Exercise-associated collapse: an evidence-based review and primer for clinicians

Chad A Asplund,1 Francis G O’Connor,2 Timothy D Noakes3,4

ABSTRACT
Exercise-associated collapse (EAC) commonly occurs after the completion of endurance running events. EAC is a collapse in conscious athletes who are unable to stand or walk unaided as a result of light headedness, faintness and dizziness or syncpe causing a collapse that occurs after completion of an exertional event. Although EAC is perhaps the most common aetiology confronted by the medical provider attending to collapsed athletes in a finish-line tent, providers must first maintain vigilance for other potential life-threatening aetiologies that cause collapse, such as cardiac arrest, exertional heat stroke or exercise-associated hyponatraemia. Previously, it has been believed that dehydration and hyperthermia were primary causes of EAC. On review of the evidence, EAC is now believed to be principally the result of transient postural hypotension caused by lower extremity pooling of blood once the athlete stops running and the resultant impairment of cardiac baroreflexes. Once life-threatening aetiologies are ruled out, treatment of EAC is symptomatic and involves oral hydration and a Trendelenburg position – total body cooling, intravenous hydration or advanced therapies is generally not needed.

DEFINITIONS
Exercise-associated collapse
Collapse in conscious athletes who are unable to stand or walk unaided as a result of light headedness, faintness and dizziness or syncpe causing a collapse that occurs after completion of an exertional event or stopping exercise.

Orthostatic intolerance
Symptoms caused by orthostatic hypotension, which is a sustained reduction of systolic blood pressure of at least 20 mm Hg or diastolic blood pressure of 10 mm Hg within 5 min of standing.

HEAT STROKE AND HYPONATRAEMIA
Exertional heat stroke (EHS) is characterised by central nervous system dysfunction, which may manifest as collapse or syncpe, associated with an increased core body temperature (>40°C), which is induced by exercise. Exercise-associated hyponatraemia (EAH) is a potentially life-threatening condition characterised by a decrease in serum sodium (<135 mmol/L) and mental status changes. Athletes with EAH may have true syncpe, confusion or disorientation but will have alteration in serum sodium.

Although EHS and EAH can be causes of collapse in endurance sporting activities, they are associated with abnormal vital signs and symptoms and should be considered and ruled out before considering a diagnosis of EAC. The focus of this review is EAC, its mechanism and treatment; therefore, EHS and EAH will not be discussed further in this review.
MECHANISM OF EAC
Endurance training is associated with an increased cardiac output and volume load on the left and right ventricles, causing the endurance-trained heart to a dilatation of the left ventricle combined with a mild-to-moderate increase in left ventricular wall thickness. This training-induced increase in cardiac output allows trained athletes to have a lower resting heart rate compared with the non-trained athletes. Furthermore, during exercise, the active muscles of the lower extremities require increased blood flow, and therefore, peripheral vascular resistance decreases to accommodate this need. To generate this large cardiac output, and to counter the resting decrease in heart rate secondary to training effect, athletes must increase their stroke volume and vascular resistance. Working skeletal muscle functions as a ‘second heart’, ensuring cardiac return to the heart from the dilated lower extremity vasculature. On cessation of activity, the second heart effect no longer assists venous return, and large volumes of blood may pool in the lower extremities and contribute to EAC. Therefore, the very adaptations that contribute to successful completion of endurance activities are also a large factor in the increased OI found in endurance athletes.

Evidence supports this increased susceptibility to OI in exercise-trained athletes. Studies support the concept of increase in calf and lower extremity compliance and increased diastolic chamber compliance and distensibility as contributors to OI in athletes. Endurance athletes have larger increases in left ventricular end-diastolic volume compared with non-athletes, which allow them to generate the necessary larger stroke volume. Trained athletes also demonstrated a decreased ventricular untwisting rate compared with non-trained athletes, demonstrating the trained heart’s ability to adapt to maintain cardiac output. Training-related expansion of vascular volume is associated with decreased heart rate response to baroreceptor stimulation. In addition, this exercise-induced change in cardiac filling volume and output may lead to a resetting of the cardiopulmonary baroreflex. Because of this reset baroreflex, trained individuals may depend more on maintenance of venous return to maintain upright body position after exercise. Finally, a critical review supports the exercise-induced increase

