less than 10%.

Coffee Preparation: Bulletproof Coffee was prepared in a ratio of 12 ounces of coffee, 1 tablespoon of Brain Octane MCT Oil and 1 tablespoon of grass fed butter. Both coffees were brewed using 2.5 tablespoons of coffee ground per 12 ounces of water. Subjects consumed different volumes of coffee, so each subject ingested 4 mg of caffeine/kg of bodyweight.

Questionnaires: A questionnaire was developed to measure secondary measurements of satiety, alertness and GI tolerance. The questionnaire consisted on three Likert scales assessing the secondary measurements. Subjects assessed satiety, alertness and GI tolerance pre and post testing sessions.

Statistical Analysis

The raw data were analyzed using a two-way (treatment x time) repeated measures ANOVA to test the differences in HR, BP, REE and RQ between standard coffee and Bulletproof Coffee conditions. Statistical significance was determined at $p < 0.05$. Tukey's post-hoc test was used when justified by ANOVA with statistical significance set to $p < 0.05$.

RESULTS

Figure 1 presents a summary of the changes in REE over time following the ingestion of Bulletproof Coffee and standard black coffee. A significant interaction between time and condition for REE was observed ($p=0.003$). In both conditions, REE rose, however, the increase was only significant during the Bulletproof condition. Significant increases in REE were seen from baseline to 30 minutes post ingestion and baseline to 60 minutes post ingestion with Bulletproof Coffee. Increases in REE were 207 ± 76 kcal/day and 224 ± 77 kcal/day 30 minutes and 60 minutes post ingestion respectively. There was no significant increase in REE during the 30 to 60 minutes post ingestion time period with Bulletproof Coffee. While a slight rise in REE was observed with the standard black coffee condition, the increase in REE was not significantly higher than the baseline measurements.

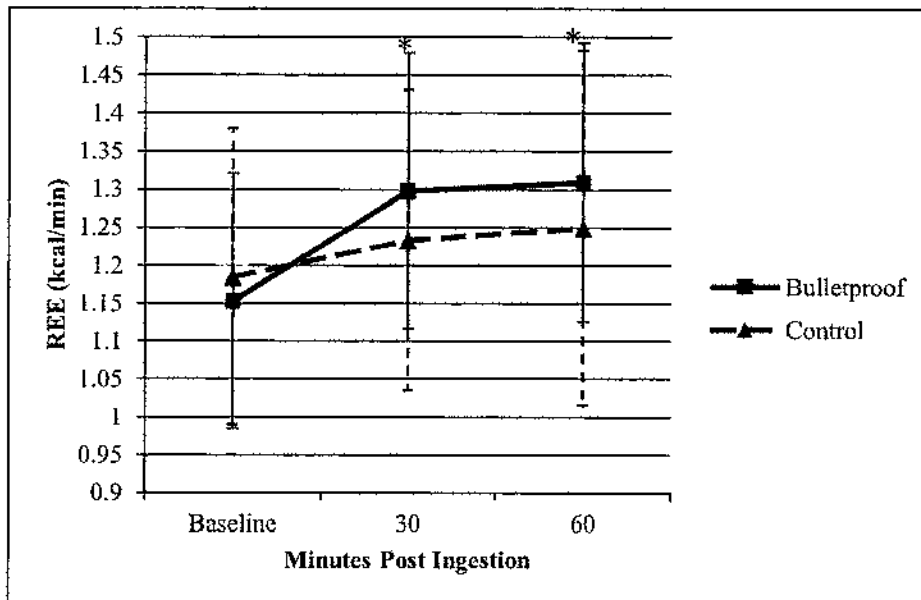


Figure 1. Change in Resting Energy Expenditure after coffee ingestion.
 * Denotes significance from baseline for Bulletproof Coffee ($p < 0.05$)

Similar results were seen with the fat oxidation rates. Figure 2 provides a summary of changes in respiratory quotient following ingestion of coffee. A significant interaction between time and condition was observed ($p=0.003$) With Bulletproof Coffee, significant decreases in RQ were seen from baseline to 30 minutes and baseline to 60 minutes, indicating an increase in fat oxidation. Decreases in RQ were 0.077 ± 0.015 and 0.068 ± 0.015 30 minutes and 60 minutes post ingestion respectively for Bulletproof Coffee. There was no significant difference between the 30 and 60 minute post ingestion RQ values for Bulletproof Coffee. There was no significant difference in RQ values from baseline after consuming black coffee.

