NSCA COACHES CONFERENCE

JANUARY
3 - 5, 2018

CHARLOTTE
N. CAROLINA

NSCA®
NATIONAL STRENGTH AND CONDITIONING ASSOCIATION

Conflict of Interest Statement

- **I have no actual or potential conflict of interest in relation to this presentation.**

Exertional Rhabdomyolysis: What Is Too Much?

Ben Gleason, PhD, CSCS*D, RSCC, USAW2

Department of Kinesiology

Louisiana Tech University

Introduction

- Definition of rhabdomyolysis (rhabdo)
- Definition & physiology of exertional rhabdo (ER)
- Pushing athletes to their limits: case studies for coaches to learn from
- Recommendations for injury prevention in S&C context

A disclaimer: What this presentation is not.

- A witch hunt
- A detailed investigation of every incident of rhabdomyolysis in every setting
  - Emphasis on athletes; some reference to youth & military settings

Rhabdomyolysis

Rhabdo … what?

Definition

- Rhabdomyolysis: massive destruction/disintegration of striated muscle

  “rhabdo” = striped, “myo” = muscle, “lysis” = broken (Ramos & Dorgo, 2014)

What Causes Rhabdo?

Musculoskeletal trauma—damage to cell membrane

- crushing injuries
- burns
- infection
- drugs (including excessive alcohol, cocaine, etc.)
- ingestion of toxins
- heat stress
- cold stress
- sickle cell trait
- **excessive [volume of] exercise**

Huerta-Alardin, Varon, & Marik (2005); Tietze & Borchers (2014)

Occurs in 85% of cases of traumatic injury

Huerta-Aladin, Varon & Marik (2005)

Who Else Gets Rhabdo?

- Racehorses
  - genetic tendency for chronic rhabdo in some
- Caged/restrained animals
- Sick people
- Drug addicts & alcoholics
- Crush victims
- …And other scenarios when muscle tissue is severely damaged

Definition

- Exertional Rhabdomyolysis (ER): rhabdo brought on by extreme exertion of some kind
  - Sport or military training, punishment, etc.
  - Perfect storm + additional cofactors

  - Numerous case studies exist from injury brought on by personal trainers, coaches, PE teachers, military training instructors, competition, etc.

Initial Symptoms of ER

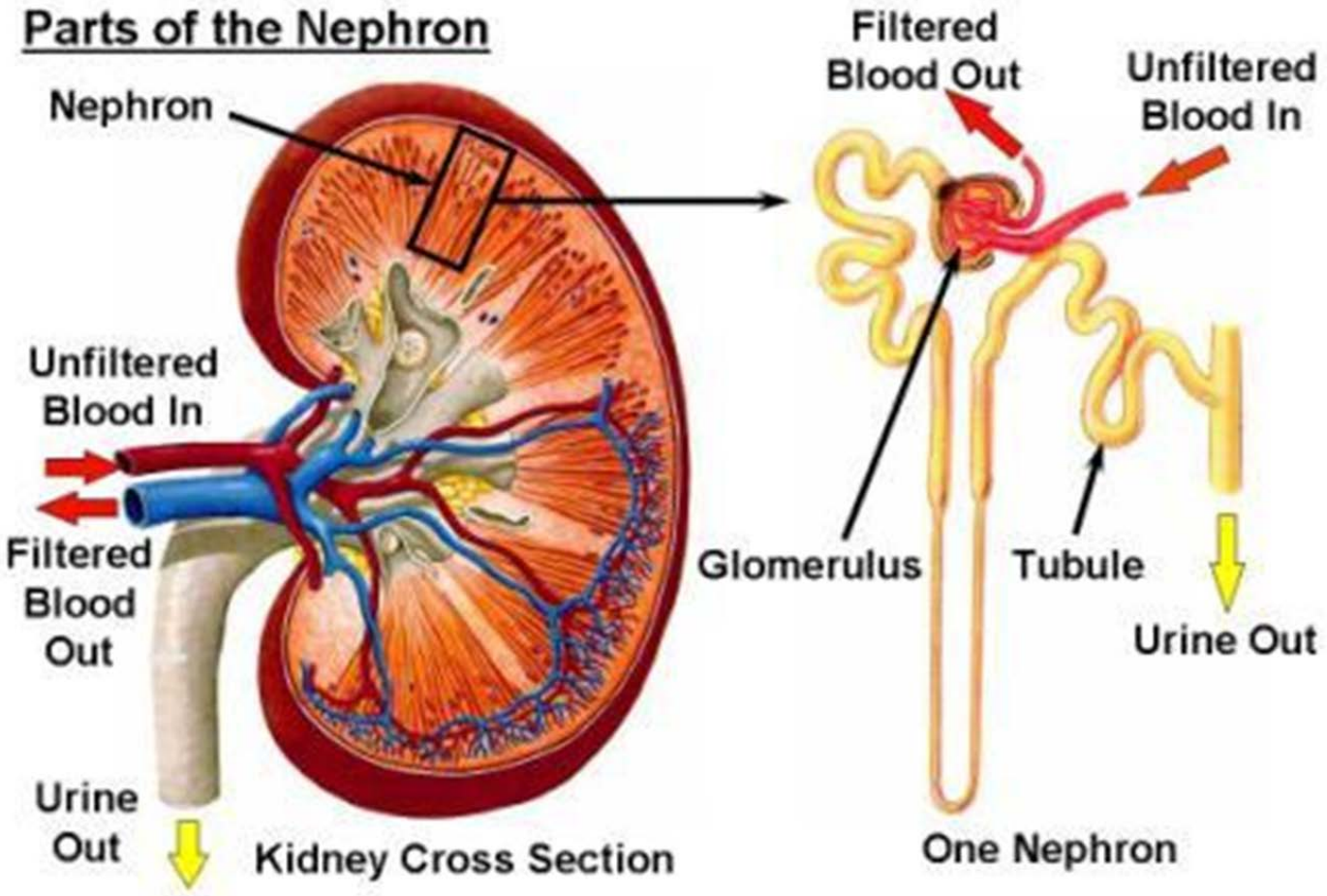
- Severe muscle pain, cramps, swelling
- Weakness
- Sometimes tea-colored urine
- Onset follows activity, may lag a day or so

