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REVIEW ARTICLE

Chocolate milk for recovery from exercise: a systematic review and meta-analysis of controlled clinical trials

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Abstract

Background/objectives Chocolate milk (CM) contains carbohydrates, proteins, and fat, as well as water and electrolytes, which may be ideal for post-exercise recovery. We systematically reviewed the evidence regarding the efficacy of CM compared to either water or other "sport drinks" on post-exercise recovery markers.

Subjects/methods PubMed, Scopus, and Google scholar were explored up to April 2017 for controlled trials investigating the effect of CM on markers of recovery in trained athletes.

Results Twelve studies were included in the systematic review (2, 9, and 1 with high, fair and low quality, respectively) and 11 had extractable data on at least one performance/recovery marker [7 on ratings of perceived exertion (RPE), 6 on time to exhaustion (TTE) and heart rate (HR), 4 on serum lactate, and serum creatine kinase (CK)]. The meta-analyses revealed that CM consumption had no effect on TTE, RPE, HR, serum lactate, and CK ($P > 0.05$) compared to placebo or other sport drinks. Subgroup analysis revealed that TTE significantly increases after consumption of CM compared to placebo [mean difference (MD) = 0.78 min, 95% confidence interval (CI): 0.27, 1.29, $P = 0.003$] and carbohydrate, protein, and fat-containing beverages (MD = 6.13 min, 95% CI: 0.11, 12.15, $P = 0.046$). Furthermore, a significant attenuation on serum lactate was observed when CM was compared with placebo (MD = −1.2 mmol/L, 95% CI: −2.06,−0.34, $P = 0.006$).

Conclusion CM provides either similar or superior results when compared to placebo or other recovery drinks. Overall, the evidence is limited and high-quality clinical trials with more well-controlled methodology and larger sample sizes are warranted.

Introduction

Post-exercise nutrition is of great importance for replenishing muscles/liver glycogen stores, replacing fluid, and electrolytes lost during exercise, as well as upregulating physiological pathways responsible for skeletal muscle adaptations [1, 2]. Different beverages including those containing carbohydrates alone (CHO beverages [3, 4], carbohydrates plus electrolytes (CHO + E) [5, 6], or carbohydrates plus protein (CHO + PRO)) have been introduced for these purposes [7, 8]. It is proposed that CHO + E beverages might improve repeated exercise performance [6] and supplementation might be effective in restoring fluid balance during short-term recovery from exercise, after an exercise-induced dehydration [9]. Furthermore, CHO + PRO beverages may improve time to exhaustion (TTE) [10, 11], attenuate the rise in creatine kinase (CK) [12], enhance glycogen re-synthesis [13, 14] and provide additional calories (~25% because of the protein content) compared to CHO beverages [10].

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Chocolate milk (CM) is composed of carbohydrates, proteins [15], flavonoids [16], and electrolytes [17]. Each 500 mL of CM provides ~16 g of protein and ~52 g of carbohydrates [18]. In addition, CM contains calcium and vitamin D (in countries with vitamin D fortification program), with potential ergogenic effects on muscles [19]. The protein content in CM is primarily casein, and the remainder is whey protein [20]. Casein causes a more prolonged postprandial hyperaminoacidemia than whey, which may suppress proteolysis and elevate muscle protein synthesis [21, 22]. CM is also an effective rehydration solutions [1, 17]. These nutritional characteristics of CM have drawn researchers' attention to consider it as a good recovery beverage for athletes [23].

Several studies have demonstrated that ingesting CM improves recovery and performance measures such as TTE [24, 25] through improving intracellular signaling stimulation for protein synthesis [24, 26], and glycogen replenishment [26], as well as reducing CK [27] and lactate [28] concentrations compared to a non-caloric drink or other isocaloric carbohydrate sport drinks. However other investigations have found contradictory findings when CM was compared to carbohydrate replacement beverages, carbohydrate-electrolyte beverages, or placebo [27, 29, 30]. Ferguson-Stegall et al. [26] found that ratings of perceived exertion (RPE) was not different between CM and other recovery beverages and the same results were found in other studies [25, 27, 29, 31]. Furthermore, Gilson et al. and Spaccarotella et al. revealed that CM might not significantly affect TTE in athletes. For instance, Spaccarotella et al. found a trend of increased time to fatigue after ingestion of CM in male athletes [27, 29]. Several studies also illustrated that muscle soreness [27, 32], heart rate [27, 31], CK [26, 30], lactate [25, 31], and glycogen content [24] were not significantly affected by CM.

Currently, there is no systematic review to summarize the efficacy CM on recovery. Furthermore, variability in recovery markers is typically high and most research in a trained population is based on small sample sizes and thus limited statistical power. Meta-analyses help to overcome these limitations by assessing large numbers of individuals simultaneously. We therefore performed meta-analyses to assess the effect of CM on recovery markers in trained participants.

Materials and methods

This systematic review was designed and conducted based on PRISMA guidelines and its protocol was registered in the international prospective register of systematic reviews (PROSPERO) database (registration no: CRD42016038090).

Search strategy

PubMed, Scopus, and Google scholar were explored with no language or time frame restriction up to April 2017. The combination of two sets of keywords were selected from medical subject heading (MeSH) and other related keywords: (1) Chocolate, cocoa (2) exercise, post-exercise, exertion, fitness, activity, sport, sports, training, train, activities, movement, post exercise, recovery, athlete, and athletic. We also checked the reference list of related papers for any other relevant articles.

Eligibility criteria

Original articles utilizing a controlled trial design on trained participants or athletes and considered the effect of post-exercise CM consumption on subsequent exercise performance or recovery indices were included. We excluded articles if CM was supplemented for other reasons, for instance, appetite regulation, energy intake, or as a pre-exercise supplementation. Study selection was independently accomplished by two reviewers (MA and AS-A) and discrepancies were resolved by discussion.

