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OPTIMIZING ATHLETE PERFORMANCE AND SAFETY: SPECIAL CONSIDERATIONS FOR INDIVIDUALS WITH SICKLE CELL TRAIT

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KEY POINTS

- During exertional activities, athletes with sickle cell trait (SCT) have a reduced oxygen carrying capacity, possibly leading to lactic acid buildup causing red blood cells (RBCs) to sickle. The practitioner should implement pre-calculated work-to-rest ratios or allow athletes to self-pace.
- Low atmospheric pressure at high altitudes lowers oxygen saturation levels, increasing the risk of RBC sickling. If travel to high-altitude areas is necessary for athletes with SCT, stakeholders (including coaching staff) will need to be educated on the risks, modify activities and set restrictions based on symptoms.
- Exercising in warm to hot environments raises core body temperature, potentially causing RBCs to sickle as warmed blood moves from the core of the body to the working muscles. Practitioners should monitor environmental conditions using wet bulb globe temperature (WBGT) and modify activities based on established heat risk zones. Heat acclimatization guidelines to promote beneficial adaptations should also be utilized.
- Competitive pressures can lead athletes with SCT to exercise beyond their current fitness levels, increasing risks associated with acidosis and hyperthermia. Whenever possible, eliminate timed fitness tests for the initial weeks of exercise exposure, foster an environment that supports work-to-rest modifications and implement a buddy system for peer support.
- Inadequate hydration reduces plasma volume, concentrating RBCs and increasing the likelihood of occlusion of vessels. Ensure euhydration among athletes with SCT by providing accessible fluids, educating athletes on hydration importance and using weight charts to track and encourage proper hydration practices.

INTRODUCTION

Athletes with sickle cell trait deserve special attention to optimize performance and prevent a medical emergency due to the complex nature of the condition. Sickle cell trait (SCT) is a hereditary blood disorder in which there is an abnormal hemoglobin S in each red blood cell (RBC). SCT is considered benign at rest yet dangerous during exercise. The abnormal hemoglobin is beneficial from the perspective that it resists malaria but is troublesome as it incumbers efficient transportation of oxygen (Grant et al., 2011).

About 73 in 1,000 Black Americans have SCT and 3 in 1,000 White Americans are identified with the condition (Ojodu et al., 2014). Be aware, that there is not a race/ethnicity in which SCT does not exist (Ojodu et al., 2014). Therefore, all types of athletes, in all sports, could potentially have SCT when status is unknown. The prevalence of athletes with SCT ranges from 1-5% according to the Historically Black Colleges and Universities (HBCU) status of the institution (Hirschhorn et al., 2020; Yeargin et al., In Press) and about 1.5% in high school athletes (Allen et al., 2021). In the armed forces, prevalence ranges from 0.4 to 1.6% depending on the military branch (Niebuhr et al., 2017). Evidence of SCT status (lab results, on-site screening) is mandated in all NCAA divisions, most professional athlete organizations and all military branches. However, there is not a mandate for high school or junior colleges to report SCT status.

During exercise, RBCs in individuals with SCT can lose their oxygen and change from round to crescent shape. The crescent shaped RBC can trigger “log jamming” of blood vessels (Quattrone et al., 2015). Resulting occlusions increase the risk of rhabdomyolysis (Naik et al., 2018) and the risk of death (Harmon et al., 2012; Nelson et al., 2016). Yet knowledge of risk factors and implementation of prevention strategies can drastically reduce these consequences (Nye et al., 2022) especially when combined with status identification (Buchanan et al., 2020). Performance optimization in individuals with SCT is routinely reported in Olympic winnings (Connes et al., 2008), length of military service and deployments (Singer et al., 2018) and scholarship-supported positions on NCAA teams (Hirschhorn et al., 2020). Therefore, the purpose of this Sports Science Exchange (SSE) article is to review the risk factors for individuals with SCT and discuss corresponding prevention strategies in order to reduce the risk of sickling and optimize performance in these athletes.

RESEARCH REVIEW AND PRACTICAL APPLICATIONS

Since it is difficult to study exertional sickling in a controlled setting, a large pool of empirical evidence does not exist. A definitive understanding of what causes the RBC to change into a crescent shape during exercise is slightly elusive. Documents discuss the idea that some of the items below are “forces” (i.e., etiology) that cause shape change in the RBC, while others consider these risk factors (i.e., predisposition) that increase the likelihood of shape change. It is outside the scope of this article to speculate which theory is accurate. For the sake of consistency, all the elements will be approached as risk factors that encourage sickling to occur during exercise.