Diagnosing ER

- Done via formal medical care (Emergency Room)
  - evaluation of blood Creatine Kinase (CK)
    - most sensitive factor
    - Clinical threshold ≈ 5X normal limit
      - Some argument ongoing
  - Myoglobinuria: myoglobin (Mb) in urine
    - suggested to not be best indicator due to short half-life
  - Severe pain & cramps
    - Not DOMS

Why Is ER A Problem?

1. Contents of muscle cells cause problems if they go elsewhere in the body
    - heavy concentrations of substances from intramuscular space (i.e. myoglobin) become toxic to kidneys



Why Is ER A Problem?

2. A certain level of local damage may lead to compartment syndrome
    - Medical emergency involving over-pressurized section of tissue within fascia
    - May require surgery to prevent further tissue necrosis

Why Is ER A Problem?

- 3. Cardiovascular problems such as arrhythmia & clotting … that may lead to ***DEATH***

- Therefore ER is a serious clinical health condition, and has been brought on in athletes usually* by poor training decisions
  - not always well-explained

*possibly combined with poor lifestyle decisions, insufficient recovery, or illness

Possible Local Precipitating Factors Leading to ER

1. Cross-bridge & structural sarcolemma damage from lots of eccentric phase
2. Muscle cell hypoxia leading to depletion of ATP
   - Anaerobic conditions of shock states
     - vascular occlusion, tissue compression, & inappropriate exercise
   - Membrane pumps, etc. don't function without ATP
     - may compound issue and lead to further necrosis

   (Huerta-Alardin, Varon, & Marik, 2005)
3. Heat injury + extreme exertion

   (Szczepanik, Heled, Capaccione, Campbell, Deuster, & O'Connor, 2014)

…or…

4. Other more unusual factors

With ER In Athletes We Must Consider…

- Possible influence of medication, trace amounts of **recreational drugs**, and tainted supplements

Huerta-Alardin, Varon, & Marik (2005)

Athletes With Increased Risk for ER

- Sickle Cell Trait
  - Sickling possibly brought on by stress or …?
  - Involves cascade of events leading to CV tissue damage
  - Some case reports/studies exist of sudden death in athletes with sickling-related ER
    - i.e. One 19 y.o. college football player (Harrykissoon et al., 2007)

What Causes ER?

- Primary causative factors in preventable cases are **acute high volume**, with **high density**, likely involving **repeated failure**
  - Consider timing of preventable cases in athletes that we'll discuss
  - We have what can be the perfect storm for inducing ER:
    - Massive muscle damage (lots of eccentric action)
    - Heavy sweating due to intramuscular heat production
      - less fluid to transport heat away
    - Environmental heat (see Casa et al., 2012)
    - Rapid ATP degradation
    - Possible electrolyte imbalance

Dehydration May Increase ER Risk

- Consider the intracellular environment
  - muscle cell is about 75% water (McArdle Katch, & Katch, 2007)
  - water provides the solvent for intracellular biological mechanisms
    - enzymes, electrolytes, etc.
  - the human body has an optimal range
    - if compromised can reduce function

Is Blood Perfusion Constant?

- Dehydration has been demonstrated to affect blood perfusion between **compartments**
  - For review see Trangmar & Gonzalez-Alonso (2017)
- Brings about some complexity to training & recovery
- Does this increase value in recovery modalities?

