An Evidence-Based Review of the Pathophysiology, Treatment, and Prevention of Exercise Associated Muscle Cramps

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ABSTRACT
Exercise-associated muscle cramps (EAMC) are common and frustrating for athletes and the physically active. We critically-appraised the EAMC literature to provide evidence-based treatment and prevention recommendations. While the pathophysiology of EAMC appears controversial, recent evidence suggests EAMC are due to a confluence of unique intrinsic and extrinsic factors rather than a singular etiology. The treatment of acute EAMC continues to include self-application or clinician-guided gentle static stretching until EAMC abatement. Once the painful EAMC are alleviated, clinicians can continue treatment on the sidelines by focusing on patient-specific risk factors that the clinician believes may have contributed to the genesis of EAMC. For EAMC prevention, clinicians should first perform a thorough medical history followed by identification of the patients’ unique risk factors that could have coalesced to elicit EAMC. Individualizing EAMC prevention strategies will likely be more effective than generalized advice (e.g., drink more fluids).

Key Words: best practice, dehydration, electrolytes, fatigue, risk factors
INTRODUCTION

Exercise-associated muscle cramps (EAMC) are painful, involuntary contractions of a skeletal muscle during or shortly after exercise. EAMC typically occur in muscles which span multiple joints and are frequently used during exercise (e.g., quadriceps).\(^1\) Severity ranges from a “cramp-prone state” to mild (i.e., usually self-treatable and do not limit exercise performance) or serious EAMC (require exercise cessation; occur with other systemic signs or symptoms requiring medical intervention; Table 1).\(^1-3\)

“Heat cramps” is a common but inaccurate term for EAMC. EAMC are not related to body temperature, occur in a variety of ambient conditions and environments, do not occur with passive heating, and are not immediately relieved by the application of cooling modalities.\(^4-6\) Similarly, spasms, contractures, tics, fasciculations, and tremors are also inaccurate terms for EAMC because they are either not painful or are associated with neuromuscular abnormalities.\(^4\)

EAMC are one of the most common conditions (or clinical syndromes) affecting athletes. Their occurrence varies considerably by sport, age, and sex.\(^2\) Cooper et al\(^7\) observed EAMC occurrence is high in the hottest months and had an incidence of 3.07/1000 athlete-exposures in a single American football season. In a 4-year study,\(^2\) the incidence of serious EAMC ranged from 1.01/1000 to 2.2/1000 race starters in a 56-km ultramarathon. EAMC incidence was highest in less experienced runners, older runners, and those running at a faster pace.\(^2\)

Despite their commonality, confusion and debate continue regarding EAMC pathophysiology, treatment, and prevention.\(^4,8,9\) Therefore, the purpose of this review is to critically-appraise the literature surrounding the pathophysiology, treatment, and prevention of EAMC and provide evidence-based recommendations to aid clinician’s diagnosis and management of this common condition.

METHODS

We did a computerized search of published articles written in English from 1900-2020 pertaining to the pathophysiology, treatment, and prevention of EAMC. We searched PubMed, Cochrane, CINAHL, SPORTDiscus, and the PEDRo databases and utilized Boolean operators combined with the following...
search terms: exercise associated muscle cramp, cramping, exercise, dehydration, electrolytes, fatigue, rehydration, treatment, and prevention. We also reviewed reference lists for further information on the topic. From this review, we developed 16 recommendations for treating and preventing EAMC and graded each recommendation using the SORT grading scale (Table 2).³⁰

PATHOPHYSIOLOGY OF EAMC

Dehydration and Electrolyte Imbalance Theory

The dehydration/electrolyte imbalance theory is the oldest theory and is primarily based on clinical observations. It proposes EAMC occur when sweating causes a contracture of the interstitial fluid space resulting in an increase in excitatory neurochemicals and mechanical pressure on motor nerve terminals.⁸