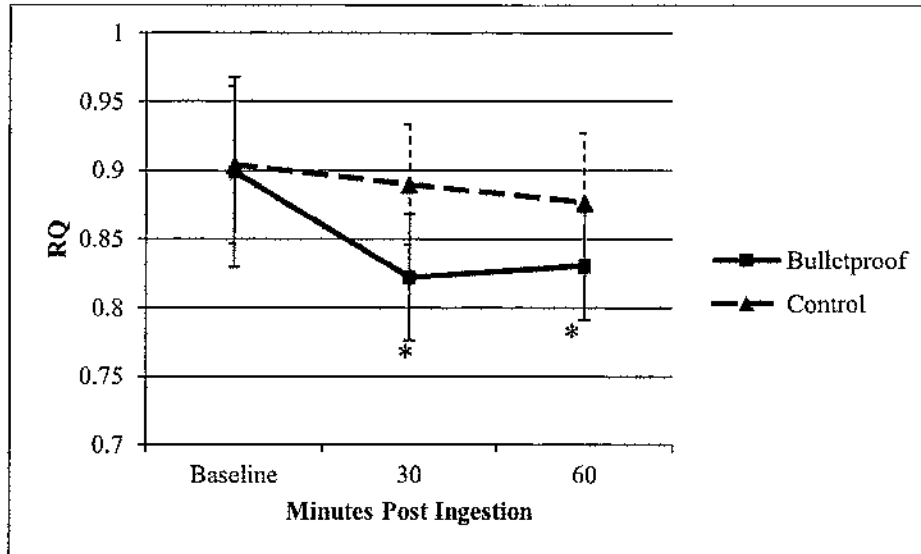


Figure 2. Change in Respiratory Quotient after coffee ingestion.
 * Denotes significance from baseline for Bulletproof Coffee ($p < 0.05$)

Figure 3 presents a summary of changes in HR following coffee ingestion. No significant interaction between time and condition was observed ($p=0.063$). However, a significant main effect for time was observed ($p=0.037$). A significant main effect for condition was observed as well ($p=0.040$), with mean HR values of 66.4 ± 2.5 and 62.6 ± 1.5 bpm for Bulletproof Coffee and black coffee, respectively.

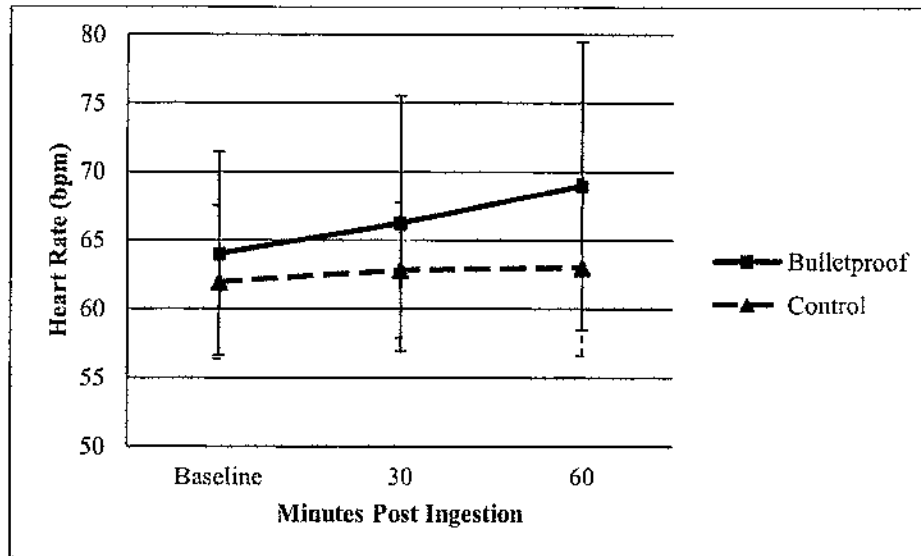


Figure 3. Change in heart rate after coffee ingestion.

No significant main effect for condition was seen in SBP ($p=0.757$). Mean values of SBP were 114 ± 1.8 and 113 ± 1.4 mmHg for Bulletproof Coffee and black coffee respectively. No significant interaction between time and condition was observed ($p=0.967$) as well. It was found that there was a significant baseline to 60 minutes overall main effect on DBP, but no interaction, indicating that the increase in DBP between groups were similar. Mean overall values of DBP were 72 ± 1.4 and 76 ± 1.5 mmHg for baseline and 60 minutes post, respectively. Figure 4 shows the changes in DBP.

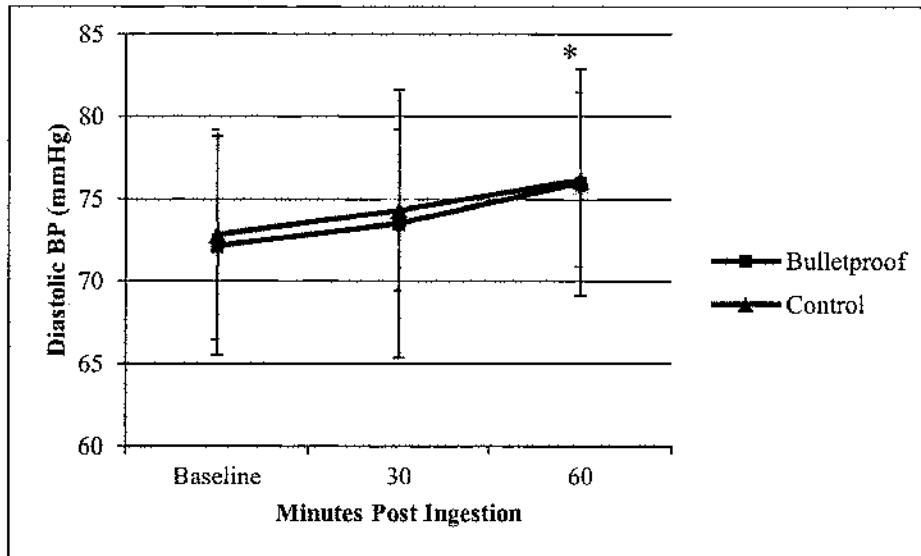


Figure 4. Change in Diastolic Blood Pressure after coffee ingestion.
 * Denotes overall significance from baseline ($p < 0.05$)

Subjects reported significantly higher ratings of satiety following ingestion of Bulletproof Coffee. On the five point scale, feeling of satiety rose by 0.875 ± 0.31 . After the black coffee tests, feelings of satiety slightly dropped by 0.417 ± 0.30 points, but was not significant. Changes in satiety can be seen in Figure 5.