Context of Blood Creatine Kinase

Context: American Football

- Many of these cases are seen in football, highlighted by media, so…
- Hoffman et al. (2005) sampled blood of D-III football players over a season
  - Creatine Kinase (CK) average values
    - Pre-camp: ≈ 50 U/L
    - **Camp** (Day 10; 2-a-days): **≈ 350** U/L starters, **≈ 175** U/L nonstarters *
    - Inseason (Week 3, 7, 10): ≈ 50 U/L
  - Myoglobin average levels were fairly consistent as measured, averaged around 25 ng/mL
- Hoffman et al. (2002) found in-game CK (starters) **≈ 175** U/L

Context: more from football

- Smoot, Cavanaugh, Amendola, West, & Herwaldt (2014) observed CK levels of 32 Iowa football athletes during camp
  - Day 1: 285 ± 801 (range: **72 - 4,659**) U/L
  - Day 3: 1,300 ± 2,284 (range: **217 - 12,067**) U/L
  - Day 7: 1,562 ± 1,497 (range: **229 - 7,453**) U/L
    - **Positions & practice reps not reported!**
  - At days 3 & 7 many athletes met diagnostic criteria for rhabdo, but athletes were asymptomatic

Context: more from football

- Ehlers, Ball & Liston (2002) monitored CK during 2-a-day camp at Northern Illinois (*n* = 12, 4 sampling times)
  - Average: **203 - 3,272** (range: **92 - 18,823**) **U/L**
  - Some WR & DBs had highest measurements

Context from multiple sports

- Mougios (2006) reported CK values from large sample of Greek club sport athletes (*n* = 483 male, 245 female)
  - track & field, swimming, cycling, rowing, kayaking, soccer, basketball, volleyball, handball, water polo, tennis, table tennis, gymnastics, judo, taekwondo, karate, boxing, weightlifting, diving, motocross, snowboarding, and bodybuilding
  - reference limits:
    - males: **82 - 1,083 U/L**
    - females: **47 - 513 U/L**
      - ***Effects of muscle damage relative to muscle mass***

Note on muscle damage reference limit differences

- Reference limits differ by sport (Mougios, 2006):
  - men's soccer (*n* = 182): **83 - 1,492 U/L**
  - men's swimming (*n* = 93): **70 - 523 U/L**
- Why this difference?
  - weight bearing activities with more ECC action
  - harsh environmental conditions may worsen muscle damage

Context: What about … “aerobic people”?

Karstoft, Solomon, Laye, & Pedersen (2013)

- Daily recreational marathon running for 1 week (*n* = 7 males, 1 female) produced CK increases
  - Pre-event 1: **199 ± 48** (range: **75 - 497**) U/L
  - Post-event 7: **640 ± 99** (range: **329 - 990**) U/L

Case Studies of ER

Case Studies

Smoot, Amendola, Cramer, Doyle, Kregel, …& Herwaldt (2013)

- University of Iowa Football, Jan 20-24, 2011
- Following a 3-week break after bowl game…

Case Studies

Smoot et al. (2013)

Jan 20, 2011:

- 15-min dynamic warm up
- Barbell snatch 3 @ 65%, 3 @ 70%, 3 @ 75%
- Back squats 100 reps @ 50%
- Sled pushes 20 yd X 5 (sled load: bigs 240 lb, mids 210 lb, speed 180 lb)
- Pull ups max reps
- Dumbbell rows 3 X 12 @ 65%
- Cable push-aways 10*
- Cable ab pulldowns 2 X 10*
- Blast strap rollouts 2 X 10
- * Player-selected load

Case Studies

Smoot et al. (2013)

Jan 21, 2011:

- 15 min dynamic warmup
- Barbell bench press 100 reps @ 50%
- Back extensions 5 X 10
- Ab cable pulldowns 1 X 15 (player-selected load)

5 athletes conducted a punishment run (described only as “extra running assignment”), 3 of these later contracted ER

Case Studies

Smoot et al. (2013)

Jan 24, 2011:

15 min dynamic warm up

Hurdle hops 3 X 3

Hang clean 2 @ 70%, 2 @ 75%, 3 X 2 @ 80%

Barbell incline press 5 @ 70%, 4 X 5 @ 75%

Barbell RDL 5 X 5 @ 75%

Pull ups 3 X 10 @ body weight

Barbell press 3 X 10 @ 60%

Case Studies

Smoot et al. (2013)

- On Jan 24, 3 players (19-21 y.o.) reported to ATC with 3-day history of dark urine, severe muscle soreness & swelling
  - CK range **166,991 - 233,167** U/L
- ATCs saw 13 total cases
  - 10 athletes permitted researchers to view medical records
  - CK range **96,987 – 331,044** U/L
- Survey issued to athletes
  - No relationship between injury & size, position, training history, etc.
  - Some athletes did extra squats
- Noted possible protective effect of drinking protein shakes…

Fallout from the Iowa case…

$15,000 legal settlement to one athlete (AP, 2016)

Case Studies

Moeckel-Cole & Clarkson (2009)

- Reported ER in a 18 y.o. D-I football placekicker
- Brought on by late summer training led by S&C coach
- The workout:
  - 10 sets of 30 shoulder-band squats (300 reps) with 60s rest between sets
    - No reference to band thickness
  - 30 RDLs using 40-lb dumbbells
  - 30 shrugs using 80-lb dumbbells
- Severe pain presented in quadriceps afterward, difficulty walking the following day
- CK **130,899** U/L upon hospital admission (8 days in hospital)

Case Studies

Shelmadine, Baltensparger, Winson & Bowden (2013)