Many observations over the last 100 years seemingly support the dehydration/electrolyte imbalance theory. First, early researchers¹¹ speculated EAMC were due to three factors: sweat induced fluid and electrolyte (primarily chloride) losses, hard work by workers unacclimated to the heat, and/or exposure to high temperatures. However, measures of fluid or electrolyte balance were often unreported and many of these individuals suffered from an acute gastrointestinal illness (e.g., vomiting/diarrhea). Regardless, EAMC were linked to work-induced fluid losses. Second, EAMC diminished with saline administration in a small case series.¹² Third, tennis players (n=17)¹² and American football players with a cramp history (n=5)¹³ tended to have high sweat rates (~2.5 L/h) and sodium losses (up to 2.7 g/h) compared to non-crampers. Similarly, American football players with sweat sodium losses >1.18 g or sweat chloride losses >2.3 g during a workout were ~9 times more likely to be EAMC-prone.¹⁴ Finally, Ohno et al.¹⁵ counted the number of volitionally-induced hamstring cramps after nine men lost 0.5% (control), 1%, 2%, and 3% of their body mass passively in a sauna. They observed no cramps with 0.5% or 1% body mass reduction. When dehydrated to -2% or -3% body mass, three subjects cramped in each condition.
Conversely, expert opinion and other evidence from experimental and observational studies do not support the dehydration/electrolyte imbalance theory. First, the theory proposes a conflicting physiological argument. Athletes with EAMC lose large volumes of sweat which would result in significant losses in plasma volume and lead to an increased plasma osmolality. Consequently, fluid should leave the interstitial fluid space and enter the vasculature. However, crampers also purportedly lose significant amounts of sodium as “salty sweaters.” The losses in electrolytes would decrease plasma osmolality leading to little or no fluid moving out of the interstitial space. Second, plasma characteristics in athletes with and without EAMC were often within normal limits and comparable after exercise. Several studies of athletes with and without EAMC during competition demonstrated no differences between groups in plasma volume, red cell volume, body mass lost, or plasma electrolyte concentrations after exercise. The comparable blood characteristics between groups would suggest similar osmotic pressures systemically though some authors argue blood samples are not reflective of the conditions near the cramping muscles. However, when subjects were dehydrated to -6% of their body mass, no changes in muscle resting membrane potential occurred. Third, while sodium and chloride losses and sweat rate predicted EAMC-prone athletes in American football, this relationship was not clinically-meaningful in 10 other sports. Moreover, when diet, hydration status, environmental conditions, and exercise intensity and duration were controlled, no differences in sweat characteristics were identified between subjects with varying EAMC susceptibilities. Fourth, since dehydration and electrolyte losses are systemic, EAMC should occur in any muscle, not just the working muscles, if the dehydration/electrolyte imbalance theory were true. Fifth, athletes prone to EAMC consume similar volumes of fluid during exercise as non-crampers. Sixth, stretching relieves cramping but does not alter the fluid or electrolyte levels of the body. Finally, electrically-induced cramp susceptibility was unchanged when subjects lost 3-5% of their body mass and ~4 g of sodium and fatigue was minimized, suggesting dehydration and electrolyte losses had minimal effect on cramp susceptibility.
Altered Neuromuscular Control Theory

The altered neuromuscular control theory was proposed in 1997 and updated in 2009 as a new explanation for EAMC etiology. The altered neuromuscular control theory suggests EAMC occur when fatigue and other risk factors contribute to a final common pathophysiological pathway of an imbalance between excitatory and inhibitory stimuli at the alpha motor nerve. The theory arose out of observations that fatigue altered muscle spindle and golgi tendon organ firing rates in an animal model. These afferent activity changes could lead to over excitation of the motor nerves. Prospective cohort studies of athletes with EAMC have consequently identified risk factors more consistent with fatigue-induced alterations in nervous system excitability (e.g., poor conditioning, higher exercise intensities) than dehydration or electrolyte losses. Most EAMC occur in exercising or actively contracting muscles that cross multiple joints (e.g., gastrocnemius, hamstrings). Muscles which cross multiple joints often contract in already shortened positions; thus, the amount of muscle inhibition coming from golgi tendon organs is reduced. EAMC also typically occur near the end of competitions when fatigue is likely greatest. Laboratory studies confirmed the importance of muscle afferents and spinal pathways to cramp development and non-crampers produced stronger amounts of inhibition than crampers. Moreover, cramps could be induced volitionally in the absence of dehydration or electrolyte losses. Collectively, these observations suggested nervous system alterations are needed for EAMC to occur and that the “final common pathway” to EAMC was alteration in neuromuscular control.

While this theory better explains clinical and laboratory observations of cramping, it is not without its limitations and questions. When first proposed, this theory emphasized the importance of fatigue-induced alterations in afferent activity resulting in over excitation at the alpha motor neuron. Yet, it is unclear how fatigue alters this signaling, if a fatigue threshold must reached before patients experience EAMC, or whether fatigue-induced changes in excitability can be modulated by other factors. What is known is well-trained and conditioned athletes still develop EAMC. Also, training history is, at times, not predictive of EAMC occurrence. Thus, fatigue cannot be the sole generator of EAMC and other factors can alter neuromuscular control. Contrary to the theory, one laboratory study observed
localized, fatiguing contractions decreased electrically-induced cramp susceptibility. Lastly, many of the laboratory studies supporting this theory utilized low frequency electrical stimulation to induce cramps. This technique allows for studying cramp susceptibility between different muscles and can discriminate between crampers and non-crampers. However, the muscles studied are often small (e.g., flexor hallucis brevis) and different than the muscles that usually develop EAMC during exercise. Thus, there are questions about the applicability of the findings to EAMC.

**Multifactorial Theory of EAMC**

Building on Schwellnus’ theory, Miller recently proposed an EAMC pathophysiology model which focused on how multiple risk factors interact to elicit a chain reaction which alters neuromuscular control and induces EAMC (Figure 1). This model theorized numerous unique intrinsic and extrinsic factors may coalesce through different pathways and elicit EAMC. For example, consider an athlete who sustains a muscle injury. This injury may cause deconditioning, pain, and an inability to tolerate the same exercise intensities and durations as before their injury. Consequently, these risk factors coalesce, alter neuromuscular control, and elicit EAMC.

This model also proposes a “factor threshold” must be reached before EAMC occur and that this threshold may be positively or negatively mitigated by other risk factors. Thus, when predisposed individuals with intrinsic risk factors are exposed to extrinsic factors and exceed their “factor threshold,” EAMC occur. This multifactorial theory and “factor threshold” may explain why EAMC occur in some individuals, and some situations, but not others. Further research is needed to clarify which factors contribute to EAMC, how these factors coalesce, and whether some factors have more or less importance to EAMC development.

