



Original research

CrossFit and rhabdomyolysis: A case series of 11 patients presenting at a single academic institution



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ABSTRACT

Objectives: CrossFit is an increasingly popular high intensity work out program geared towards high repetition and intensity done in short intervals. Recently, documented cases of rhabdomyolysis (muscle necrosis and extreme muscle breakdown) after CrossFit participation have become increasingly concerning to physicians and participants alike.

Design: Retrospective cohort study.

Methods: All patients who presented to the main hospital at a major academic center complaining of an injury sustained performing CrossFit between June 2010 and June 2016 were identified by the key phrases 'CrossFit', 'crossfit', 'Crossfit' or 'cross fit'.

Results: 523 patients incurred injuries associated with CrossFit activities. 11 patients presented to our institution ultimately received a diagnosis of rhabdomyolysis (2.1%). The average age of Rhabdomyolysis patient was 34.9 years, with 81.9% of patients being male. The average BMI was 24.2, and the average experience level was beginner (54.5%). The most common presenting symptom was dark urine (90.9%), followed by upper extremity pain (54.5%). Average symptom duration was 2.9 days with 81.8% of patients presenting initially to the ED. The average hospital stay was roughly 2.9 days, and patients had an average of 1.44 clinical follow up visits.

Conclusion: CrossFit participation poses significant risks to participants including exercise induced rhabdomyolysis. Further study is needed in order to raise awareness of this issue and further quantify risk factors that may promote injury during participation.

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Practical implications

- CrossFit is an increasingly popular workout regimen with a high-risk injury profile.
- Rhabdomyolysis may occur more frequently after CrossFit than was previously identified and further study on the matter is needed.
- Participating in intense CrossFit may require appropriate build-up of stamina to avoid potentially serious complications.

Abbreviations: ERI, exercise related injuries; ED, emergency department; BMI, body mass index; CK, creatinine kinase; ALT, alanine amino transferase; AST, aspartate amino transferase.

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1. Introduction

Exercise-related injuries (ERIs) are a common cause of non-fatal emergency room and hospital visits.¹ In the United States alone, up to 7 million ERIs are treated annually, with over 4.3 million of these representing visits to the emergency room.^{2,3} Similarly, the number of new and creative exercise modalities continues to grow faster than ever before, with an industry wide revenue of roughly \$24.2 billion yearly.^{4,5} As such, an appropriate understanding of ERI is complicated by the constant introduction of new, potentially high-impact, exercise modalities.^{1,6–12}

Among the most popular and rapidly growing high intensity style workout routines is CrossFit. With an estimated 2–4 million participants worldwide, CrossFit has quickly developed a “cult-like” following and culture that takes special pride in the sport’s flirtation with near dangerous levels of physical exertion.^{13,14} The program involves heavy and rapid weight-lifting, gymnastics, pull-ups, and rope climbing combined into short, repetitive,

high-intensity workouts.^{15,16} Since its commercial release in 2000, CrossFit has grown rapidly and been adopted by many military and civilian sport gyms worldwide with an estimated 13,000 affiliate gyms.¹³ CrossFit's appeals such as fitness gains, decreased blood pressure, lower resting heart rates, increased aerobic capacity and associated weight loss, have led to widespread adoption of its program.^{16–21}

While numerous health benefits have been documented, injury risks have also become a relevant concern.^{16,22–28} The intensity and high-impact nature of CrossFit has led to an injury rate reported as high as 20–73%^{16,23} ranging from injuries as minor as muscle tears to retinal detachment and carotid artery dissection.^{16,22–27} Retrospective studies have even suggested that as many as 7% of documented CrossFit injuries go on to require surgical intervention, with numerous others requiring emergency room visits and subsequent hospitalization.^{16,23}

Recently, documented cases of rhabdomyolysis after CrossFit participation have become increasingly concerning to physicians and participants alike, with reported cases resulting from participation in as few as one CrossFit exercise session.²⁹ Exertional rhabdomyolysis is a rare, yet dangerous condition with an estimated incidence of 29.9 per 100,000 patients.³⁰ Muscle necrosis, breakdown, and large amounts of leakage of intracellular muscle enzymes cause complications ranging from dangerous electrolyte abnormalities to renal solute overload and Acute Kidney Injury (AKI).³¹ Patients most commonly present with myalgias and commonly with dark urine.³¹ In severe cases this condition can present with symptomatology as severe as muscle ischemia, arrhythmia or even death.³⁰