Data extraction

Data including first authors specifications, publication year, number and mean age of the subjects, type of sport, study design, composition of CM and the beverage used as control, exact time of receiving supplementation, total intervention duration, baseline and after exercise mean and mean change from baseline, and its corresponding standard deviation of outcomes variables including lactate, CK, time trial (TT), TTE, RPE, plasma glucose, insulin, glycogen, heart rate (HR), plasma myoglobin, cortisol, and muscle soreness were extracted. Data extraction was performed by two researchers (MA and AS-A) and disagreements were discussed with the third author (RG).

Quality assessment

The quality of included studies was assessed according to Cochrane Collaboration's tool for assessment of the risk of bias [33]. Random sequence generation, allocation concealment, blinding of outcome assessment or personnel, incomplete outcome data, and selective reporting were assessed as the main domains, and we did not assess blinding of participants as a key domain because of the nature of the intervention and flavor of the chocolate milk. Those studies with low risk score of bias in less than two domains, two domains, and more than two domains were classified as low quality, fair, and high-quality studies, respectively.

Statistical analysis

Mean changes from baseline and their standard deviation (SD) for relevant outcomes were extracted and used to calculate the unstandardized difference in means (MD) as the effect size for meta-analyses. An overall effect was calculated by determining the effect of CM compared to the control beverage. Some studies readily reported the mean change ± SD for intervention and control for TTE [24, 25, 29–32], RPE [25–27, 29–31, 34], CK [26, 27, 30, 32], and HR [25–27, 31, 35, 36]; therefore, based on standard deviation reported for pre- and post-intervention and change in recovery markers, we estimated the correlation coefficient for TTE [$r = 0.62$, from three studies [24, 31, 32]], RPE [$r = 0.79$, from two studies [26, 27]], CK [$r = 0.53$, from one study [32]], and HR [$r = 0.63$, from three studies [26, 27, 36]], which were used to calculate the SD for change for studies in which the mean change and the corresponding SD were not reported. The SDs for change in lactate levels were not reported in studies included in the current systematic review; therefore we used a conservative estimate of $r = 0.5$ as the correlation coefficient. To ensure that this correlation did not alter the findings we replicated the analysis using a correlation coefficient of 0.1 and 0.9 [37].

Random-effect models were used to conduct all meta-analyses because it takes the between-study heterogeneity into account. Cochran's Q test and I-squared (I^2) were used to demonstrate the between-study heterogeneity [38]. I^2 more than 25% was considered as significant heterogeneity. Sources of heterogeneity were explored using subgroup analysis based on beverage used for the control group/duration. Three types of control beverages were used: (1) placebo (water and flavored or sweetened drinks), (2) carbohydrate and protein beverages (CHO + PRO: solutions that contain carbohydrate and protein but did not contain fat or other minerals or vitamins), (3) beverages with carbohydrate, protein, and fat (CHO + PRO + FAT) but differed in mineral and vitamin content. And we performed sub-analyses on athletes' sport. As the majority of included studies were conducted on cyclists we categorized the studies into two groups (1) cyclists, (2) others (including judo, running, soccer, and climbing), and in addition, the subgroup analysis was done based on the quality categorization of articles. Publication bias was assessed by reviewing Begg's funnel plot [39]. The sensitivity of the overall estimates to a specific trial was checked by using the sensitivity analysis. All the statistical procedures were performed using STATA (Version 11.2, Stata Corp, College Station, TX). $P < 0.05$ was regarded as statistically significant.

Results

Database search led to 1574 research items and 23 publications were selected for full text screening. After reading their full text, 11 studied were excluded from the systematic review [28, 40–49]. One of them assessed the effect of CM in animals [40], another study was conducted to optimize a new version of CM [41], a study by Fraga et al. [28] did not consider exercise recovery markers as outcome, 2 studies assessed CM effect in untrained subjects [42, 43], and a study conducted by Alberici et al. [44] used CM as a pre-exercise supplement. Furthermore, we found four review articles [45–48] and one letter to the editor [49] on CM consumption and exercise. Finally, 12 clinical trials were included in the present systematic review [24–27, 29–32, 34–36, 50]. Eleven studies were included in the meta-analysis [24–27, 29–32, 34–36]. The study done by Bellar et al. [50] was excluded because the data needed in the current meta-analysis was not assessed in their study (Fig. 1). The characteristics of the studies included in the systematic review are summarized in Table 1.

Assessment of risk of bias

From studies included in the systematic review, 2 achieved positive score in more than 2 main domains, and were classified as high quality [25, 27], 9 were classified as fair, because they were low risk in 2 key domains [24, 26, 30, 31, 34–36, 45, 50], and one study was categorized as low quality [29]. The quality assessment results for included studies are reported based on each domain in Table 2. In regards to the good quality studies, Karp et al. [25] found that CM consumption can significantly affect TTE compared to carbohydrate replacement drink but not a fluid replacement drink; however, heart rate, RPE, and post-exercise lactate did not differ between CM and control. Gilson et al. [27] also report no significant differences for RPE and HR between CM and a high-carbohydrate beverage; however, after CM consumption CK was significantly lower.

