[Primary Care]

Acute Exertional Rhabdomyolysis and Triceps Compartment Syndrome During a High School Football Camp

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Background: Acute exertional rhabdomyolysis has been infrequently reported among adolescents. In August 2010, several high school football players from one team developed rhabdomyolysis and triceps compartment syndrome following an upper arm exercise held in a non-air-conditioned wrestling room.

Purpose: To confirm the diagnoses, characterize the spectrum of illnesses, and determine the factors contributing to rhabdomyolysis and triceps compartment syndromes.

Study Design: Descriptive epidemiology study.

Methods: The authors reviewed hospital medical records and interviewed players, coaches, school administrators, and hospital staff, using a standardized questionnaire that assessed symptoms, exposures, and activities.

Results: Among 43 players, 22 (51%) experienced rhabdomyolysis (peak creatine kinase range, 2434-42 000 U/L): 22 patients had upper arm myalgia; 12 were hospitalized; 3 experienced triceps compartment syndrome; none experienced renal failure. Illnesses started 1 to 3 days after the triceps exercise. Forty players (93%) completed questionnaires. Among 19 players receiving at least 1 vote from a teammate as 1 of the 3 hardest working players, 13 (68%) experienced rhabdomyolysis versus 7 (33%) of 21 not considered hardest working (relative risk, 2.1; 95% confidence interval, 1.04-4.0). Of 40 players, 10 (25%) reported creatine supplement use, which was not associated with rhabdomyolysis. No player acknowledged use of alcohol, illicit drugs, or performance-enhancing drugs; results of performance-enhancing drug tests on the 4 players tested were negative. Environmental investigation did not identify additional factors contributing to illness.

Conclusions: The upper arm exercise, possibly exacerbated by heat, led to rhabdomyolysis and compartment syndrome. Greater awareness of specific exercise hazards and prevention strategies can minimize risk for clinically significant muscle injury.

Keywords: rhabdomyolysis, compartment syndromes, motor activity, adolescent

Muscle injury from overexertion can lead to rhabdomyolysis,[6] which has been reported among athletes, military recruits, police officers, and firefighters.[12,20,26] Acute exertional rhabdomyolysis, distinct from genetic, toxicologic, and infectious causes,[8] has been infrequently reported among children and adolescents.[16,22,24] Approximately half of all patients with rhabdomyolysis present with the triad of myalgias, muscle weakness, and dark urine.[16] Pathophysiologically, damage to skeletal muscle releases intracellular muscle components into the circulation, including myoglobin, creatine kinase (CK), potassium, and phosphate, while permitting the intracellular influx of calcium, which causes persistent contraction of the myofibers.[16] Excessive circulating myoglobin can precipitate in the renal tubules leading to acute kidney injury and patient death.

Compartment syndrome, which occurs less frequently than rhabdomyolysis after excessive exertion, most commonly affects the limbs and is characterized by severe pain, often out of proportion to findings on physical examination.[29] The classic symptoms of paresthesias and pulselessness are inconsistently identified. In compartment syndrome, elevated intracompartmental pressure impedes blood flow, leading to

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ischemia and threatening limb viability. Although compartment pressures are typically measured, compartment syndrome is often a clinical diagnosis.[3,4] Immediate fasciotomy is indicated to release the pressure, ensure adequate perfusion, and preserve limb function.

During August 17 and 18, 2010, a total of 6 players on a high school football team in Oregon were taken to the local emergency department for severe upper arm muscle pain and swelling and were hospitalized for rhabdomyolysis and/or triceps compartment syndrome. Before these hospitalizations, on August 15, the team had begun a weeklong preseason "football immersion camp." After additional players received diagnoses of rhabdomyolysis during August 19 and 20, Oregon Public Health Division began investigating this cluster. We sought to confirm the diagnoses, characterize the spectrum of illnesses, and determine the factors associated with illnesses to mitigate future morbidity from competitive and recreational physical activities.

METHODS

This was a retrospective cohort study among high school football players who participated in the immersion camp. The investigation was considered public health practice; therefore, review by the institutional review board was not required.

