

Sudden Deaths in Young Competitive Athletes

Analysis of 1866 Deaths in the United States, 1980–2006

Barry J. Maron, MD; Joseph J. Doerer, BS; Tammy S. Haas, RN;
David M. Tierney, MD; Frederick O. Mueller, PhD

Background—Sudden deaths in young competitive athletes are highly visible events with substantial impact on the physician and lay communities. However, the magnitude of this public health issue has become a source of controversy.

Methods and Results—To estimate the absolute number of sudden deaths in US competitive athletes, we have assembled a large registry over a 27-year period using systematic identification and tracking strategies. A total of 1866 athletes who died suddenly (or survived cardiac arrest), 19 ± 6 years of age, were identified throughout the United States from 1980 to 2006 in 38 diverse sports. Reports were less common during 1980 to 1993 (576 [31%]) than during 1994 to 2006 (1290 [69%], $P < 0.001$) and increased at a rate of 6% per year. Sudden deaths were predominantly due to cardiovascular disease (1049 [56%]), but causes also included blunt trauma that caused structural damage (416 [22%]), commotio cordis (65 [3%]), and heat stroke (46 [2%]). Among the 1049 cardiovascular deaths, the highest number of events in a single year was 76 (2005 and 2006), with an average of 66 deaths per year (range 50 to 76) over the last 6 years; 29% occurred in blacks, 54% in high school students, and 82% with physical exertion during competition/training, whereas only 11% occurred in females (although this increased with time; $P = 0.023$). The most common cardiovascular causes were hypertrophic cardiomyopathy (36%) and congenital coronary artery anomalies (17%).

Conclusions—In this national registry, the absolute number of cardiovascular sudden deaths in young US athletes was somewhat higher than previous estimates but relatively low nevertheless, with a rate of < 100 per year. These data are relevant to the current debate surrounding preparticipation screening programs with ECGs and also suggest the need for systematic and mandatory reporting of athlete sudden deaths to a national registry. (*Circulation*. 2009;119:1085-1092.)

Key Words: cardiomyopathy ■ death, sudden ■ cardiovascular diseases

Competitive athletes represent a unique segment of the general population, with a lifestyle characterized by vigorous and systematic physical exertion.^{1–7} However, some athletes are subject to the risk of sudden death, usually due to underlying (and predominantly unsuspected) cardiovascular disease^{8–14} but also due to trauma or other causes.^{13,15} Such catastrophes are always unexpected events, and although clearly uncommon relative to the vast number of athletes participating safely in a wide variety of organized sports,^{5,16} they nevertheless have a devastating impact on families, communities, and physicians and attract considerable public and media attention.^{1,3,5,14}

Editorial p 1072 Clinical Perspective p 1092

Over the past several years, there has been heightened interest in and focus on preventive strategies such as preparticipation cardiovascular screening^{2,4,6,7,17–20} and utilization of disqualifi-

cation criteria,^{4,11} as well as availability of automated external defibrillators for secondary prevention.²¹ However, prior estimates of the frequency with which these catastrophes occur have been particularly low,^{9,22,23} which has impacted the debate over this public health problem significantly, specifically with regard to the most effective and practical strategies for mass screening.^{2,7,24,25} To place this important medical issue into proper context, we report the analysis of a large registry spanning 27 years, with a primary focus on the number of sudden deaths occurring in young US athletes.

Methods

The US National Registry of Sudden Death in Athletes was instituted at the Minneapolis Heart Institute Foundation for the purpose of prospectively and retrospectively assembling data on the deaths of young athletes participating in organized competitive sports. Over a 27-year period (1980 to 2006), 1866 such sudden deaths (and survivors of cardiac arrest) have been tabulated. This project was reviewed by the Allina Institutional Review Board.

Continuing medical education (CME) credit is available for this article. Go to <http://cme.ahajournals.org> to take the quiz.

Received July 8, 2008; accepted December 15, 2008.

From the Hypertrophic Cardiomyopathy Center, Minneapolis Heart Institute Foundation and Abbott Northwestern Hospital, Minneapolis, Minn (B.J.M., J.J.D., T.S.H., D.M.T.), and the National Center for Catastrophic Sports Injury Research and the University of North Carolina, Chapel Hill, NC (F.O.M.).

Correspondence to Barry J. Maron, MD, Minneapolis Heart Institute Foundation, 920 E 28th St, Suite 620, Minneapolis, MN 55407. E-mail hcm.maron@mhif.org

© 2009 American Heart Association, Inc.

Circulation is available at <http://circ.ahajournals.org>

DOI: 10.1161/CIRCULATIONAHA.108.804617

Athletes were classified with respect to race on the basis of death reports, available either in the public domain (eg, newspaper accounts) or from autopsy reports. Race has been cited previously as an important demographic variable with respect to sudden deaths in young athletes.¹²

The study population was identified by targeted searches that used a variety of sources at the time each of these strategies became available during the duration of the study: (1) LexisNexis archival informational database with searchable access to authoritative news, business, legal, and public records ($n=5$ billion searchable documents available from thousands of sources), 2003 to 2006 (457 cases); (2) news media accounts systematically assembled through Burrelle's Information Services (Livingston, NJ), with access to 18 000 US newspapers and international media sources daily, 1990 to 2006 (847 cases); (3) Internet searches, with access to online information via World Wide Web-based search engines (eg, Google, Yahoo), 2003 to 2006 (200 cases); (4) reports from the US Consumer Product Safety Commission (Washington DC), 1988 to 2006 (15 cases); (5) accumulated records of the National Center for Catastrophic Sports Injury Research (University of North Carolina, Chapel Hill), 1985 to 2006 (187 cases); (6) National Heart, Lung, and Blood Institute Pathology Branch archives, 1980 to 1990 (68 cases); and (7) reports submitted directly to the registry and the Minneapolis Heart Institute Foundation Web site (US National Registry of Sudden Death in Athletes, <http://www.suddendeathathletes.org>) or personal reports from physicians, attorneys, coroners/medical examiners, high schools/colleges, and patient advocacy and support organizations, 1980 to 2006 (92 cases).