Findings from the systematic review

Except Papacosta et al. [34] who indicated a significant indirect effect, Pritchett and Gilson et al. showed a non-significant differences for muscle soreness between CM consumption and control [27, 30, 32]. There was also no significance on water consumption during the recovery period [25, 31], plasma myoglobin [26, 27], and maximal voluntary isometric contraction of the right quadriceps [27]. CM consumption was shown to have a direct effect on intracellular signaling protein phosphorylation (i.e.,

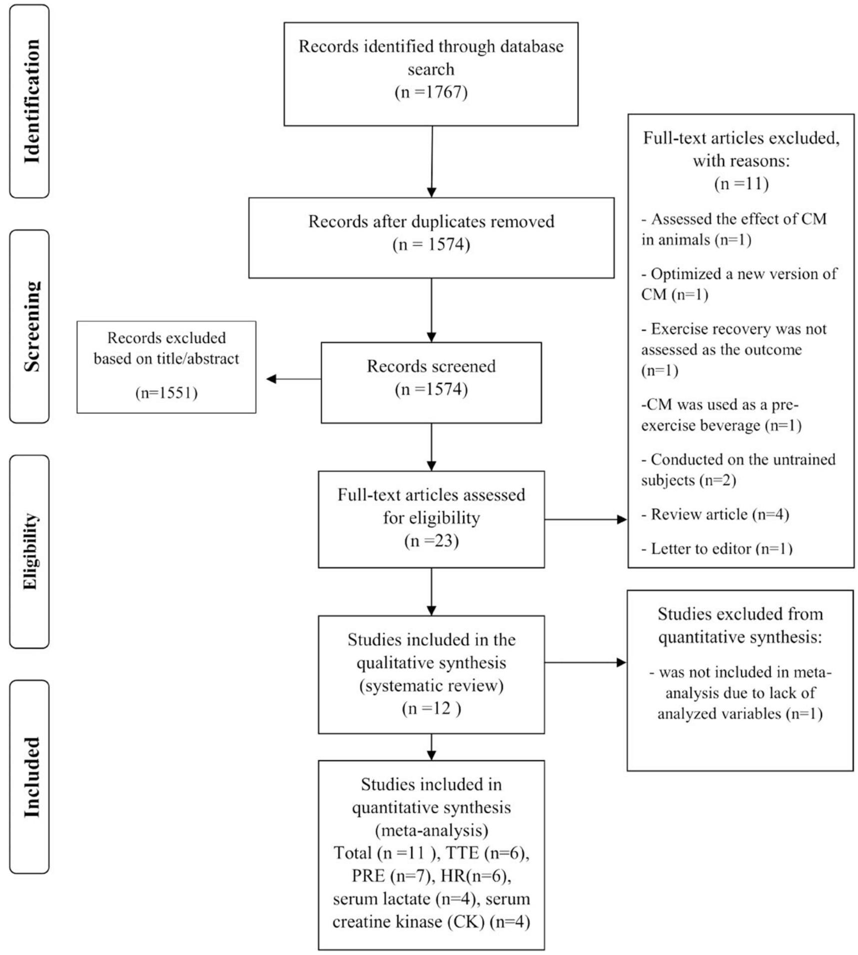

Fig. 1 Study selection process

mammalian target of rapamycin (mTOR) and ribosomal protein S6 (rpS6) phosphorylation) [24, 26]. The variables reported above were limited and insufficient data were extracted to warrant meta-analytical analysis. In total, 9 studies considered time trial as a performance test from which five found no effect of CM consumption [25, 27, 29, 31, 34] and a study done by Ferguson-Stegall et al. [26] found a detrimental effect. A positive effect of CM was shown in three other studies [31, 35, 36]. We could not conduct meta-analysis on this variable because it was measured in with different methodology including mode of exercise and duration.

Findings from meta-analysis

Time to exhaustion (TTE)

In total, 6 studies [24, 25, 29–32] with 57 participants assessed the effect of CM consumption on TTE (Table 3): the analysis revealed that CM did not significantly affect TTE (MD) = 1.46 min, 95% confidence interval (CI): −0.31, 3.22, $P = 0.144$. Although, between-study heterogeneity was not significant using Cochrane Q test, the I-squared statistic revealed moderate heterogeneity (Cochrane Q test, Q statistic = 8.36, $P = 0.132$, I^2: 40.9%). Removing one of the studies from analyses [31], led to substantial decrease in the heterogeneity between studies (Cochrane Q test, Q statistic = 0.53, $P = 0.971$, I^2: 0.0%) and the effect of CM on TTE became statistically significant (MD = 0.79 min, 95% CI: 0.3, 1.28, $P = 0.002$).

The subgroup analysis based on control beverages, revealed that CM significantly increased TTE when compared with placebo beverages (MD = 0.78 min, 95% CI: 0.27, 1.29, $P = 0.003$) and CHO + PRO + FAT-containing beverages (MD = 6.13 min, 95% CI: 0.11, 12.15, $P = 0.046$). Subgroup analysis showed that CM significantly effects TTE in athletes that were not cyclists (MD = 0.80 min, 95% CI: 0.30, 1.29, $P = 0.002$). Subgroup analysis based on quality of articles is represented in Table 3. The effect of CM consumption on TTE was not different between the quality of studies.

Ratings of perceived exertion (RPE)

Seven studies [25–27, 29–31, 34] with a total of 76 participants considered the influence of CM on RPE (Table 3).