Cluster Summary and Relevant Exposures

The overnight camp was held at the high school on August 15 to 20 and included 43 varsity football players. On the first day of camp, the players participated in a team-building and conditioning exercise of the upper arm in a non-air-conditioned wrestling room. Although the room temperature was not recorded, the outdoor temperature at that time was 92°F (33.3°C), and several interviewed players reported that the room was hot and poorly ventilated. The head coach had used the exercise drill numerous times with other teams, but this was the first time that any of the players or assistant coaches had experienced or witnessed the exercise. According to the head coach, the intent of the drill was primarily to build team unity and accountability to other team members. Team members voluntarily picked partners for the exercise drill. The exercise was described as an alternating chair-dip/push-up exercise. The first partner, with the second partner spotting, performed chair dips using a folding chair as support for 30 seconds, immediately followed by push-ups for 30 seconds. (Chair dips involved positioning oneself with legs extended in front of a chair, grabbing the front of the chair with arms at each side, and lowering and raising the body while keeping the upper torso vertical, without allowing the buttocks to rest on the ground. The exercise isolated triceps muscle flexion and extension.) This sequence was repeated in consecutively shorter intervals: 20 seconds, 10 seconds, 7 seconds, 5 seconds, with no scheduled rest periods. For incorrect performance by any team member, the exercise was suspended and then restarted by all team members at the beginning of the exercise component and time interval that team members had been engaged in at the time of suspension. The spotting partner was responsible for providing support for muscle fatigue and assistance in both phases of muscle contraction: the concentric phase (muscle fiber shortening) and the eccentric phase (muscle fiber lengthening). After the first group completed the exercise, the roles were switched. The exercise, without transition time, lasted 144 seconds. The actual estimated time for one partner to complete the exercise, including transition time and repeated interval times, was approximately 4 to 5 minutes. During the estimated 20 to 25 minutes that players were in the room, few reportedly drank fluids.

The hospital was located in the same city as the high school and provided all the emergency and inpatient care for the players. After 6 players presented to the hospital complaining of severe triceps muscle pain and swelling and were hospitalized for rhabdomyolysis, the hospital offered voluntary CK testing of all remaining players on August 19 and 20 at the high school. An additional 34 players were tested, which led to further diagnoses of rhabdomyolysis and hospitalizations. The football team physician, a hospitalist, recommended intravenous hydration and alkalinization of urine for players with CK ≥ 3000 U/L and hospitalization for players with CK ≥ 10 000 U/L. No toxicologic tests for illicit or performance-enhancing drugs were conducted during emergency department or hospitalization evaluation.

Epidemiologic Investigation

We began an epidemiologic field investigation on August 23 by reviewing hospital medical records and interviewing players, coaches, school administrators, and hospital staff. On the basis of the initial open-ended interviews, we attempted to interview all players by telephone or in person, using a standardized questionnaire that systematically assessed symptoms, exposures, and activities. Significant arm pain compatible with rhabdomyolysis was determined by asking whether the pain was "much more compared with your usual workout." Questions were included on underlying medical conditions; exercises and physical conditioning before and during camp; use of nutritional supplements and prescription, illicit, and performance-enhancing drugs; and hydration and symptoms of heat-related illness. Players were asked to name 3 teammates whom they considered to have worked the hardest during camp. Interviews with all players were conducted August 26 to 29.

For this epidemiologic study, rhabdomyolysis was defined as triceps muscle pain, on the basis of the medical record or questionnaire, plus CK > 2320 U/L (10 times the upper limit of normal). CK thresholds to define rhabdomyolysis have varied among investigators, but we chose the higher threshold of 10 times the upper limit of normal to increase specificity of diagnosis.[6] Triceps compartment syndrome was defined by clinical diagnosis requiring treatment with fasciotomy. We tested urine specimens for performance-enhancing drugs from a convenience sample of 4 players who voluntarily agreed to testing after hospital discharge. We tested archived serum

Table 1. Symptoms and peak creatine kinase for high school football team players who responded to questionnaire, Oregon, August 2010 (n = 40).[a]