EXTRINSIC RISK FACTORS

Acidosis

- **Risk.** Any exertional event (practice, conditioning, training, competition, etc.) requires oxygen to assist in the breakdown of glucose for energy. Athletes with SCT have a reduced oxygen carrying capacity, decreasing the availability of oxygen to help with the process. A byproduct of the inferiorly supplied process is lactic acid, which is then deposited in the blood from the muscle (Robergs et al., 2004). A build up of lactate from the reduced oxygen levels, decreases blood pH and this lower pH may influence RBCs to change shape and/or increase rigidity and adhesions (Monchanin et al., 2007). This may be true during, and immediately following, exercise in individuals with SCT (Messonnier et al., 2021).
- **Relevant Research.** Various studies have reported significant drops of pH (<7) within 1-5 min of different types of exercise (Robergs et al., 2004). Lactic acidosis can occur quickly, particularly with higher intensity levels. This corresponds with reports of exertional sickling transpiring in as little as 3 min of intense exercise (Harris et al., 2012). However, contradictory research does exist, reporting that individuals with SCT did not have higher lactate accumulation than controls (Messonnier et al., 2022).
- **Prevention Strategy.** Appropriate work-to-rest ratios during exercise likely reduces lactic acid accumulation. Rest, proportional to the length or intensity of an exercise activity, allows for lactate clearance from the blood before the next exercise bout. This can be achieved by allowing the athlete with SCT to self-pace, particularly during conditioning activities, or, by using pre-calculated work-to-rest ratio recommendations based on the season and situation (Caterisano et al., 2019).
- **Prevention Strategy.** Since blood lactate and pH are altered through the post-exercise recovery period (<45 minutes), a cool down exercise period may be warranted in athletes with SCT to encourage acid/base restoration and clearance of lactate (Monchanin et al., 2007).

Altitude

- **Risk.** Low atmospheric pressure at altitude lowers oxygen saturation levels. Oxygen saturation refers to how much oxygen is attached to hemoglobin (Mathew & Sharma, 2023). This is a risk factor for athletes with SCT as the hemoglobin S already reduces oxygen carrying capacity. Therefore, it is theorized there is a cumulative effect of the hemoglobin S and altitude that significantly decreases oxygen reaching muscles, creating a hypoxemic situation.
- **Relevant Research.** In a study of military personnel who exercised at varying simulated altitudes, individuals with SCT had significantly more RBCs sickle at 4000 m of simulated altitude, compared to 1270 m. Sickled cells were measured within 2-5 min of beginning exercise in the high altitude (hypobaric) conditions (Martin et al., 1989).
- **Prevention Strategies.** When traveling for competition or special training, stakeholders providing care to athletes with SCT should determine if the location is considered above an altitude of 2500 m. If so, athletes with SCT should consider not participating in the event or not traveling at all. If they still choose to participate, a meeting between applicable stakeholders (e.g., coaching staff, athletic trainers, etc.) should be held prior to the travel date. Education of the risks associated with high altitude should be fully disclosed, activity modifications set *a priori* to ensure the work-to-rest ratio is optimized during activity and pre-set restrictions are written and enforced if symptoms were to arise.

Hyperthermia

- **Risk.** When exercising in warm to hot environments, core body temperature rises due to heat gain externally via conductive, convective and radiative means. This can be due to a variety of factors including combinations of ambient temperature, sun, turf/grass, uniforms, etc. (Pryor et al., 2017). As heat is gained from the environment, blood is warmed more than normal while transferring it between the body's limbs and core. It is theorized that the warmed blood encourages the RBCs to sickle.
- **Relevant Research.** A retrospective study examined military bases that utilized wet bulb globe temperature (WBGT) by checking it hourly, modifying exercise intensity, adding rest breaks and adjusting the amount of clothing worn (Kark & Ward, 1994). This study found those military bases that implemented these adjustments based on WBGT did not have any recruits with SCT die, whereas those military bases that had not started implementing WBGT measures experienced 4 deaths associate with exertional sickling.
- **Prevention Strategy.** Environmental conditions should always be monitored, and activities modified, in warm to hot conditions. WBGT is considered the gold standard measurement in sports and military settings. Activity modifications should be based on the region of the country that the activity is being held using already established heat risk color zones/flags (Grundstein et al., 2015). Each WBGT color/flag provides guidance for team sports that can be used to reduce risk in athletes with SCT. Exercising in lower WBGT colors/flags and modifying activity both reduce heat gained from the environment and attenuates increases in core body temperature.
  - *Special note.* During the heat acclimatization process, the athlete's original region of the country should be considered if they have recently moved to a new school / university /military base.
  - *Special note.* Exertional sickling can happen at any environmental temperature as it is considered an "intensity syndrome" (Eichner, 2010), meaning the exercise is a stronger predictor of sickling then the environment itself.