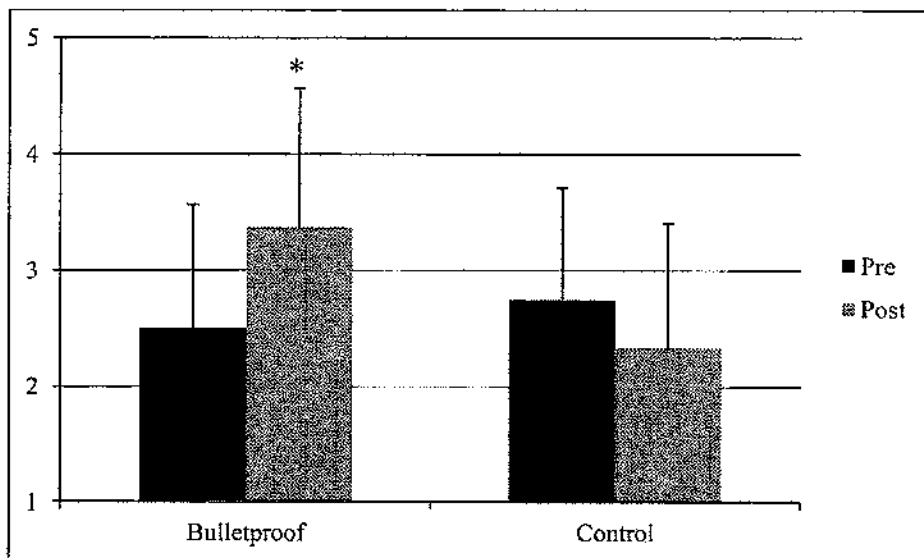


Figure 5. Change in Satiety scores after coffee ingestion.
 * Denotes significance from pre to post testing ($p < 0.05$)

Significant increases in alertness scores from pre to post ingestion were observed with both testing conditions, however no significant difference in change scores was observed between the two testing conditions. Alertness scores rose 0.875 ± 0.10 points for Bulletproof Coffee. For black coffee, alertness scores saw a rise 1.083 ± 0.10 points. Changes in alertness scores can be seen in Figure 6.

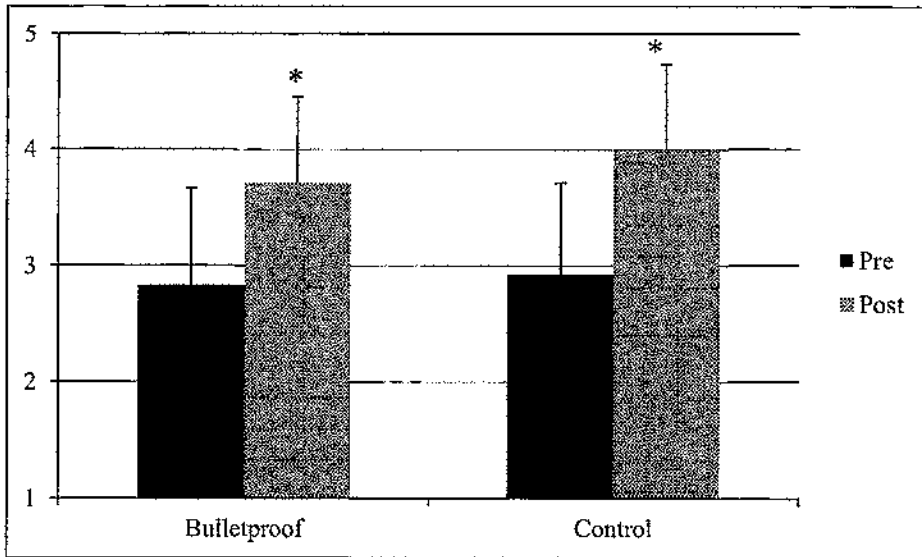


Figure 6. Change in Alertness scores after coffee ingestion.
*Denotes significance from pre to post testing ($p < 0.05$)

Figure 7 presents a summary of changes in GI tolerance after coffee consumption. A significant decrease in the feeling of GI tolerance was seen from following ingestion during the Bulletproof testing. Bulletproof Coffee saw a decrease of 1.33 ± 0.21 in GI tolerance scores. Although a decrease of 0.25 ± 0.10 GI tolerance points was observed after black coffee, it was not significantly different than pretesting measurements.