	Case (n = 20)	Noncase (n = 20)
Muscle pain, no. (%)	18 (90)	3 (15)
Muscle pain score (0-10), median	6	0
Muscle swelling, no. (%)	16 (80)	1 (5)
Arm numbness, no. (%)	3 (15)	0 (0)
Dark urine, no. (%)	1 (5)	0 (0)
Peak creatine kinase, mean (range)	15 825 (2434-42 000)	1323 (180-6545)

[a]Does not include 2 players with rhabdomyolysis and 1 without who did not complete the questionnaire.

specimens from 4 other hospitalized players for illicit drugs. In conjunction with an industrial hygienist, we conducted an environmental investigation of the school facilities and measured levels of carbon monoxide, carbon dioxide, and volatile organic compounds.

Statistical Analysis

Analyses were conducted in SAS 9.2 (SAS Institute, Inc, Cary, North Carolina). The χ^2 test compared categorical variables; 2-sample *t* tests compared continuous variables. Statistical significance was set at $P < 0.05$.

RESULTS

Among 43 players, 22 (51%) met our case definition. All had myalgia referable to the upper arm; 12 (55%) were hospitalized (median length of day 4.5 days). There were no cases of acute kidney injury; the highest creatinine among all players was 1.2 mg/dL. Peak CK for the players with rhabdomyolysis ranged from 2434 to 42 000 U/L. Among the 12 hospitalized cases, each had a peak CK > 10 000 U/L, including 6 with CK ≥ 20 000 U/L. One additional team member who did not meet our case definition for rhabdomyolysis or compartment syndrome was hospitalized overnight for triceps muscle pain and swelling. None of the cases included a diagnosis of heat-related illness. Hospitalized patients were treated with rest, intravenous hydration, and sodium bicarbonate without complications.

Two independently practicing orthopaedic surgeons diagnosed triceps compartment syndrome in 3 players on the basis of significant triceps pain, swelling, and reduced range of motion. None of the 3 players with triceps compartment syndrome had evidence of infection or external trauma. One player had paresthesias and decreased sensation in the musculocutaneous nerve distribution unilaterally. No player had vascular deficits on examination. Compartment pressures, measured on the hospital's single pressure monitoring device (Stryker Intra-Compartmental Pressure Monitor System, Kalamazoo, Michigan), exceeded 50 mmHg in each of the cases (normal, 0-10 mmHg). These 3 patients had peak CK levels of 17 030, 18 480, and 35 658 U/L; each underwent uncomplicated fasciotomy. Among the 2 other players who had compartment pressures measured, the maximum pressure was 37 mmHg; the remaining players on the team did not have physical findings warranting compartment pressure measurement. Both orthopaedic surgeons had extensive experience with the pressure monitoring device and reported no recent technical problems.

Questionnaires were completed by 40 (93%) of 43 players. Among the 20 teammates with rhabdomyolysis who completed questionnaires, 18 (90%) reported arm pain and 16 (80%) reported arm swelling; arm numbness (n = 3, 15%) and dark urine (n = 1, 5%) were uncommon (Table 1). Among the 18 who reported arm pain on the questionnaire, 10 (56%) had onset on August 17, and 9 (50%) had peak pain on that date (Figure 1). The 2 players with rhabdomyolysis who did not report arm pain on the questionnaire had reported arm pain during medical evaluation at the hospital.

Players with rhabdomyolysis were statistically significantly shorter than those without rhabdomyolysis (mean, 69.7 [177.0 cm] vs 71.6 in. [181.96 cm]; $P = 0.05$); weight and body mass index were also lower, but differences did not reach statistical significance (Table 2). The frequency of aerobic and resistance exercises during the summer was similar between the 2 groups. Among 19 players receiving at least 1 vote from a teammate as being 1 of the 3 hardest working players, 13 (68%) experienced rhabdomyolysis, compared with 7 (33%) of 21 not considered hardest working (relative risk, 2.1; 95% confidence interval, 1.04-4.0).