Table 1 Characteristic of included studies that investigated the effect of CM consumption on recovery indices

Authors	Publication year	No. of participant/ gender/exercise	Design	Intervention exercise	Control drink composition	Drinking time	Chocolate milk volume	Outcome measured
Pritchett et al. [32]	2009	10/cyclists and triathletes	Crossover	Cycling	-Carbohydrate replacement beverage(CRB): (Energy (kcals): 384.3 ± 36.6 Carbohydrate (g): 72.1 ± 6.9 protein(g): 19.2 ± 1.8 Fat (g): 2.0 ± 0.2 Volume (oz) 17.3 ± 1.8)	Immediately after exercise and 2 h into the recovery period	17.3 ± 1.8 oz	-TTE (NS) -CK (NS) -Muscle soreness (NS)
Ferguson-Stegall et al. [26]	2011	10/male_ female/ trained cyclists and triathletes	Crossover	Cycling	(1) Placebo: (water flavored with Splenda and non-caloric Kool Aid flavoring CHO (g): 0 PRO (g): 0 Fat (g): 0 Energy (kcals): 0 Ratio of CHO:PRO: 0) (2) CHO: carbohydrate + fat (dextrose and canola oil): (500–700 mL CHO (g): 15.15 PRO (g):0 Fat (g): 2.05 Energy (kcals): 79.05)	Immediately after exercise and 2 h into a 4-h recovery period	500–700 mL	-TTT↓ -Power out put↑ -HR↑ -RPE (NS) -Muscle glycogen re-synthesis ↑ -Plasma glucose ↑ -Plasma insulin (NS) -Lactate↑ -plasma glycerol and FFAs (NS) -CK (NS) -Plasma myoglobin (NS) -Cortisol (NS) -Cytokines (NS) -Intracellular signaling protein phosphorylation -mTOR ↑ -rpS6[8]↑ -FOXO3a (NS) -p-eIF2B (NS)
Spaccarotella et al. [29]	2011	13/male_ female/ soccer players	Crossover	Shuttle run	-Carbohydrate-electrolyte beverage (CE) (volume: 615 ± 101 mL per 240 mL: Energy (kcal, kJ): 50, 209 Protein (g): 0 Fat (g): 0 Carbohydrate (g):14 Calcium (mg): 0 Sodium (mg): 110)	Immediately after the first practice and again 2 h later	615 ± 101 mL	-TTE (NS) -RPE (NS) -Run time (NS)
Lunn et al. [24]	2012	All: 14 Study 1: 8	Crossover	Run	-Non nitrogenous isocaloric carbohydrate (CHO) control		480 mL	-FSR ↑ -Intracellular

Table 1 (continued)

Authors	Publication year	No. of participant/ gender/exercise	Design	Intervention exercise	Control drink composition	Drinking time	Chocolate milk volume	Outcome measured
		Study 2: 6 /male/runners			beverage (CON): 480 mL (isocaloric at 296 kcal, 74.0 g of sweetened grape-flavored drink mix, non nitrogenous, CHO content (74 g, 296 kcal))	After a 45-min running, participants consumed beverages.		signaling protein phosphorylation -eIF4E-BP1↑ -mTOR↑ -rpS6 ↑ -eEF2 (NS) -FOXO3a (NS) -Caspase-3 activity↓ -26S proteasome (not change) -Plasma insulin ↑ -Glycogen content (NS) -TTE↑
Karp et al. [25]	2006	9/male/cyclists	crossover	cycling	(1) Fluid replacement drink (FR): (Volume (mL): 509.1 ± 36.0 Carbohydrate (g): 29.7 ± 2.1 Protein (g): 0.0 ± 0.0 Fat (g): 0.0 ± 0.0 Energy (kcals): 106.1 ± 7.5 Na(mg): 233.3 ± 16.5 K: 63.6 ± 4.5) (2) Carbohydrate replacement drink: (Volume (mL): 509.1 ± 36.0 Carbohydrate (g): 70.0 ± 4.9 Protein (g): 18.5 ± 1.300 Fat (g): 1.5 ± 0.10 Energy (kcals): 381.8 ± 27.00 Na(mg): 311.2 ± 22.0 K: 169.7 ± 12.0)	Immediately following the glycogen depletion exercise and again 2 h into the post-exercise recovery	509.1 ± 36.0	-TTE ↑ -HR (NS) -RPE (NS) -water consumed (NS) -Min of cycling during initial exercise (NS) -Lactate (NS)
Gilson et al. [27]	2010	13/male/soccer players	Crossover	Soccer-specific training drills and aerobic development Strength and sprint training	Carbohydrate beverage: (Volume (mL): 672 Energy (kcal): 504 Carbohydrate (g): 122 Protein (g): 0 Fat (g):2 Sodium (mg): 277 Potassium (mg): 202 Vitamin C (mg): 302	Within 5 min of completion of each exercise session	672 mL	-HR (NS) -Daily training time (NS) -CK ↓ -Muscle soreness(NS) -RPE (NS) -MVC (NS) -Plasma myoglobin (NS)

Table 1 (continued)

Authors	Publication year	No. of participant/ gender/exercise	Design	Intervention exercise	Control drink composition	Drinking time	Chocolate milk volume	Outcome measured
					Vitamin E (mg): 101 Calcium (mg) 101)			
Pritchett et al. [30]	2011	10/male/cyclists tri-athlete	Crossover	Cycling	-Commercial recovery beverage: (CRB): (Volume (mL): 531 ± 63 energy (kcals): 396 ± 49.7 Carbohydrate (g): 73.2 ± 8.7 Protein (g): 19.4 ± 2.3 Fat (g): 2.7 ± 1.5)	Immediately after their workout and again at 2 h into the recovery period	531 ± 63 mL	-Muscle soreness (NS) -RPE (NS) -Daily average kilometers (NS) -TTE (NS) -CK (NS)
Thomas et al. [31]	2009	9/male/cyclists	Crossover	Cycling	(1) Carbohydrate replacement drink (CR): (Volume (mL): 526.3 ± 60.4 Carbohydrate (g): 72.5 ± 8.3 Protein (g): 18.9 ± 2.2 Fat (g): 1.6 ± 0.2 Energy (kcal): 394.9 ± 45.2 Sodium (mg): 321.1 ± 36.8 Potassium (mg) 173.7 ± 19.9) (2) Fluid replacement drink (FR): (Volume (mL): 526.3 ± 60.4 Carbohydrate (g): 30.7 ± 3.5 Protein (g): 0 Fat (g): 0 Energy (kcal): 109.5 ± 12.6 Sodium (mg): 242.2 ± 27.8 Potassium (mg): 90.0 ± 79.1)	At 0 and 2 h into the recovery period	459.2 ± 52.6	-Exercise time for the initial glycogen depletion cycle (NS) -Water Consumed (NS) -Lactate (NS) -HR (NS) -RPE (NS) -TTE↑
Papacosta et al. [34]	2015	12/male/judo athletes	1st week: water 2nd: CM	Intensive judo training	Water	Immediately post-training	1000 mL	-RPE (NS) -Time spent in each training zone (NS) -Training load (NS) -General muscle soreness↓
Upshaw et al. [36]	2016	8/male/cyclists	Crossover	Cycling	(1) Chocolate soy beverage (SOYCHOC), (2) chocolate hemp beverage (HEMPCHOC), (3) low-fat dairy milk (MILK), (4) low-energy artificially sweetened, flavored beverage (PLACEBO)	Immediately after the glycogen-lowering trial and at 30-min intervals for the first 2 h of a 4-h recovery period	649 ± 166 mL	-HR (NS) -20-km time trial↑