Individual athletes were included in the registry when identified through the aforementioned sources and if 2 criteria were met: (1) The athlete participated in organized team or individual sports that required regular competition against others as a central component, placed a high premium on excellence and achievement, and required systematic and, in most instances, vigorous training¹¹ (individuals participating in only college-sponsored intramural sports were not included); and (2) the athlete experienced sudden death (or survived cardiac arrest) at ≤ 39 years of age. Sudden death was defined as an unexpected collapse (with or without physical exertion) associated with a previously uneventful clinical course.

A systematic tracking process was established to assemble detailed information on each case, which included the autopsy report (with gross anatomic, histological, and toxicological findings) and pertinent clinical and demographic information. Selected data (eg, circumstances of collapse) were often derived from written accounts or telephone interviews with family members, witnesses, or coaches. When necessary, autopsy findings were verified by direct communication with the medical examiner, and primary pathological materials were selectively requested and analyzed.

Of the 1866 athletes, a specific cause of death could be documented in 1353 on the basis of the autopsy findings ($n=1236$) and/or information obtained on clinical office evaluations ($n=117$). However, it was not possible to reliably assign a precise cause of death in the other 513 athletes owing to a variety of factors: (1) Autopsy examination was not performed; (2) access to postmortem and/or clinical findings was restricted by confidentiality and privacy obstacles (10 states prohibit the public release of demographic or medical information under the Family Educational Rights and Privacy Act or the Federal Health Insurance Portability and Accountability Act); or (3) the official autopsy report was available, but the descriptions of gross and histopathologic findings were judged ambiguous and insufficient in detail.

Because of privacy restrictions, we could not confirm the race of 55 athletes (3%). For the purpose of the present analysis, 359 athletes in whom a precise cause of death was not documented were considered most likely to have died of cardiovascular conditions, given their sudden collapse during physical activity in the absence of potentially detrimental environmental or other factors.

Eighty-five athletes who survived cardiac arrest by virtue of defibrillation and/or cardiopulmonary resuscitation are considered to have experienced sudden death for the purpose of the present analysis. Selected diagnostic and demographic data from 377 regis-

try cases have appeared in prior reports.^{8,12,15} Specific diagnostic criteria for the cardiovascular diseases reported here, as well as commotio cordis, have been reported previously.^{8,12,15}

Statistical Methods

Data are expressed as mean \pm SD. Proportions were compared with the χ^2 or Fisher exact tests. Continuous variables were compared with the unpaired Student *t* test or Mann-Whitney rank sum test, where appropriate. Trends in counts over time were assessed by Poisson regression analysis with log link and likelihood ratio tests and in binary variables by logistic regression with likelihood ratio tests. Trends in age were assessed with linear regression.

To calculate the incidence of sudden deaths, the average number of these events that occurred during the 6 years from 2001 to 2006 was divided by the estimated number of participants in all competitive sports ≤ 39 years old in the United States during the same time period. First, the number of participations was assembled from the records of several sports organizations, including the National Federation of State High School Associations (41 291 690),²⁶ the National Collegiate Athletic Association (2 288 407),²⁷ the National Junior College Athletic Association (278 780), and the National Association of Intercollegiate Athletics (285 411) for high school and college athletes. The number of participations was converted to the number of participants with the correction factors suggested by Van Camp et al⁹ (1.9 for high school and 1.2 for college). In addition, by search of online Web sites, direct email, or telephone contact, we assembled the number of participants in public competitive sports, including marathons, triathlons, cycling, skiing, skating, and boxing, as well as youth sports such as Little League baseball, karate/judo, ice hockey, and soccer. Finally, the number of participants in major and minor US professional sports (including baseball, basketball, football, and hockey) was tabulated.

The authors had full access to and take full responsibility for the integrity of the data. All authors have read and agree to the manuscript as written.

Results

Overall Study Population

Over a 27-year period, a total of 1866 athletes with sudden death events (including 85 cardiac arrest survivors) were enrolled in the registry (Figure 1). Reports of these sudden deaths have increased at a rate of 6% per year ($P<0.001$; 95% CI 5.0% to 6.9%). The proportion of the 1866 events in the 13-year period from 1994 to 2006 (1290 [69%]) was significantly higher than in the 14 years from 1980 to 1993 (576 [31%], $P<0.001$). The proportion of all deaths reported in female athletes has increased over time ($P<0.0001$; 95% CI 1.4 to 2.3), reaching 13% in 2000 to 2006; age at death showed no trend for change over time ($P=0.81$). Deaths were reported from all 50 states and the District of Columbia and were most common in states with large populations: California ($n=181$), Texas ($n=116$), Florida ($n=115$), and New York ($n=113$).

Cardiovascular Diseases

Causes of Death

Of the 1866 sudden death events, 1049 (56%) were judged to be probably or definitely due to cardiovascular causes. Of these 1049 deaths, 690 could be reliably attributed to 44 documented primary cardiovascular diseases. Hypertrophic cardiomyopathy was most common, occurring in 251 cases (36%), with maximum left ventricular wall thickness of 23 ± 5 mm (range 15 to 40 mm) and heart weight of 521 ± 113 g^{12,28} (Figure 2). Coronary artery anomalies of wrong sinus origin