Prior use of creatine supplements, reported by 10 (25%) of the 40 players completing questionnaires, was not associated with illness. No genetic or infectious causes of rhabdomyolysis were identified, and no prescription drug, nutritional supplement, or toxin was associated with illness. Players denied use of alcohol, illicit drugs, or performance-enhancing drugs. No positive results were reported from the 4 urine specimens tested for performance-enhancing drugs or the 4 archived serum specimens tested for illicit drugs. The environmental investigation of the high school facilities disclosed no additional findings that might have contributed to rhabdomyolysis; furthermore, levels of carbon monoxide, carbon dioxide, and volatile organic compounds were normal.

DISCUSSION

We identified 22 (51%) of 43 football players participating in a preseason camp who experienced acute exertional rhabdomyolysis, including 3 with a diagnosis of triceps compartment syndrome. Among the rhabdomyolysis cases,

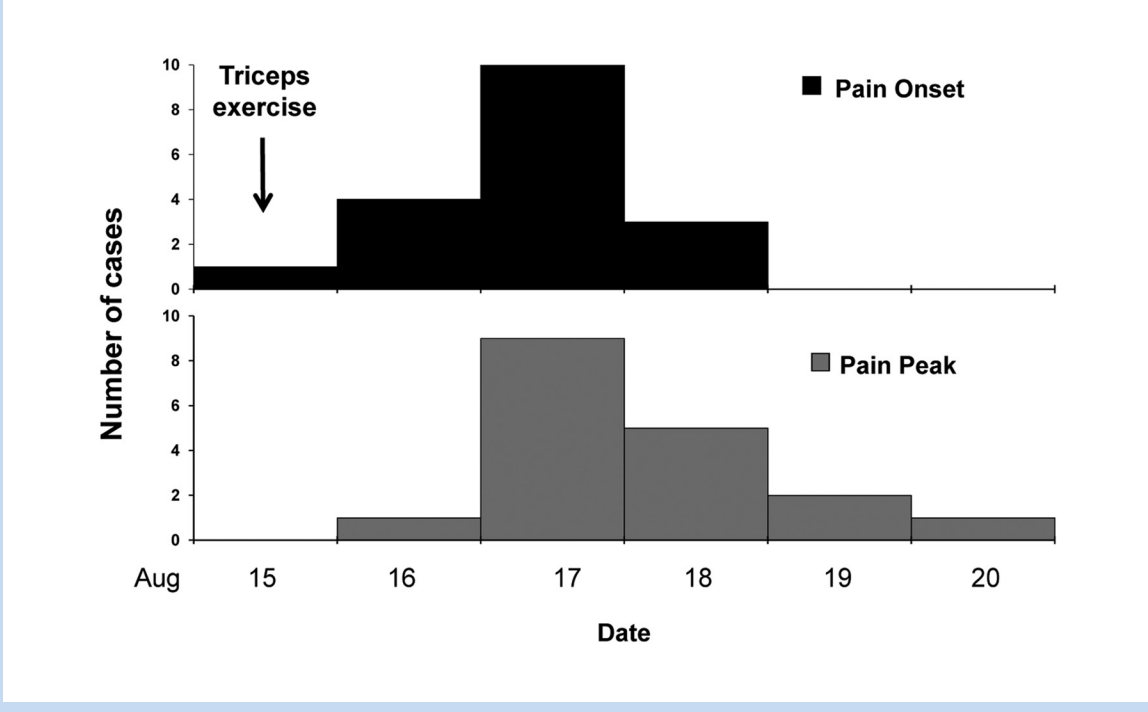

Figure 1. Onset and peak of arm muscle pain among 18 rhabdomyolysis patients who reported arm pain on questionnaire, Oregon, August 2010.

Table 2. Characteristics of football team players who responded to questionnaire, Oregon, August 2010 (n = 40).[a]

	Case (n = 20)	Noncase (n = 20)	*P*
Age, y, mean	15.8	16.0	0.69
Height, in. (cm), mean	69.7 (177.0)	71.6 (181.96)	0.048
Weight, lbs (kg), mean	180.4 (82.0)	202.4 (92)	0.08
Body mass index, mean	26.0	27.6	0.28
Aerobic training days per week over summer, mean	3.0	3.0	0.90
Resistance training days per week over summer, mean	3.0	3.5	0.21
Participated in Aug 15 triceps exercise	100%	85%	0.11

[a]Does not include 2 players with rhabdomyolysis and 1 without who did not complete the questionnaire.