While exercise-induced rhabdomyolysis has been documented in various other exercise populations,^{32–45} CrossFit's unique culture and emphasis on high-intensity, repetitive exercise lends itself to an especially high risk profile.¹⁴ There remains a need to further quantify and assess the risks associated with CrossFit participation and associated rhabdomyolysis in order to better guide physician recommendations and educate participants of their own high-risk behavior. This current case series is the first to attempt to quantify the proportion of patients with CrossFit related injuries that end up needing admission due to rhabdomyolysis. This case series provides a starting point towards a goal of estimating the resulting prevalence of such injuries.

2. Materials and methods

All patients who presented to the main hospital at a major academic center complaining of an injury sustained performing CrossFit between June 2010 and June 2016 were identified using the Electronic Data Warehouse (EDW), which is a clinical data repository. Institutional Review Board approval was given for retrospective review, and a comprehensive query of all archived medical records containing the key phrases 'CrossFit', 'crossfit', 'Crossfit' or 'cross fit' was run. Initially, 955 unique patients were identified having 1926 associated medical records all containing one of the mentioned key phrases. Records were reviewed and all patients were selected that had sustained injuries associated with the mention of concurrent CrossFit participation. Reports were excluded that either had no chief complaint or had complaints unrelated to participation in CrossFit exercise. Patients with injuries known to have been sustained outside of CrossFit were further excluded. A total of 498 patients with 523 injuries sustained from CrossFit met the inclusion criteria of this study (Table 1). Patient charts were reviewed for relevant clinical laboratory test values, demographic information and treatment characteristics. Medically, rhabdomyolysis is defined by a breakdown of striated muscle causing a rise in Creatine Kinase (CK) to five times the upper limit of normal. Due

Table 1
Distribution of CrossFit related injuries.

Overall injury type (n = 523)	Count (%)
Musculoskeletal	426 (81.5%)
Cardiopulmonary complaints	36 (6.9%)
Other neurologic complaints ^a	32 (6.1%)
Other injuries/conditions ^b	29 (5.5%)
Musculoskeletal injury type (n = 426)	Count (%)
Spine	89 (20.9%)
Shoulder	78 (18.3%)
Knee	66 (15.5%)
Gluteal region	27 (6.3%)
Elbow	24 (5.6%)
Leg	24 (5.6%)
Wrist	18 (4.2%)
Ankle	16 (3.8%)
Foot	15 (3.5%)
Hand	12 (2.8%)
Other musculoskeletal ^c	38 (8.9%)

^a Headaches, migraines, weakness, paresthesia.

^b Rhabdomyolysis, ocular dysfunction, abdominal pain, pulmonary symptoms, scrotal inflammation, proteinuria, dehydration.

^c Groin, fingers, arm, musculoskeletal chest pain.

Table 2
Patient demographics, CrossFit experience, and clinical presentation (n = 11).

Patient characteristics	
Age (years)	34.9 ± 9.7
Sex (male)	9 (81.8%)
BMI	24.2 ± 3.7
CrossFit experience	
Beginner	6 (54.5%)
Advanced	1 (9.1%)
Unknown	4 (36.4%)
Presenting symptoms	
Dark urine	10 (90.9%)
Fever	2 (18.2%)
Swelling	1 (9.1%)
Thigh and lower extremity pain	2 (18.2%)
Upper extremity pain	6 (54.5%)
Back pain	2 (18.2%)
Duration of symptoms (days)	2.9 ± 1.5
ED vs OP (ED)	9 (81.8%)

to the retrospective nature of our study, however, distinguishing rhabdomyolysis patients from other patients was difficult. As such for the purposes of our study, rhabdomyolysis was instead defined by reviewing clinician notes for each admission and was considered positive when the main reason for admission was documented as rhabdomyolysis by the attending physician on staff at the time of admission. Patient demographics and CrossFit experience are summarized in Table 2. Clinical laboratory values at time of admission and time of last follow up are noted in Tables 3 and 4. Treatment characteristics are noted in Table 5.

