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Epidemiology of Sudden Death in Organized Youth Sports in the United States, 2007-2015

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Epidemiology of Sudden Death in Organized Youth Sports in the United States, 2007-2015

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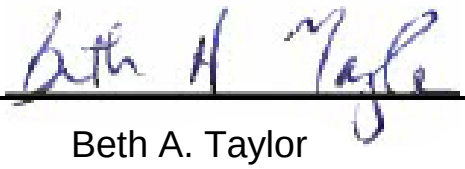
Associate Advisor: 

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Epidemiology of Sudden Death in Organized Youth Sports in the United States, 2007-2015

Purpose: Describe the epidemiology of sudden death in organized youth sport in the United States from 2007-2015.

Methods: Sudden death surveillance was conducted from 8/1/2011 to 6/1/2017 via LexisNexis and other publicly available news or media reports. Cases of sudden death that occurred in youth athletes 17 years of age and younger in non-high school organized sports were included. The study was approved by the Institutional Review Board at the author's institution.

Results: From 2007-2015, 45 sudden deaths were reported in American youth sports. The mean age of sudden death was 13±2 years old. The overall incidence rate was 1.83 deaths/10,000,000 athlete-years. Males experienced a greater number of sudden deaths compared to females (n=36/45, 80%). Basketball had the highest number of sudden deaths from 2007-2015, with a total of 16 occurrences. The most frequent cause of sudden death was cardiac-related (n=34/45, 76%).

Conclusions: Sudden deaths in organized youth sport in the United States from 2007-2015 were most often during practice, experienced by males, cardiac-related, and while playing basketball. These findings are similar to those in high school and collegiate sport. This study affirms the need for further epidemiological research into sudden death at the organized youth sport level.

Key Words: Pediatric sports medicine, injury surveillance, catastrophic injury, sport safety

Review of the Literature

Current Understanding of Sudden Death in American Sport

The epidemiology of sudden death in sport at the high school and collegiate levels has been described extensively in the literature.[1–5] Currently, it is well known that the top four causes of sudden death in organized high school and collegiate sport in the United States are sudden cardiac arrest (SCA), traumatic brain injury (TBI), exertional heat stroke (EHS), and exertional sickling, respectively.[1,4,6] These four causes of sudden death in sport amount to over 90% of all sudden deaths in these settings, with sudden cardiac death (SCD) comprising 75% of all sports-related deaths.[1,4] Figure 1 (Boden, et al 2013) describes the occurrence of common causes of sudden death in high school and collegiate American football from 1990 to 2010.[1]

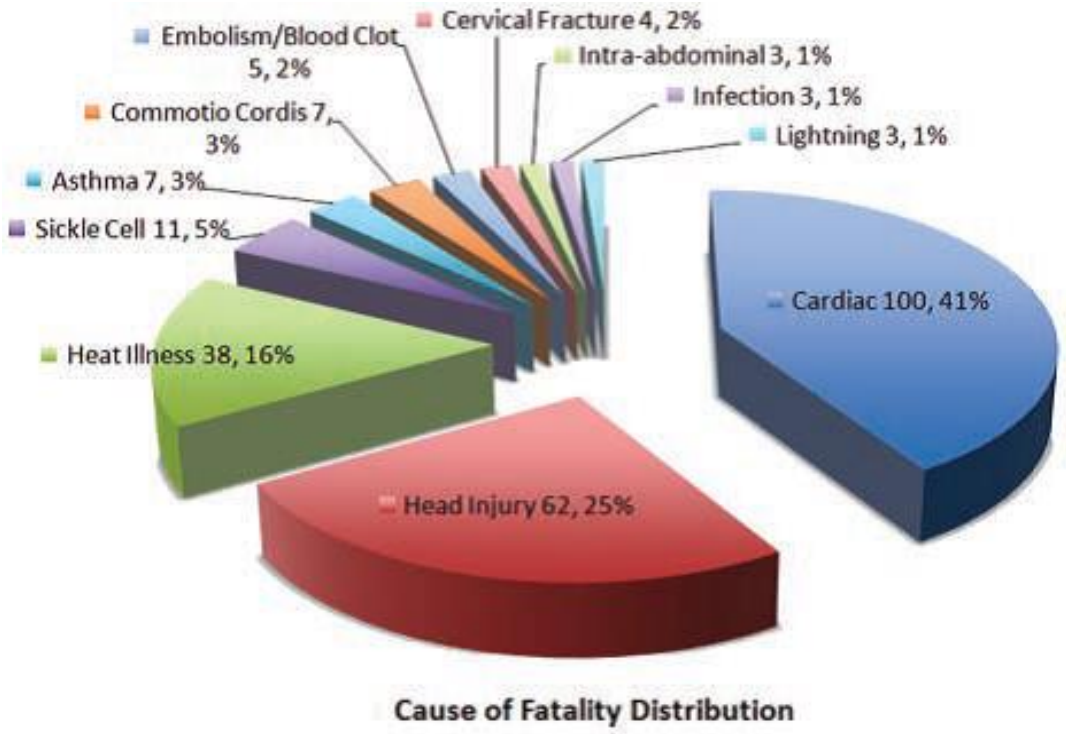

Figure 1. Number and percentage of football fatalities by diagnosis., 1990-2010

Additional findings suggest that males have an overall higher incidence of sudden death than females at both the high school (0.28 per 100,000 participants versus 0.13 per 100,000 participants) and collegiate levels (2.03 per 100,000 participants versus 1.79 per 100,000 participants).[4] Furthermore, male African-American basketball athletes are identified as the subgroup with the highest risk of SCA.[2,3,7] The incidence rate of SCA in male basketball players has been reported to be 1:5200 athlete-years in the Division I setting[3] and 1:37,087 athlete-years in the high school setting.[2] The incidence rate of SCA in African-American athletes in the collegiate setting was reported to be 1:21,491 athlete-years.[3] This incidence rate was 3.2 times greater than the incidence rate of SCA in Caucasian collegiate athletes.[3] In regards to TBI, American football is the sport with the highest reported number of cases.[8] Over a 30-year span from 1980-2009, American football accounted for nearly 60% of all fatalities due to blunt trauma.[8] Of these American football-related fatalities, 93% were caused by a blow to the head/neck.[8] Additionally, studies investigating sudden death in high school and collegiate American football reported between 16-18% of fatalities due to TBI had a history of concussion within 30 days of the fatality.[1,9] Most EHS incidents are also reported in American football,[4] and over 90% of EHS incidents occur during practice.[10] Over a six-year period from academic years 2005/06-2010/11, the exertional heat illness rate in American football (4.42 per 100,000 athlete exposures) was 11.4 times greater than that of all other sports combined.[11] In regards to exertional sickling, African American athletes are at the greatest risk since 1 in 12 African Americans are thought to carry the sickle-cell trait.[12,13] Most fatalities due to exertional sickling occur during training and conditioning sessions.[14] Clearly, epidemiological study is an important aspect of sport, and it has long been this way.