### Table 1 Mechanism

<table>
<thead>
<tr>
<th>Ref</th>
<th>Author/journal</th>
<th>Year</th>
<th>Study type</th>
<th>Patients</th>
<th>Outcome</th>
<th>LOE</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>Morikawa et al Med Sci Sports Exerc</td>
<td>2001</td>
<td>Controlled trial</td>
<td>26 female runners, 23 age-matched controls</td>
<td>Exercise-trained females have a high level of orthostatic intolerance during LBNP. Increase in leg compliance may play an important role</td>
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<tr>
<td>17</td>
<td>Levine et al Circulation</td>
<td>1991</td>
<td>Controlled trial</td>
<td>7 athletes and 6 controls</td>
<td>Endurance athletes have greater diastolic chamber compliance and distensibility than non-athletes</td>
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<td>18</td>
<td>Levine et al J Appl Physiol</td>
<td>1991</td>
<td>Controlled trial</td>
<td>8 high fit, 8 mid fit and 8 low-fit athletes</td>
<td>Calf compliance and carotid baroreflex response contributed to individualised response to LBNP</td>
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<tr>
<td>19</td>
<td>Esch et al Am J Physiol Heart Circ Physiol</td>
<td>2007</td>
<td>Controlled trial</td>
<td>8 athletes and 8 controls</td>
<td>Endurance athletes had larger increases in left ventricular end-diastolic volume compared with non-athletes despite similar right ventricular cavity area</td>
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<tr>
<td>20</td>
<td>Esch et al J Appl Physiol</td>
<td>2010</td>
<td>Controlled trial</td>
<td>8 athletes and 8 controls</td>
<td>Endurance athletes demonstrated a decreased left ventricular untwisting rate compared with non-athletes</td>
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<td>21</td>
<td>Convertino Med Sci Sports Exerc</td>
<td>2003</td>
<td>Controlled trial</td>
<td>8 men</td>
<td>Expansion of vascular volume after exercise is associated with reduced heart rate response to baroreceptor stimulation</td>
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<tr>
<td>22</td>
<td>Ogoh et al J Appl Physiol</td>
<td>2006</td>
<td>Clinical trial</td>
<td>8 men</td>
<td>Cardiopulmonary baroreflex may be reset during exercise to a new operating point associated with exercise-induced change in cardiac filling volume</td>
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<tr>
<td>23</td>
<td>Ogoh et al J Physiol</td>
<td>2003</td>
<td>Clinical trial</td>
<td>14 men</td>
<td>Highly fit individuals depend more on maintenance of venous return to maintain upright body position</td>
<td>2</td>
</tr>
<tr>
<td>24</td>
<td>Convertino Med Sci Sports Exerc</td>
<td>1993</td>
<td>Critical review</td>
<td>NA</td>
<td>Increased stroke volume is the main mechanism of compensation in aerobic trained individuals</td>
<td>3</td>
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</table>

LBNP, lower body negative pressure; LOE, level of evidence.

### Table 2 Dehydration/heat

<table>
<thead>
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<tr>
<td>23</td>
<td>Ogoh et al J Physiol</td>
<td>2003</td>
<td>Clinical trial</td>
<td>14 men</td>
<td>Baroreflex response to progressive depletion of central blood volume is attenuated in endurance training</td>
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<tr>
<td>26</td>
<td>Crandall Am J Physiol Heart Circ Physiol</td>
<td>2000</td>
<td>Controlled trial</td>
<td>12 subjects</td>
<td>Reduced baroreflex response coupled with a reduction in ability to increase heart rate may contribute to increased susceptibility to OI</td>
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<tr>
<td>27</td>
<td>Cheuvront et al J Appl Physiol</td>
<td>2010</td>
<td>Critical review</td>
<td>NA</td>
<td>Dehydration augments hyperthermia and reduced plasma volume, which accentuates cardiovascular strain</td>
<td>3</td>
</tr>
<tr>
<td>28</td>
<td>Wilson et al Am J Physiol Regul Integr Com Physiol</td>
<td>2006</td>
<td>Controlled trial</td>
<td>15 men</td>
<td>Heat stress decreases cerebral blood velocity and increases cerebral vascular resistance</td>
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<td>29</td>
<td>Charkoudian et al J Physiol</td>
<td>2003</td>
<td>Controlled trial</td>
<td>13 healthy subjects</td>
<td>Exercise-induced dehydration leads to changes in baroreflex control of blood pressure</td>
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<td>30</td>
<td>Holtzhausen et al Med Sci Sports Exerc</td>
<td>1995</td>
<td>Clinical trial</td>
<td>31 runners</td>
<td>All runners were volume depleted (average of 4.6% deficit), 68% developed asymptomatic EAPH, dehydration did not compromise cardiovascular status</td>
<td>2</td>
</tr>
</tbody>
</table>

EAPH, exercise-associated postural hypotension; LOE, level of evidence; OI, orthostatic intolerance.
in stroke volume as a compensatory mechanism against OI24 (table 1).