12 of 22 were hospitalized; each hospitalized player had a CK > 10 000 U/L. We conclude that the extreme triceps exercise on the first day of camp, possibly exacerbated by heat and subclinical dehydration, led to muscle injury and the observed illnesses. Hyperthermia lowers the threshold for muscle injury.[5] Although the outdoor temperature of 92°F (33.3°C) was not extreme compared with certain parts of the country, it was 13°F (7.2°C) higher than that city's average for that date.

Clusters of acute exertional rhabdomyolysis after intense, repetitive, short-duration resistance exercises have been reported.[10,18,21] Failure to recognize rhabdomyolysis has caused diagnostic delays and inappropriate training regimens.[23,24,33] In this cluster, players exercised a single muscle compartment to total muscle fatigue; the exercise involved both concentric and eccentric contractions. Eccentric muscle contraction poses substantially greater risk for muscle injury.[31]

Although rhabdomyolysis is variably defined as muscle symptoms and a CK > 5 to 10 times the upper limit of normal, milder cases likely have minimal clinical significance. The degree of CK elevation does not necessarily correlate with

muscle fiber damage.[17] Moreover, CK levels are commonly elevated among athletes.[9,25] Ehlers et al reported a mean CK level of 5125 U/L on the fourth day of 2-a-day football practice among 12 college football players.[15] Consequently, CK can best contribute to diagnosis and management when obtained after, or in conjunction with, clinical evaluation. In the absence of dark urine or unusually significant postexertional muscle pain or swelling, CK should not be drawn. In those with elevated CK levels, athletes with CK < 5000 U/L and no evidence of urinary or kidney abnormalities likely only require sufficient rest and hydration for muscle recovery.

Rhabdomyolysis was related to overall physical effort during camp; players considered by peers to have worked harder were twice as likely to experience illness compared with other teammates. The association between physical effort and physical conditioning, however, was unknown; objective individual fitness data were unavailable. Although rhabdomyolysis can occur even among conditioned athletes, physical conditioning reduces the degree of myoglobinuria after strenuous exercise.[28,32,33,36]

The 3 cases of exertional triceps compartment syndrome are novel. Exertional compartment syndrome primarily involves the leg and, less commonly, the forearm[7]; the triceps compartment has greater capacity to absorb increased extravascular volume from muscle injury than the leg or forearm.[19] The rare cases of triceps compartment syndrome that have been reported have been secondary to trauma or crush injury.[4,11,13,27,35] We are unaware of any other reports of exertional nontraumatic triceps compartment syndrome clustered among athletes.

The findings in this study are subject to limitations. First, toxicologic testing was not performed on any cases during hospitalization. Illicit drugs, including cocaine and amphetamines, are known causes of rhabdomyolysis, and case reports have linked creatine and performance-enhancing drugs to rhabdomyolysis.[14,30] Given the magnitude of the attack rate, however, undetected illicit drug or performance-enhancing drug use was unlikely to have had a major role in causing illness. Second, interviews, conducted 11 to 14 days after the camp began, might have been affected by recall bias. Peer perception of teammates' effort might have been influenced by knowledge of whether illness had developed. In addition, players might have deliberately withheld sensitive incriminating information.

Our investigation highlights that acute exertional rhabdomyolysis and compartment syndrome can complicate intense, short-duration, repetitive resistance exercise among adolescent athletes, particularly exercises to total muscle fatigue that involve eccentric muscle contractions. Despite the known risk for acute exertional rhabdomyolysis from specific resistance exercises, sports medicine guidelines, educating health professionals in recognizing and minimizing this risk, are limited.[1-3] Although physical activity and participation in organized sports is beneficial, recognizing and counteracting specific exercise and heat hazards can minimize the risk for clinically significant muscle injury.

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