Overview of Sport Injury Epidemiology

The National Collegiate Athletics' Association, more widely recognized as the NCAA, was formed in large part as a necessary response to the high incidence of catastrophic injury and sudden death in the game of football at the turn of the 20th century.[15] Today, the NCAA continues to participate in many epidemiological initiatives aimed at preventing serious injury in sport. These initiatives include the NCAA Injury Surveillance System (ISS),[16] National Center for Catastrophic Sport Research (NCCSIR),[4] and the Consortium for Catastrophic Injury Monitoring in Sport (Consortium).[17] Programs such as the National Athletic Treatment, Injury and Outcomes Network (NATION)[18] and the National High School Sports-Related Injury Surveillance Study (High School RIO)[19] similarly report sports injury epidemiology for the high school setting.

In the beginning, sports injury epidemiology was a pen-and-paper affair that was mostly concerned with tracking both the number of injuries or sudden deaths due to sport as well as the amount of time participating in sport.[16] As the field of study evolved, the understanding of sport participation also evolved and become more well-defined. Today, participation data used in epidemiological study is often termed as "exposure" and broken into various units that are specific to the sport or level of play. Some common units for exposure include athlete-exposure, athlete-season, or team-season. An athlete-exposure has been defined as one athlete participating in one practice or game in which he or she was exposed to the possibility of athletic injury or sudden death, regardless of the time associated with that participation.[16,18] An athlete-season has been defined as one player participating in one season.[20] With this unit, players may have participated in more than one sport season in a given year but are counted separately each season. This unit is especially useful when reporting youth sport injury epidemiology since youth athletes often participate in multiple sports in a given year. A team-season has been

defined as one team participating in one season.[20] Table 1 from Dompier et al. (2015)[20] gives detailed definitions of terms common to sports injury epidemiology.

Term	Definition
Injury	Defined as occurring as a result of participation in an organized practice or game and requiring attention from an athletic trainer or physician.
Concussion	Defined locally by the institution or state guidelines in the communities where the athletic trainers were located. In lieu of state or local guidance, athletic trainers were encouraged to follow the definition provided by the Consensus Statement on Concussion in Sport.[14]
Athlete exposure	One player participating in one game or one practice.
Team-season	One youth team, high school team, or college team participating in one season.
Athlete-season	One player participating in one season. Players may have participated in more than one season but are counted separately each season. The term is used as the denominator to calculate athletes at risk or the prevalence.
Risk (incidence proportion)	The proportion of athletes injured. Risk is calculated as the sum of injured athletes (numerator) who sustained at least one injury during the season divided by the sum of athlete-seasons (denominator) or the number of athletes who began the football season. The risk does not count multiple concussions sustained by the same player. Risk is often expressed as a percentage.
Rate	An estimate of the incidence that includes player-time of exposure. The injury (concussion) rate is calculated as the sum of all concussions (numerator) divided by the sum of athlete exposures. Injury rates are expressed per 1000 athlete exposures.

Table 1. Definitions of common terms in sports epidemiology

Participation data is particularly useful in epidemiological study as it allows researchers to determine the incidence rate of disease, illness, or injury. For those studying catastrophic injury and sudden death, incidence rates allow for an equal comparison between years that corrects for any changes in sport participation rates. For example, the current year may have a slightly higher number of sudden deaths than last year, but if greater exposures were also reported in the current year, then the incidence rate of sudden death this year may actually be lower than the previous years'. Therefore, incidence rates are extremely useful in showing trends over time. These trends over time can then be overlaid with the timeline of various sports safety policy implementation to provide strong evidence for or against the effectiveness of policy change. Without question, sports injury epidemiology is a fundamental component of optimizing safety throughout all levels and settings of sport.

Overview of Youth Sport Safety in the United States

Sport participation in the United States continues to be popular among youth athletes. In 2015 alone, 28,646,000 youth athletes between the ages of 6 and 17 participated in sport.[21] With such a large number of athletes, it may come with little surprise that many injuries are also attributed to sport participation. Numerous studies have used emergency room data to report the epidemiology of athletic injuries at the youth level.[22–25] For example, Meehan and Mannix (2013)[24] reported 459,000 life-threatening injuries occurred while playing sports in youth athletes between the ages of 6-18 from 1999-2008. These sport-related life-threatening injuries accounted for 40% of all life-threatening injuries sustained by children ages 6-18. Unfortunately, some cases of life-threatening injuries due to sport participation resulted in death. A national study from Nalliah et al. (2014)[25] reported that 30 Americans between the ages of 13-19 died as a result of sports-related injuries in 2008. However, they did not specify if these deaths occurred in non-organized recreational sports, organized youth sport, or high school athletics.

While many settings operate under the umbrella of "youth sport", each setting is unique. For the purposes of this review, we divided youth sports into three categories: (1) middle school athletics, (2) organized youth sport leagues, and (3) organized recreational youth sporting events. For instance, middle schools operate under the guidance of the superintendent of a school district and may be the most likely youth sport setting to adopt safety policies and procedures that have been implemented at the high school level. For example, the Alabama High School Athletic Association (AHSAA) governs both high school and middle school athletics.[26] Organized youth sport leagues in the United States, on the other hand, are part of a 5 billion dollar business that is largely organized and maintained by non-profit groups with highly variable degrees of sport safety policies and procedures in place to promote the well-being of the youth athletes that participate.[27] Recreational youth sporting events have even less

oversight[27,28] and are often made up of participants wanting to take part in an individual event or sport of interest as a hobby or purely for leisure.