**ACUTE EAMC DIAGNOSIS AND TREATMENT**

EAMC normally present acutely during or after exercise. The diagnosis of EAMC is based on a thorough clinical examination and history. Acutely, patients present in noticeable pain, often resulting in slowing or ceasing activity altogether. Patients often report subtle muscle “twitching” prior to
EAMC (“cramp-prone state”). Cramping muscles appear rigid with the joint often “locked” in its end range of motion. Clinicians will observe visible knotting/tautness that is palpable—a key sign differentiating EAMC from exertional sickling “cramps.” Fasciculations that “wander” over the muscle are also possible.\textsuperscript{35} Athletes with more serious EAMC that occur concomitantly with other serious medical conditions (e.g., hyponatremia) warrant additional evaluation and diagnosis and should be immediately referred for further medical care (Table 1).\textsuperscript{2,35}

Clinicians should develop treatment protocols for acute EAMC. Ideally, clinicians would take an individualized treatment approach (Figure 2 and Table 3) and continue EAMC treatments for up to an hour since susceptibility to EAMC remains high even after cessation.\textsuperscript{29}

Rest and Pain-Relieving Agents

While most patients can finish exercise following mild EAMC, some athletes cannot complete athletic contests because of EAMC.\textsuperscript{3,36} In these cases, rest will help normalize neuromuscular activity and allow an opportunity for treatments to address the underlying risk factors that contributed to EAMC development (e.g., depleted muscle energy).\textsuperscript{35} Ideally, the patient should be placed in a position of comfort. Similarly, pain relieving agents (e.g., cryotherapy, massage, electrical stimulation) may provide relief from the EAMC by interrupting the pain-spasm-pain cycle.\textsuperscript{4} While the athlete is resting, clinicians should identify and address the factors which may have precipitated EAMC development.

Stretching

The fastest, safest, and most effective treatment for an active EAMC is clinician-administered or self-administered gentle stretching.\textsuperscript{5,22,35} While no research has examined which type of stretching most effectively relieves active EAMC, static stretching increases tendon tension and elongated muscles produce the highest amount of golgi tendon organ inhibition.\textsuperscript{26} This may help restore balance between excitatory and inhibitory signaling and may explain the reduction in muscle activity observed when cramping muscles are stretched.\textsuperscript{9} Stretching also physically separates the contractile proteins which is
beneficial since muscle shortening is required for cramping. If stretching fails to relieve EAMC, clinicians should seek advanced medical care.

**Rehydration: Beverage Type**

If tolerated, athletes can drink water or carbohydrate-electrolyte beverages *ad libitum* during EAMC treatment since both restore plasma volume and osmolality over time and rehydrate effectively. However, stretching will alleviate EAMC more quickly than rehydration. Oral fluids require \( \geq 13 \) minutes to be absorbed into the blood stream though this timing can be prolonged depending on the beverage’s contents (e.g., acidity, electrolyte and carbohydrate content). Also, because these drinks are hypotonic compared to plasma, it can be dangerous to try and fully replace the electrolytes lost during exercise by only consuming sport drinks (Table 4). Ingesting such large volumes of hypotonic fluids will dilute the blood and could result in life-threatening hyponatremia.

**Rehydration: Delivery Method**

In most situations, rehydration should be completed orally due to its simplicity, accessibility, and myriad of delivery options (e.g., cup, water bottle, prepacked container). While intravenous fluids (IV) are popular amongst professional athletes, they require training in their administration and pose some risks (e.g., infection, air embolism, arterial punctures). Numerous studies have examined oral versus IV fluid administration on hydration status and noted comparable restoration in plasma osmolality, plasma volume, skin blood flow, stroke volume, cardiac output, heart rate, skin temperature, rectal temperature, performance, and fluid regulatory hormone responses. Interestingly, perceptual measures (e.g., thirst, thermal sensation, and rating of perceived exertion) are often lower with oral rehydration because IV fluid delivery bypasses fluid volume receptors in the mouth (i.e., baroreceptors). While either fluid delivery method can be used to treat EAMC, IV fluid administration should be saved for time-sensitive situations (i.e., <15 minutes) or situations where patients cannot orally consume fluids (e.g., too much pain, repeated vomiting).
Transient Receptor Potential (TRP) Receptor Agonists

TRP receptors detect temperature and sensations in the mouth, oropharynx, esophagus, and stomach. Ingredients like vinegar, cinnamon, capsaicin, and ginger activate these receptors and, in theory, potentially affect neural function if potent enough. Two of the more popular TRP agonists are pickle juice and mustard due to their high concentrations of vinegar and/or salt. In one single-blinded study, ingesting small volumes (<100 mL) of pickle juice during cramping relieved cramps 45% faster (68.6 seconds) than no fluids and 37% faster (49.1 seconds) than water. This effect was not immediate (~90 s) nor due to the electrolytes consumed since small volumes of pickle juice did not affect plasma volume, plasma electrolyte concentrations, or plasma osmolality. Instead, the authors hypothesized vinegar triggered an oropharyngeal reflex that inhibited cramping. Conversely only anecdotal evidence exists to mustards efficacy at relieving acute EAMC. However, the efficacy of mustard is unlikely due to electrolyte replacement since ingesting large volumes (~135 g) had no impact on plasma electrolyte concentrations, plasma osmolality, or plasma volume up to 60 minutes post-ingestion.