- 19 y.o. SCT college football player (lineman) diagnosed with ER & heat exhaustion following preseason conditioning test
- Test consisted of 5 X 300 m intervals in > 100° F (4:15pm)
  - Collapsed upon completion
    - Severe muscle pain, cramps, weakness, etc.
  - Hospitalized, CK **408,545** U/L on Day 2, placed on blood dialysis
  - CK values peaked at **880,000** U/L on Day 4

Case Studies

Anzalone, Green, Buja, Sanchez, …& Eichner (2010)

- 19-y.o. SCT college football player in TX
- Late Sept, 4pm 30-min lift, then ran outdoors in 76° F
- Ran 16 X 100 yd
  - Rest 1 min for 1st 4, rest 2 min between next 4, 1 min between last 8
  - Some reports suggested he lagged behind others and was encouraged to continue
  - Collapsed after, given IV fluids by ATCs, lost consciousness
  - Taken to hospital by EMTs, died in hospital 15 h later
  - SCT not known to athlete or family
  - autopsy showed sickling-related rhabdo

Case Studies

Oh, Laidler, Fiala, & Hedberg (2012)

- Aug 17-18, 2010 HS football team from McMinnville HS, Oregon
- 22/43 athletes were diagnosed with ER following a football team-building event, 12 of them hospitalized
- Alternated chair dips and push ups each for 30s, 20s, 10s, 7s, 5s with no rest in hot room, estimated 20-25 min of work for team
  - ≈ 4 sets each
- Incorrect performances became group punishment
- Reported symptoms 1-3d following workout, pain, weakness, dark urine
- Diagnostic CK threshold used was >2,320 U/L (range **2,434 - 42,000**)
- 3 athletes diagnosed with triceps compartment syndrome, underwent fasciotomy

Case Studies

Stanfa, Silles, Cooper, Arena, Landis-Piwowar,… & Hew-Butler (2017)

- March, 2014 D-I swimmers after 1-week off following league championship
- Week 2 of training 13 swimmers contracted ER, 6 of them hospitalized, male & female
- 3d consecutive workouts prior, ≥ 5,000 m swimming daily + circuit training (no details)
- ER-inducing event occurred on training day 9

Case Studies

Stanfa et al. (2017)

- Novel “team building” competition
- Teams of 3, goal = beat other groups
  - 2 cycles through:
    - Max pull ups
    - Max rows
    - Max bench press
  - 2 groups tied, entered tiebreaker round (details not disclosed)
  - During tiebreaker round, other groups alternated push ups and isometric arm holds horizontal & perpendicular to floor (further details not disclosed)
- Followed by 5,000m swim
- CK values **73 - >20,000** U/L
- 6 swimmers hospitalized were “exceptionally motivated”
- Authors linked ER with recovery beverage intake (all 6 had >50% recommended intake of protein shake)

Insufficiently Descriptive Case Studies

Galvez, Stacy, & Howley (2008)

University of South Carolina Swimming, fall conditioning

- Day 1 workout: alternating 1-min of push ups and body weight squats for 10 mins, then swim practice (no details)
- Day 2 workout: 40-minute weight training circuit (no details), swim practice
- Day 3 workout: max pull ups, unclear ab exercises including “tripods” & bridges, then swim practice (no details)
  - Athletes presented between Days 1-7
  - 7 athletes diagnosed with ER, severe pain & swelling in triceps & pectorals, dark urine
  - CK range: **30,524 - 81,795** U/L (female) & **38,400 - 157,700** U/L (male)

Insufficiently Descriptive Case Studies

Cleary, Sadowski, Lee, Miller, & Nichols (2011)

- 16 y.o. high school wrestler in Hawaii, no info on training history
- Day 1: out of camp due to unrelated concussion
- Day 2: 60-minutes of circuit training including wall-sits, squats, sit ups, push ups, lunges, plyometric jumps (played catch up for Day 1 absence)
  - Limited water breaks in training
- Day 3: undisclosed volume of running in practice
- Day 4: presented to ATC with severe bilateral quad pain
- Day 5: practiced with pain, stiffness, difficulty walking
- Day 6: admitted to hospital, peak CK **146,340** U/L