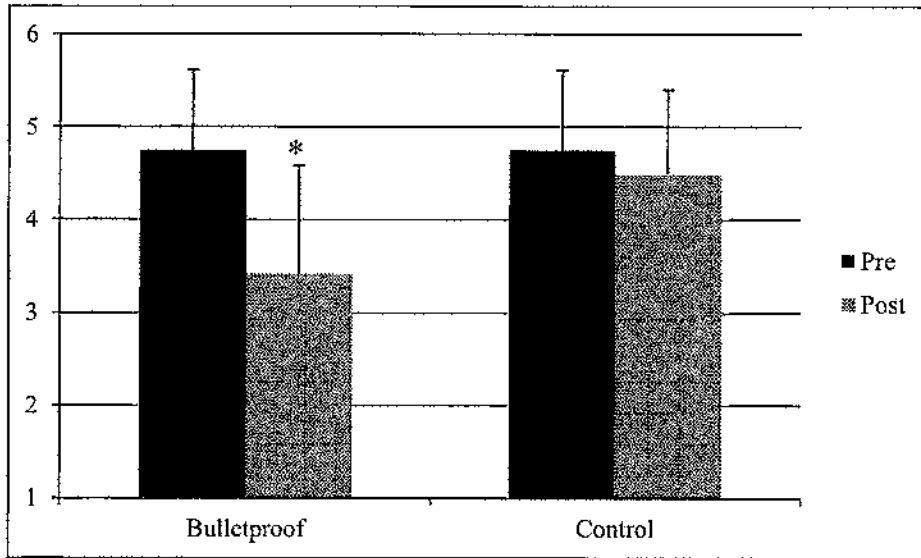


Figure 7. Change in GI Tolerance after coffee ingestion.
*Denotes significance from pre to post testing ($p < 0.05$)

DISCUSSION

Results from this study suggest that the addition of butter and MCT oil may augment increases in REE following ingestion compared to standard coffee. It was concluded that Bulletproof Coffee significantly increased REE, whereas black coffee did not. Dulloo et al. (1989) showed that the thermic effect of food is increased by the ingestion of caffeine. It should be noted that the addition of the MCT oil and butter used in the current study equated to an additional 200-550 kcal. Therefore it is unknown whether the reported increase in REE would offset the additional calories consumed if the goal is weight loss. The Bulletproof Coffee contained approximately 230 kcal per 12 ounces of coffee. Previous research has shown ingestion of a 300 kcal meal causes a sharp rise in metabolic rate that reached peak levels in 30-60 minutes (Dulloo et al., 1989). Therefore, further research needs to be done comparing the acute metabolic effects of Bulletproof Coffee to black coffee with a meal of equal caloric value. Although black coffee's increase in REE did not reach significance, this may have been due to the dosage of caffeine. One review on caffeine stated that a habitual consumption of 6 cups coffee causes an increase in REE of approximately 100 kcal/day (Greenberg, Boozer & Geliebter, 2006). This suggests that higher dosages of caffeine may have been needed to increase REE when consuming standard coffee because of the habitual dosages reported by the subjects in the current study.

Results from this study also suggest that Bulletproof Coffee may enhance acute rates of fat oxidation as evidenced by the lower RQ values. Previous research on caffeine's effect on fat oxidation is consistent with the findings of the present study (Acheson et al., 1980). The addition of MCT appeared to exacerbate this response, which is contrary to previous findings. Scalfi et al. saw an increase in RQ with a meal rich in MCTs compared to a meal rich in LCTs.

The consumption of coffee does not appear to influence SBP and the addition of MCT oil and butter to standard coffee does not appear to further influence SBP, which is in opposition to previous findings. A review of the literature by Nurminen et al. (1999) on caffeine and BP stated 200-250 mg of caffeine increases SBP 3-14 mmHg (Nurminen, Niittynen, Korpela & Vapaatalo, 1999). Though the present study's findings on SBP are inconsistent with Nurminen et al., DBP results were consistent. Diastolic blood pressure overall significantly increased from baseline to 60 minutes post ingestion. Nurminen et al. (1999) also stated 200-250 mg of caffeine increase DBP 4-13 mmHg. The suggested mechanisms of action for the increases in DBP are caffeine's activation of the sympathetic nervous system and an increase in total peripheral resistance.

Although a secondary finding, the fact that reports of satiety improved following ingestion of Bulletproof Coffee could provide a benefit to individuals seeking to reduce calorie intake as this practice is often confounded with increased hunger and cravings. Conversely, satiety was not significantly different following ingestion of standard coffee. It is likely that the added MCTs and butter in Bulletproof Coffee led to increased feelings of satiety in the current study. Previous research has observed decreased subsequent food

intake by individuals following the ingestion of MCT compared with LCT (St-Onge & Jones, 2002).

Significant increases in alertness scores were seen pre to post for both testing conditions, which is a common byproduct of caffeine ingestion as it acts as a central nervous stimulant (Lazarus et al., 2011). There was no significant difference in the increases of alertness between conditions, suggesting alertness is primarily associated with the caffeine. Caffeine acts as an adenosine receptor antagonist. Adenosine is an inhibitory neuromodulator involved in sleep-wake regulation (Huang et al., 2005). Caffeine promotes wakefulness by blocking adenosine A_{2A} receptors in the brain (Huang et al., 2005).

A common reported side-effect in the current study were issues relating to gastrointolerance following the ingestion of Bulletproof Coffee as evidenced by the significant reduction on the GI tolerance questionnaire scores with 7 subjects reporting issues. Several subjects reported difficulty relaxing during the test, either due GI intolerance (n=5) or the urge to urinate (n=7). The inability to relax during the end of testing sessions may have also influenced the REE and RQ values which is a limitation of the current study.

Another limitation of the study that may have affected the results is the caloric difference of the two testing conditions as was previously mentioned.