Sport safety is currently an active area of research and advocacy at the high school and collegiate setting in the United States. Numerous position and consensus statements have been published in order to disseminate clinical best-practices that have been shown to improve sport safety and prevent sudden death in athletics.[12,28–33] Additionally, recently published research studied how closely state high school organizations were following these best-practices in their sports safety policies and procedures.[34] It was observed that implementation of these sports safety best-practices varied greatly from state-to-state throughout the country. Clearly, more advocacy is warranted in order to improve sports safety throughout the United States.

Collaborations currently exist that bring together many of the experts in preventing sudden death in sport and sports injury epidemiology.[17] As mentioned previously, the Consortium for Catastrophic Injury Monitoring in Sport (Consortium) is spearheaded by the NCCSIR at the University of North Carolina at Chapel Hill and is divided into three research divisions – the division on traumatic injury at The University of North Carolina at Chapel Hill, the division on exertional injury at The University of Connecticut, and the division on cardiac injury in sport at The University of Washington. Other research and funding partners assist in supporting the Research Divisions in their endeavors to study, understand, and disseminate to the public evidence-based data pertaining to catastrophic injury and sudden death in sport. The mission of the Consortium is “to develop a stronger national active surveillance program to improve reporting and monitoring of these catastrophic sports injuries.”[17] Fortunately, this epidemiological surveillance is currently possible at the high school and collegiate settings because structures are in place to facilitate case capturing and reporting. Unfortunately, as a consequence of the lack of unified oversight over youth sports, no such epidemiological framework currently exists at the organized youth sport level. Therefore, epidemiological study

of catastrophic sports injury and sudden death at the youth sport level has many obstacles to overcome before it is on par with more advanced epidemiological research at the high school and collegiate setting.

Current Issues in Youth Sport Sudden Death Epidemiology

Huggins, et al (2017)[28] published an inter-association task force document addressing many issues facing youth sport safety in the United States. In that document, it was suggested that current sudden death and catastrophic injury epidemiology specific to the youth sports setting in the United States is lacking.[28] Two pressing issues facing youth sports sudden death epidemiology include the lack of quality participation data and the lack of formal surveillance of sudden death. Ultimately, the quality of sport injury epidemiology relies on the quality of descriptive information regarding the cases of interest as well as the accuracy of participation data in the population being studied.

The first major issue in youth sport sudden death epidemiology is the need for high-quality participation data specific to children participation in organized youth sports. While there are studies that have investigated the epidemiology of sudden death in "young" athletes,[5,8,25,35] due to the lack of participation data specific to youth sports, these studies are forced to cluster the sudden death data of 6-17 year old youth athletes who are not participating in high school athletics with those participating in high school and collegiate athletics. Maron et al (2009)[35] and Maron et al (2016)[5] are two such examples of robust studies that analyzed sudden deaths in the youth sport setting in the United States over 27- and 32-year periods, respectively, but only utilized participation data from high school and collegiate athletics to calculate incidence rates. Maron et al (2009)[35] even reported an age range of 8-39 years old in the sudden cardiac arrest cases they captured. Because of the limitation of inappropriate participation data, generalization

of current reported incidence rates of sudden death in young athletes may be inaccurate. A solution to this issue could be found in the collaboration between research institutions. Currently, the Sport and Fitness Industry Association™ (SFIA) collects participation data of individuals between the age of 6-17 years old across 111 team and individual sports.[21] The SFIA obtains participation data annually via online interviews from a nationwide sample of 5,067 individuals and 5,711 households representing people ages 6 and older. After receiving these surveys, a weighting technique is used to calculate the total number of sport participants age 6 years old and above. The SFIA reports participation statistics in athlete-years, which means that athletes may have participated in more than one sport in a calendar year and are counted separately for each sport. By collaborating with organizations like the SFIA, epidemiologists studying sudden death in the youth sport setting could realistically have access to the highest-quality participation data available for that population. However, access to participation data alone is not enough for epidemiological research of sudden death in youth sport. In order to fully describe these trends, formal surveillance of sport-related sudden death at the organized middle school, youth, and recreational levels is warranted.[28]

Currently, sudden death surveillance focuses primarily on organized high school and collegiate sports.[3–5,35] Improved and ongoing surveillance is critical to the safety and well-being of youth athletes in the following ways. First, national youth sport governing bodies can tangibly and publicly support the safety of their youth athletes by mandating reporting of catastrophic injuries and sudden deaths to an organized database. Second, medical professionals (i.e. athletic trainers, ER physicians, emergency medical services) would be able to report all relevant information about the death, greatly enhancing the accuracy of epidemiological injury data. Currently, multiple injury surveillance platforms[16,18,19] are available that collect data directly from the reports of medical professionals. Third, youth sport league national governing bodies would benefit from having access to surveillance data on sport-related sudden death, thereby

enabling greater collaboration and communication between the groups in evaluating existing and creating new policies aimed to improve the safety of youth sport in the United States. Fourth, the impact of state-level or organizational policies on youth sport safety could be examined. For example, if a state implemented a policy mandating AEDs at all youth athletic contests, ongoing surveillance data could be used to illustrate whether or not the policy reduces cardiac-related sudden death. Fifth, ongoing surveillance could also be used to describe the impacts of requiring qualified medical professionals (such as athletic trainers or emergency medical services) at all youth sporting events.

Summary

Although sudden death in sport at the high school and collegiate levels in the United States has been described extensively in the literature,[1–5] the same attention has not been applied to the organized youth sport setting. To our knowledge, no previous studies have described the epidemiology of sudden death specifically in organized middle school, youth, and recreational youth sport (6-17 years old). Additionally, specific participation data for this setting has not been utilized to describe the incidence of sudden death. Future study should address these deficient areas in the literature in order to promote the health and safety of youth athletes throughout the United States.

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Introduction

Sport participation in the United States continues to be popular among youth athletes. In 2015 alone, 28,646,000 youth athletes between the ages of 6 and 17 participated in sport.[1] With such a large number of athletes, it may come with little surprise that many injuries are also attributed to sport participation. Numerous studies have used emergency room data to report the epidemiology of athletic injuries at the youth level.[2–5] For example, Meehan and Mannix [4] reported 459,000 sport-related, life-threatening injuries that occurred in youth athletes between the ages of 6-18. These sport-related, life-threatening injuries accounted for 40% of all life-threatening injuries in this age group. Unfortunately, some cases of life-threatening injuries due to sport participation resulted in death. A national study from Nalliah et al.[5] reported that 30 Americans between the ages of 13-19 died as a result of sports-related injuries in 2008. However, they did not specify if these deaths occurred in non-organized recreational sports, organized youth sport, or high school athletics.