Microsoft Excel 2011 (Microsoft, Redmond, WA, USA) was used to conduct all statistical analysis. Parametric data was given as mean ± standard deviation. T- tests were run to compare patients requiring surgical intervention to those not needing intervention. Variables run include age, sex, duration of symptoms and number of clinic visits. A value of $p < 0.05$ was considered statistically significant.

3. Results

523 patients incurred injuries associated with CrossFit activities. The most common presenting injuries were musculoskeletal (81.5%) (Table 1). Of those, spine, shoulder, and knee- related

Table 3
Lab values.

Patient #	CK ^a		DC		Follow up		CK-MB		Creatinine		ALT		AST		P		K		Ca		BUN	
	ED	>20,000	ED	>20,000	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final
Patient 1	111,100	>20,000	39,200	>20,000	1.66	1.77	n/a	n/a	576	426	2266	1290	n/a	n/a	5.1	4.5	9.2	9.1	21	21	24	24
Patient 2	>20,000	>20,000	15,976	>20,000	0.81	1.21	n/a	n/a	n/a	440	n/a	262	4	4	4.1	4	9.2	8.8	15	15	11	11
Patient 3	>20,000	>20,000	>20,000	>20,000	0.73	0.87	n/a	n/a	269	298	925	732	3.3	3.3	4.5	3.9	9.9	9.1	14	14	6	6
Patient 4	>20,000	>20,000	12,024	>20,000	0.55	0.69	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	3.8	3.8	9.1	8.3	12	12	7	7
Patient 5	>20,000	>20,000	6300	>20,000	0.98	1.14	n/a	n/a	192	105	592	169	n/a	n/a	4.4	4.1	9.8	8.9	18	18	12	12
Patient 6	4953	>20,000	1794	>20,000	0.82	1.1	n/a	n/a	43	41	118	67	n/a	n/a	5.2	3.5	10.3	10	15	15	8	8
Patient 7	n/a	>20,000	n/a	>20,000	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Patient 8	70,280	>20,000	56,000	>20,000	0.83	0.89	n/a	n/a	197	235	765	731	n/a	n/a	4.3	4.2	9.6	8.2	27	27	9	9
Patient 9	8110	>20,000	n/a	>20,000	n/a	0.78	n/a	10	n/a	15	n/a	n/a	n/a	3.1	n/a	9.1	n/a	13	13	13	n/a	
Patient 10	>20,000	>20,000	>20,000	>20,000	0.87	1.22	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	4.2	4.2	9.9	8.5	35	35	9	9
Patient 11	>20,000	>20,000	4380	>20,000	0.7	0.8	n/a	n/a	165	172	691	197	n/a	n/a	4.1	3.4	8.6	8.8	12	12	11	11
Average values	39,195 ^a	>20,000	12,024 ^a	>20,000	0.883 ± 0.31	1.05 ± 0.32	22.8	10.5	207 ± 186	245 ± 152	767 ± 741	492 ± 442	3.3	3.46 ± 0.47	4.28 ± 0.60	3.95 ± 0.35	9.47 ± 0.35	8.86 ± 0.53	18.2 ± 7.5	18.2 ± 7.5	10.7 ± 5.3	10.7 ± 5.3

^a CK values were analyzed using different laboratories over the years included in the study. As such, some of the CK lab values had upper limits preset at 20,000 and therefore registered 20,000 as the highest possible recorded CK. Median values instead of averages are reported for CK only due to these discrepancies.

Table 4
Average lab values.

Lab values	
CPK	
ED	31,444 ± 33,131
DC	19,519 ± 17,697
Follow up	2569 ± 2194
CK-MB	
Initial	22.8
Final	10.5
Creatinine	
Initial	1.05 ± 0.32
Final	0.883 ± 0.31
ALT	
Initial	207 ± 186
Final	245 ± 152
AST	
Initial	767 ± 741
Final	492 ± 442
P	
Initial	3.3
Final	3.46 ± 0.47
K	
Initial	4.28 ± 0.60
Final	3.95 ± 0.35
Ca	
Initial	9.47 ± 0.35
Final	8.86 ± 0.53
BUN	
Initial	18.2 ± 7.5
Final	10.7 ± 5.3

Table 5
Treatment and characteristics.