Insufficiently Descriptive Case Studies

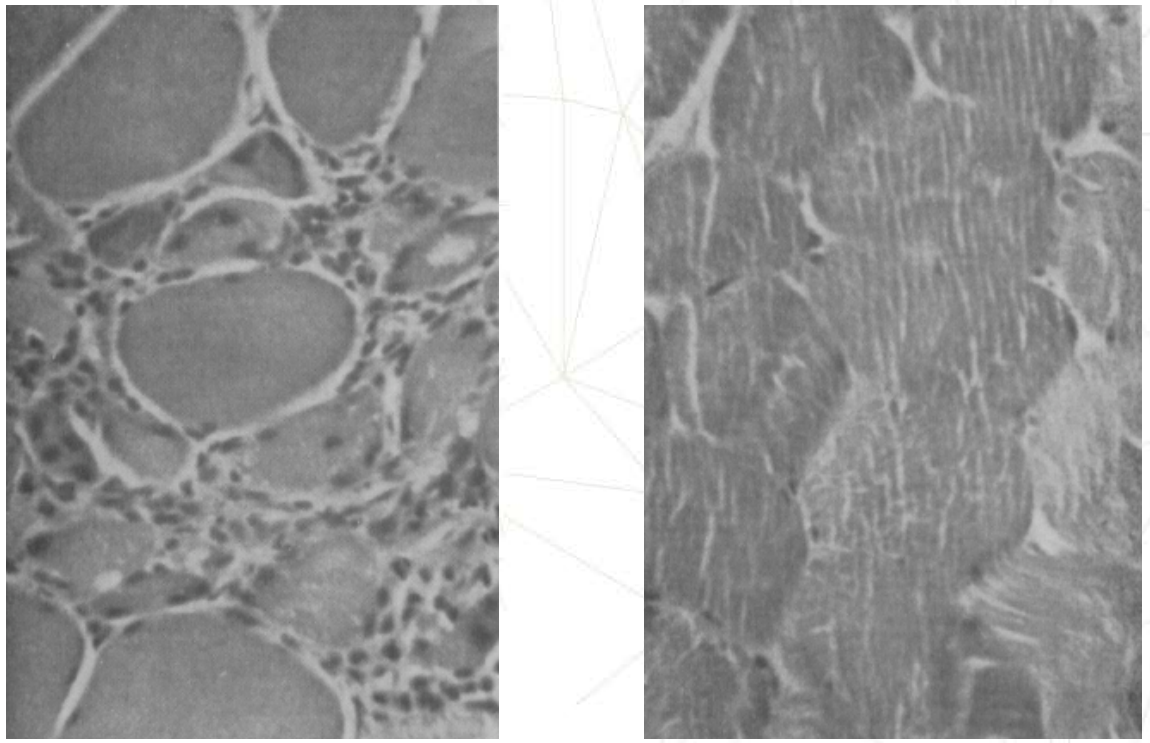
Register, Mihalik, Hirth, & Brickner (2006)

- D-I female lacrosse players at UNC (*n* = 8, 18-22 y.o.)
- No details about other activities
- First workout back from summer break (most reported no training)
  - Precipitous aspect of workout reported to be:
    - 3 X 20 biceps curls with 15 lb or 10 lb dumbbells
  - CK range: **4,287 – 20,247** U/L

Insufficiently Descriptive Case Studies

Greenberg & Arneson, 1967

- Officer Commissioning School, Ft Benning, GA
- Trainee contracted ER from ≈200 push ups in 1.5 - 2 h on Day 2
  - Pain & swelling in pecs & arms
  - Muscle biopsies taken
- 23/586 trainees contracted ER
- Further reduced ER occurrence by ensuring TIs implement progressive activity w/rest



Cross-sectional view of triceps biopsies taken after ER & 3 mo after

Insufficiently Descriptive Case Studies

Oh, Arter, Tiglao, & Larson (2015)

- Reviewed military injury database for ER injuries 2010-2012 at Tripler Army Medical Center (HI)
- 30 cases identified (not associated with toxins, heat illness, etc.)
- Resulted from
  - Military-style physical training & ruck marches (40%)
  - Nonspecific training including martial arts (43%)
  - High volume training from crossfit (*n* = 4) and P90X (*n* = 1) workouts
  - One case: 300+ lunges for 2 days in a row…
- CK range **697 - 233,180** U/L

Insufficiently Descriptive Case Studies

Hummel, Gregory, Desai & Diamond (2016)

- Described 8 cases of diagnosed ER at a hospital in Nashville, TN area
  - 7 high school football athletes (inseason & offseason)
    - 1 case combined with heat exhaustion
  - 1 first-time crossfit participant (15 y.o.)
- Implicated ADHD medication (stimulant) and caffeine in 2 cases
- CK levels ranged from **1,744** to **154,000** U/L between cases

Insufficiently Descriptive Case Studies

Borrione et al. (2009)

- ER diagnosed following high volume preparation for Nationals in 16 y.o. male swimmer
  - swimming 5d/wk, 2-3 hr/day + school-based PE (4h in week)
  - CK = **9,952** U/L
- Progressive weakness, intermittent muscle aches, malaise, episodic tachycardia, nausea
- **poorly controlled vegetarian diet** was proposed to be cause
- increased PRO intake & no further issues occurred

Insufficiently Descriptive Case Studies

Eliakim, Ben Zakin, Meckel, Yamin, Dror, & Yamet (2015)

- 17 y.o. “elite” water polo player underwent 2-day military pre-selection activity
- primarily endurance, loaded + unloaded movements
- CK values recorded **98,740** U/L
- Genetic testing diagnosed genetic tendency for ER
  - IL-6 174C allele single polymorphism
- Possible that previous water polo activities (goalie) not sufficiently damaging

…So What If We Boost Recovery???

- 2 case studies exist of ER exist with steroid-using bodybuilders

Braseth, Allison, & Gough (2001)

Farkash, Shabsin, & Pritsch (2009)

  - Neither are very descriptive of onset activities
  - Purity of “restorative”?

Practical Recommendations & Prevention Tips for Coaches

Key Takeaways for Coaches: Who Is At Risk for ER?