In conclusion, the addition of MCT oil and butter to standard coffee appears to result in an acute increase in REE and fat oxidation rates. Further, the added ingredients also appear to positively influence ratings of satiety. These acute metabolic effects and feelings of satiety raise the question of the whether long term use of Bulletproof Coffee

could be useful in weight loss management however it is important to note that overall calorie intakes would have to be adjusted to account for the additional fat and energy content of the coffee in order to elicit a reduction in body weight. Lopez-Garcia et al. (2006) and St-Onge et al. (2003) have shown caffeine and MCT, respectively, can aid in weight management over time. However, no study has investigated the long term weight management effects of caffeine and MCTs in combination. Previous research also supports the idea that the initial increase in REE with MCT consumption compared with LCT is lessened when measured again after 14 days (St-Onge et al., 2003). This further illustrates the needs to investigate the long term effects of Bulletproof Coffee on REE. In addition the effects of long term use of Bulletproof Coffee on the subjects' lipid profile should also be investigated.

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APPENDIX A
INFORMED CONSENT

INFORMED CONSENT FORM

Protocol Title: The Acute Metabolic Effects of Bulletproof Coffee

Principal Investigator: Josh Fritchen
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La Crosse, WI 54601
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Emergency Contact: Dr. Andrew Jagim
136 Mitchell Hall
University of Wisconsin-La Crosse
608-785-6538

Purpose and Procedure

This study is designed to compare the acute metabolic effects of Bulletproof Coffee and standard black coffee after ingestion. This study looks to determine the differences in changes of energy expenditure, fat oxidation rates, heart rate and blood pressure.

My participation will involve 2 experimental tests (Bulletproof and standard black coffee). My participation requires a history of habitual caffeine consumption prior to this study. Each test will require approximately 90 minutes. Testing will take place in the Human Performance Laboratory, Mitchell Hall 225.

12 hour prior to both tests, I will consume a standardized meal. This standardized meal will consist of two slices of wheat bread, two tablespoons of peanut butter, one banana and 12 ounces of orange juice. I will fast for the 12 hours prior to each test.

During the tests, I will lay reclined underneath a metabolic canopy. I will also wear a heart rate monitor strapped around my chest and have my blood pressure measured. These measurements will be recorded 30 and 60 minutes post ingestion.

During both tests, I will complete a questionnaire about how I am feeling that day.

Potential Risks

I will be consuming 4 mg/kg of caffeine with each coffee drink (1 – 2 cups of coffee). An increase in heart rate and blood pressure may occur.

Individuals trained in CPR, Advanced Cardiac Life Support and First Aid will be in the laboratory, and the test will be terminated if complications occur.

This risk of serious or life-threatening complications, for healthy individuals, like myself, is near zero.

Rights and Confidentiality

My participation is voluntary. I can withdraw or refuse to answer any questions without consequences at any time.

I can withdraw from the study at any time, for any reason, without penalty.

The results of this study may be published in the scientific literature or presented at professional meetings using grouped data only.

All information will be kept confidential through the use of number codes. My data will not be linked with personally identifiable information.

Possible Benefits

The primary beneficiary of this study is the nutrition and exercise community. Individually, I should have a better understanding of my metabolic rates and how they are affected by coffee ingestion.

Questions regarding the requirements of the study may be directed to Josh Fritchen (414-852-5626 or fritchen.josh@uwlax.edu), or his advisor (Dr. Andrew Jagim, 608-785-6538). Questions regarding the protection of human subjects may be addressed to the UW-La Crosse Institutional Review Board for the Protection of Human Subjects (irb@uwlax.edu)

Participant's name _____

Participant's signature _____

Date _____

Researcher's signature _____

Date _____

APPENDIX B

PAR-Q

Physical Activity Readiness Questionnaire (PAR-Q)

Please mark YES or NO to the following)	YES	NO
Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?	_____	_____
Do you feel pain in your chest when you do physical activity?	_____	_____
In the past month, have you had chest pain when you were not doing physical activity?	_____	_____
Do you lose your balance because of dizziness or do you ever lose consciousness?	_____	_____
Do you have a bone or joint problem (for example, back, knee, or hip) that could be made worse by a change in your physical activity?	_____	_____
Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?	_____	_____
Do you know of any other reason why you should not do physical activity?	_____	_____

Please note: If your health changes such that you then answer YES to any of the above questions, please tell your fitness or health professional. Ask whether you should change your physical activity plan.

I have read, understood, and completed the questionnaire. Any questions I had were answered to my full satisfaction.

Print Name: _____ Signature: _____

Date: _____

APPENDIX C
CAFFEINE CONSUMPTION QUESTIONNAIRE

CAFFEINE COMSUMPTION QUESTIONNAIRE

Prior to participation in this study, subjects must complete this caffeine consumption questionnaire. Please answer all questions to the best of your knowledge.

Please log your daily consumption of the following items:

	Caffeine		Dose	Average/Day
Coffee (8 oz.)	125 mg	x	_____	_____
Decaf Coffee (8 oz.)	7 mg	x	_____	_____
Espresso (1 oz.)	50 mg	x	_____	_____
Green Tea (8 oz.)	35 mg	x	_____	_____
Iced Tea (8 oz.)	25 mg	x	_____	_____
Soft Drinks (12 oz.)	40 – 60 mg	x	_____	_____
5-Hour Energy (2 oz.)	200 mg	x	_____	_____
Energy Drinks (8 oz.)	80 mg	x	_____	_____

TOTAL MG. CAFFEINE PER DAY: _____

Please check any of the following caffeine intolerances you have experienced from your normal caffeine consumption.