Hyperthermia (cont.)

- **Risk.** During exercise, core body temperature also rises as metabolic heat is internally generated as a byproduct of the contracting muscles. The hypothalamus will increase skin blood flow to distal areas to dissipate heat. It is theorized that the warmed blood, moving from the core to the body's limbs encourages the RBCs to sickle.
- **Research Gap.** There are no controlled studies examining hyperthemia, in isolation or in combination with exercise, in which the percentage of RBCs that are sickled is an outcome measure.
- **Prevention Strategy.** Utilization of heat acclimatization guidelines promotes the semi-permanent addition of beneficial adaptations (Adams et al., 2021; Yeargin et al., 2006). Examples of these adaptations include improved sweat response, increased cardiovascular efficiency because of plasma volume expansion and ultimately, a decreased core body temperature.
- **Prevention Strategy.** Appropriate work-to-rest ratios, no matter the environmental conditions, attenuate increases in core body temperature. Self-pacing or ratio guidelines can be used, as previously mentioned. Rest proportional to the length or intensity of an exercise activity allows for heat dissipation mechanisms to lower core body temperature.
    - *Special note.* Specific work-to-rest ratios have been recommended for each WBGT heat zone for military personnel with SCT that could be applied to athletes in sport settings (O'Connor et al., 2021).

External pressure or overzealousness

- **Risk.** Competitions, coach observance and performance earmarks can lead an athlete to engage in an exercise intensity higher than their current fitness level. Individuals attempting to make a team, retain their starting position in a line-up or provide "exemplary" role modeling may be more inclined to engage in a physical effort that their fitness level does not yet match. The greater effort leads to the risk factors previously explained regarding acidosis and hyperthermia.
- **Prevention Strategy.** Removal of timed fitness tests all together, or at least for the first two weeks of exercise exposure (season transitions) (Caterisano et al., 2019; O'Connor et al., 2021).
- **Prevention Strategy.** Create an atmosphere at the institution in which self-pacing and work-to-rest ratio modifications are accepted and supported. Physical efforts that correspond to individual fitness levels can prevent exertional hyperthermia and lactic acidosis. Use of "buddy systems" for peers to encourage suitable exercise expectations and recognize concerning behaviors (Heat Stress Control and Heat Casualty Management, 2024).
- **Prevention Strategy.** Employ an interprofessional team approach to healthcare and performance optimization. Examples include regular reminders to relevant stakeholders (sport coaches, strength and conditioning coaches, etc.) of which individuals have SCT and recurring meetings with coaches to discuss upcoming training plans. Additionally, staff may consider the development of a comprehensive policy and procedures (P&P) on exertional sickling in which all stakeholders are required to review annually. This will encourage acceptance of strategies needed for individuals with SCT (Yeargin et al., In Press).
- **Prevention Strategy.** Wearing visual cues by athletes that have SCT, can assist stakeholders in avoiding inadvertent pressure. Examples include wearing a red belt, yellow wrist bands or a sticker on equipment or uniforms. These visual cues allow for intervention earlier when an athlete with SCT starts to fall behind on a task and also minimizes questions from stakeholders when such interventions are needed.
    - *Special note.* Though this risk factor has been apparent from the beginning of organized sport and the creation of minimum cut-off thresholds, recent focus by experts have brought it into the limelight in exertional related emergencies (Lalli et al., 2024; O'Connor et al., 2021).