(otherwise healthy)

- Children & adolescents
- Very intrinsically motivated athletes
- Athletes who go to failure with high volume
  - especially repeated failure
- Athletes training in the heat
- Dehydrated athletes

Key Takeaways for S&C Coaches: Who Is At Risk for ER?

- Athletes coming back from semi-sedentary breaks
  - NCAA rules are ***part of this problem***
    - Supervised active rest period may be better than nothing at all
    - Many sport coaches don't understand training theory or psychology
      - No accountability of what coaches program
      - Athletic Directors need to be aware so they know who to fire or refer to educational resources
  - 2 of 4 possible mechanisms for atrophy are disuse & unloading (Urso, 2009)
    - post-season = sport-specific adaptations
    - not necessarily loading-specific

A Progressive Point

- The Repeated Bout Effect is demonstrated following ECC loading (Hyldahl, Chen, & Nosaka, 2017)
  - Rapid protective adaptation to musculature seen after first eccentric (ECC) exposure
  - Results in less muscle damage in subsequent ECC loading due to:
    - possible neural adaptations (follow after >12 h)
    - adapted muscle-tendon complex behaviors
      - including pennation angle changes
    - structural remodeling of extracellular matrix*
    - modified inflammatory response
  - Part of adaptation!

*Also supported by high volume eccentric endurance in Hoffman, Cresswell, Carroll, & Lichtwark (2016)

Weight Room Wisdom Point #1

- Be careful with volume.
- Amirthalingam et al. (2017) compared 6 weeks of
  - German volume training (10 X 10) primary lifts
  - 5 X 10 primary lifts
    - Both programs performed 3-4 X 10 assistance lifts
    - Both programs 3-day split
  - Greater strength gains for 5 X 10 group
  - No difference in muscle thickness (DEXA) between groups

Weight Room Wisdom Point #2

- Dr. Mike Stone:
  - *Highest* volumes with weightlifters have been 10 work sets of 10 back squats
    - Broken up into 2 sessions in a day
      - AM squats
      - PM squats & a few assistance lifts ≈ 5 sets
- At ETSU, strength-endurance phases don't often exceed 3 X 10 for primary & secondary lifts
  - Athletes doing other stuff
  - It works
  - Advanced strength athletes can handle > 5 X 10 (i.e. weightlifters)…?

Weight Room Wisdom Point #3

- Be careful with going to failure
  - Especially through repeated failure
  - Remember Selye's GAS…

A Cautionary Note for Coaches

- The CSCS can be revoked … don't be the first.
- From the NSCA Professional Standards & Guidelines (NSCA, 2009):

"...[An] S&C professional is negligent if he/she is proven to have a duty to act, and to have failed to act with the appropriate standard of care, proximately causing injury or damages to another person."

Appendix

Recommendations for Coaches

- 1. Do ***NOT*** punish your athletes with acute vigorous physical activity
  - Acute high density + high volume = great risk
    - If leaked to press, PR issue could get you fired
    - Coaches should not be programming exercise that may be potentially injurious to athletes
      - NSCA Code of Ethics
      - NCAA Sport Science Institute: http://www.ncaa.org/health-and-safety/medical-conditions/ten-factors-can-increase-risk-exertional-rhabdomyolysis

Recommendations for Coaches

- 2. Hydrate & Fuel!
  - Smoot et al. (2013) and several other physicians proposed connection between dilution of body fluids and better tolerance to aggressive exercise
  - Is there also a benefit to taking in PRO+ CHO drinks?
    - Anabolic environment vs. further catabolic?
      - Mixed results at this stage regarding reduction in inflammation (Kerksick et al., 2008)
    - Some association in literature of supplements with ER events
  - Immediate treatment for ER = IV hydration

Recommendations for Coaches

- 3. Get information and **use it**
  - Sickle cell trait athletes
    - Periodically quiz assistants & GAs on who is SCT
    - Do they know what that means? Are you sure?
    - See Fidler (2012) for review
  - Hydration status
  - Medication status of athletes
    - Many athletes may be on STIMULANTS (ADHD)
    - Requires excellent communication with ATCs

Recommendations for Coaches

- 4. Teach!
  - Your athletes need to know the consequences of partying extend beyond the party
  - Dehydration may take several days to overcome
    - Basketball athletes?
    - Hot climates?
  - Teach sport coaches about case studies to watch out for

Recommendations for Coaches

- 5. Have a plan.
  - Annual plan coordinated & agreed upon by sport coaches
  - Best practice in S&C
  - Chronic damage control is bad for the athletes' progression
    - talk to your supervisor (or AD) if you see a problem at your institution
    - being silent about issues may introduce liability to YOU
  - Any team-building, etc. MUST fit into plan
    - athletes should be prepared for it
    - assume NOTHING about athletes' preparedness

Recommendations for Coaches

- 6. Don’t use heat as a “mental toughness” training tool
  - may increase risk for ER via heat illness
  - questionable risk vs. reward – intensity of the session WILL decrease and you may not get desirable adaptations…
  - adaptation to heat should be considered in context of sport
    - (i.e. introduce in late off-season or preseason for outdoor sports)
    - *Do my athletes need this stressor?*

Key Concepts for S&C Coaches

- Best practice: test often and see if your programming works
  - Once or twice a year may not be sufficient
  - Can test & monitor in many ways
  - Are you able to test thoroughly?
  - Do your results support your programming with ALL athletes on a team?
  - Are there non-responders?