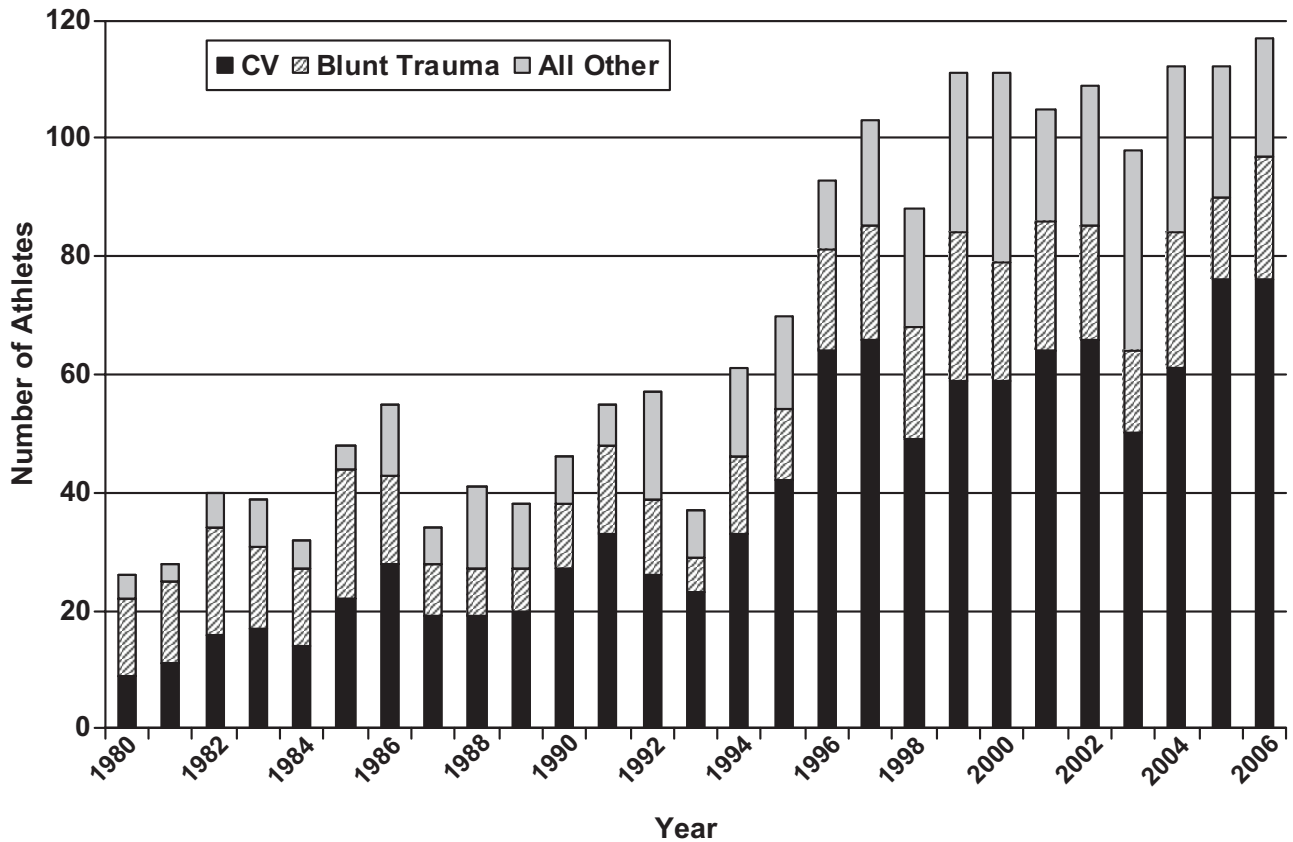


Figure 1. Number of cardiovascular (CV), trauma-related, and other sudden death events in 1866 young competitive athletes, tabulated by year.

were next in frequency (119 cases [17%]).²⁹ Several other cardiovascular diseases each accounted for $\leq 6\%$ of the total, with the most common of these being myocarditis (41 cases [6%]), arrhythmogenic right ventricular cardiomyopathy (30 [4%]),³⁰ and ion channelopathies identified clinically by 12-lead ECG or genotyping (25 [4%], including 23 with long-QT syndrome and 2 with Brugada syndrome; Figure 2). Seventy-five athletes were previously diagnosed with cardiac disease during life (usually triggered by transient symptoms or heart murmur) but continued in organized competitive sports, including 6 who participated despite formal disqualification (4 after signing a medical waiver).

Frequency of Death

The highest number of sudden cardiovascular death events recorded in any single year was 76 (in 2005 and 2006), followed by 66 in 1997 and 2002 and 64 in 1996 and 2001 (Figure 1). Over the most recent 6 years of reporting (2001 to 2006), the average number of cardiovascular deaths per year was 66 (range 50 to 76). The cardiovascular mortality rate in young athletes was calculated for the most recent 6-year period (2001 to 2006) with an estimated 10.7 million participants per year ≤ 39 years of age in all organized amateur and competitive sports. The incidence of sudden deaths in these athletes was 0.61/100 000 person-years.

Demographics: Age and Gender

These athletes ranged in age from 8 to 39 years at the time of death or cardiac arrest (mean 18 ± 5 years); 677 (65%) were

≤ 17 years old, 300 (29%) were 18 to 25 years old, and 72 (7%) were ≥ 26 years old. A total of 937 athletes were male (89%), and only 112 were female (11%; Table). The proportion of cardiovascular deaths reported in female athletes has increased over time ($P=0.023$; 95% CI 1.05 to 1.92), reaching 12% in 2000 to 2006.

Race

The absolute number of cardiovascular deaths reported in white athletes (581 [55%]) exceeded that in black athletes (377 [36%]), Hispanics (34 [3%]), Asians (13 [1.2%]), or Native Americans (2 [0.2%]; Table). White and nonwhite athletes did not differ significantly with respect to age (18 ± 5 versus 18 ± 4 years, $P=0.4$) or gender (87% versus 93% males, $P=0.5$).

Deaths due to cardiovascular disease, however, were more common in nonwhite than white athletes (64% versus 51%, $P=0.001$). The fraction of reported deaths attributable to hypertrophic cardiomyopathy and congenital coronary anomalies was higher among nonwhites (predominantly blacks) than whites: 136/676 (20%) versus 112/1135 (10%; $P<0.001$) for hypertrophic cardiomyopathy and 66/676 (10%) versus 52/1135 (5%; $P=0.001$) for coronary anomalies. Conversely, the fraction of reported deaths attributable to ion channelopathies was higher among whites than nonwhites: 22/1135 (2%) versus 2/676 (0.3%, $P=0.004$; Figure 3).