Table 1 (continued)

Authors	Publication year	No. of participant/ gender/exercise	Design	Intervention exercise	Control drink composition	Drinking time	Chocolate milk volume	Outcome measured
Bellar et al. [50]	2016	12/male/had more than a year of experience with resistance training	Repeated measures design	Back squat exercise	(1) Water (2) Low-fat Chocolate goat's milk: (Total caloric (kcal): 225 Carbohydrates (g):42 Protein (g):15 Fat (g): 0.5 Cholesterol (mg): 0 Sodium (mg): 217 Vitamin A (% RDV[a]): 0% Vitamin C (% RDV): 15% Iron (% RDV): 3% Calcium (% RDV): 48%)	Chocolate milk consumption was in the 25th min of the exercise trial	236 mL	-IMPT (NS) -Cortisol (NS) -DHEA (NS) -Testosterone (NS)
Potter et al. [35]	2014	10 male climbers	Crossover	Climbing	Water	Immediately post exercise and with their evening meal 2 h after finishing the climb	1000 mL	-HR↑ -Lactate (NS) -Distance climbed↑ -Duration climbed↑ -Post-recovery climb speed (NS)

TTE time to exhaustion, *CK* serum creatine kinase, *TTT* time trial time, *HR* heart rate, *RPE* perceived exertion, *mTOR* mammalian target of rapamycin, *rpS6* ribosomal protein S6, *FOXO3a* is a human protein encoded by the FOXO3 gene, *p-eIF2B* human genes which encode eIF2B (eukaryotic initiation factor 2), *eIF4EBP1* a gene which encoded eukaryotic translation initiation factor 4E-binding protein 1, *eEF2* eukaryotic elongation factor 2, *FSR* muscle protein fractional synthetic rate, *MVC* maximal voluntary contraction, *RER* respiratory exchange ratio, *IMPT* isometric mid-thigh pull, *NS* non-significant effect, ↑ significant increasing effect, ↓ significant reducing effect

Table 2 study quality and risk of bias assessment using Cochrane collaboration tool

First author (year)	Random Sequence generation	Allocation concealment	Blinding of participants	blinding of outcome assessment or personnel	Incomplete outcome data	Selective reporting	score	Overall quality
Pritchett (2009)[32]	?	?	−	?	+	+	2	Fair
Ferguson-Stegall (2011)[26]	?	?	−	?	+	+	2	Fair
Spaccarotella (2011)[29]	?	?	−	?	+	?	1	Low
Lunn (2011)[24]	?	?	−	?	+	+	2	Fair
Karp (2006)[25]	?	?	−	+	+	+	3	Good
Gilson (2010)[27]	?	+	−	+	+	+	3	Good
Pritchett (2011)[30]	?	?	−	?	+	+	2	Fair
Thomas (2009)[31]	?	?	−	?	+	+	2	Fair
Papacosta (2015)[34]	−	?	−	−	+	+	2	Fair
Upshaw (2016)[36]	?	?	−	?	+	+	2	Fair
Bellar (2016)[50]	?	?	−	?	+	+	2	Fair
Potter(2014) [35]	+	−	−	?	+	−	2	Fair

Meta-analysis revealed that CM does not decrease RPE in athletes (MD = −0.04, 95% CI: −0.52, 0.44, $P = 0.883$), and there was a significant heterogeneity among studies (Cochrane Q test, Q statistics = 20.98, $P = 0.002$, I^2: 71.3%). Subgroup analysis revealed that RPE does not significantly change after CM consumption when compared with placebo, CHO + PRO, and CHO + PRO + FAT drinks. The effect remained non-significant was assessed in either cyclists or other athletes,

Table 3 The effect of CM on time to exhaustion (TTE) and ratings of perceived exertion (RPE) as well as subgroup analyses based on exercise type and control beverage