Sudden death in sport at the high school and collegiate levels has been described extensively in the literature.[6–10] Currently, it is well known that the top four causes of sudden death in organized high school and collegiate sport in the United States are sudden cardiac arrest (SCA), traumatic brain injury (TBI), exertional heat stroke (EHS), and exertional sickling, respectively.[6,9,11] These four causes of sudden death in sport amount to over 90% of all sudden deaths in these settings, with sudden cardiac death (SCD) comprising 75% of all sports-related deaths.[6,9] Additional findings suggest that males have an overall higher incidence of sudden death than females at both the high school (0.28 per 100,000 participants versus 0.13 per 100,000 participants) and collegiate levels (2.03 per 100,000 participants versus 1.79 per 100,000 participants).[9] Furthermore, male African American basketball athletes are identified as the subgroup with the highest risk of SCD.[7,8,12] The incidence rate of SCD in male basketball players has been reported to be 1:5200 athlete-years in the Division I setting[8] and 1:37,087

athlete-years in the high school setting.[7] The incidence rate of SCD in African American athletes in the collegiate setting was reported to be 1:21,491 athlete-years.[8] This incidence rate was 3.2 times greater than the incidence rate of SCD in Caucasian collegiate athletes.[8] In regards to TBI, American football is the sport with the highest reported number of cases.[13] Over a 30-year span from 1980-2009, American football accounted for nearly 60% of all fatalities due to blunt trauma.[13] Of these American football-related fatalities, 93% were caused by a blow to the head/neck. Additionally, studies investigating sudden death in high school and collegiate American football reported between 16-18% of fatalities due to TBI had a history of concussion within 30 days of the fatality.[6,14] Most EHS incidents are also reported in American football,[9] and over 90% of EHS incidents occur during practice.[15] Over a six-year period from academic years 2005/06-2010/11, the exertional heat illness rate in American football (4.42 per 100,000 athlete exposures) was 11.4 times greater than that of all other sports combined.[16] In regards to exertional sickling, African American athletes are at the greatest risk since 1 in 12 African Americans are thought to carry the sickle-cell trait.[17,18] Most fatalities due to exertional sickling occur during training and conditioning sessions.[19,20] While there are studies that have investigated the epidemiology of sudden death in "young" athletes,[5,10,13,21] these studies tend to cluster the sudden death data of 6-17 year old youth athletes who are not participating in high school athletics with those participating in high school and collegiate athletics. As a result, generalization of current reported incidence rates of sudden death in young athletes may be inaccurate.

To our knowledge, no previous studies have described the epidemiology of sudden death specifically in organized middle school, youth, and recreational youth sport (6-17 years old) in the United States. Additionally, specific participation data for this setting has not been utilized to describe the incidence of sudden death. Therefore, the purpose of our study is to describe the epidemiology of sudden death in athletes aged 6-17 years old participating in

organized middle school, youth league, and recreational sport in the United States. Specifically, this study will examine distributions of characteristics related to the athlete (age and gender), event (sport, level of play, event type), and death (year of death, location of death, official cause of death, speculated cause of death).

Methods

Study Design

The study utilized a descriptive epidemiological design and was approved by the Institutional Review Board at The University of Connecticut. Organized youth sport was classified into three divisions: organized youth leagues, middle school athletics, and organized recreational youth sports (e.g., marathons, triathlons). We did not include high school student-athletes who were under the age of 18 while participating in school-sanctioned athletics because the epidemiology of sudden death in high school student-athletes has already been well described in the literature.[9,22,23]

Acquisition of Case Data

We defined sudden death as a death occurring while engaged in sport participation or as the result of sports participation (i.e., head impact incurred during American football that led to death at the emergency department). Sudden death data from cases occurring between August 1, 2007 and December 31, 2015 were obtained via two methods: 1) a search using LexisNexis and 2) through other internet searches (e.g., Google) of publicly-available news reports. The search for sudden death cases began in August of 2013 and included search terms such as “death”, “fatality”, “exercise”, “race”, “sport”, “practice”, “game”, etc. Information related to the

athlete (age, gender), event (sport, level of play, event type), and death (date of death, location of death, official cause of death, speculated cause of death) were obtained. Deaths were reviewed by researchers and classified into five event types (cardiac/cardiovascular, exertional/heat/environmental, traumatic injury, other, or inconclusive/unknown). If an official cause of death was not provided in the media source, one member of the research team reviewed all available information and provided a speculated cause of death. For example, if an official cause of death was not reported for an athlete who collapsed and died despite an advised shock from an AED (automated external defibrillator), their case was classified as "cardiac". Through these methods, we were able to obtain 97% (438 out of 450 total measures) of the descriptive measures listed above for each case included in this study. The breakdown of missing measures included 10 cases of unknown official causes of death, and 2 cases of "inconclusive" speculated causes of death.

Inclusion criteria included deaths that were characterized by the following: (1) reported in publically-available media outlets; (2) occurred between August 1, 2007 and December 31, 2015; (3) occurred between the ages of 6 and 17 years old; and (4) occurred during sanctioned middle school sporting events, in organized youth sport leagues, or while taking part in organized recreational athletic events or training for said events. Exclusion criteria included deaths that were characterized by the following: (1) occurred in athletes that were less than 6 years of age or greater than 17 years of age; (2) occurred outside of organized middle school, youth league or recreational sport or training for said events; or (3) occurred during sanctioned high school or collegiate athletic events.

Because of the variability of sport settings in youth sport in the United States, the sudden deaths were categorized as follows: (1) middle school athletics; (2) organized youth sport leagues; (3) youth athlete participation in organized recreational athletic events or training for said events.

Acquisition of Participation Data

Total number of youth sport participants between the age of 6-17 years old in 111 team and individual sports from 2007-2015 was provided by the Sport and Fitness Industry Association™ (SFIA).[1] The SFIA obtains participation data annually via online interviews from a nationwide sample of 5,067 individuals and 5,711 households representing people ages 6 and older. After receiving these surveys, a weighting technique is used to calculate the total number of sport participants age 6 years old and above. The SFIA reports participation statistics as one athlete per sport per year, which we describe in this study as an athlete-year. Athlete-year is defined as one youth athlete participating in one sport in a calendar year.[24] Athletes may have participated in more than one sport in a calendar year and are counted separately for each sport.