Other studies investigated the effect of spicy, capsaicin-based TRP agonists on cramp susceptibility. While one study reported longer times before cramping; higher contraction forces necessary to induce cramping; and lower muscle activity during cramping, all subjects still cramped post-ingestion of the TRP-agonist drink. Conversely, Behringer et al. noted insignificant changes in cramp susceptibility, perceived muscle pain, cramp intensity, or maximal isometric force from 15 minutes to 24 hours post-ingestion of a TRP agonist. Further research is needed on TRP agonists and EAMC.

While TRP-agonist ingestion is usually benign, gastrointestinal tolerance varies considerably. If utilized, clinicians should provide small volumes (<100 mL), only provide them when oral solutions are tolerated, and no food allergies are known. If relief of symptoms does not occur relatively quickly (<2 minutes), other treatments should be utilized.

Bananas
While potassium is generally not considered an electrolyte of interest in EAMC etiology, bananas are sometimes used during EAMC treatment due to their high potassium and glucose content. However, no evidence exists on their efficacy. Some data suggest they are unlikely to help by increasing blood potassium since dehydrated subjects who ingested 1 or 2 servings of bananas post-exercise did not experience an increase plasma potassium concentrations or plasma volume until 60 minutes after consumption. Interestingly, plasma glucose increased significantly in the 2 servings trial but this effect occurred 15 minutes post-ingestion. If poor nutrition is suspected as a risk factor for an athlete’s EAMC, we advise clinicians advocate a well-rounded pre-exercise nutrition plan and consult with a nutritionist before implementing dietary interventions.

**Quinine**

Quinine and quinine products (e.g., tonic water) were once a popular treatment for cramping. It has fallen out of favor because it requires a prescription and the United States Food and Drug Administration banned all over-the-counter quinine products for cramping in the mid-1990s. A Cochrane review of 23 trials reported quinine reduced the number of cramps experienced and cramp intensity though the extent of this reduction was clinically unimpressive with a mean reduction of <2 cramps over a two week period (95% CI = -2.2 to -1.42). Interestingly, cramp duration was not significantly reduced which is the variable of interest in the acute treatment of EAMC. Importantly, minor and major adverse events were reported in many of the trials (e.g., gastrointestinal distress, thrombocytopenia). Consequently, we do not recommend using quinine for EAMC.

**CHRONIC OR RECURRENT EAMC DIAGNOSIS AND TREATMENT**

The first step in the diagnosis and treatment of a patient presenting with recurrent EAMC is to do a thorough medical evaluation to rule out any intrinsic risk factors including underlying history of injury, past EAMC history, chronic medical conditions, medication use, or allergies (Figure 2 and Table 3). If an underlying condition is identified, that condition should be treated before attempting EAMC prevention strategies.
Upon ruling out underlying conditions, clinicians should thoroughly question patients to identify pertinent extrinsic or intrinsic risk factors. Risk factors shown to be consistently associated with EAMC include pain,21 a prior history or previous occurrence of EAMC,21,22,48 muscle damage/injury,18,21,31,48 prolonged exercise durations,1,20,30,48 and faster finishing times than anticipated.2,22 Consequently, setting realistic goals, obtaining regular and sufficient sleep,49 incorporating rest and recovery sessions in training schedules, and training at similar intensities and in similar environments to competition may help stave off many risk factors known to contribute to EAMC.

Since the strongest and most recent evidence suggests EAMC are due to changes in the neuromuscular system,4,9 the majority of diagnostic questions revolve around factors which affect nervous system excitability (Table 3). These questions can be asked before and after each EAMC to help clinicians identify consistency in risk factors. Targeted prevention strategies for those risk factors can then be attempted.

PREVENTION OF EAMC

Unfortunately, many EAMC prevention recommendations have been advocated but most lack support from strong patient-oriented studies or are based on anecdote (Table 2). Indeed, much of the published EAMC prevention advice is based on data from studies on electrically-induced cramps rather than EAMC, is anecdotal, is often too generic (e.g., consume more salt), or fails to appreciate the complexity of EAMC pathogenesis. Moreover, many patients and clinicians lack an understanding of the possible causes and risk factors for EAMC and have an overconfidence in the contribution of hydration and electrolytes to EAMC etiology.50 Sadly, an overemphasis on hydration and electrolyte consumption to prevent EAMC contributed to two high-school athlete deaths from hyponatremia in 2014.4 Therefore, we advocate clinicians educate athletes about EAMC etiologies and safe hydration practices before implementing prevention strategies,38 take a multi-factorial approach to EAMC prevention, implement EAMC prevention strategies cautiously and with thorough documentation, and, at minimum, perform a thorough medical exam before implementing any of the following strategies.
Carbohydrate-Electrolyte Beverages, Electrolyte Supplements, and Stimulants