Markers	Studies (*n*)	Participants (*n*)	Effect	Heterogeneity			
			Mean difference (CI)	*P* value	*Q* statistics	*P* value	I^2 (%)
Time to exhaustion (TTE) (min)							
Exercise type							
Cyclist	4	38	2.83 (−2.14, 7.79)	0.264	6.13	0.106	51
Others	2	19	0.80 (0.30, 1.29)	0.002	0.07	0.793	0.0
Control beverages							
Placebo	1	6	0.78 (0.27, 1.29)	0.003	0	—	—
CHO + PRO beverages	3	31	3.08 (−2.53, 8.70)	0.282	7.07	0.029	71.7
CHO + PRO + fat beverages	4	38	6.13 (0.11, 12.15)	0.046	9.42	0.024	68.1
Quality of articles							
Fair	4	35	2.62 (−1.29, 6.53)	0.189	8.17	0.043	63.3
Low	1	13	1.08 (−1.11, 3.27)	0.333	0	—	—
High	1	9	−1.30 (−9.76, 7.16)	0.763	0	—	—
Overall	6	57	1.46 (−0.31, 3.22)	0.144	8.36	0.132	40.9
Ratings of perceived exertion (RPE)							
Exercise type							
Cyclist	4	38	−0.18 (−0.94, 0.58)	0.648	10.77	0.013	72.2
Others	3	38	0.15 (−0.61, 0.90)	0.700	9.02	0.011	77.8
Control beverages							
Placebo	2	22	0.18 (−0.29, 0.65)	0.453	1.79	0.181	44.0
CHO + PRO beverages	3	31	−0.08 (−1.30, 1.14)	0.897	13.20	0.001	84.8
CHO + PRO + fat beverages	5	51	−0.16 (−0.67, 0.36)	0.551	9.05	0.06	55.8
Quality of articles							
Fair	4	41	−0.05 (−0.64, 0.53)	0.862	10.83	0.013	72.3
Low	1	13	1.30 (0.29, 2.31)	0.012	0	0.863	0
High	2	22	−0.53 (−1.04, −0.02)	0.042	0.03	—	—
Overall	7	76	−0.04 (−0.52, 0.44)	0.883	20.98	0.002	71.3

All analyses were conducted using random effects model

CHO carbohydrate, *Pro* protein

but the subgroup analysis based on quality of studies in the meta-analysis revealed that CM consumption had a reducing effect on RPE in high-quality articles (MD: −0.53, 95% CI: −1.04, −0.02, $P = 0.042$) and a significant but direct effect was shown in low quality articles (MD: 1.30, 95% CI: 0.29, 2.31, $P = 0.012$). The heterogeneity was significant among all subgroup analysis (Table 3). Removing any of the studies did not alter the results.

Lactate

Four studies with 38 participants considered the effect of CM consumption on blood lactate and were included in the meta-analysis [25, 26, 31, 35]. Lactate was measured four times for each subject during the intervention days in all the included studies: (A) before the baseline exercise bout (glycogen depletion exercise), (B) after the first exercise bout, (C) before the second exercise bout (recovery trial), and (D) after the second exercise bout. CM was consumed after the first exercise bout and before the recovery trial. We used the mean change in lactate between B and C and also the mean change between B and D to compare MD in lactate changes between CM and other beverages in separate meta-analyses (Fig. 2).

The comparison between lactate at the end of the first exercise bout with the start of second exercise bout (B–C) revealed that CM does not significantly reduce the lactate concentration (MD = −0.67 mmol/L, 95% CI: −1.49, 0.16, $P = 0.112$). The heterogeneity was not significant using Cochrane Q test (Q statistic = 4.51, $P = 0.211$), however, there was a moderate level of heterogeneity using I-squared (I^2: 33.5%). Exclusion of the study done by Karp et al. significantly altered the result (MD = −1.1 mmol/L, 95% CI: −1.83, −0.36, $P = 0.004$).

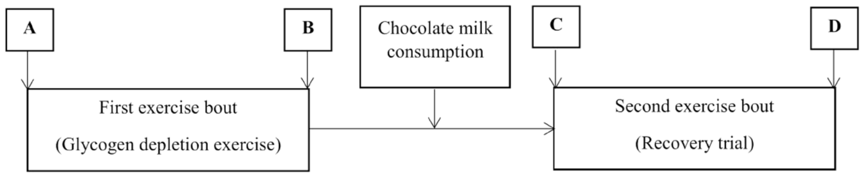

Fig. 2 The time points in which serum lactate was measured on the intervention days: **a** before the baseline exercise bout (glycogen depletion exercise), **b** after the first exercise bout, **c** before the second exercise bout (recovery trial), and **d** after the second exercise boat

Meta-analysis on the effect of CM consumption on lactate change using correlation coefficients of 0.1 and 0.9 showed no effect on the findings ($r = -0.1$ = MD = −0.66 mmol/L, 95% CI: −1.62, 0.3, $P = 0.178$; $r = 0.9$: MD = −0.81 mmol/L, 95% CI: −1.63, 0.01, $P = 0.053$). Subgroup analysis based on control beverage type, showed that CM significantly reduced lactate when compared with placebo (MD = −1.2 mmol/L, 95% CI: −2.06,−0.34, $P = 0.006$, I^2: 0.0%). The subgroup analysis using 0.1 as the correlation coefficient, also led to an inverse but marginal effect when CM was compared to placebo subgroup (MD = −0.66, 95% CI: −1.62, 0.30, $P = 0.095$) while the reported associations remained significant when 0.9 was used as a correlation coefficient (MD = −0.81 mmol/L, 95% CI: −1.63, 0.01, $P < 0.01$). Subgroup analysis based on the quality of articles revealed that lactate was significantly attenuated after CM ingestion in fair quality articles (MD = −1.10, 95% CI: −1.83, −0.36, $P = 0.004$), the effect was not significant in the high-quality article. The effect of CM consumption on lactate was not significant neither in cyclists nor in other athletes (Table 4).

When the change in lactate was assessed comparing lactate concentration at the end of first exercise bout with the end of second exercise bout (B–D), CM did not significantly affect lactate compared to other beverages (MD = −0.03 mmol/L, 95% CI: −0.79, 0.73, $P = 0.945$). There was no evidence of heterogeneity between results of studies (Cochrane Q test, Q statistic = 0.31, $P = 0.959$, I^2: 0.0%). According to subgroup analysis, lactate concentration did not change significantly in any subgroups after CM consumption. In addition, the effect was not sensitive to correlation coefficient used to measure lactate changes. Removing any of the studies did not change the result. The effect was not significant in different subgroups (Table 4).