Sports and Level of Participation

Athletes participated in a wide variety of 38 competitive sports, most commonly basketball ($n=349$ [33%]) and football ($n=281$

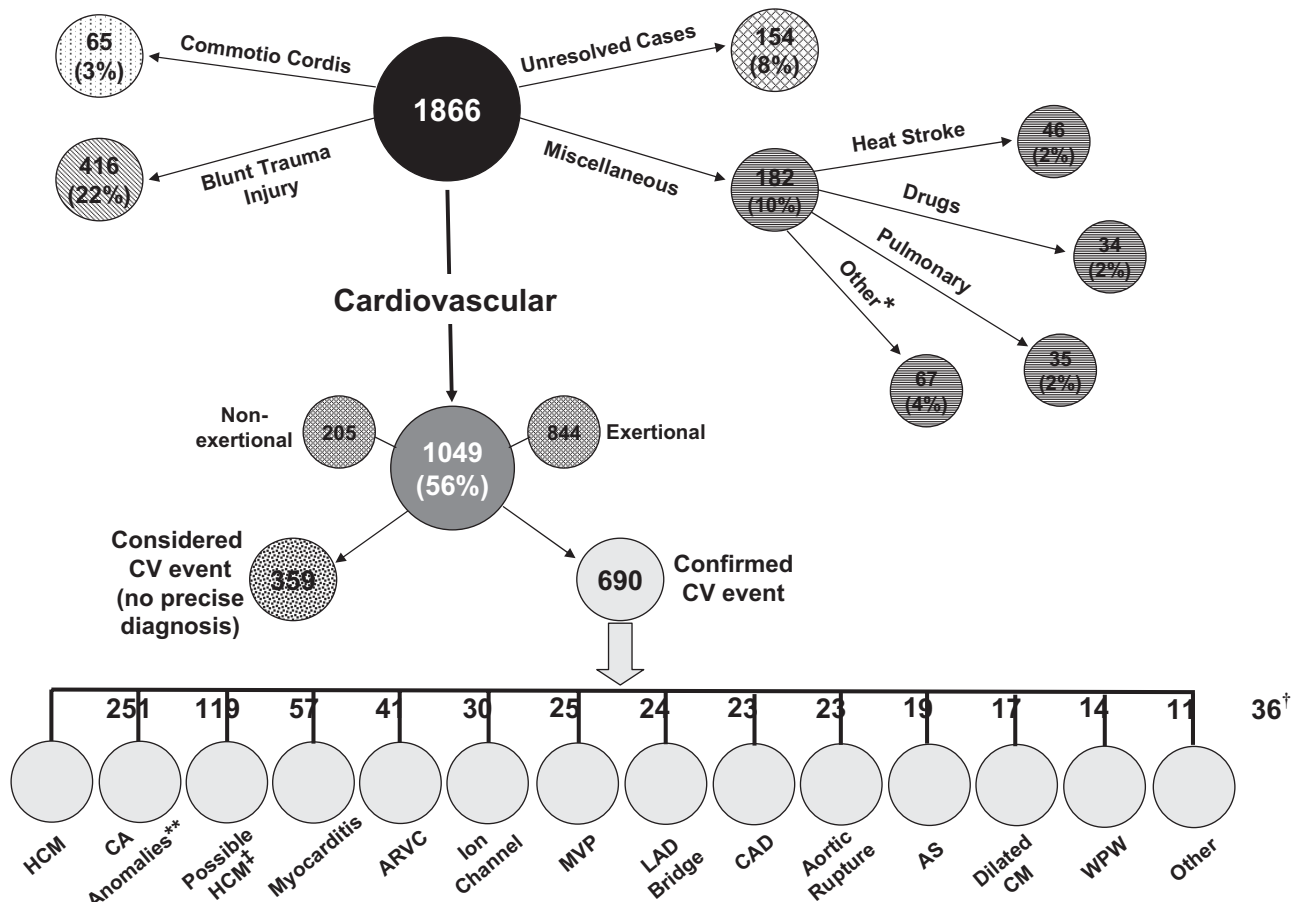


Figure 2. Flow diagram summarizing causes of death in 1866 young competitive athletes. *Suicide (n=22); lightning (n=12); drowning (n=10 and 3 during the swimming segment of triathlon events); cerebral aneurysm (n=9); rhabdomyolysis (n=8); epilepsy (n=2); and miscellaneous (n=4). †Congenital heart disease (n=8); myocardial infarction (n=6); Kawasaki disease or related conditions (n=5); sickle cell trait (n=5); sarcoidosis (n=4); stroke (n=3); cardiac tumor (n=1); conduction system disease (n=2); and miscellaneous (n=2). ‡Regarded as possible (not definitive) evidence for hypertrophic cardiomyopathy at autopsy with mildly increased left ventricular wall thickness (18±4 mm) and heart weight (447±76 g). **Of wrong sinus origin coursing between aorta and pulmonary trunk; most commonly, anomalous left main coronary artery from right (anterior) sinus of Valsalva (n=65) and anomalous right coronary artery from the left sinus (n=16). ARVC indicates arrhythmogenic right ventricular cardiomyopathy; AS, aortic stenosis; CA, coronary artery; CAD, coronary artery disease; CM, cardiomyopathy; CV, cardiovascular; HCM, hypertrophic cardiomyopathy; LAD, left anterior descending coronary artery; MVP, mitral valve prolapse; and WPW, Wolff-Parkinson-White.

[25%]; Table). The other 36 sports individually comprised 0.1% to 7.6% of the deaths. Most athletes who died of cardiovascular-related causes were engaged in sanctioned competitive high school (n=623 [59%]), middle school (120 [11%]), or youth (26 [2%]) sports. The remainder had advanced beyond the high school level, which included college (179 [17%]), professional (55 [5%]), and amateur sports such as road racing and triathlon (46 [4%]). Seventy-two athletes (7%) were considered elite by virtue of achieving professional status or a national level of excellence in amateur sports.

Circumstances

Sudden cardiovascular death events occurred most commonly during or just after physical exertion, while the athlete was engaged in practice sessions, organized competition, or other sports activities (844 [80%]). Another 205 trained athletes (20%) died suddenly in circumstances unassociated with sports, during routine daily activities or while sedentary or asleep. In 16 athletes, sudden death events occurred while submerged in water (ie, swimming pool, lake, or ocean).

Trauma-Related and Other Causes

Four hundred sixteen deaths (22%) resulted directly from blunt trauma that caused profound bodily injury, most frequently of the head and neck (n=313; Figure 2; Table). In 65 other athletes (3%), blunt precordial blows caused sudden death or cardiac arrest without structural injury to the heart or chest wall (commotio cordis).¹⁵ Additional non-trauma-related causes of death occurred in 182 athletes (10%), the most common of which were heat stroke (n=46), illicit drug use (n=34), and pulmonary conditions (bronchial asthma with status asthmaticus [n=15] or pulmonary embolus [n=13]).