Insomnia	_____	Nausea	_____
Nervousness	_____	Vomiting	_____
Restlessness	_____	GI Intolerance	_____
Other	_____		

If Other is checked, please explain.

I have answered the following questions honestly and to the best of my knowledge.

Print Name: _____ Signature: _____ Date: _____

APPENDIX D
TESTING RESULTS RECORDER

Testing Results

Subject ID: _____ Date: _____ Time: _____

Parvo #: _____ Test Session: _____ Age: _____

Height: _____ Weight: _____ BMI: _____

Ounces of Coffee: _____

Baseline Measurements:

Heart Rate: _____ Blood Pressure: _____

Test Measurements:

Heart Rate at 30 min: _____ Blood Pressure at 30 min: _____

Heart Rate at 60 min: _____ Blood Pressure at 60 min: _____

Testing Questionnaire:	Pretest	Post
Satiety (1 = Very hungry, 5 = Full):	_____	_____
Alertness (1 = Very tired, 5 = wide awake):	_____	_____
GI Tolerance (1 = very nauseous, 5 = no symptoms):	_____	_____

APPENDIX E
REVIEW OF LITERATURE

REVIEW OF LITERATURE

The purpose of this paper is to review the literature related to the effects of caffeine, coffee and medium-chain triglycerides (MCT) on energy expenditure (EE) and fat oxidation.

Indirect Calorimetry

The goal of nutrient metabolism is to produce energy. The most common way of extracting chemical energy of a substrate is to completely oxidize it to carbon dioxide (CO₂) and water. This chemical energy can then be utilized for various functions within the body. Indirect calorimetry is the method by which metabolic rate is estimated from measurements of oxygen (O₂) consumption and CO₂ production. After O₂ uptake and CO₂ release are measured, the amounts of glucose and lipids oxidized by the body can be estimated. Once the oxidation rates of glucose, lipid and proteins have been calculated, the total EE can be computed (Ferrannini, 1988).

In the late 1980's, the use of indirect calorimetry in metabolic investigation was rising rapidly. Ferrannini (1988) suggested that indirect calorimetry was gaining in popularity among clinical investigators due to its noninvasiveness and quality of information. Technical requirements for indirect calorimetry include an air-tight canopy with airflow, O₂ and CO₂ analyzers and software to store and analyze the data (Ferrannini, 1988). Subjects lie in a supine position and breathe calmly underneath the canopy.

Caffeine

While the use of caffeine can be dated back thousands of years, it was not until more recently that its effects were being researched. One of the earliest studies on caffeine was conducted by Arthur Grollman. Grollman (1930) wanted to determine caffeine's effect on the cardiovascular system. He suggested that larger doses of caffeine would cause a rise in O₂ consumption, pulse rate and cardiac output (Grollman, 1930).

Knowing that caffeine can elevate O₂ consumption, a study was conducted to determine the thermogenic response to caffeine in lean and obese women (Jung, Shetty, James, Barrand & Callingham, 1980). Subjects were divided into three groups: lean, obese and post-obese. Subjects completed a caffeine questionnaire and results showed that all three groups consumed similar amounts of caffeine. After an overnight fast and 16-hour caffeine abstinence, resting metabolic rate was measured using a ventilated hood. Caffeine was given as a drink dissolved in water or through intravenous injection dissolved in water. Dosages of caffeine differed so that each subject was given 4mg/kg of their ideal bodyweight. Resting metabolic rate was then measured 2 hours after the drink and 1-5 hours after intravenous injection. Blood samples were also taken before and after caffeine was given to the subjects. Results showed a rise in resting metabolic rate with caffeine in both the lean and obese groups, whereas the post-obese had a reduced response (Jung et al., 1980). Jung et al. (1980) also stated that the metabolic effects of caffeine seem to be mediated by increases in adipocyte lipolysis.

Arciero, Bougopoulos, Nindl and Benowitz (2000) wanted to examine age-related differences in the magnitude of caffeine-induced thermogenesis. Ten younger (21 to 31 years) and ten older (50 to 67 years) healthy, moderate caffeine-consuming women

participated in a placebo-controlled double-blind study. Baseline fasting plasma glucose, insulin, free fatty acid (FFA) and EE were measure. Subjects performed two tests, either ingesting caffeine (5 mg/kg fat free mass) or a placebo pill. Plasma glucose, insulin, FFA, and EE in response to the placebo and caffeine ingestion were recorded in 15-minute intervals for 90 minutes. Following caffeine ingestion, EE for both younger and older women significantly increased, with a higher thermic response seen in younger women (Arciero et al., 2000). Arciero et al. (2000) also reported caffeine was positively associated with the body weight and weight circumference in younger women.

Dulloo, Geissler, Horton, Collins and Miller (1989), wanted to examine not only resting metabolic rate and thermogenesis but also 24-hour EE. Looking at the acute metabolic effects, eighteen sedentary individuals were divided into two groups: lean and post-obese. These individuals all consumed similar diets and between 250 to 500 mg of caffeine per day. Individuals were given four randomized treatments on four different days with at least two days between treatments. The four treatments included: 100-mg tablet of caffeine, 300-kcal liquid meal, 300-kcal liquid meal plus a 100-mg tablet of caffeine and 200-mL glass of water. After a 12-hour fast, individuals' baseline resting metabolic rates was measured. Following the baseline measurements, treatments were administered. For the next 150 minutes, metabolic rate was measured for 5 minutes with 10-15 minutes between measurements. Results of the study showed increases in metabolic rate in both lean and post-obese groups (4.38 & 3.16% respectively) with consumption of caffeine (Dulloo et al., 1989).