INTRINSIC RISK FACTORS

Respiratory Conditions

- **Risk.** Respiratory conditions such as asthma or exercise-induced bronchospasm can reduce efficient oxygen intake. When coupled with the diminished oxygen carrying capacity of hemoglobin S, a hypoxic situation can develop. Theoretically this type of event may encourage RBCs to change shape, or in the very least, less oxygen is able to reach the contracting muscles.
- **Prevention Strategy.** Keep both asthma and exercise-induced bronchospasm well managed. The sports medicine team should have an individualized action plan on file for each athlete with SCT that also has these conditions (Gatheral et al., 2017). Such a plan might include maintenance of long-term medications, having short acting medications on-hand for acute symptoms and possibly regular check-ins to monitor peak flow expiratory readings.
- **Prevention Strategy.** The same individual action plan should note the most common triggers for symptoms associated with the condition (Gatheral et al., 2017). If environmental contaminates (pollen, ragweed) or stressors (cold air) are triggers, monitoring of conditions when forecasts forewarn of high levels or cold air should be done prior to exercise beginning that day. Activity modifications such as completing exercise indoors may be needed if triggers are severe enough.

Illness

- **Risk.** Viral or bacterial mediated illness can cause pre-exercise fatigue. Athletes with SCT may be more vulnerable in this situation as exercise-related fatigue may set in earlier, putting the athlete or individual at risk for developing acidosis.
- **Risk.** The common cold may also mildly reduce oxygen intake as discussed in the respiratory conditions section. In addition, some illnesses may involve a fever-induced rise in baseline core body temperature to combat pathogens. Instead of exertional induced hyperthermia as discussed above, febrile illness could encourage RBCs to sickle.
- **Prevention Strategy.** Institutions should have policies in place in which athletes are removed from activity at certain febrile thresholds (i.e., 100.5 ºF or 38 ºC).
- **Prevention Strategy.** Athletes should be removed from activity if experiencing significant symptoms related to underlying illness. If symptoms are mild, the medical team should ensure regular observations of the athlete during exercise are possible and consider the addition of activity modifications (extra rest breaks).

Insufficient Hours of Sleep

- **Risk.** The exact reasoning whether this may be a risk factor for exertional sickling is unknown, as is also the case for exertional heat illnesses. The theory indicates that the pons (sleep center) and the hypothalamus (thermostat) sections of the brain communicate with each other. When insufficient sleep occurs (<7 hr), thermoregulation is affected (Kräuchi, 2007). If heat dissipation is hindered, warmed blood may encourage RBCs to sickle.
- **Prevention Strategy.** Curfews should be enforced by the institution if traveling. Sleep amounts are published based on age and should be considered when educating athletes on sleep routines and sleep hygiene (Chaput et al., 2018).

Inadequate Nutrition

- **Risk.** When glucose stores are not adequate for the exercise demand, the likelihood of lactic acidosis increases and the risk of sickling increases, as explained earlier. Examples of inadequate nutrition for exercise include not having breakfast before practice/training and skipping lunch before an after-school practice e.g. not adequately refueling pre/ during / post to cover daily activity demands.
- **Prevention Strategy.** Increase access to nutrition throughout the day. This can be in the form of training table hours or "grab and go" options. In addition, different educational techniques should be considered when discussing this as a risk factor, with the importance of regular meals and snacks emphasized (Boidin et al., 2021).

Hypohydration

- **Risk.** Dehydration during exercise reduces plasma volume, which composes the largest proportion of readily available blood being used by the cardiovascular system. When an individual engages in exercise, sweating is activated to dissipate heat. If the athlete does not adequately replace sweat losses with fluids, some level of hypohydration is inevitable. For athletes with SCT, this means that RBCs are more concentrated within the blood vessels (Nader et al., 2019). Less fluid (i.e., plasma volume) will hasten log jamming of the sickled cells.
- **Relevant Research.** In one study, participants with SCT exercised in a heat chamber for 45 min. When fluids were withheld, RBCs progressively sickled over the exercise trial (3-6% of RBCs). However, when fluids were provided and hydration status maintained, sickling remained lower throughout the exercise (<1% of RBCs) (Bergeron et al., 2004).
- **Prevention Strategy.** Euhydration encourages the free movement of both round and sickled RBCs. Euhydration can be encouraged in a variety of manners. Accessibility to fluids is paramount as research indicates it encourages ad libitum consumption (Engell et al., 1996; Yeargin et al., 2015). Examples include multiple fluid stations, personal water bottles or on-body water systems.
- **Prevention Strategy.** Education on the importance of euhydration to optimize performance and reduce sickling risk could be completed in an assortment of ways (Boidin et al., 2021). This could be accomplished with handouts, individual one-on-one sessions or group presentations.
- **Prevention Strategy.** The use of weight charts to track hydration can provide athletes with individual fluid intervention to replace lost fluids (Eith et al., 2020). This information will assist the athlete in beginning the next exercise session in an euhydrated state. Weight charts can be reinforced by having institutional policies in place that indicate when verbal, written or activity modification interventions should occur depending on the hypohydration threshold. Research indicates that weight charts can successfully encourage euhydration in athletes with and without SCT (Hirschhorn et al., 2021). They can promote a positive atmosphere so that good hydration habits are encouraged on an individual level.