Statistical Analyses

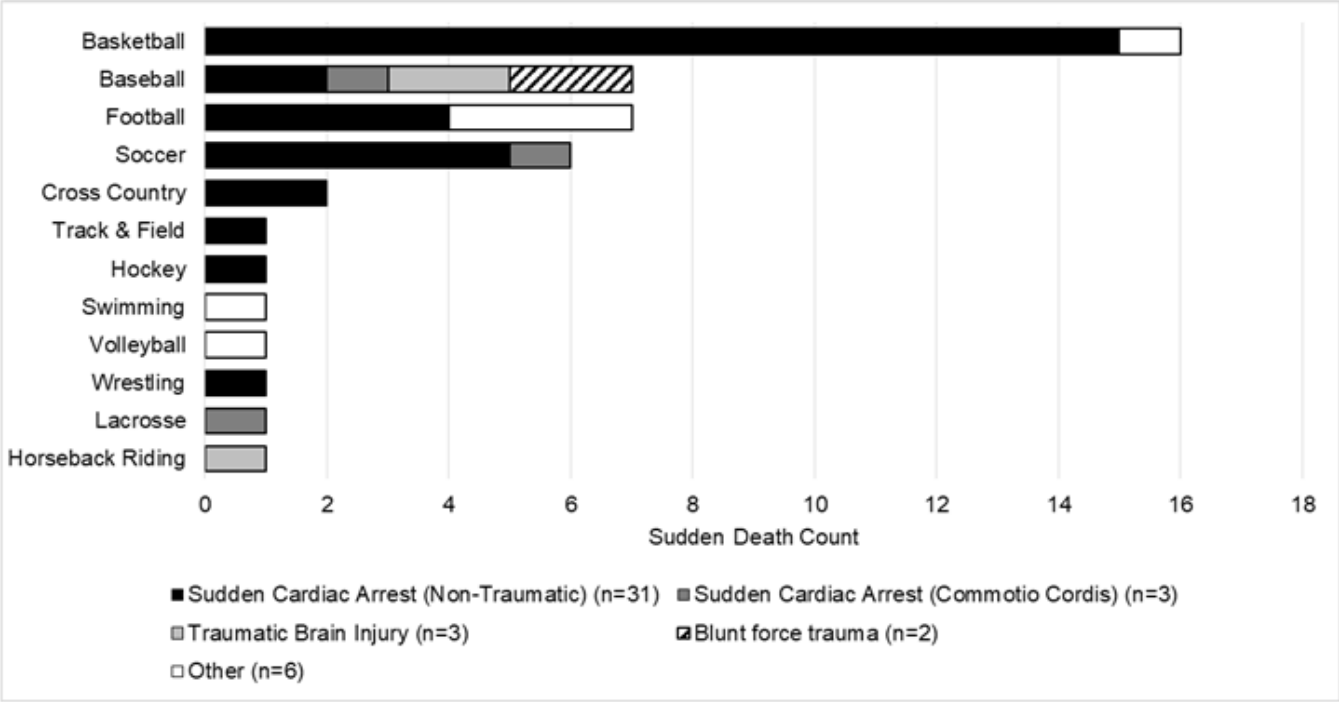
Data were analyzed using SAS 9.4 (SAS Institute Inc., Cary, NC, USA), Microsoft® Excel® 2013 (Microsoft Corporation, Redmond, WA), and VRP Injury Statistics Software for analysis.[25] Descriptive analyses included the frequency and proportion of sudden death cases and mean, range, and standard deviation of continuous measures. Distributions of characteristics related to the athlete (age, gender), event (sport, level of play, event type), and death (year of death, location of death, official cause of death, speculated cause of death) were measured. Sudden death incidence rates were presented as the sum of the number of sudden death cases divided by the sum of the number of athlete-years. Sudden death incidence rates were expressed per 10,000,000 athlete-years and 95% confidence intervals (CI) were calculated. Trends in incidence rates across time were examined via linear regression. All statistics yielding p-values <0.05 were considered statistically significant.

Results

Sudden death athlete, setting, and injury characteristics

From 2007-2015, a total of 45 deaths resulting from participation in organized youth sports in the United States were reported in publicly available online media sources (Tables 1-3). The average number of sudden deaths in youth sports per year was 5 deaths per year during this nine year period. The average age at the time of death was (mean±SD) 13±2 (range=9-17) years.

Figure 1. Frequency of Sudden Death in Youth Sport, by Sport and Cause of Death: 2007-2015



Other includes anaphylactic shock (n=1), lightning (n=1), drowning (n=1), exertional heat stroke (n=1), and inconclusive (n=2)

Overall, 73% (n=33/45) of sudden deaths occurred in individuals aged 12-14 years. Four in 5 sudden deaths occurred to males (80%, n=36/45). Of all cases of sudden death in our population, basketball comprised the largest proportion of sudden deaths (36%, n=16/45), followed by baseball (16%, n=7/45), American football (16%, n=7/45), and soccer (13%, n=6/45;

Figure 1). Over half of all sudden deaths occurred during organized middle school sports (58%, n=26/45), followed by youth sport leagues (40%, n=18/45); one sudden death was reported in recreational race training (2%). Over two-thirds of sudden deaths occurred during practice (71%, n=32/45); nearly one-third occurred during competition (29%, n=13/45). The 45 sudden deaths were distributed across 27 states. New York reported the largest number of sudden deaths (n=5), followed by Illinois (n=4), and California, Georgia, and New Jersey (n=3 each). Of the 45 deaths, the official cause of death was provided in the media source via coroner or medical examiner report for 35 (78%) cases. For the remaining 10 (22%) cases, speculated causes were assigned by a member of the research team based on the information available in the media report. The most frequent causes of sudden death were cardiac-related (76%, n=34/45; Figure 1). Of the 34 SCDs, 31 were non-traumatic and 3 were due to commotio cordis. Interestingly, 15 of the 16 sudden deaths (94%) in youth basketball were the result of SCD. Of these 15 cases of SCD in basketball, 12 occurred in males and 3 in females. TBI were the second most frequent cause of sudden death (7%, n=3/45), followed by blunt force trauma to the body (4%, n=2/45). Other causes of death included anaphylactic shock (2%, n=1), lightning (2%, n=1), drowning (2%, n=1), and EHS (2%, n=1). Two deaths (4%) were considered inconclusive due to lack of publically available information.