**THE ROLES OF HEAT AND DEHYDRATION**

Although dehydration leading to hyperthermia has been postulated as a primary factor for OAC,5–7 there is no evidence to support its overall responsibility for OI or EAC in endurance athletes.25 Evidence, however, supports both heat stress and increased skin temperature as contributing factors in OI. Heat stress results in the reduction of baroreflex control in response to an orthostatic challenge.26 Heat stress has also been postulated to impair aerobic exercise performance, primarily through increased cardiovascular strain.27 In addition, increasing body temperature may increase cerebral vascular resistance, reducing the cerebral threshold for neurogenic collapse.28

Two small studies found that laboratory-induced hypovolemia may lead to changes in baroreflex control of blood pressure in certain individuals, which may increase susceptibility to EAC.22,29 However, a larger clinical trial following the body composition of 31 runners completing an ultramarathon event found that the collapsed runners did not have a higher body temperature than those who did not collapse, and all the runners were dehydrated, but this level of dehydration was unrelated to the degree of postural hypotension after the event.30 (table 2). Therefore, although heat and dehydration have not been found to be true causes of EAC or OI in endurance running events, they may possibly be risk factors for EAC or contribute by impairing peripheral vasconstriction leading to the orthostatic state.

**BAROREFLEX MODULATION**

Pooling of blood in the lower extremities at the cessation of exercise has been implicated as a mechanism of EAC; if the systemic vascular resistance, which is reduced during exercise, is not triggered by an intact baroreflex to increase after stopping exercise, a lower body negative pressure (LBNP) situation develops and pos-

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<td>Murrell et al</td>
<td>2007</td>
<td>Clinical trial</td>
<td>7 athletes</td>
<td>After exercise, hypotension and postural reduction in autonomic function or baroreflex control place the brain at risk for hypoperfusion</td>
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<td>Halliwill et al</td>
<td>1996</td>
<td>Controlled trial</td>
<td>9 men</td>
<td>Baroreflex control of sympathetic activity into vascular resistance is altered after dynamic exercise</td>
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<tr>
<td>Gratze et al</td>
<td>2008</td>
<td>Clinical trial</td>
<td>51 men</td>
<td>Postexercise OI is associated with a high basal sympathetic modulation of vasomotor tone in combination with diminished orthostatic response to resistance vessels</td>
<td>2</td>
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<tr>
<td>Privett et al</td>
<td>2010</td>
<td>Clinical trial</td>
<td>10 experienced male runners</td>
<td>After prolonged exercise, SBP decreases as a result of inadequately compensated decrease in SV and resultant CO from standing</td>
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<tr>
<td>Fu et al</td>
<td>2004</td>
<td>Controlled trial</td>
<td>10 women and 13 men</td>
<td>Lower orthostatic intolerance in women is associated with decreased cardiac filling rather than decreased vascular resistance compared with men</td>
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<tr>
<td>Adler et al</td>
<td>2009</td>
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<td>20 men</td>
<td>Baroreflex sensitivity and response to hypotensive stress are attenuated by antecedent hypoglycaemia</td>
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<td>Howden et al</td>
<td>2004</td>
<td>Case-control</td>
<td>9 subjects</td>
<td>Increased arterial CO₂ may be associated with increased cerebral blood flow</td>
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<tr>
<td>Lucas et al</td>
<td>2008</td>
<td>Crossover</td>
<td>9 men</td>
<td>During prolonged exercise, postural-induced hypotension and hyocapnia exacerbate cerebral hyperperfusion</td>
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<td>Middleton et al</td>
<td>1987</td>
<td>Case-control</td>
<td>7 women and 7 controls</td>
<td>Significant impairment of cardiovascular reflex responses while taking antidepressant medications</td>
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<tr>
<td>Lockwood et al</td>
<td>2005</td>
<td>Randomized-controlled trial</td>
<td>14 healthy men and women</td>
<td>H1 receptor antagonist reduces vasodilatation after exercise and blunts postexercise hypotension</td>
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<tr>
<td>McCard et al</td>
<td>2006</td>
<td>Randomised-controlled trial</td>
<td>10 healthy men and women</td>
<td>H2 receptor antagonist reduces vasodilatation after exercise and blunts postexercise hypotension</td>
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**Table 3** Baroreflex modulation