NCAA Information for Prevention of ER

- 10 factors that increase risk of ER (NCAA, 2013):
  - Athletes who try hardest
  - Arbitrary programming (not planned)
  - Novel stimuli
  - Irrationally “intense” workouts (high density + volume)
  - Exercise to failure & beyond
  - Fast repetitions to failure
  - Increasing # of sets and time needed to finish
  - Loading as % of body weight
  - Rapid return to fitness goal
  - Using training tools as physical punishment

Remaining Questions

- Why do some get rhabdo & others don't?
  - This requires detailed **athlete monitoring programs** to provide answers
- Some have proposed that mentally tougher athletes are at greater risk—how do we protect them?
  - "Normal" people know when to stop
- Quantify risk increase from dehydration

Future Research Opportunities

- Nutritional interventions following high volume
- CK comparison in Northern vs. Southern (U.S.) outdoor sport training
  - i.e. outdoor football conditioning of similar volumes
  - requires collaborative sport science work
- Effect of recovery modalities on perfusion
- Perform case studies when things go wrong!!!
  - Requires collaboration with medical professionals & sport medicine

References

Amirthalingham, T., Mavros, Y., Wilson, G. C., Clarke, J. L., Mitchell, L., & Hackett, D. A. (2017). Effects of a modified German volume training program on muscular hypertrophy and strength. *J Strength Cond Res, 31*(11), 3109-3119.

Anzalone, M. L., Green, V., S., Buja, M., Sanchez, L. A., Harrykissoon, R. I., & Eichner, E. R. (2010). Sickle cell trait and fatal rhabdomyolysis in football training: A case study. *Med Sci Sports Exerc, 42*(1), 3-7.

AP (2016). Iowa to pay $15K settlement to player hurtin 2011 workout. Retrieved from: https://www.usatoday.com/story/sports/ncaaf/2016/01/08/iowa-settles-lawsuit-with-ex-player-injured-in-2011-workout/78517930/

Borrione, P., Spaccamiglio, A. Salvo, R. A., Mastrone, A., Fagnani, A., & Pigozzi, F. (2009). Rhabdomyolysis in a young vegetarian athlete. *Am J Phys Med Rehabil, 88,* 951-954.

Braseth, N. R., Allison, E. J., & Gough, J. E. (2001). Exertional rhabdomyolysis in a body builder abusing anabolic androgenic steriods. *Eur J Emergency Med, 8*, 155-157.

Casa, D. J., Anderson, S. A., Baker, L., Bennett, S., Bergeron, M. F., …& Thompson, C. (2012). The inter-association task force for preventing sudden death in collegiate conditioning sessions: Best practices and recommendations. *J Ath Training, 47*(4), 477-480.

Cleary, M.A., Sadowski, K.A., Lee, S., Y., Miller, G. L., & Nichols, A. W. (2011). Exertional rhabdomyolysis in an adolescent athlete during preseason conditioning: A perfect storm. *J Strength Cond Res, 25*(12), 3506-3513.

Ehlers, G.G., Ball, T.E., & Liston, L. (2002). Creatine kinase levels are elevated during 2-a-day practices in collegiate football players. *J Ath Training, 37*(2), 151-156.

Eliakim, A., Ben Zaken, S., eckel, Y., Yamin, C., Dror, N., & Nemet, D. (2015). Rhabdomyolysis after out-of-water exercise in an elite adolescent water polo player carrying the IL-6 174C allele single-nucleotide polymorphism. *J Strength Cond Res, 29*(12), 3506-3508.

Farkash, U., Shabshin, N., & Pritsch, M. (2009). Rhabdomyolysis of the deltoid muscle in a bodybuilder using anabolic-androgenic steroids: A case report. *J Athl Train, 44*(10), 98-100.

Fidler, E. (2012). Sickle cell trait: A review and recommendations for training. *Strength Cond J, 34*(3), 28-32.

Galvez, R., Stacy, J., & Howley, A. (2008). Exertional rhabdomyolysis in seven Division-I swimming athletes. *Can J Sport Med, 18,* 366-368.

Harrykissoon, R. I., Patel, B., Warner, M. T., Estrada-Y-Martin, R. (2007). Fatal rhabdomyolysis in a college athlete due to sickly cell trait. *Chest, 132*(4), 673.

References

Huerta-Alardin, A. L., Varon, J., & Marik, P. E. (2005). Bench-to-bedside review: Rhabdomyolysis—an overview for clinicians. *Critical Care, 9*(2), 158-169.

Hoffman, B., Creswell, A. G., Carroll, T. J., & Lichtwark, G.A. (2016). Protection from muscle damage in the absence of changes in muscle mechanical behavior. *Med Sci Sports Exerc, 48*(8), 1495-1505.