UNIVERSAL PRECAUTIONS

Many of the prevention strategies above are considered "universal precautions" by the military and sports medicine organizations (Nye et al., 2022; Roberts et al., 2023). If these are implemented on a regular basis, it can prevent not just exertional sickling but other conditions and injuries as well (exertional heat stroke, exertional heat exhaustion, musculoskeletal injuries). Therefore, their utilization should be paramount as it could optimize performance and increase safety in all athletes.

SUMMARY

During exertional activities, athletes with SCT have a reduced oxygen carrying capacity, leading to lactic acid accumulation, decreasing pH and potentially causing RBCs to sickle. Implementation of appropriate work-to-rest ratios, allowing athletes to self-pace or using pre-calculated ratios are important prevention strategies. Exercising in warm to hot environments raises core body temperature, potentially causing RBCs to sickle as warmed blood moves from the core to the body's limbs. Environmental conditions should be monitored using WBGT and activities modified based on established heat risk zones. Heat acclimatization guidelines should be used to promote beneficial adaptations and appropriate work-to-rest ratios during initial or re-exposure to heat. Competitive pressures can lead athletes to exercise beyond their fitness levels, increasing risks associated with acidosis and hyperthermia. Timed fitness tests should be eliminated for the initial weeks of exercise exposure, as well as fostering an environment supporting self-pacing and work-to-rest modifications and implementing a buddy system for peer support. Inadequate hydration reduces plasma volume, concentrating RBCs and increasing the likelihood of vessel occlusion. Euhydration should be ensured by providing accessible fluids, educating athletes on the importance of hydration and using weight charts to track and encourage proper hydration practices. Adequate nutrition is another important consideration to ensure glucose stores are optimal to reduce the likelihood of lactic acidosis and the risk of sickling. Increased access to nutrition, in combination with nutrition education, should be implemented to SCT athletes.

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REFERENCES

Adams, W.M., Y. Hosokawa, D.J. Casa, J.D. Périard, S. Racinais, J.E. Wingo, S.W. Yeargin, S.E. Scarneo-Miller, Z.Y. Kerr, L.N. Belval, D. Alosa, D. Csillan, C. LaBella, and L. Walker (2021). Roundtable on preseason heat safety in secondary school athletics: Heat acclimatization. J. Athl. Train. 56:352–361.

Allen, G., M.S. Smith, M. Bruner, K. Agrawal, J.R. Clugston, and B.R. Prine (2021). Screening by self-report underestimates sickle cell trait in high-school athletes. Cureus 13:e19247.

Bergeron, M.F., J.G. Cannon, E.L. Hall, and A. Kutlar (2004). Erythrocyte Sickling during exercise and thermal stress. Clin. J. Sport Med. 14:354.

Boidin, A., R. Tam, L. Mitchell, G.R. Cox, and H. O'Connor (2021). The effectiveness of nutrition education programmes on improving dietary intake in athletes: A systematic review. Br. J. Nutr. 125:1359–1373.

Buchanan, B.K., D.M. Siebert, M.L. Zigman Suchsland, J.A. Drezner, I.M. Asif, F.G. O'Connor, and K.G. Harmon (2020). Sudden death associated with sickle cell trait before and after mandatory screening. Sports Health 12:241–245.

Caterisano, A., D. Decker, B. Snyder, M. Feigenbaum, R. Glass, P. House, C. Sharp, M. Waller, and Z. Witherspoon (2019). CSCCa and NSCA Joint consensus guidelines for transition periods: Safe return to training following inactivity. Strength Cond. J. 41:1.

Chaput, J.-P., C. Dutil, and H. Sampasa-Kanyinga (2018). Sleeping hours: What is the ideal number and how does age impact this? Nature Sci. Sleep 10:421–430.

Connes, P., H. Reid, M.-D. Hardy-Dessources, E. Morrison, and O. Hue. (2008). Physiological responses of sickle cell trait carriers during exercise. Sports Med. 38:931–946.