Treatment	
Treatment	
Fluids	11 (100%)
Bicarbonate	1 (12.5%)
Duration of treatment (days)	2.25 ± .83
Length of hospital stay (days)	2.87 ± 2.1
Number of clinic visits	1.44 ± .73

injuries encompassed more than half of musculoskeletal injuries (54.7%) 11 patients presenting to our institution were diagnosed and admitted for rhabdomyolysis (2.1%). The average age of rhabdomyolysis patient was 34.9 years, with 81.9% of patients being male. The average BMI was 24.2, and the average experience level was beginner (54.5%) (Table 2). The most common presenting symptom was dark urine (90.9%), followed by upper extremity pain (54.5%) (Table 3). Overall musculoskeletal complaints (upper and lower extremity pain, as well as back combined) were seen in 90.9% of patients who presented to the emergency department after CrossFit activities. Fever was only present in 2 patients (18.2%). Average symptom duration was 2.9 days with 81.8% of patients presenting initially to the emergency department (Table 3). CK lab values averaged at over 1000× the upper limit of normal CK values and remained elevated through follow up appointment (Table 3). Alanine and Aspartate amino transferase, ALT and AST respectively, were also well above the upper limit of the normal range for patients who presented with rhabdomyolysis with values of 207 IU/L (range 10–576 IU/L) and 767 IU/L (range 15–2266 IU/L) on admission respectively. This corresponds to 83.3% and 100% of patients having ALT and AST values above the normal range, indicating high sensitivity. BUN and Creatinine were similarly elevated at an average of 18.2 mmol/L (range 12–21 mmol/L) and 1.05 g/24 h (range 0.69–1.77 g/24 h) respectively, both of which decreased by

the end of their hospital stay. Other lab abnormalities associated with cell injury or renal injury, namely potassium, were generally on the higher end of normal with an average of 4.28 mmol/L (range 3.1–5.2 mmol/L). All patients were treated with fluids (100%) with only 1 patient requiring bicarbonate. The average hospital stay was roughly 2.87 ± 2.1 days, and patients had an average of 1.44 ± 0.73 clinical follow up visits (Table 4).

4. Discussion

To this date only a handful of cases have been documented of rhabdomyolysis after CrossFit.^{46,47} To the best of our knowledge, our study is the first to document a case series of patients presenting with rhabdomyolysis after CrossFit workouts. Of all presenting CrossFit related injuries at our institution, 11 (2.1%) presented with rhabdomyolysis. Rhabdomyolysis is a condition constituted by the breakdown of striated muscle tissue, and the subsequent release of intracellular contents into circulation. It is defined by a rise in CK five times the upper limit of normal, ranging from 1500 to over 100,000 IU/L. Although not included in diagnostic criteria, many patients, including those that participate in CrossFit, also experience myoglobinuria as demonstrated by dark urine.^{46,48}

This condition is typically treated without complications. Factors associated with this condition include high intensity, little exercise experience, eccentric muscle contraction, hot environment, history of electrolyte imbalances, male sex, low protein diets, statin use, alcohol and creatine supplementation.⁴⁸ However, serious complication such as acute renal failure, compartment syndrome, hyperkalemia, and disseminated intravascular coagulation can occur.^{44,47} The most common clinical manifestations of rhabdomyolysis are extremity pain and dark urine. Acute kidney injury remains the most prevalent organ system complication, thought to be caused by the accumulation of myoglobin with dehydration as a precipitating factor.⁵² Dehydration is also a notable factor in rhabdomyolysis as is commonly associated with rhabdomyolysis and is commonly observed in CrossFit.⁴⁹