Hoffman, J. R., Maresh, C. M., Newton, R. U., Rubin, M. R., French, D. N., Volek, J.S., … Kraemer, W. J. (2002). Performance, biochemical, and endocrine changes during a competitive football game. *Med Sci Sports Exerc, 34*(11), 1845-1853.

Hoffman, J. R., Kang, J., Ratamess, N. A., & Faigenbaum, A. D. (2005). Biochemical and hormonal responses during an intercollegiate football season. *Med Sci Sports Exerc, 37*(7), 1237-1241.

Hyldahl, R.D., Chen, T.C., & Nosaka, K. (2017). Mechanisms and mediators of the skeletal muscle repeated bout effect. *Exerc Sport Sci Rev, 45*(1), 24-33.

Karstoft, K., Solomon, T. P., Laye, M. J., & Pederson, B. K. (2013). Daily marathon running for a week—the biochemical and body compositional effects of participation. *J Strength Cond Res, 27*(11), 2927-2933.

Kerksick, C., Harvey, T., Stout, J., Campbell, B., Wilborn, C., …, Antonio, J. (2008). International Society of Sports Nutrition position stand: Nutrient timing. *J Int Society Sport Nutr, 5,* 1-12.

McArdle, Katch & Katch (2007). Exercise physiology: Energy, nutrition, and human performance. Lippincott, Williams, & Wilkins: Baltimore, MD. pp. 366.

McKay, B. D., Yeo, N. M., Jenkins, N. D. M., Miramonti, A. A., & Cramer, J. T. (2017). Exertional rhabdomyolysis in a 21 year-old healthy woman: A case report. *J Strength Cond Res, 31*(5), 1403-1410.

Moeckel-Cole, S. & Clarkson, P. M. (2009). Rhabdomyolysis in a collegiate football player. J Strength Cond Res, 23(4), 1055-1059.

Mougios, V. (2007). Reference intervals for serum creatine kinase in athletes. *Br J Sports Med, 41,* 674-678

NCAA (2013). Ten factors can increase the risk of exertional rhabdomyolysis. *NCAA.org.* Retrieved from http://www.ncaa.org/health-and-safety/medical-conditions/ten-factors-can-increase-risk-exertional-rhabdomyolysis

NSCA (2009). National Strength and Conditioning Association: strength and conditioning professional standards and guidelines. *J Strength Cond, 31*(5), 14-38.

References

Oh, J. Y., Laidler, M., Fiala, S. C., & Hedberg, K. (2012). Acute exertional rhabdomyolysis and triceps compartment syndrome during a high school football lcamp. *Sports Health, 4*(1), 57-62.

Oh, R. C., Arter, J. L., Tiglao, S. M., Larsen, S. L. (2015). Exertional rhabdomyolysis: A case series of 30 hospitalized patients. *Mil Med 180,* 201-207.

Ramos, D.A., & Dorgo, S. (2014). Rhabdomyolysis: Considerations for recognition andprevention for practitioners. *J Strength Cond, 36*(6), 56-61.

Register, J. K., Mihalik, J. P., Hirth, C. J., & Brickner, T. E. (2006). Exertional rhabdomyolysis in 8 Division I female lacrosse athletes: A case series. *Athletic Therapy Today, 11*(4), 26-28.

Shelmadine, B. D., Baltensparger, A., Wilson, R. L., & Bowden, R. G. (2013). Rhabdomyolysis and acute renal failure in a sickle cell trait athlete: A case study. *Clin J Sport Med, 23,* 235-237.

Smoot, M.K., Amendola, A., Cramer, E., Doyle, C., Kregel, K. C., … & Herwaldt, L.A. (2013). A cluster of exertional rhabdomyolysis affecting a Division I football team. *Clin J Sport Med, 23,* 365-372.

Smoot, M. K., Cavanaugh, J. E., Amendola, A., West, D.R., & Herwaldt, L.A. (2014). Creatine kinase levels during preseason camp in National Collegiate Athletic Association Division I football athletes. *Clin J Sport Med, 24,* 438-440.

Stanfa, M. R., Silles, N. N., Cooper, A., Arena, S., Landis-Piwowar, K., Aprik, C., & Hew-Butler, T. (2017). Risk factors for collegiate swimmers hospitalized with exertional rhabdomyolysis. *Clin J Sport Med, 27*(1), 37-45.

Szczepanik, M. E., Heled, Y., Capaccione, J., Campbell, W., Deuster, P., & O'Connor, F. G. (2014). Exertional rhabdomyolysis: Identification and evaluation of the athlete at risk for recurrence. *Curr Sport Med Reports, 13*(2), 113-119.

Tietze, D. C., & Borchers, J. (2014). Exertional rhabdomyolysis in the athlete: A clinical review. *Sports Health, 6*(4), 336-339.

Urso, M. (2009). Disuse atrophy of human skeletal muscle: Cell signaling and potential interventions. *Med Sci Sports Exerc, 41*(10), 1860-1868.

Thank you!

Ben Gleason, PhD, CSCS*D, RSCC, USAW2

gleasonb@latech.edu