Discussion

The present registry of sudden deaths in young US athletes (comprising 1866 systematically assembled cases) is a largely autopsy-based data set that encompasses events over a 27-year period in 38 organized sports performed at several competitive levels and provides insight into the number of such events that occur in trained athletes. Indeed, such deaths

Table. Demographics of Sudden Death in Young Athletes

Sport	No. (%)	Age, y	Male, n (%)	Female, n (%)	Race, n			Survivors, n (%)	Cause of Death, n (%)		
					White	Black	Other*		Trauma Injury	Commotio Cordis	CV Diseases†
Football	565 (30)	17±4	564 (99.8)	1 (0.2)	280	205	80	13 (2)	140 (25)	12 (2)	281 (50)
Basketball	405 (22)	17±4	364 (90)	41 (10)	142	243	20	30 (7)	4 (1.0)	0	349 (86)
Soccer	115 (6)	16±4	93 (81)	22 (19)	81	14	20	7 (6)	11 (10)	4 (4)	80 (70)
Baseball	111 (6)	16±4	111 (100)	0	95	5	11	14 (13)	16 (14)	30 (27)	54 (49)
Motor vehicle racing‡	104 (6)	28±8	103 (99)	1 (1)	102	0	2	0	97 (93)	0	5 (5)
Track and field	96 (5)	17±4	74 (77)	22 (23)	62	22	12	3 (3)	25 (26)	0	61 (64)
Wrestling	69 (4)	22±8	69 (100)	0	56	4	9	2 (3)	7 (10)	1 (1.4)	37 (54)
Boxing	56 (3)	25±6	55 (98)	1 (2)	21	19	16	0	42 (75)	0	11 (1.8)
Swimming§	46 (2)	17±4	30 (65)	16 (35)	43	1	2	1 (2)	0	0	35 (76)
Cross country	38 (2)	17±4	29 (76)	9 (24)	30	6	2	2 (5)	0	0	29 (76)
Hockey	29 (1.5)	18±5	29 (100)	0	28	1	0	3 (10)	4 (14)	7 (24)	11 (38)
Horse riding	27 (1.4)	27±8	17 (63)	10 (37)	21	1	5	0	24 (89)	0	2 (7)
Softball	22 (1.2)	19±6	6 (27)	16 (73)	19	0	3	2 (9)	3 (14)	1 (5)	12 (55)
Marathon	20 (1.1)	28±7	15 (75)	5 (25)	16	0	4	3 (15)	0	0	13 (65)
Lacrosse	19 (1.0)	18±2	19 (100)	0	18	1	0	2 (11)	1 (5)	8 (42)	9 (47)
Skiing¶	19 (1.0)	25±8	14 (74)	5 (26)	19	0	0	0	15 (79)	0	1 (5)
Triathlon	17 (0.9)	32±5	15 (88)	2 (12)	16	0	1	0	3 (18)	0	8 (47)
Rugby	16 (0.9)	21±3	16 (100)	0	13	2	1	0	3 (19)	0	7 (44)
Martial arts	15 (0.8)	23±7	14 (93)	1 (7)	12	3	0	0	5 (33)	2 (13)	2 (13)
Others#	14 (0.8)	26±9	12 (86)	2 (14)	14	0	0	2 (14)	3 (21)	0	5 (36)
Rowing	11 (0.6)	22±6	8 (73)	3 (27)	10	0	1	0	0	0	9 (82)
Cycling	10 (0.5)	29±8	8 (80)	2 (20)	7	2	1	0	7 (70)	0	3 (30)
Tennis	10 (0.5)	19±4	8 (80)	2 (20)	8	0	2	0	0	0	8 (80)
Volleyball	10 (0.5)	18±5	1 (10)	9 (90)	5	3	2	1 (10)	0	0	10 (100)
Gymnastics	9 (0.5)	15±3	5 (56)	4 (44)	6	0	3	0	4 (44)	0	3 (33)
Surfing	9 (0.5)	23±8	9 (100)	0	7	0	2	0	2 (22)	0	1 (11)
Figure skating	2 (0.1)	24±6	2 (100)	0	2	0	0	0	0	0	1 (50)
Golf	2 (0.1)	18±0.7	2 (100)	0	2	0	0	0	0	0	2 (100)
Totals	1866	19±6	1692	174	1135	532	199	85	416	65	1049

CV indicates cardiovascular.

*Hispanic (n=103); Asian (n=20); Native American (n=5); Pacific Islander (n=5); Middle Eastern (n=3); Indian (n=1); Japanese (n=1); mixed (n=6); unknown (n=55).

†Documented by autopsy and/or clinical findings.

‡Includes automobile (n=63) and motorcycle (n=41) racing.

§Swimming (n=40); water polo (n=6).

||Jockey (n=16); equestrian (n=11).

¶Skiing (n=12); snowboarding (n=5); ski-jumping (n=2).

#Skateboarding (n=5); jai-alai (n=4); field hockey (n=2); bobsledding (n=1); bowling (n=1); riflery (n=1).

constitute a unique medical issue with substantial societal impact given the youthful age and apparent good general health of the victims^{1,3,5,7,14} and are also relevant to the controversy surrounding the most efficacious and practical approach to preparticipation cardiovascular screening of large populations of athletes.^{2,7,24,25,31}

The primary impetus of the present report was to estimate the absolute number of these tragic events that occur in the United States annually. Such data have not been assembled previously over long periods of time in a large, informative registry format such as presented here. To acquire this

information, we were largely dependent on identifying those sudden deaths that became part of the public domain and record. Consequently, the present data were assembled through the use of a variety of sources, including powerful LexisNexis and newspaper informational services, as well as Internet search engines. It is likely that the steady increase in the number of sudden deaths observed over the 27 years of this registry reflects enhanced public recognition due to increased media attention and the more robust search strategies that have become available recently, rather than a true acceleration in the occurrence of these events. Nevertheless,