Table 1: Descriptive Results of Sudden Death in Youth Sport: 2007-2015, Athlete Characteristics

	Count, *n* (%)	Age, y (±SD)	Sex	
			Male, *n* (%)	Female, *n* (%)
Basketball	16 (35.6)	13.3 (1.4)	13 (81)	3 (19)
Football	7 (15.6)	11.4 (1.5)	7 (100)	0 (0)
Baseball	7 (15.6)	12.1 (2.3)	7 (100)	0 (0)
Soccer	6 (13.4)	12.6 (2.5)	3 (50)	3 (50)
Cross Country	2 (4.4)	13.5 (0.7)	1 (50)	1 (50)
Hockey	1 (2.2)	14	1 (100)	0 (0)
Horseback Riding	1 (2.2)	13	0 (0)	1 (100)
Lacrosse	1 (2.2)	12	1 (100)	0 (0)
Swimming	1 (2.2)	14	1 (100)	0 (0)
Track & Field	1 (2.2)	14	1 (100)	0 (0)
Volleyball	1 (2.2)	14	0 (0)	1 (100)
Wrestling	1 (2.2)	14	1 (100)	0 (0)
Total	45	13 (2)	36 (80)	9 (20)

Table 2: Descriptive Results of Sudden Death in Youth Sport: 2007-2015, Sport Setting

		Setting			Event Type				
	Count, *n* (%)	Middle School, *n* (%)	Youth Sport League, *n* (%)	Recreation, n (%)	School Sanctioned Practice, *n* (%)	School Sanctioned Game, *n* (%)	Youth Sport League Practice, *n* (%)	Youth Sport League Game, *n* (%)	Race Training, *n* (%)
Basketball	16 (35.6)	12 (75)	4 (25)	0 (0)	6 (37)	6 (37)	2 (13)	2 (13)	0 (0)
Football	7 (15.6)	4 (57)	3 (43)	0 (0)	3 (43)	1 (14)	3 (43)	0 (0)	0 (0)
Baseball	7 (15.6)	3 (43)	4 (57)	0 (0)	3 (43)	0 (0)	4 (57)	0 (0)	0 (0)
Soccer	6 (13.4)	1 (17)	5 (83)	0 (0)	1 (17)	0 (0)	5 (83)	0 (0)	0 (0)
Cross Country	2 (4.4)	2 (100)	0 (0)	0 (0)	0 (0)	2 (100)	0 (0)	0 (0)	0 (0)
Hockey	1 (2.2)	0 (0)	1 (100)	0 (0)	0 (0)	0 (0)	0 (0)	1 (100)	0 (0)
Horseback Riding	1 (2.2)	0 (0)	0 (0)	1 (100)	0 (0)	0 (0)	0 (0)	0 (0)	1 (100)
Lacrosse	1 (2.2)	1 (100)	0 (0)	0 (0)	0 (0)	1 (100)	0 (0)	0 (0)	0 (0)
Swimming	1 (2.2)	0 (0)	1 (100)	0 (0)	0 (0)	0 (0)	1 (100)	0 (0)	0 (0)
Track & Field	1 (2.2)	1 (100)	0 (0)	0 (0)	1 (100)	0 (0)	0 (0)	0 (0)	0 (0)
Volleyball	1 (2.2)	1 (100)	0 (0)	0 (0)	1 (100)	0 (0)	0 (0)	0 (0)	0 (0)
Wrestling	1 (2.2)	1 (100)	0 (0)	0 (0)	1 (100)	0 (0)	0 (0)	0 (0)	0 (0)
Total	45	26 (58)	18 (40)	1 (2)	16 (36)	10 (22)	15 (33)	3 (7)	1 (2)

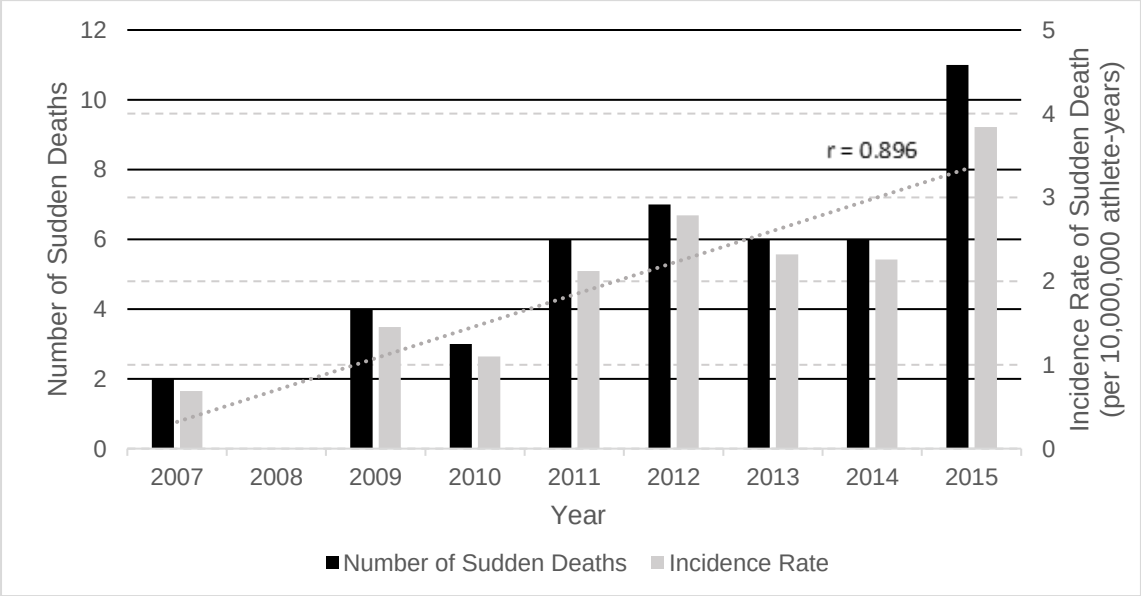
Table 3: Descriptive Results of Sudden Death in Youth Sport: 2007-2015, Cause of Death