Eichner, E.R. (2010). Sickle cell trait in sports. Curr. Sports Med. Rep. 9:347–351.

Eith, J.M., C.R. Haggard, D.M. Emerson, and S.W. Yeargin (2020). Practices of athletic trainers using weight charts to determine hydration status and fluid-intervention strategies. J. Athl. Train. 56:64–70.

Engell, D., M. Kramer, T. Malafi, M. Salomon, and L. Lesher (1996). Effects of effort and social modeling on drinking in humans. Appetite 26:129–138.

Gatheral, T.L., A. Rushton, D.J. Evans, C.A. Mulvaney, N.R. Halcovitch, G. Whiteley, F.J. Eccles, and S. Spencer (2017). Personalised asthma action plans for adults with asthma. Cochrane Database System. Rev. 4. https://doi.org/10.1002/14651858.CD011859.pub2

Grant, A.M., C.S. Parker, L.B. Jordan, M.M. Hulihan, M.S. Creary, M.A. Lloyd-Puryear, J.C. Goldsmith, and H.K. Atrash (2011). Public health implications of sickle cell trait: A report of the CDC Meeting. Am. J. Prevent. Med. 41(Supplement 4):S435–S439.

Grundstein, A., C. Williams, M. Phan, and E. Cooper (2015). Regional heat safety thresholds for athletics in the contiguous United States. Appl. Geog. 56:55–60.

Harmon, K.G., J.A. Drezner, D. Klossner, and I.M. Asif (2012). Sickle cell trait associated with a RR of death of 37 times in national collegiate athletic association football athletes: A database with 2 million athlete-years as the denominator. Br. J. Sports Med. 46:325–330.

Harris, K.M., T.S. Haas, E.R. Eichner, and B.J. Maron (2012). Sickle cell trait associated with sudden death in competitive athletes. Am. J. Card. 110:1185–1188.

Heat Stress Control and Heat Casualty Management. Retrieved June 14, 2024, from https://apps.dtic.mil/sti/citations/ADA433236

Hirschhorn, R.M., D. Cadet, R. Delus, J. Phillips, T.E. Murphy, C. Haggard, J. Razayeski, and S. Yeargin (2020). The prevalence of sickle cell trait in Division I university athletics programs. Physic. Sportsmed. 48:430–436.

Hirschhorn, R.M., J.L.P. Gilbert, D.A. Cadet, T.E. Murphy, C. Haggard, S. Rosehart, and S.W. Yeargin (2021). Examination of body mass changes among Division I collegiate football players with sickle cell trait. Int. J. Athl. Ther. Train. 27:36–41.

Kark, J.A., and F.T. Ward (1994). Exercise and hemoglobin S. Sports Hemat. 31:181–225.

Kräuchi, K. (2007). The human sleep–wake cycle reconsidered from a thermoregulatory point of view. Physiol. Behav. 90:236–245.

Lalli, K., N. Charkoudian, Y. Moreh, and D.W. Degroot (2024). The role of motivation to excel in the etiology of exertional heat stroke. J. Spec. Operat. Med. 4TIV-HQLO.

Martin, T.W., I.M. Weisman, R.J. Zeballos, and S.R. Stephenson (1989). Exercise and hypoxia increase sickling in venous blood from an exercising limb in individuals with Sickle cell trait. Am. J. Med. 87:48–56.

Mathew, T.M., and S. Sharma (2023). High altitude oxygenation. https://www.ncbi.nlm.nih.gov/books/NBK539701

Messonnier, L.A., P. Bartolucci, T. d'Humières, E. Dalmais, J.-R. Lacour, H. Freund, F. Galactéros, and L. Féasson (2021). Preventive measures for the critical postexercise period in sickle cell trait and disease. J. Appl. Physiol. 130:485–490.

Messonnier, L.A., S. Oyono-Enguéllé, L. Vincent, H. Dubouchaud, B. Chatel, H. Sanchez, A. Malgoyre, C. Martin, F. Galactéros, P. Bartolucci, P. Thiriet, and L. Féasson (2022). Lower muscle and blood lactate accumulation in sickle cell trait carriers in response to short high-intensity exercise. Nutrients 14:501.

Monchanin, G., L.D. Serpero, P. Connes, J. Tripette, D. Wouassi, L. Bezin, A. Francina, J. Ngongang, M. de la Peña, R. Massarelli, D. Gozal, P. Thiriet, and C. Martin (2007). Effects of progressive and maximal exercise on plasma levels of adhesion molecules in athletes with sickle cell trait with or without α-thalassemia. J. Appl. Physiol. 102:169–173.