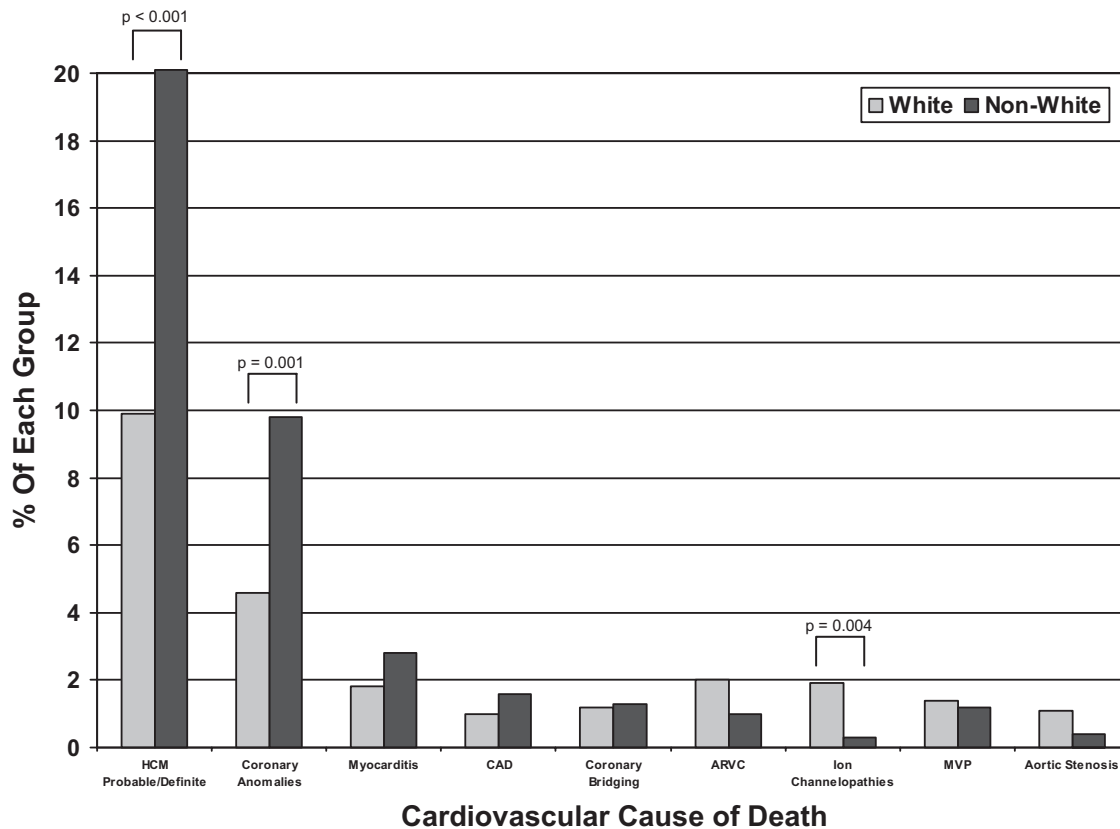


Figure 3. Cardiovascular deaths according to race, with respect to the number of white and nonwhite athletes with each disease. ARVC indicates arrhythmogenic right ventricular cardiomyopathy; HCM, hypertrophic cardiomyopathy; CAD, coronary artery disease; and MVP, mitral valve prolapse. Analysis excludes 55 athletes for whom race could not be established.

the present study design achieves a broad and inclusive perspective that involves virtually all major and minor organized sports at all competitive levels, including those known to be associated predominantly with trauma-related risks (eg, automobile racing). In addition, to provide the most comprehensive data set addressing the question of how many sudden deaths in fact occur among young participants in competitive sports, our observations were not limited to high school and college sports.⁹

It has been our intuition that the previous estimates for sudden deaths in young people engaged in competitive sports (ie, ≤ 20 per year)^{9,22,23} had underestimated the true magnitude of this public health issue. Furthermore, such a mischaracterization has the potential to dampen enthusiasm for important and related initiatives focused on the prevention of sudden death in athletes (eg, detection of cardiovascular abnormalities by mass preparticipation screening,^{2,6,17–20,24,25,31} application of standards for disqualification,^{4,11} dissemination of automatic external defibrillators,²¹ and novel design of protective equipment to minimize trauma-related deaths³²).

Indeed, the present study shows the overall number of sudden deaths in young athletes to be substantially greater than prior estimates.^{9,22,23} However, on the basis of tabulations from the most recent 6 years of the registry, for which the reporting of events is judged to be most robust, fewer than 100 athletes in the United States die each year (76 in 2005 and 2006) of a variety of cardiovascular diseases; furthermore,

an estimated 30% of these causes of death cannot be identified reliably by preparticipation screening, even with ECG (eg, congenital coronary anomalies of wrong sinus origin^{20,29} and some cases of hypertrophic cardiomyopathy, aortic dilatation, atherosclerotic coronary artery disease, and dilated cardiomyopathy).

Despite our considerable investigative efforts and systematic tracking methods over a long period of time, we cannot exclude the possibility of ascertainment bias and the likelihood that the number of these deaths may have been modestly underestimated. Sudden deaths that do not occur in the competitive season or on the athletic field or that involve non-elite school-age participants residing in small population centers probably are less likely to achieve visibility in the public record. Only a national government–subsidized program with mandatory reporting, a centralized database, and dedicated resources^{2,17} would be capable of establishing the precise incidence of sudden death in young athletes in the United States.