Out of the eighteen individuals from the acute study, eleven participated in the daily EE portion of the study (five lean, six post-obese). On two separate occasions, each

subject completed a 24-hour EE measurement in a human respirometer. On one test day, individuals would receive nothing, to establish their baseline daily EE. On the other test day, individuals would be given a 100-mg caffeine tablet every 2 hours for 12 hours. Results of the study showed an increase in EE during the first 12 hours but no significant increase was seen the following 12 hours. The net effect in daily EE was an increase of 150 kcal in the lean group and 79 kcal in the post-obese group (Dulloo et al., 1989). Dulloo et al. (1989) suggested that caffeine can have a significant influence EE and research should investigate its promotion of thermogenesis as a treatment of obesity.

Knowing that caffeine ingestion stimulates both lipolysis and EE, Acheson et al. (2004) wanted to determine whether the lipolysis effect of caffeine is associated with increased lipid oxidation or futile cycling between triacylglycerol and free fatty acids (FFAs). Eight healthy, male subjects performed four experiments either consuming caffeine (10 mg/kg) or a 500 mg lactose placebo. Using respiratory exchange, lipid oxidation and FFA turnover were measured 90 minutes before and 240 min post ingestion. The ingestion of caffeine increased EE by 13% and doubled the turnover of lipids, of which 24% were oxidized and 76% were recycled (Acheson et al., 2004). Acheson et al. (2004) stated that the increase in nonoxidative is much greater than the increase in oxidative lipid disposal. This implies that a large increase in turnover rate is necessary to cause a small increase in lipid oxidation.

Lopez-Garcia et al. (2006) looked to assess the relation between caffeine intake and long term weight gain. The study included 18,417 men and 39,740 women with no chronic diseases at baseline. Subjects were then assessed every 2 – 4 years from 1986 to 1998. Results showed that a lower mean weight in participants who increased their

caffeine consumption than in those who decreased their consumption. Lopez-Garcia et al. (2006) suggests increases in caffeine intake may lead to a small reduction in long-term weight gain.

A secondary measurement being investigated in this study is changes in blood pressure (BP). Nurminen, Niittynen, Korpela and Vapaatalo (1999) conducted a review of the literature on data relating intake of caffeine on BP in man. The review of the literature by Nurminen et al. (1999) stated 200-250 mg of caffeine increases SBP 3-14 mmHg. Nurminen et al. (1999) also stated 200-250 mg of caffeine increase DBP 4-13 mmHg. Their suggested possible mechanisms of the cardiovascular effects of caffeine included the blocking of adenosine receptors and the inhibition of phosphodiesterases.

Caffeine's effect on alertness will be investigated throughout the study. Huang et al. (2005) investigated the mechanisms of caffeine effect on wakefulness. Huang et al. (2005) knocked out adenosine receptor subtypes in mice and measured their wakefulness in response to caffeine. It was reported wakefulness was not increased in mice when adenosine A_{2A} receptors were knocked up. Thus caffeine induced wakefulness depends on adenosine A_{2A} receptors (Huang et al., 2005).

Coffee

Although the effects of caffeine have been widely researched, fewer studies have specifically examined the metabolic effects of coffee. One of the more important studies looking a coffee looked to determine the effects of coffee on metabolic rate and substrate utilization (Acheson et al., 1980). Four different trials were conducted in the study. Trial 1 was a single blind study to investigate the effects of pure caffeine (8 mg/kg) versus a placebo on normal weight individuals. Metabolic rate significantly increased in the

caffeine group after ingestion (Acheson et al., 1980). In trial 2, the metabolic effect of coffee (4 mg/kg) was compared to the effect of decaffeinated coffee on normal weight individuals. In trial 3, the metabolic effect of coffee (4 mg/kg) was compared to the effect of decaffeinated coffee on obese individuals. Metabolic rates significantly increased in the presence of caffeine in both the normal weight and obese groups. However, fat oxidation rates did not significantly increase in the obese group. Trial 4 was a double blind study investigating the effects of coffee and decaffeinated coffee when taken with a meal. Once again, the metabolic rates after caffeine consumption was significantly greater than the decaffeinated coffee. Acheson et al. (1980) concluded that coffee stimulates the metabolic rate in both normal weight and obese individuals, with greater oxidation of fat seen in the normal weight individuals.

Bracco, Ferrarra, Arnaud, Jequier & Schultz (1995) conducted similar research, but looked specifically at the metabolic effects on women. Bracco et al. (1995) wanted to investigate the magnitude of coffee-induced thermogenesis and coffee's influence on substrate utilization. The study included ten lean and ten obese women and each participated in two 24-hour tests. On one test day, subjects would consume caffeinated coffee and on the other test day, decaffeinated coffee. After ingestion, subjects would spend 24 hours in a respiratory chamber. During the coffee test, increases in both EE and fat oxidation were seen in both the lean and obese groups. However, thermogenesis and lipid oxidation rates in the obese group saw less of an effect than the lean group.