Creatine kinase (CK) is an enzyme which has peak activity in striated muscle, cardiac tissue, and the brain. Therefore, testing the levels of this enzyme is an integral tool in examining damage to any of the related organ systems.⁴⁵ Upon laboratory testing in rhabdomyolysis cases, creatine kinase levels are typically elevated. Although there are no set guidelines in the diagnosis of rhabdomyolysis, a common clinical feature is CK levels greater than five times the upper limit of normal values.⁵¹ 72% of patients who presented to the ED with CrossFit related Rhabdomyolysis had a CK level of >20,000 IU/L, as seen in Table 3. The median CK level in admitted patients, 39,195 IU/L, is roughly 1200 times the upper limit of normal CK levels (the normal range of CK values is from 45 to 260 IU/L). While CK levels are typically elevated after any intense exercise, it is important to always consider such values in appropriate context.⁴⁴ A strong positive correlation has been observed between peak CK levels, and length of hospital stay.⁴⁸

The dangers of CrossFit and exercise related injuries are extremely relevant, as the popularity and prevalence of CrossFit has grown immensely in the past decade. CrossFit currently has an estimated 2–4 million participants globally.^{13,14} With an average injury rate of about 19%, and an unofficial mascot designated as “Uncle Rhabdo”,⁴⁹ roughly 380,000–760,000 CrossFit participants are at risk for injury.⁴⁷ This is very problematic, given that many CrossFit participants are beginners, and have not been thoroughly trained in the proper techniques and exercises involved in a CrossFit workout. The majority (54%) of patients who presented to the ED with CrossFit induced rhabdomyolysis had a beginner level of training, as seen in Table 2.

The result of this growth has been an increased incidence of CrossFit induced rhabdomyolysis and injuries overall. The most

common injuries associated with CrossFit are sprains and strains that led to pain and inflammation.⁴⁷ The risk of CrossFit induced rhabdomyolysis is more worrisome than other common injuries, due to the possibility of life-threatening complications, such as organ failure. Although a small portion (2.1%) of patients presenting to the clinic with CrossFit associated injuries were diagnosed with rhabdomyolysis, the overall prevalence of the sport makes this finding worrisome.

CrossFit participants should be aware of the common symptoms associated with rhabdomyolysis and be informed of the warning signs and symptoms so he or she may receive timely care. If one experiences soreness or pain that is beyond what is reasonably expected after an intense workout, they should consider going to the hospital. This is especially true if observed in conjunction with dark urine, which itself is a worrisome symptom that may require medical attention. Although the clinical presentation of rhabdomyolysis varies between individuals, the common symptoms are characteristic of the majority of CrossFit induced rhabdomyolysis cases. Participants of CrossFit should make sure to receive proper training before participating in CrossFit. Beginners should physically prepare for high intensity workouts with exercise and should increase exercise intensity in a stepwise fashion to avoid injury. Participating in warm-up activities each workout is also an important step in avoiding injury.^{46,48}

Currently, there are no set guidelines in the treatment of rhabdomyolysis.⁴⁹ Because acute kidney injury is the most common complication, immediate intravenous fluid administration is a very important treatment modality associated with better outcomes, as well as effectively preserving renal function.^{50, 52} Statin and other lipid lowering agents are known risk factors in rhabdomyolysis.^{50, 52} If clinical suspicion for this diagnosis exists, these agents should be immediately discontinued.

Our study has several limitations. Due to its retrospective nature, this study is subject to bias. As there is no control group in our study, our study was descriptive, and cannot identify predictors of injury. Furthermore, the specific mechanism of injury is a relevant but absent variable that would enhance our understanding of the problem. Loss to follow up was also high, with specific relevant variables often absent in follow up medical records. This made it difficult to determine return to participation time, whether patients were compliant with recommended treatment or even whether participants continued to participate in CrossFit after injury. Next steps may include case-control series that can identify risk factors, including specific workout routines and baseline physical conditioning that are specifically associated with the development of injuries.

5. Conclusion

CrossFit participation poses significant risks to participants including exercise induced rhabdomyolysis. Further study is needed in order to raise awareness of this issue and further quantify risk factors that may promote injury during participation.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <https://doi.org/10.1016/j.jsams.2019.01.019>.