The public visibility afforded sudden deaths in young athletes may be disproportionate to the actual numeric magnitude of these events. This is perhaps understandable given the apparent good health of young participants in competitive sports activities generally perceived as free of such profound risks. Indeed, the present findings may place this public health issue into a more realistic context. Despite the inclusive data collection methods used, which involved a particularly broad spectrum of sports and deaths not confined to

occurrence on the athletic field itself, at a wide range of ages and with individuals from each of the 50 states, the absolute number of all sudden deaths (as well as those specifically due to cardiovascular disease) reported here is significantly less than that observed in association with many other risks of living in this age group, for example, cancer, leukemia, cystic fibrosis, automobile fatalities, and homicides.³³ Cardiovascular deaths in athletes occurred in fewer numbers than accidental electrical fatalities,³³ meningococemia deaths,³⁴ or phenylketonuria diagnoses and were similar in number to lightning-related fatalities.³⁵

Of note, the focus of the present investigation was the absolute number of deaths that occur in young competitive athletes, which has some relevance to the current controversy surrounding national mandatory cardiovascular screening programs with routine ECG.^{24,25} It proved impractical to provide an analysis with a reliable denominator for the overall at-risk athlete population in the United States and a precise calculation of incidence over the substantial 27-year study period (particularly with the large number of sporting disciplines involved).^{26,27} Nevertheless, using available data from the most recent 6-year period, we were able to estimate the frequency of these events at ≈ 0.6 deaths per 100 000 person-years, a rate similar to that reported in competitive athletes over a recent 11-year period from the Veneto region of northeastern Italy (0.87 deaths/100 000 person-years), in which screening routinely included a 12-lead ECG,² as well as from the state of Minnesota (0.93 deaths/100 000 person-years), in which only history and physical examination were used.³⁶

A mandatory national preparticipation screening strategy with routine ECGs has been promoted vigorously by the European Society of Cardiology,⁶ International Olympic Committee,³⁷ and some investigators,²⁵ although the American Heart Association has been more conservative in its recommendations by expressing considerable restraint and skepticism with respect to the practicality of such a nationwide screening program in the United States.⁷ Indeed, the relatively low absolute number of cardiovascular sudden death events reported here in young athletes raises some doubt regarding the ambitious considerations for preparticipation cardiovascular screening based on the rigorous Italian model.^{2,4,6} Without a systematic and mandatory reporting system for sudden cardiac deaths in young competitive athletes, however, the true absolute number of these events occurring in the United States cannot be known. Indeed, given that improved surveillance systems over the last 6 years largely accounted for the higher number of sudden deaths detected during this time period, it is likely that the number of deaths we identified would have been higher overall if a mandatory reporting system had been implemented throughout the 27-year period.

Once again,^{1,8,9,12,14} hypertrophic cardiomyopathy was the most frequent cardiovascular cause of sudden death, accounting for one third of all such deaths, with coronary artery anomalies responsible for $\approx 15\%$. These findings are consistent with previous analyses in smaller US cohorts.^{1,8,9,12} In addition, 42 other cardiovascular diseases each accounted for $\leq 6\%$ of the deaths, including arrhythmogenic right ventricular cardiomyopathy, which paradoxically has been reported

as the most common cause of sudden death in young athletes within the Veneto region of northeastern Italy.^{2,30}

In conclusion, sudden death in US competitive athletes is a low-frequency event (although significantly more common than previously estimated). These events are predominantly due to cardiovascular disease, but with a substantial minority attributable to blunt trauma. Nevertheless, these defined risks of athletic training and competition support both continued efforts at preparticipation screening^{18,19,24,25} and the importance of disqualification standards.^{4,11} The low overall event rate reported here should provide a measure of reassurance regarding sports participation but underscores the need for mandatory reporting of sudden deaths in young athletes, and it is also relevant to the question of whether a national screening program with noninvasive testing should be considered for US athletes.

Acknowledgments

We wish to thank James S. Hodges, PhD, statistician at the Minneapolis Heart Institute Foundation and University of Minnesota School of Public Health, for his superb statistical assistance.

Sources of Funding

This study was supported in part by the National Operating Committee on Standards for Athletic Equipment (NOCSAE), Chapel Hill, NC, and the William Randolph Hearst Foundation, San Francisco, Calif.

Disclosures

Dr Maron has received honoraria from Medtronic, has served as an expert witness on medicolegal cases involving hypertrophic cardiomyopathy, and serves as a consultant/advisory board member of GeneDx. The remaining authors report no conflicts.

References

1. Maron BJ. Sudden death in young athletes. *N Engl J Med.* 2003;349:1064–1075.
2. Corrado D, Basso C, Pavei A, Michieli P, Schiavon M, Thiene G. Trends in sudden cardiovascular death in young competitive athletes after implementation of a preparticipation screening program. *JAMA.* 2006;296:1593–1601.
3. Maron BJ. Sudden death in young athletes: lessons from the Hank Gathers affair. *N Engl J Med.* 1993;329:55–57.
4. Pelliccia A, Fagard R, Björnstad HH, Anastassakis A, Arbustini E, Assanelli D, Biffi A, Borjesson M, Carrè F, Corrado D, Delise P, Dorwarth U, Hirth A, Heidbuchel H, Hoffmann E, Mellwig KP, Panhuyzen-Goedkoop N, Pisani A, Solberg EE, van-Buuren F, Vanhees L, Blomstrom-Lundqvist C, Deligiannis A, Dugmore D, Glikson M, Hoff PI, Hoffman A, Hoffmann E, Horstkotte D, Nordrehaug JE, Oudhof J, McKenna WJ, Penco M, Priori S, Reybrouck T, Senden J, Spataro A, Thiene G. Recommendations for competitive sports participation in athletes with cardiovascular disease: a consensus document from the European Society of Cardiology. *Eur Heart J.* 2005;26:1422–1445.
5. Maron BJ. Cardiovascular risks to young persons on the athletic field. *Ann Intern Med.* 1998;129:379–386.
6. Corrado D, Pelliccia A, Björnstad HH, Vanhees L, Biffi A, Borjesson M, Panhuyzen-Goedkoop N, Deligiannis A, Solberg E, Dugmore D, Mellwig KP, Assanelli D, Delise P, van-Buuren F, Anastassakis A, Heidbuchel H, Hoffmann E, Fagard R, Priori SG, Basso C, Arbustini E, Blomstrom-Lundqvist C, McKenna WJ, Thiene G. Cardiovascular preparticipation screening of young competitive athletes for prevention of sudden death: proposal for a common European protocol: consensus statement of the Study Group of Sport Cardiology of the Working Group of Myocardial and Pericardial Diseases of the European Society of Cardiology. *Eur Heart J.* 2005;26:516–524.
7. Maron BJ, Thompson PD, Ackerman MJ, Balady G, Berger S, Cohen D, Dimeff R, Douglas PS, Glover DW, Hutter AM Jr, Krauss MD, Maron MS, Mitten MJ, Roberts WO, Puffer JC. Recommendations and considerations related to preparticipation screening for cardiovascular abnormalities in competitive athletes: update 2007: a Scientific Statement from the American Heart Association, Nutrition, Physical Activity, and Metabolism Council. *Circulation.* 2007;115:1643–1655.