Sport drink consumption and electrolyte supplementation are frequently touted as effective remedies to prevent EAMC though large variability exists in the content of sports drinks and electrolyte supplementation products (Table 4). While electrolyte tablets and magnesium supplementation are frequently touted for cramping, a Cochrane review reported magnesium supplementation offered no clinically-meaningful benefits in terms of cramp frequency, intensity, or duration compared to placebo. However, investigators in the 1920s observed workers prevented EAMC by consuming saline or adding salt to their beverages. Bergeron reported a tennis player prevented EAMC by increasing dietary salt intake by 6,000-8,000 mg/day, increasing caloric intake by 5000-6000 kcal/day, improving pre-event hydration status, and adding salt to sports drinks when the player felt EAMC were imminent. When subjects ingested a 6% carbohydrate-electrolyte beverage with added salt during a calf-fatiguing protocol, EAMC occurred after 36.8±17.3 minutes compared to 14.5±5.0 minutes when nothing was consumed. More recently, authors observed a 2% carbohydrate-electrolyte beverage decreased electrically-induced muscle cramp susceptibility. Unfortunately, in both of these studies, the experimental designs prohibited identification of the ingredient responsible for this effect since the drink contained multiple ingredients (e.g., electrolytes and carbohydrates). However, the large carbohydrate load (18.2 g/L to 57 g/L) may be responsible since plasma electrolyte values decreased post-ingestion. In theory, carbohydrate-electrolyte drinks could help prevent EAMC by increasing muscle glycogen and delaying fatigue but more well-designed studies are needed to identify the active ingredients and minimal and optimal dosage for efficacy. Clinicians should be wary of sport drinks which contain stimulants (e.g., caffeine) since these may cause an increase in nervous system excitability which, in theory, could predispose patients to EAMC. Conversely, several studies failed to show differences in plasma electrolyte concentrations in athletes with and without EAMC. Sodium supplementation did not differ between
ultramarathoners with and without EAMC. Further research is needed on electrolyte supplemen-
tation and EAMC.

Hydration Assessment

If clinicians suspect hydration is a risk factor for recurrent EAMC, we recommend sweat testing.
Determining sweat rate is relatively simple and requires measuring body weight before and after exercise.
Clinicians must also know the duration of exercise and the volume/weight of any fluids ingested or lost
(i.e., urination). Determining sweat electrolytes lost is more complicated and requires expensive
equipment. However, sweat electrolyte estimates are available for many sports. Ideally, sweat tests
would be performed under similar environmental, equipment, and exercise parameters as competition for
accuracy. Combining an athletes’ sweat test results with a well-balanced, nutritious diet that considers
the athlete’s unique carbohydrate, fluid, and electrolyte needs will better ensure the athlete is prepared for
exercise and minimize the risk of hyponatremia.

Intravenous Fluids

Some clinicians use IV fluids to prevent EAMC and believe they are effective. Unfortunately, no large scale clinical trials have demonstrated IV fluid administration reduces the occurrence of EAMC or shown it is more effective than oral fluid administration. Since EAMC are non-life threatening and oral rehydration can safely restore fluid and electrolyte deficits, we recommend clinicians avoid using IVs prophylactically.

Prophylactic Stretching

While static stretching effectively treats EAMC, it appears to be ineffective as a prophylactic strategy. In a laboratory study, three, one-minute bouts of static or proprioceptive neuromuscular facilitation (hold-relax with agonist contraction) stretching did not lower cramp susceptibility. Observational studies in athletes also consistently failed to demonstrate relationships between flexibility, range of motion, and stretching frequency, duration, or timing with EAMC occurrence. Moreover,
golgi tendon organ inhibition was unaffected by a single bout of clinician-applied static stretching immediately and up to 30 minutes post-stretching in the triceps surae. Thus, it is unlikely pre-event stretching would produce long-lasting inhibition from golgi tendon organs that would help prevent the over excitation to the alpha motor neuron pool thought to contribute to EAMC development.

Exercise and Neuromuscular Retraining Protocols

Neuromuscular retraining with exercise shows promise for EAMC prevention. Wagner et al. reported a triathlete’s hamstring EAMC were eliminated by lowering hamstring activity during running and improving gluteal strength and endurance. Encouragingly, the patient required few professional visits (once a month for 8 months) and a short (20 minute), daily at home protocol to achieve this outcome. More recently, marathoners who experienced EAMC were less likely to include once per week lower extremity strength training in the three months leading up to a race than their non-cramping counterparts (25% v. 48%, respectively) suggesting strength training may be helpful to prevent EAMC. Since fatigue is hypothesized to be a main factor in EAMC development, it is vital to ensure athletes exercise with appropriate work-to-rest ratios since overexertion is often tied to EAMC. Further research should explore how sport-specific exercise or endurance activities can prevent EAMC.