Nader, E., S. Skinner, M. Romana, R. Fort, N. Lemonne, N. Guillot, A. Gauthier, S. Antoine-Jonville, C. Renoux, M.-D. Hardy-Dessources, E. Stauffer, P. Joly, Y. Bertrand, and P. Connes (2019). Blood rheology: Key parameters, impact on blood flow, role in sickle cell disease and effects of exercise. Front. Physiol. 10:1329.

Naik, R.P., K. Smith-Whitley, K.L. Hassell, N.I. Umeh, M. de Montalembert, P. Sahota, C. Haywood, J. Jenkins, M.A. Lloyd-Puryear, C.H. Joiner, V.L. Bonham, and G.J. Kato (2018). Clinical outcomes associated with sickle cell trait. Ann. Intern. Med. 169:619–627.

Nelson, D.A., P.A. Deuster, R. Carter, O.T. Hill, V.L. Wolcott, and L.M. Kurina (2016). Sickle cell trait, rhabdomyolysis, and mortality among U.S. army soldiers. New Engl. J. Med. 375:435–442.

Niebuhr, D.W., L. Chen, S. Shao, J. Goldsmith, C. Byrne, and D.E. Singer (2017). Sickle cell trait prevalence among U.S. military service members: 1992–2012. Mil. Med. 182:e1819–e1824.

Nye, N.S., T. Grubic, M. Kim, F. O'Connor, and P.A. Deuster (2022). Universal training precautions: A review of evidence and recommendations for prevention of exercise-related injury, illness, and death in warfighters and athletes. J. Athl. Train. 58:232–243.

O'Connor, F.G., M.A. Franzos, N.S. Nye, D.A. Nelson, D. Shell, J.D. Voss, S.A. Anderson, N.J. Coleman, A.A. Thompson, K.G. Harmon, and P.A. Deuster (2021). Summit on exercise collapse associated with sickle cell trait: Finding the "way ahead." Curr. Sports Med. Rep. 20:47.

Ojodu, J., M.M. Hulihan, S.N. Pope, and A.M. Grant (2014). Incidence of sickle cell trait—United States, 2010. Morbid. Mortal. Weekly Rep. 63:1155–1158.

Pryor, J.L., R.R. Pryor, A. Grundstein, and D.J. Casa (2017). the heat strain of various athletic surfaces: A comparison between observed and modeled wet-bulb globe temperatures. J.Athl. Train. 52:1056–1064.

Quattrone, R. D., Eichner, E. R., Beutler, A., Adams, W. B., & O'Connor, F. G. (2015). Exercise Collapse Associated with Sickle Cell Trait (ECAST): Case Report and Literature Review. Current Sports Medicine Reports, 14(2),

Robergs, R.A., F. Ghiasvand, and D. Parker (2004). Biochemistry of exercise-induced metabolic acidosis. Am. J. Physiol. 287:R502–R516.

Roberts, W.O., L.E. Armstrong, M.N. Sawka, S.W. Yeargin, Y. Heled, and F.G. O'Connor (2023). ACSM Expert Consensus Statement on exertional heat illness: recognition, management, and return to activity. Curr. Sports Med. Rep. 22:134.

Singer, D.E., L. Chen, S. Shao, J. Goldsmith, C. Byrne, and D.W. Niebuhr (2018). The association between sickle cell trait in U.S. service members with deployment, length of service, and mortality, 1992–2012. Mil. Med. 183:e213–e218.

Yeargin, S.W., D.J. Casa, L.E. Armstrong, G. Watson, D.A. Judelson, E. Psathas, and S.L. Sparrow (2006). Heat acclimatization and hydration status of American football players during initial summer workouts. J. Strength Cond. Res. 20:463.

Yeargin, S.W., M.E. Finn, L.E. Eberman, M.J. Gage, B.P. McDermott, and A. Niemann (2015). Ad libitum fluid consumption via self- or external administration. J. Athl. Train. 50:51–58.

Yeargin, S.W., C. Meyer, R.M. Hirschhorn, A. Lane, S. Arent, and C. Haggard, C. (2024). Characterization of health and safety resources for athletes with sickle cell trait at NCAA institutions. J Strength Cond. Res. Published online July 26.In press.