Creatine kinase (CK)

Four studies with 43 subjects were included in the analysis [26, 27, 30, 32]. In total, CM consumption did not change serum CK significantly (MD = −70.61 U/L, 95% CI: −169.26, 28.04, $P = 0.161$). There was a moderate level of heterogeneity (Cochrane Q test, Q statistics = 6.11, $P = 0.107$, I^2: 50.9). The effect was also not significant in different subgroup analyses (Table 4). The overall effect was sensitive to removing a study done by Ferguson-Stegal et al. [26] and removing this study turned the overall effect significant (MD = −108.98 mmol/L, 95% CI: −209.38, −8.59, $P = 0.033$) and the heterogeneity was reduced (Cochrane Q test, Q statistic = 2.94, $P = 0.23$, I^2: 31.9%).

Heart rate (HR)

Meta-analysis of six studies with 59 participants regarding the effect of CM consumption on recovery heart rate [25–27, 31, 35, 36] was not significant (MD = −0.24 bpm, 95% CI: −4.22, 3.75, $P = 0.908$). The heterogeneity between-study results was moderate (Cochrane Q test, Q statistic = 10.64, $P = 0.059$, I^2: 53%). The overall effect was not sensitive to removing any study included in the meta-analysis. The effect was also not significant in different subgroups (Table 4).

Publication bias

In the present study, although there was a slight asymmetry in Begg's funnel plots (Supplementary Figure 1), there was no evidence of publication bias using statistical asymmetry tests in meta-analyses considering the effect of CM consumption on TTE (Begg's test, $P = 1.0$, Egger's test, $P = 0.446$), RPE (Begg's test, $P = 0.368$, Egger's test, $P = 0.581$), lactate when considering the difference between the post-exercise and before the recovery exercise (B–C, Begg's test, $P = 1$, Egger's test, $P = 0.42$) and in comparison between the post-exercise values and the post recovery exercise values (B–D, Begg's test, $P = 0.734$, Egger's test, $P = 0.547$), CK (Begg's test, $P = 1$, Egger's test, $P = 0.648$), and HR (Begg's test, $P = 0.133$, Egger's test, $P = 0.177$).

Discussion

The present systematic review and meta-analysis revealed that CM consumption as a post-exercise recovery drink did not significantly influence TTE, RPE, HR, lactate, and CK when compared with other recovery drinks. However, there

Table 4 The effect of CM on serum lactate (post-glycogen depletion exercise levels (B) compared to pre (C) and post-endurance trial (D), serum creatine kinase (CK), and heart rate (HR)) subgroup analyses based on exercise type and control beverage

Markers	Studies (*n*)	Participants (*n*)	Effect	Heterogeneity			
			Mean difference (CI)	*P* value	*Q* statistics	*P* value	I^2 (%)
Serum lactate (mmol/L)							
Post-glycogen depletion vs. pre-endurance trial levels (B–C)							
Exercise type							
Cyclist	3	28	−0.58 (−1.50, 0.34)	0.215	3.94	0.139	49.3
Others	1	10	−1.90 (−5.13, 1.33)	0.249	0	—	—
Control beverages							
Placebo	2	20	−1.20 (−2.06, −0.34)	0.006	0.19	0.661	0
CHO + PRO beverages	2	18	−0.16 (−1.23, 0.90)	0.766	1.4	0.273	28.6
CHO + PRO + FAT beverages	3	28	−0.03 (−0.61, 0.54)	0.916	0.55	0.760	0
Quality of articles							
Fair	3	29	−1.10 (−1.83, −0.36)	0.004	0.42	0.811	0
High	1	9	0.30 (−0.83, 1.43)	0.604	0	—	—
Overall	4	38	−0.67 (−1.49, 0.16)	0.112	4.51	0.211	33.5
Post-glycogen depletion vs. post-endurance trial levels (B-D)							
Exercise type							
Cyclist	3	28	−0.02 (−0.8, 0.76)	0.960	0.3	0.862	0.0
Others	1	10	−0.2 (−4.05, 3.65)	0.919	0	—	—
Control beverages							
Placebo	2	20	−0.3 (−1.69, 1.1)	0.677	0	0.958	0
CHO + PRO beverages	2	18	0.09 (−0.82, 0.99)	0.851	0.1	0.754	0
CHO + PRO + FAT beverages	3	28	−0.01 (−0.72, 0.70)	0.985	0.02	0.988	0
Quality of articles							
Fair	3	29	−0.20 (−1.22, 0.81)	0.694	0.04	0.981	0
High	1	9	0.20 (−0.95, 1.35)	0.733	0	—	—
Overall	4	38	−0.03 (−0.79, 0.73)	0.945	0.31	0.959	0
Creatine kinase (CK) (U/L)							
Exercise type							
Cyclist	3	30	−57.76 (−198.63, 83.11)	0.422	5.91	0.052	66.2
Others	1	13	−100.0 (−231.39, 31.39)	0.136	0	—	—
Control beverages							
Placebo	1	10	19.09 (−104.51, 142.69)	0.762	0	—	—
CHO + PRO + FAT beverages	4	43	−68.73 (−165.1, 27.64)	0.162	6.77	0.08	55.7
Quality of articles							
Fair	3	30	−57.76 (−198.63, 83.11)	0.422	5.91	0.052	66.2
High	1	13	−100.00 (−231.39, 31.39)	0.136	0	—	—
Overall	4	43	−70.61 (−169.26, 28.04)	0.116	6.11	0.107	50.9
Heart rate (HR) (bpm)							
Exercise type							
Cyclist	4	36	0.27 (−5.06, 5.60)	0.921	7.58	0.056	60.4
Others	2	23	−0.11 (−9.82, 9.60)	0.982	2.74	0.098	63.5
Control beverages							
Placebo	3	28	5.24 (−4.03, 14.51)	0.268	7.16	0.028	72.1
CHO + PRO beverages	2	18	−3.00 (−7.96, 1.96)	0.235	0	1.00	0.0
CHO + PRO + FAT beverages	4	41	2.60 (−5.33, 10.53)	0.521	12.8	0.005	76.6

was a moderate level of heterogeneity between studies and subsequent sub-analyses revealed a significant positive effect for CM on TTE when compared to placebo or CHO + PR + FAT beverages. Furthermore, post-exercise blood lactate was attenuated following CM compared with placebo and in studies categorized as fair quality articles.