		Speculated Cause of Death					
	Count, *n* (%)	**Cardiac (Non-Traumatic), *n* (%)**	**Cardiac (Commotio Cordis), *n* (%)**	**Traumatic Brain Injury, *n* (%)**	**Trauma to Body, *n* (%)**	**Other, *n* (%)**	**Inconclusive, *n* (%)**
Basketball	16 (35.6)	15 (94)	0 (0)	0 (0)	0 (0)	0 (0)	1 (6)
Football	7 (15.6)	4 (57)	0 (0)	0 (0)	0 (0)	2 (29)	1 (14)
Baseball	7 (15.6)	2 (29)	1 (14)	2 (29)	2 (29)	0 (0)	0 (0)
Soccer	6 (13.4)	5 (83)	1 (17)	0 (0)	0 (0)	0 (0)	0 (0)
Cross Country	2 (4.4)	2 (100)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Hockey	1 (2.2)	1 (100)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Horseback Riding	1 (2.2)	0 (0)	0 (0)	1 (100)	0 (0)	0 (0)	0 (0)
Lacrosse	1 (2.2)	0 (0)	1 (100)	0 (0)	0 (0)	0 (0)	0 (0)
Swimming	1 (2.2)	0 (0)	0 (0)	0 (0)	0 (0)	1 (100)	0 (0)
Track & Field	1 (2.2)	1 (100)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Volleyball	1 (2.2)	0 (0)	0 (0)	0 (0)	0 (0)	1 (100)	0 (0)
Wrestling	1 (2.2)	1 (100)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Total	45	31 (69)	3 (7)	3 (7)	2 (4)	4 (9)	2 (4)

Sudden death incidence rate

The overall incidence rate of sudden death from 2007-2015 was 1.83 per 10,000,000 athlete-years (95% CI: 1.30 to 2.37). Figure 2 shows the number and incidence rate of sudden death in youth sports per year. The year 2015 had the highest number (n=11) and rate of sudden death in youth sport with an incidence rate of 3.84 per 10,000,000 athlete-years. A linear trend was found in the annual sudden death incidence rates during the study period (p<0.001), suggesting an increase in reported sudden death incidence rates across years. This finding was still retained when excluding 2015, which had a larger incidence rate than all other annual rates (p<0.001).

Figure 2: Frequency and Incidence Rate of Sudden Death in Youth Sport, by Year: 2007-2015[a,b,c]



[a] Exclusion criteria included deaths that were characterized by the following: (1) Occurred to athletes over the age of 18; (2) occurred outside of organized sport; (3) occurred during sanctioned high school or collegiate athletic events

[b] Total youth sport participation rates of athletes aged 6-17 years old taking part in 111 team and individual sports from 2007-2015 were provided by the Sport and Fitness Industry Association™. Total youth sport participation from 2007-2015 was 245,567,000 athlete-years

[c] Athlete-year is defined as one youth athlete participating in one sport in a calendar year. Athletes who participate in more than one sport would be counted multiple times.

Discussion

The purpose of this study was to describe the epidemiology of sudden death in organized middle school, youth and recreational sport in the United States from 2007-2015. Youth sport was categorized into (1) middle school athletics; (2) organized youth sport leagues; and (3) youth athlete participation in organized recreational athletic events or training for said events. The overall incidence rate of sudden death in organized youth sport in America from 2007-2015 was 1.83 per 10,000,000 athlete-years (95% CI: 1.30 to 2.37). We found that the highest number of organized youth sport-related sudden deaths from 2007-2015 occurred in males (80%), occurred during practice (67%), were cardiac-related (76%), and happened while playing basketball (36%). Furthermore, the frequency and incidence rate of sudden death in youth sports increased from 2007-2015 (Figure 2), highlighting the need for continued surveillance to inform our current and future prevention efforts among youth athletes. Although the exact cause of the increase in the incidence of sudden death in youth sport remains unknown, we may speculate as to why this trend is occurring.

One cause may be that sudden deaths in youth sport are actually occurring at a greater rate and frequency in recent years. With a greater number of youth athletes participating in sports, it would be expected to see an increase in the number of injuries and sudden deaths. However, if the increase in sudden deaths and athlete-years was equivalent, the incidence rate would stay constant rather than rise. Therefore, our findings suggest that the frequency of sudden death in youth sport may actually be increasing at a faster rate than the increase in the rate of participation. However, it is important to note that the total number of participants includes all sports. Therefore, some athletes are counted more than once if they are multi-sport athletes.

An agenda-setting effect may also contribute to the increase in sudden death incidence rate over the past few years. Agenda-setting is a concept of communication theory[26,27] that is

defined by Scheufele and Tewksbury as “the idea that there is a strong correlation between the emphasis that mass media place on certain issues (e.g., based on relative placement or amount of coverage) and the importance attributed to these issues by mass audiences.”[27] In other words, increased media attention to cases of sudden death leads to an increased interest on the subject by media consumers such as parents, athletes, coaches, sport body officials, etc. Eventually, this increased interest by the public leads to increased attention from medical providers and researchers. Indeed, there has been a considerable rise in the national interest and corresponding research in sport-related injury and death over the past few years.[28–31] With this rise in interest and research, sport-related injury and sudden deaths become more apparent to a hyper-aware public and thus the media reporting continues to increase in response. Therefore, an increase in reporting of sudden death cases in recent years may also explain the increased sudden death incidence rates.

Finally, searches conducted retrospectively may have resulted in an under-capture of deaths that occurred during 2007-2012, which may have contributed to the increase in death rates observed over the study period. Other currently unknown causes could also be behind the increase in the frequency and incidence rate of sudden deaths in youth sport. Ultimately, the increase in the rate of sudden death in youth sports in recent years in an important and interesting finding that warrants further research.

Our study also found that most reported sudden deaths in youth sport were among males, occurred while playing basketball, and were cardiac-related. These findings are similar to other studies reporting sudden death epidemiology in older athletic populations.[10,21] Furthermore, our data suggest that the incidence of SCD is higher than any other cause of death in youth sports. In the present investigation, SCD accounted for 76% of the total deaths in youth sport from 2007-2015. These results are also consistent with findings in older athletic populations.[8,9,32] This is concerning since SCD often occurs with no warning signs or

symptoms.[33] Interestingly, 15 of the 16 sudden deaths reported in basketball from 2007-2015 were cardiac-related. Future research should investigate the epidemiology of SCD in youth sports as a whole. Special consideration for the sport of basketball may also be warranted in order to investigate the unique factors leading to the high frequency of basketball-related SCD.