Greenberg, Axen, Schnoll and Boozer (2005) conducted a study to assess the effect of weight change on the relationship between coffee and tea consumption and diabetes risk. The study used data from the First National Health and Nutrition

Examination Survey Epidemiologic Study. From this data, 7,006 subjects with no reported history of diabetes were included in this study. Follow-ups of subjects occurred for 8.4 years, where caffeine consumption and BMI were recorded. Greenberg et al. (2005) concluded that for subjects less than 60 years old, there was a negative association between beverage consumption and diabetes risk and weight gain. Greenberg et al. (2005) stated caffeine accounted for the significance of negative association between weight gain and ground-caffeinated coffee.

Greenberg, Boozer and Geliebter (2006) reviewed epidemiologic and laboratory studies of the effects of coffee and its constituents on diabetes risk, focusing on weight loss and glucose metabolism. Greenberg et al. (2006) stated there is considerable evidence that supports that coffee consumption induces weight loss by increasing thermogenesis. It has been estimated that a habitual consumption of 600 mg caffeine/day causes an increase in EE of around 100 kcal/day. Greenberg et al. (2006) also stated that several human studies found that an acute increase in lipolysis resulted from caffeine and caffeinated coffee.

Medium-Chain Triglycerides

Medium-chain triglycerides (MCT) are made up of medium-chain fatty acids (MCFA) containing 6, 8, 10 or 12 carbon tails. It wasn't until the 1950's that MCTs were first introduced as treatment of lipid absorption disorders. The uses of MCTs as treatment sparked an interest within the research community to further investigate the possible functions of MCTs. With an influx of MCT studies being published, it was difficult for individuals to stay up to date on what had been investigated.

In order to create a better understanding of MCTs, Bach & Babayan (1982) reviewed the early literature. After reviewing 128 different MCT studies, an analysis was written explaining the pertinent information that was observed. The first observation made on MCTs was their ability to be absorbed quicker than traditional long-chain triglycerides (LCT). While MCTs have MCFAs with tails ranging from 6 – 12 carbons, LCTs have long-chain fatty acids (LCFA) with tails over 12 carbons long. Due to their smaller molecular size, MCTs are hydrolyzed both faster and more completely than LCTs. Once hydrolyzed, MCFAs can be absorbed through the intestinal mucosa and transported to the liver via the venous portal system. This process is long and involves more steps with the LCTs. When passing through the intestinal mucosa LCFAs are converted into acyl-CoAs, which are then incorporated into triacylglycerols. These triacylglycerols become a part of chylomicrons and travel toward the liver via the lymphatic system. Upon arrival, the chylomicrons must be broken down to release the LCFAs.

Not only are MCTs absorbed quicker than LCTs, but their fatty acids are also metabolized quicker. LCFAs are actively fixed on the fatty-acid binding protein and are activated into acyl-CoAs in the endoplasmic reticulum of the hepatocytes. Due to the fact that MCFAs do not bind easily to the protein, the acyl-CoA synthetase for MCFAs is found in the mitochondrial matrix. Therefore, MCFAs are not significantly incorporated in the lipids synthesis by the hepatic tissue. These MCFAs are then rapidly available for oxidation, creating an excess of acetyl-CoA. This acetyl-CoA can then be used either for the Krebs cycle or ketogenesis.

Scalfi, Coltorti & Contaldo (1991) wanted to investigate the thermic effect of MCTs by evaluating postprandial thermogenesis after ingestion. The study included six lean and six obese young males. Each subject performed a test eating a meal high in LCT and a meal high in MCT. Subjects performed the tests sitting in a reclined position and meals were given in random order. Tests began by drawing blood samples and determining the resting metabolic rate of the subjects. After each test meal was consumed, EE was measured every 15 minutes for 6 hours. Blood samples were also taken 1, 2, 3, and 6 hours post meal ingestion. Results showed increases in postprandial thermogenesis in both lean and obese subjects with MCTs compared to LCTs. Scalfi et al. (1991) also raised the question of whether MCTs could be used a tool of treatment with severe obesity.

St-Onge and Jones (2002) reviewed the literature on the potential agents in MCTs in the prevention of obesity. Summarizing the literature, St-Onge and Jones (2002) concluded replacing dietary LCT with MCT causes a rise in EE, a depression of food intake and lower body fat mass. The authors suggested replacing dietary LCT with MCT could facilitate weight maintenance in humans (St-Onge & Jones, 2002).

St-Onge, Ross, Parsons & Jones (2003) wanted to compare the metabolic effects of diets rich in MCT or LCT for 28 days. The study used a randomized crossover feeding design with two 28-day periods, with a 4-week washout period in between. The two diets were identical, except one diet contained MCT and the other LCT. Bodyweight was measured every morning and body composition was measured the beginning and end of each diet. Energy expenditure was measured with a metabolic monitor on days 2 or 3 and 27 or 28. Results of the study showed a greater loss of adipose tissue with the MCT diet

compared to the LCT diet. Increases in EE and fat oxidation were also higher in the MCT diet compared to the LCT diet.

Summary

In conclusion, caffeine, coffee and MCTs have all shown to increase metabolic effects after ingestion. Energy expenditure and fat oxidation both showed increases rates when caffeine, coffee or medium-chain triglycerides were tested separately. However, there is a lack of knowledge on the acute metabolic effects when coffee and MCTs were consumed together. By completing this study, we hope to determine if the combination of the coffee and MCT in combination will significantly increase metabolic rates in comparison to standard black coffee.

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