CONCLUSIONS

Advances in our understanding of EAMC pathogenesis have emerged in the last 100 years and suggest alterations in neuromuscular excitability, and to a much lesser extent, dehydration and electrolyte losses, are the predominant factors in their pathogenesis. Strong evidence suggests EAMC treatments should include exercise cessation (rest) and gentle stretching until abatement followed by techniques which address the underlying factors which precipitated EAMC occurrence. Unfortunately, little patient-oriented evidence exists on the best methods for EAMC prevention. Therefore, we recommend clinicians take a multi-faceted and targeted approach that incorporates an individual’s unique EAMC risk factors when trying to prevent EAMC rather than generalized advice.
FIGURE LEGEND

Figure 1. Multifactorial theory for pathogenesis of EAMC. Dashed arrows used to help with clarity of understanding the “hot and/or humid environmental conditions” and “repetitive muscle exercise” pathways.

Adapted from Miller KC. Exercise Associated Muscle Cramps. In: Adams WM, Jardine JF, eds. Exertional Heat Illness: A Clinical and Evidence-Based Guide. Springer. Cham, Switzerland. 2020. Used with permission.

Figure 2. Decision tree for the individualized treatment of EAMC.
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Table 1. Clinical severity of EAMC

Cramp-prone State or Pre-Cramping

- A heightened neuromuscular excitability ("near cramping" state) identified by involuntary muscle fasciculations or twitching.
- Higher resting EMG activity than non-cramping muscles.
- Cramp-prone state is usually self-limiting and self-treatable if activity stops or decreases.

Mild or Moderate (benign) EAMC

- EAMC localized to a muscle or muscle group.
- Higher resting EMG activity than non-cramping muscles.
- EAMC without other systemic symptoms/signs of a concomitant, more serious injury (e.g., hyponatremia).
- These EAMC are usually self-limiting and treatable if activity stops or decreases.

Severe or Serious EAMC or EAMC as a Sign of Systemic Pathology

- Localized or generalized EAMC that may occur alongside more serious systemic symptoms/signs including dizziness, collapse, nausea/vomiting, dark urine or altered state of consciousness (e.g., confusion, coma). These symptoms/signs indicate the presence of a more serious underlying/concomitant medical condition (e.g., serum electrolyte abnormality, kidney injury).
- Higher resting EMG activity in cramped and non-cramping muscles at rest indicating general neuromuscular excitability.
- These EAMC necessitate immediate exercise cessation; correct diagnosis and medical intervention for the underlying medical condition; and likely transport to a hospital.

EAMC can progress in severity from mild to severe (as a continuum) during exercise. EAMC = exercise-associated muscle cramps. EMG = electromyographic activity.
Table 2. Exercise-associated muscle cramping prevention and treatment recommendations with SORT grading.

| Recommendation | SORT Grade |
|----------------|------------|
| **Treatment**  |            |
| 1. Athletes or clinicians should apply gentle static stretching to the EAMC until it abates.\(^1\,2\,5\,2\,2\,6\,3\,5\) | A |
| 2. Food items containing acetic acid (i.e., vinegar) or transient receptor potential activators (e.g., capsaicin) may help relieve acute EAMC. If these items are used, they should be administered infrequently and in small volumes (<100 mL). Moreover, they should only be attempted in those patients without applicable food allergies.\(^4\,1\,4\,2\,4\,4\,4\,5\) | B |
| 3. Once EAMC have abated and an athlete has been removed from exercise, clinicians may attempt or encourage: | |
| a. Rest in a position of comfort in which treatments can be applied.\(^6\) | C |
| b. Continued gentle stretching, as necessary.\(^6\) | C |
| c. Oral ingestion of fluids containing carbohydrates and electrolytes *ad libitum.*\(^6\) | C |
| d. Intravenous fluid administration and emergency transport if an athlete cannot tolerate fluids orally or has severe gastrointestinal distress (e.g., vomiting, diarrhea).\(^6\,3\,9\) | C |
| e. Interventions that reduce muscle pain or soreness in the cramping muscles (e.g., cryotherapy, massage, electrical stimulation).\(^6\) | C |
| 4. EAMC treatments should continue in the hours after an initial episode to reduce recurrence.\(^2\,9\) | C |
| 5. No medications should be administered for EAMC without a physician’s consent or presence.\(^3\,5\) | C |
Table 2, continued.

| Recommendation                                                                 | SORT Grade |
|--------------------------------------------------------------------------------|------------|
| **Treatment, continued**                                                        |            |
| 6. Quinine, or products containing quinine (e.g., tonic water), should not be administered for EAMC treatment. | A          |
| **Prevention**                                                                 |            |
| 1. Thoroughly evaluate athletes for underlying general medical conditions, allergies, or medication usage that may contribute to EAMC occurrence. | C          |
| 2. Thoroughly question athletes with EAMC history to identify athletes’ unique extrinsic and intrinsic risk factors and then target those risk factors with interventions. | C          |
| 3. Incorporate neuromuscular re-education, plyometrics, or strength training into training sessions when neuromuscular fatigue has been identified as a factor in an athlete's EAMC. | B          |
| 4. Train at intensities, and in environments (e.g., temperature, altitude), similar to competition. | B          |
| 5. Include suitable rest periods following training and competition to allow recovery and minimize residual effects of muscle damage. | C          |
| 6. Educate athletes about the various causes of EAMC and safe hydration and drinking behaviors before beginning an EAMC prevention strategy. | C          |
| 7. Consume a nutritious, well-balanced diet that takes into account the unique carbohydrate, electrolyte, and fluid needs before training and competitions. | C          |
Table 2, continued.