References

- Hauret KG, Bedno S, Loring K et al. Epidemiology of exercise- and sports-related injuries in a population of young, physically active adults: a survey of military servicemembers. *Am J Sports Med* 2015; 43(11):2645–2653.
- Centers for Disease Control and Prevention. Nonfatal sports- and recreation-related injuries treated in emergency departments—United States, July 2000–June 2001. *MMWR Morb Mortal Wkly Rep* 2002; 51(33):736–740.
- Conn JM, Annett JL, Gilchrist J. Sports and recreation related injury episodes in the US population, 1997–99. *Inj Prev* 2003; 9(2):117–123.
- Garcia T. *Boutique fitness studios are leading growth in the health club industry*, MarketWatch, 2015.
- Bornstein A. *The 6 biggest trend shifts in fitness*, Men's Fitness, 2016.
- Gilchrist J, Jones BH, Sleet DA et al. Exercise-related injuries among women: strategies for prevention from civilian and military studies. *MMWR Recomm Rep* 2000; 49(RR-2):15–33.
- Hootman JM, Dick R, Agel J. Epidemiology of collegiate injuries for 15 sports: summary and recommendations for injury prevention initiatives. *J Athl Train* 2007; 42(2):311–319.
- Hootman JM, Macera CA, Ainsworth BE et al. Epidemiology of musculoskeletal injuries among sedentary and physically active adults. *Med Sci Sports Exerc* 2002; 34(5):838–844.
- Jones BH, Cowan DN, Knapik JJ. Exercise, training and injuries. *Sports Med* 1994; 18(3):202–214.
- Jones BH, Knapik JJ. Physical training and exercise-related injuries. Surveillance, research and injury prevention in military populations. *Sports Med* 1999; 27(2):111–125.
- Koplan JP, Powell KE, Sikes RK et al. An epidemiologic study of the benefits and risks of running. *JAMA* 1982; 248(23):3118–3121.
- Lauder TD, Baker SP, Smith GS et al. Sports and physical training injury hospitalizations in the army. *Am J Prev Med* 2000; 18(Suppl. 3):118–128.
- Price K. *No sign of CrossFit boom slowing down*, Pittsburgh Tribune Review, 2015.
- Gregory S. Lift squat repeat. Crossfit gyms' cultish painiacs love their max-out-and-do-it-again training regimen. Their critics are getting a workout too. *Time* 2014; 183(2):40–44.
- Glassman G. Understanding CrossFit. *CrossFit J* 2007; 56:1–2.
- Weisenthal BM, Beck CA, Maloney MD et al. Injury rate and patterns among CrossFit athletes. *Orthop J Sports Med* 2014; 2(4), 2325967114531177.
- Eather N, Morgan PJ, Lubans DR. Improving health-related fitness in adolescents: the CrossFit teens randomised controlled trial. *J Sports Sci* 2016; 34(3):209–223.
- Fisher J, Sales A, Carlson L et al. A comparison of the motivational factors between CrossFit participants and other resistance exercise modalities: a pilot study. *J Sports Med Phys Fitness* 2016; 57(September (9)):1227–1234.
- Gilmore KE, Heinrich KM. Crossfit & heart health: effects of crossfit participation on resting blood pressure and heart rate: 1020 board #336 June 1, 2: 00 PM–3: 30 PM. *Med Sci Sports Exerc* 2016; 5(Suppl. 1):293.
- Heinrich KM, Feito Y. Weight management and appearance motivate non-competitive CrossFit participants: 2521 board #44 June 3, 11: 00 AM–12: 30 PM. *Med Sci Sports Exerc* 2016; 5(Suppl. 1):696.
- Kliszczewicz B, Quindry CJ, Blessing LD, Oliver DG, Esco RM, Taylor JK. Acute exercise and oxidative stress: CrossFit™ vs. treadmill bout. *J Hum Kinet* 2015; 47:81–90.
- Friedman MV, Stensby JD, Hillen TJ et al. Traumatic tear of the latissimus dorsi myotendinous junction: case report of a CrossFit-related injury. *Sports Health* 2015; 7(6):548–552.