**Table 4** Other
## Table 5  Treatment

<table>
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<th>Author/journal</th>
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<th>Study type</th>
<th>Patients</th>
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<th>LOE</th>
</tr>
</thead>
</table>
| 42  | Journeay et al  
Aviat Space Environ Med | 2004 | Randomised controlled trial | 6 subjects | Lower body positive pressure promoted restoration of haemodynamics | 1 |
| 43  | Anley et al  
Br J Sports Med | 2010 | Randomised controlled trial | 28 athletes | EAPH was effectively treated with Trendelenburg positions and oral hydration | 1 |
| 44  | Davis and Fortney  
Int J Sports Med | 1997 | Controlled trial | 5 men | Fluid ingestion is an effective treatment for orthostatic intolerance | 2 |
| 45  | Durand et al  
Am J Physiol Regul Integr Comp Physiol | 2004 | Randomised controlled trial | 8 subjects | Skin surface cooling is effective in improving orthostatic tolerance in otherwise normothermic individuals | 1 |
| 46  | Wilson et al  
J Appl Physiol | 2002 | Clinical trial | 9 subjects | Skin surface cooling may protect against orthostatic intolerance in heat stressed humans | 3 |
| 47  | Cui et al  
Am J Physiol Heart Circ Physiol | 2005 | Controlled trial | 9 subjects | Skin surface cooling induced an upward shift in central venous pressure | 2 |
| 48  | Privett et al  
Clin J Sport Med | 2010 | Controlled trial | 6 subjects | Runners who are prone to OI after exercise may reduce this risk by wearing compression stockings while running | 2 |

EAPH, exercise-associated postural hypotension; OI, orthostatic intolerance.

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**Figure 1**  Exertional collapse algorithm.
there are several other factors that have been studied, which may also exacerbate this response.

Hypoglycaemia has been found to attenuate baroreflex sensitivity, which may be important because serum glucose levels will decrease as length of exercise increases, which may make endurance and ultraendurance athletes more susceptible to EAC.38 Pushing the pace or aiming for a time goal has also been implicated in EAC.30 As the respiratory rate of athletes increases as they try to attain a cutoff or time goal, their level of carbon dioxide will decrease as a result. Studies have shown that hypercarbia may be protective,37 and this resultant hypocapnia may further attenuate the baroreflex response.38 Medications may also affect response to LBNP – antidepressor medications have been shown to lead to a significant impairment in cardiovascular reflex response after exercise, which may implicate neurochemicals as possible factors in EAC.39 In addition, in two separate randomised controlled clinical trials H1 and H2 receptor antagonist medications may blunt the body’s postexercise hypotension, suggesting that histamine may also play a role in EAC.40 41 (table 4).

TREATMENT

The evidence points towards a lower extremity pooling of blood with an attenuated baroreflex response as the primary mechanism of EAC; therefore, treatment options should be directed primarily at correcting these deficits. Because there is no good evidence to support hyperthermia or dehydration as the primary aetiologies of EAC, total body cooling and intravenous fluids should not have a role in the initial treatment of EAC.

In a randomised controlled trial, it has been shown that lower body positive pressure, such as what occurs in the Trendelenburg positions, promoted restoration of normal haemodynamics.42 43 Studies also suggest that oral hydration may be preventive against EAC and may also be used as an effective treatment for EAC.43 44 A randomised controlled trial and two smaller trials suggest that skin surface cooling may act towards directing peripheral blood flow centrally and decreasing cardiovascular strain, thus treating EAC.45–47 Finally, the results of a study of compression stockings in runners suggest that runners who are prone to OI after exercise may benefit from wearing compression hose while running.48 Those prone to EAC may also potentially benefit from taking H1 or H2 blocking medications, skin surface cooling along the course and ensuring adequate glucose levels during participation (table 5).

ALGORITHM

Using the evidence for aetiology, mechanism and treatment, we propose an algorithm, which is currently used at the Marine Corps Marathon,49 50 as a clinical framework for the treatment of EAC in endurance athletes (figure 1). The key to using the EAC algorithm is to approach a collapsed athlete with a wide differential that includes potential life-threatening causes such as EAH or EHS and ruling those out with a concise physical examination evaluating mental status and body temperature before proceeding down the EAC algorithm.

CONCLUSION

EAC is a common occurrence in medical tents after endurance sporting activities, which is typically characterised by collapse after completion of the event in the absence of neurological, biochemical or thermal abnormalities. Although EAC is perhaps the most common aetiology confronted by the medical provider attending to collapsed athletes in a finish-line tent, the provider needs to be reminded that EAC is a diagnosis of exclusion and that he or she needs to be vigilant for other aetiologies that cause collapse. There is no evidence to support the previous idea that EAC is caused primarily by dehydration or heat stroke. These factors, however, along with medications, hypocapnia and hypoglycaemia, may be contributory to EAC. Evidence currently supports that postural hypotension caused by pooling of blood in the lower extremities, secondary to decreased vascular resistance in the face of an attenuated baroreflex response, as the principal mechanism of EAC. Women may sustain EAC more from decreased cardiac filling than from altered baroreflex. Treatment of EAC is usually symptomatic and involves oral hydration and a Trendelenburg position – total body cooling, intravenous hydration or advanced therapies are generally not needed.

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REFERENCES

Review