| Recommendation                                                                 | SORT Grade |
|--------------------------------------------------------------------------------|------------|
| Prevention, continued                                                          |            |
| 8. Consume carbohydrates or a carbohydrate-electrolyte drink during exercise to help stave off fatigue and encourage greater absorption and retention of ingested fluids.\(^6,38\) | C          |
| 9. Identify athletes’ fluid and electrolyte needs based on sweat rate and composition to avoid under or over-hydration or under or over-electrolyte supplementation if fluid and electrolyte monitoring is included in an EAMC prevention strategy.\(^38\) | C          |
| 10. Intravenous fluids should not be administered before events for the sole purpose of preventing EAMC.\(^6\) | C          |

EAMC: exercise-associated muscle cramp.
Table 3. Questions to aid in the identification of EAMC risk factors.

| Question                                                                 | Justification                                                                 | Risk factor                                      |
|--------------------------------------------------------------------------|------------------------------------------------------------------------------|--------------------------------------------------|
| 1. Do you have any illnesses, allergies, or medical conditions?          | Muscle cramping may be associated with allergies or diseases.                 | Underlying illness                                |
| 2. Did EAMC occur after a change or start of medication or drug use?     | Muscle cramping may be associated with medication use (e.g., beta-2 agonists). | Medication side effect                            |
| 3. Do you regularly cramp during exercise?                               | Muscle cramping has a genetic component. Asking about prior history of EAMC  | Multiple mechanisms                               |
|                                                                          | is helpful to identify recurrent crampers.                                   |                                                  |
| 4. How intense and long were you exercising before you developed EAMC?  | EAMC occur in athletes with the fastest actual and predicted race times.     | Fatigue                                          |
| 5. When did the EAMC occur during exercise (i.e., beginning, middle, end)? | EAMC tend to occur near the end of exercise or competitions.                  | Fatigue                                          |
| 6. How much sleep did you get the night before your exercise session when EAMC occurred? | Sleep loss reduced muscle glycogen and time to exhaustion.                  | Premature fatigue                                 |
| 7. How hot and humid was it when you developed EAMC?                    | EAMC can occur under any environmental conditions though they do occur most frequently in summer months (e.g., August). | Hypohydration, premature fatigue, unacclimatized to environment |
| 8. Was the exercise session during which EAMC occurred novel in any way?  | EAMC tended to occur more in untrained individuals or during harder than anticipated events. | Overexertion and/or fatigue                       |
| Question                                                                 | Answer                                                                                                                                                                                                 | Potential Cause                                      |
|------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------|
| 9. What was your diet like in the days preceding the EAMC?             | Was your diet nutritious, balanced (i.e., containing the major essential nutrients like protein, fat, and carbohydrates), and varied (i.e., nutrients coming from fruits, vegetables, meats)? Diets low in carbohydrates may reduce muscle glycogen and the amount of work or exercise performed. Athletes’ diets should be well-balanced and include electrolytes and carbohydrates to stave off fatigue. | Premature fatigue                                    |
| 10. Did you consume supplements or stimulants (e.g., caffeine) before or during your exercise session? | Stimulants and supplements can increase excitability of the nervous system. | Over excitation of nervous system                     |
| 11. Were you recently injured?                                         | Pain and prior injury are predictors of cramping.                                                                                                                                                | Over excitation of nervous system                     |
| 12. What was your psychological state during the exercise session when EAMC developed? | Stress or unrealistic expectations may increase nervous system and/or excitability. | Over excitation of nervous system                     |
| 13. Did you consume enough fluids and/or electrolytes to replace your sweat losses? | The contribution of sweat losses to EAMC genesis is minor for most athletes. However, American football players with an EAMC history may benefit from fluid and electrolyte monitoring. | Hypohydration; premature fatigue                      |
| 14. Did the EAMC tend to stop once you stopped the activity?           | Activity cessation and/or reduced pace can relieve EAMC. | Over excitation of nervous system                     |
| 15. Do the EAMC tend to occur only in the muscles that were doing the most work? | EAMC tend to affect working muscles and may be mitigated with reeducation of synergistic muscles. | Over excitation of nervous system                     |
Table 3, continued.

| Question                                             | Answer                                                                 | Source |
|------------------------------------------------------|------------------------------------------------------------------------|--------|
| 16. Did EAMC occur during training or during competition? | While EAMC can occur at any time and in any sport, they tend to affect athletes who run faster or exercise harder during competitions than training. | 2, 22, 30, 31 |
|                                                      | Over excitation due to stress of competition; premature fatigue due to overexertion |        |

EAMC = exercise-associated muscle cramps. Questions appear in no particular order or level of importance after Questions 1 and 2.