- Hak PT, Hodzovic E, Hickey B. The nature and prevalence of injury during CrossFit training. *J Strength Cond Res* 2013.
- Joondeph SA, Joondeph BC. Retinal detachment due to CrossFit training injury. *Case Rep Ophthalmol Med* 2013; 2013:189837.
- Poston WS, Haddock CK, Heinrich KM et al. Is high-intensity functional training (HIFT)/CrossFit safe for military fitness training? *Mil Med* 2016; 181(7):627–637.
- Raske A, Norlin R. Injury incidence and prevalence among elite weight and power lifters. *Am J Sports Med* 2002; 30(2):248–256.
- Verma A, Vega AR. Survey of incidence of injuries in crossfit training: 3047 board #112 June 3, 2: 00 PM–3: 30 PM. *Med Sci Sports Exerc* 2016; 5(Suppl. 1):861.
- Hopkins BS, Cloney MB, Kesavabhotla K et al. Impact of CrossFit-related spinal injuries. *Clin J Sport Med* 2017.
- Glassman G. CrossFit-induced rhabdo. *CrossFit J* 2005; 38:1–3.
- Tietze DC, Borchers J. Exertional rhabdomyolysis in the athlete: a clinical review. *Sports Health* 2014; 6(4):336–339.
- Knochel JP. Rhabdomyolysis and myoglobinuria. *Annu Rev Med* 1982; 33:435–443.
- Bhalla MC, Dick-Perez R. Exercise induced rhabdomyolysis with compartment syndrome and renal failure. *Case Rep Emerg Med* 2014; 2014:735820.
- Caban G, Marin L, Scavone F. Exercise-induced rhabdomyolysis. *J Am Podiatr Med Assoc* 2007; 97(3):234–237.
- Chlibkova D, Knechtle B, Rosemann T et al. Rhabdomyolysis and exercise-associated hyponatremia in ultra-bikers and ultra-runners. *J Int Soc Sports Nutr* 2015; 12:29.
- Clark BC, Manini TM. Can KAATSU exercise cause rhabdomyolysis? *Clin J Sport Med* 2016:2016.
- Ellis C, Cuthill J, Hew-Butler T et al. Case report: exercise-associated hyponatremia with rhabdomyolysis during endurance exercise. *Phys Sportsmed* 2009; 37(1):126–132.
- Furman J. When exercise causes exertional rhabdomyolysis. *JAAPA* 2015; 28(4):38–43.
- Gagliano M, Corona D, Giuffrida G et al. Low-intensity body building exercise induced rhabdomyolysis: a case report. *Cases J* 2009; 2(1):7.
- Keah S, Chng K. Exercise-induced rhabdomyolysis with acute renal failure after strenuous push-UPS. *Malays Fam Phys* 2009; 4(1):37–39.
- Lee G. Exercise-induced rhabdomyolysis. *R J Med J (2013)* 2014; 97(11):22–24.
- Lozowska D, Liewluck T, Quan D et al. Exertional rhabdomyolysis associated with high intensity exercise. *Muscle Nerve* 2015; 52(6):1134–1135.
- Reese JM, Fisher SD, Robbins DP. Exertional rhabdomyolysis: attrition through exercise, a case series and review of the literature. *J Spec Oper Med* 2012; 12(3):52–56.
- Sayers SP, Clarkson PM. Exercise-induced rhabdomyolysis. *Curr Sports Med Rep* 2002; 1(2):59–60.
- Tran M, Hayden N, Garcia B et al. Low-intensity repetitive exercise induced rhabdomyolysis. *Case Rep Emerg Med* 2015; 2015:281540.
- Yamin C, Meckel Y, Oliveira J et al. Genetic aspects of exercise and rhabdomyolysis. *Pediatr Endocrinol Rev* 2014; 11(4):400–408.
- Meyer M, Sundaram S, Schafhalter-Zoppoth I. Exertional and CrossFit-induced rhabdomyolysis. *Clin J Sport Med* 2017; 28(November ((6))):e92–e94.
- Larsen C, Jensen MP. Rhabdomyolysis in a well-trained woman after unusually intense exercise. *Ugeskr Laeger* 2014; 176(25).
- Kim J, Lee J, Kim S et al. Exercise-induced rhabdomyolysis mechanisms and prevention: a literature review. *J Sports Health Sci* 2015:1–11.
- News.com.au. *What CrossFit doesn't want you to know*, 2013 [Accessed 3 August 2017].