Sudden deaths occurred in various youth sport settings from 2007-2015. While all settings operate under the umbrella of "youth sport", each setting is unique. For instance, middle schools operate under the guidance of the superintendent of a school district and may be the most likely youth sport setting to adopt policies and procedures that have been implemented at the high school level. For example, the Alabama High School Athletic Association governs both high school and middle school athletics.[34] Organized youth sport leagues in the United States, on the other hand, are part of a 5 billion dollar business that is largely organized and maintained by non-profit groups with highly variable degrees of sport safety policies and procedures in place to promote the well-being of the youth athletes that participate.[35] Many recreational youth sporting events have even less oversight[35,36] and are often made up of participants wanting to take part in an individual event or sport of interest as a hobby or purely for leisure. Fifty-eight percent (n=26) of sudden deaths occurred in organized middle school sports while 40% (n=18) occurred to athletes participating in youth sport leagues. Furthermore, 67% of the sudden deaths occurred during practice. This is an important finding as it has been suggested that these settings (practices and organized youth sport leagues) have poor medical coverage.[36] Our findings support current and future efforts to implement best practices as outlined in recent consensus statements on the prevention of sudden death in sport.[33,37] Annual meetings held from 2014-2017 such as the Collaborative Solutions for Safety in Sport and Youth Sports Safety Governing Bodies have been organized to discuss sport safety throughout the country from youth sport all the way through high school sport.[32,36] The primary purpose of these meetings was to educate, review, and update state high school athletics association executive committee

members, sports medicine advisory committee members, and youth sport governing body representatives on health and safety best practice policies. While evidence depicts the vast variability in the implementation of current best practices for preventing sudden death and catastrophic injury from an organizational level in high school athletics,[38] future research is warranted in order to describe the impacts of state athletics associations and youth sport governing body's health and safety policies on the incidence and characteristics of sudden death in youth sport.

In order to describe the impacts of policies on sudden death in youth sport, surveillance of sport-related sudden death in addition to the preceding catastrophic injury at the organized middle school, youth, and recreational levels is needed. Currently, sudden death surveillance focuses primarily on organized high school and collegiate sports.[8–10,21] Improved and ongoing surveillance is critical to the safety and well-being of youth athletes in the following ways. First, youth sport governing bodies can tangibly and publicly support the safety of their youth athletes by mandating reporting of all catastrophic injuries and sudden deaths to an organized database. Second, medical professionals responding to these catastrophic injuries and sudden deaths would be able to report all relevant information about the injury or death, greatly enhancing the accuracy of epidemiological injury data. Currently, multiple injury surveillance platforms[23,39,40] are available that collect data directly from the reports of medical professionals. Third, youth sport governing bodies would benefit from having access to surveillance data on sport-related catastrophic injury and sudden death, thereby enabling greater collaboration and communication between the groups in evaluating existing and creating new policies aimed to improve the health and safety of youth athletes in the United States. Fourth, impacts of state-level or organizational policies on youth sport safety could be examined. For example, if a state implemented a policy mandating AEDs at all youth athletic contests, ongoing surveillance data could be used to illustrate whether or not the policy reduces cardiac-related sudden death by

improving the rate of SCA saves via AEDs. Fifth, ongoing surveillance could also be used to describe the impacts of requiring qualified medical professionals (such as athletic trainers or emergency medical services) at all youth sporting events.

Limitations

This study is not without limitations. First, we were unable to obtain yearly practice and competition exposure data of youth athletes. Therefore, incidence rates reported in this study were derived from estimates of yearly youth-level sport participation. Though these estimates were made with previously established methodology,[1] the incident rates in this study may not reflect true incidence in the organized youth sport population. Without question, there is a need for further research into describing the participation of young athletes in youth and recreational sports in order to create more accurate sudden death incident rates in organized youth sport. Second, sudden death information was obtained via on-line and print media, which was derived from medical records and health professionals through families, police, and schools. This process may hamper the collection and recall of details about the event and ultimately limit the quality of the data. Third, we found that some media reports did not differentiate between catastrophic injuries that occurred during non-organized recreation and those that occurred during organized competitions. One of the inclusion criteria in this study was that the sudden death occurred during organized youth sporting competitions. These cases were ultimately excluded, and as a result, some sudden deaths may have been missed due to lack of information within the media reports. Fourth, a total of 10 media reports did not include an official cause of death as assigned by the medical examiner/coroner or listed the official cause of death as “unknown or inconclusive.” The certified athletic trainer involved in reviewing the sudden death cases therefore had to use the information that was provided in the media report to assign a “speculated cause of death”. Fifth, as mentioned previously our period of data collection only included the past nine years from 2007-2015 and our data collection of years

2007-2012 was performed retrospectively. These retrospective searches may have resulted in an under-capture of sudden deaths in the earlier years of this study and contributed to the increase in incidence rates observed over the entire study period. While this is a limitation, it also supports the need for ongoing surveillance of sudden death in youth sports and ongoing discussion about how to best capture youth sudden deaths. Sixth, we were not able to report race and ethnicity of sudden death cases. Previous studies have reported race and ethnicity from death reports included in the public domain (eg, media reports) or from autopsy reports.[21,41] However, we did not have access to these death reports and the media reports we utilized in our surveillance did not explicitly report race nor ethnicity. This limitation further emphasizes the need for better surveillance methods that include collection of details on race and ethnicity in youth sport sudden death cases. Future epidemiological research specific to sudden death in organized youth sport should consider investigating death information via interviews, medical records, or autopsy reports. Finally, our study only focused on organized youth sports below the high school level. We recognize that there are still many other settings of organized sports outside of the youth, high school, collegiate, and professional levels. These settings include adult sporting events such as adventure racing, adult recreational leagues, and organized recreational events such as triathlons and marathons. In order to promote safety at all levels of sport, surveillance of sudden death at these levels is also encouraged.

Conclusion

From 2007-2015, 45 youth athletes died while playing organized sport in the United States, with an increasing number of sudden deaths captured in more recent years. The overall incidence rate of sudden death was 1.83 deaths/10,000,000 athlete-years. The majority of deaths occurred at the middle school and youth league levels, occurred during practice, were experienced by males, were cardiac-related, and happened while playing basketball. This study

supports the need for continued surveillance of sudden deaths in all levels of youth sport. This surveillance is critical for the development and assessment of evidence-based policies aimed at preventing sudden death and promoting overall athlete health and safety.

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