Adapted from Miller KC. Exercise Associated Muscle Cramps. In: Adams WM, Jardine JF, eds. Exertional Heat Illness: A Clinical and Evidence-Based Guide. Springer. Cham, Switzerland. 2020. Used with permission.
Table 4. Dangerous volumes of some popular sports drink an athlete with EAMC would need to ingest to completely replace sweat sodium and potassium losses during exercise.

| Sports drink                  | [Na\(^+\)] of beverage, (g/L) | Volume needed to fully replace Na\(^+\) lost, L (gal) | [K\(^+\)] of beverage, (g/L) | Volume needed to fully replace K\(^+\) lost, L (gal) |
|-------------------------------|-------------------------------|------------------------------------------------------|-------------------------------|------------------------------------------------------|
| A-Game                        | 0.49                          | 10.0 (2.7)                                           | 0.32                          | 2.9 (0.8)                                             |
| Accelerade*                   | 0.62                          | 7.9 (2.1)                                            | 0.25                          | 3.8 (1.0)                                             |
| All Sport                     | 0.24                          | 20.5 (5.4)                                           | 0.25                          | 3.8 (1.0)                                             |
| Body Armor SuperDrink         | 0.09                          | 54.6 (14.4)                                          | 1.48                          | 0.64 (0.2)                                            |
| Gatorade,                     |                               |                                                     |                               |                                                      |
| Original/Fierce/G2/Organic/Flow/Zero/Frost | 0.46                      | 10.7 (2.8)                                           | 0.13                          | 7.23 (1.9)                                            |
| Infuse Thirst Quencher        | 0.42                          | 11.7 (3.1)                                           | 0.13                          | 7.23 (1.9)                                            |
| K+ Organic Sports Drink       | 0.25                          | 19.6 (5.2)                                           | 0.15                          | 6.3 (1.7)                                             |
| Monster Energy Hydro Sports Drink | 0.21                      | 23.4 (6.2)                                           | 0.17                          | 5.53 (1.5)                                            |
| PowerAde, Original/Zero       | 0.42                          | 11.6 (3.1)                                           | 0.10                          | 9.4 (2.5)                                             |
| Propel Fitness Water          | 0.46                          | 10.7 (2.8)                                           | 0.12                          | 7.8 (2.1)                                             |
| SoBe Water                    | 0.13                          | 37.8 (9.9)                                           | 0.15                          | 6.3 (1.7)                                             |
| Squincher                     | 0.23                          | 21.3 (5.6)                                           | 0.19                          | 4.9 (1.3)                                             |
| Staminade                     | 0.38                          | 12.9 (3.4)                                           | 0.19                          | 4.9 (1.3)                                             |
| Vitamin Water, Active Werk it | 0.51                          | 9.8 (2.6)                                            | 0.18                          | 5.2 (1.4)                                             |

Estimates are based on the following assumptions and data from the literature on cramp-prone athletes: (1) an average sweat sodium concentration of 48.4 mmol/L (1.1 g/L),\(^{12,13,51}\) (2) an average sweat potassium concentration of 5.4 mmol/L (0.21 g/L),\(^{51}\) (3) an average sweat rate of 2.23 L/h,\(^{12,13,51}\) and (4) a 2-hour, continuous exercise bout. Based on these assumptions, the athlete would need to replace 4.91 g of Na\(^+\) and 0.94 g of K\(^+\). EAMC = exercise-associated muscle cramp; [Na\(^+\)] = sodium concentration; [K\(^+\)] = potassium concentration. * = product sold as a powder and made per manufacturer instructions.

From Miller KC. Exercise Associated Muscle Cramps. In: Adams WM, Jardine JF, eds. *Exertional Heat Illness: A Clinical and Evidence-Based Guide*. Springer. Cham, Switzerland. 2020. Used with permission.
Figure 1.

[Diagram showing various factors contributing to muscle cramps, including hot and humid environmental conditions, increased exercise duration, hypohydration, preponderance of type 2 muscle fibers, lack of sleep, older age, decreased muscle energy, inadequate conditioning, underlying medical condition, medication usage, contraction of a muscle in a shortened position, altered central nervous system function, reflex contraction, increased excitatory afferent activity (e.g., muscle spindle), increased muscle temperature, pain, decreased inhibitory afferent activity (e.g., Golgi tendon organ), final common pathway altered neuromuscular control (spinal), increased alpha motor neuron activity (spinal), prior cramp during the same exercise session, increased muscle cell membrane activity, and EAMC (exercise-associated muscle cramps).]
START: Confirm EAMC diagnosis and severity by a thorough medical assessment. Specifically ask:

1. Does the patient have serious EAMC or any signs/symptoms (e.g., dizziness, collapse, nausea/vomiting, dark urine or altered state of consciousness) that would be indicative of a more serious, systemic medical condition?
2. Does the patient have any predisposing medical conditions, medication usage, or food allergies that may affect the treatment plan?

Yes to 1 OR 2

Consult with physician before implementing or continuing treatment.

No to 1 AND 2

Will this treatment cause harm to my patient? Does the treatment have any banned substances?

Yes to either question

Apply treatment. Following treatment ask, “Did this treatment cause harm (e.g., gastrointestinal distress, skin reactions, other symptoms)?”

Yes

Document side effects and any negative outcomes. Discontinue treatment.

No

Did the treatment alleviate EAMC?

Yes

Continue use of treatment while considering EAMC preventive measures, recurring treatment costs, and safety of repeated use. Re-evaluate treatment effectiveness regularly. Take note of any signs of habituation (e.g., higher dosages required for same levels of effectiveness) or decreased treatment effectiveness.

No