Chocolate milk seems to be a good candidate to aid in recovery since it contains carbohydrates, proteins, water, and electrolytes. Mechanistically, carbohydrate beverages may prevent hypoglycemia and delay the onset of fatigue during prolonged exercise [51]. The addition of protein to a carbohydrate beverage may further improve exercise performance [52, 53]. Potentially, the gluconeogenic amino acids and hyperinsulinemic response may enhance glycogen re-synthesis during recovery [13, 54] compared to CHO only drinks. The glycogen content is an important factor for time to fatigue and lactate concentrations [25, 55]. It is understood that accumulation of lactate may occur in the blood when muscle glycogen content is depleted [25]. Therefore, macronutrients of CM as fuel for skeletal muscle cells might significantly reduce lactate concentration. Central fatigue may also be influenced by CHO + PR beverages. Carbohydrates attenuate the ratio of free tryptophan, which increases the brain serotonin level and might lead the onset of fatigue [56]; it is suggested that addition of protein may stimulate this effect of carbohydrates [57]. Lastly, the fat in CM can increase circulating free fatty acids that can be used as a fuel source and spare glycogen [32, 58].

In the present study we revealed that CM increases TTE when compared with placebo. We also found a significant increase in TTE compared to CHO-PRO-FAT beverages, suggesting that other factors beyond the macronutrients may further augmented performance with CM ingestion. In addition, the fat content of CM in the included studies was more than CHO-PRO-FAT beverages which contain maximum 2.7 g fat, therefore, the fat content of CM might cause its effect on TTE when compared with CHO-Pr-FAT beverages. It is shown that increment in free fatty acids under hyperinsulinemic conditions (induced by carbohydrate and protein content of CM) lead to marked increase in intramyocellular lipids (IMCL) [59].

From a muscle perspective, CHO + PRO may attenuate muscle damage and aid in muscle repair. Nutritional supplements containing carbohydrates and protein decrease muscle disruption by reducing the initial mechanical damages [60]. Protein is well known to increase protein synthesis as well as suppress proteolysis therefore enhances muscle tissue repair and adaptation [26]. Addition of protein to a carbohydrate beverage cause an interactive effect to induce hyperinsulinemia for protein synthesis [10] and the protein outside cells might increase this action [61]. However, in the present study, the pooled analysis of studies did not show any significant difference between CM and other recovery beverages for muscle damage marker (CK). Future studies are required to determine whether CM induced acute increases in protein synthesis translate to whole body tissue changes over time.

We are aware of four narrative review articles regarding the effect of CM as one of CHO + PRO beverages [45–48]. Two review articles done by Kelly and Prittchet [45] and Spaccarotella and Andzel [47] reported that CM serves as a convenient, inexpensive and palatable beverage option for athletes but more research is needed to investigate the benefits of CM on recovery indices. Saunders [46] based on 5 studies about CM, concluded that this beverage is likely to be a good recovery beverage, and the other review article just summarize 2 studies which one of them was conducted on CM [48]. To the best of our knowledge, this is the first systematic review and meta-analysis in this regard. We included 12 studies in the systematic review and 11 studies were included in the meta-analysis, of which 6, 7, 4, 6, and 4 studies had data to derive the overall effect of CM on TTE, RPE, serum lactate, HR, and serum CK, respectively.

The present meta-analysis has some limitations that should be noted. There were only two studies with high quality in the current systematic review [25, 27] and the majority of the included studies were high risk or unclear regarding the randomization method and the concealment of allocation to the intervention periods. Furthermore, we could not conduct the meta-analysis on a number of markers because there was insufficient data [for instance, water consumption [25, 31], intracellular signaling proteins [24, 26], glycogen [24, 26], and myoglobin [26, 27]]. In addition, although the time trial was considered as a performance index in some articles, it was measured in different methods, such as exercise time [44], time trial [26, 27] or run and climb time [29, 35], duration of initial exercise [25] or duration of each exercise zone [34] and time to complete a given distance [36]. It should also be noted that the majority of the participants included in the present systematic review were men, and only two studies included female athletes [26, 29].

In conclusion the present systematic review and meta-analysis, revealed that CM consumption after exercise improved TTE compared to placebo or CHO + PRO + FAT drinks. Furthermore, CM consumption led to lower blood lactate compared to placebo. Therefore, CM either provides similar or superior results on recovery indices compared to other recovery drinks and thus represents an alternative and often economic replacement. Further investigations with larger sample sizes and more rigorous methodology will help to elucidate the effect of CM on recovery from exercise.

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Author contributions AS-A and MA conceived the study. All authors contributed in defining the search strategy. MA and AS-A carried out the literature search and data extraction. MA and AS-A accomplished the quality assessment of the included studies and data analysis. MA, AS-A, and RG contributed in the interpretation of study results. MA wrote the first draft of the manuscript. MA, AS-A, MK, and SF facilitated with preparation of the manuscript, its finalization. All authors contributed to the study conception, design, and drafting of the manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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