8. Maron BJ, Shirani J, Poliac LC, Mathenge R, Roberts WC, Mueller FO. Sudden death in young competitive athletes: clinical, demographic and pathological profiles. *JAMA*. 1996;276:199–204.
9. Van Camp SP, Bloor CM, Mueller FO, Cantu RC, Olson HG. Non-traumatic sports death in high school and college athletes. *Med Sci Sports Exerc*. 1995;27:641–647.
10. Burke AP, Farb A, Virmani R, Goodin J, Smialek JE. Sports-related and non-sports-related sudden cardiac death in young athletes. *Am Heart J*. 1991;121:568–575.
11. Maron BJ, Zipes DP. 36th Bethesda Conference: eligibility recommendations for competitive athletes with cardiovascular abnormalities. *J Am Coll Cardiol*. 2005;45:1312–1375.
12. Maron BJ, Carney KP, Lever HM, Barac I, Casey SA, Sherrid MV. Relationship of race to sudden cardiac death in competitive athletes with hypertrophic cardiomyopathy. *J Am Coll Cardiol*. 2003;41:974–980.
13. Mueller FO, Cantu RC, Van Camp SP. *Catastrophic Injuries in High School and College Sports*. Champaign, Ill: Human Kinetics; 1996. Human Kinetics Sport Science Monograph Series, Vol. 8.
14. Maron BJ, Pelliccia A. The heart of trained athletes: cardiac remodeling and the risks of sports, including sudden death. *Circulation*. 2006;114:1633–1644.
15. Maron BJ, Gohman TE, Kyle SB, Estes NAM, Link MS. Clinical profile and spectrum of commotio cordis. *JAMA*. 2002;287:1142–1146.
16. Maron BJ, Gohman TE, Aeppli D. Prevalence of sudden cardiac death during competitive sports activities in Minnesota high school athletes. *J Am Coll Cardiol*. 1998;32:1881–1884.
17. Corrado D, Basso C, Schiavon M, Thiene G. Screening for hypertrophic cardiomyopathy in young athletes. *N Engl J Med*. 1998;339:364–369.
18. Pfister GC, Puffer JC, Maron BJ. Preparticipation cardiovascular screening for US collegiate student-athletes. *JAMA*. 2000;283:1597–1599.
19. Glover DW, Glover DW, Maron BJ. Evolution in the process of screening United States high school student-athletes for cardiovascular disease. *Am J Cardiol*. 2007;100:1709–1712.
20. Maron BJ, Douglas PS, Graham TP, Nishimura RA, Thompson PD. Task Force 1: preparticipation screening and diagnosis of cardiovascular disease in athletes. *J Am Coll Cardiol*. 2005;45:1322–1326.
21. Myerburg RJ, Estes NAM III, Fontaine JM, Link MS, Zipes DP. Task Force 10: automated external defibrillators. *J Am Coll Cardiol*. 2005;45:1369–1371.
22. Guidelines for pediatricians: sudden cardiac death (SCD). In: *Sports Shorts*. Issue No. 9, November 2002. American Academy of Pediatrics, Section on Sports Medicine and Fitness.
23. Pegula SM. Fatal occupational injuries to athletes, 1992–2002. US Department of Labor, Bureau of Labor Statistics Web site. Compensation and Working Conditions. Available at: www.bls.gov/opub/cw/sh20040719ar01pl.htm. Accessed June 19, 2004.
24. Chaitman BR. An electrocardiogram should not be included in routine preparticipation screening of young athletes. *Circulation*. 2007;116:2610–2615.
25. Myerburg RJ, Vetter VL. Electrocardiograms should be included in preparticipation screening of athletes. *Circulation*. 2007;116:2616–2626.
26. National Federation of State High School Associations. NFHS Participation Figures Search. Available at: http://www.nfhs.org/custom/participation_figures/default.aspx. Accessed December 28, 2007.
27. National Collegiate Athletic Association. NCAA Sports Sponsorship and Participation Rates Report 1981–82 – 2005–06. Available at: http://www.ncaa.org/library/research/participation_rates/1982–2006/1982_2006_participation_rates.pdf. Accessed December 28, 2007.
28. Maron BJ, McKenna WJ, Danielson GK, Kappenberger LJ, Kuhn HJ, Seidman CE, Shah PM, Spencer WH, Spirito P, ten Cate FJ, Wigle ED. American College of Cardiology/European Society of Cardiology Clinical Expert Consensus Document on Hypertrophic Cardiomyopathy: a report of the American College of Cardiology Task Force on Clinical Expert Consensus Documents and the European Society of Cardiology Committee for Practice Guidelines Committee to Develop an Expert Consensus Document on Hypertrophic Cardiomyopathy. *J Am Coll Cardiol*. 2003;42:1687–1713.
29. Basso C, Maron BJ, Corrado D, Thiene G. Clinical profile of congenital coronary artery anomalies with origin from the wrong aortic sinus leading to sudden death in young competitive athletes. *J Am Coll Cardiol*. 2000;35:1493–1501.
30. Thiene G, Nava A, Corrado D, Rossi L, Pennelli N. Right ventricular cardiomyopathy and sudden death in young people. *N Engl J Med*. 1988;318:129–133.
31. Thompson PD, Levine BD. Protecting athletes from sudden cardiac death. *JAMA*. 2006;296:1648–1650.
32. Link M, Bir C, Dau N, Madias C, Estes NA III, Maron BJ. Protecting our children from the consequences of chest blows on the playing field: a time for science over marketing. *Pediatrics*. 2008;122:437–439.
33. Minino AM, Heron MP, Murphy SL, Kochanek KD. Deaths: final data for 2004. In: *National Vital Statistics Reports*. Vol 55, No 19. Hyattsville, Md: National Center for Health Statistics; 2007.
34. *Meningococcal Vaccine Information Statement (Interim)*. Atlanta, Ga: US Department of Health and Human Services, Centers for Disease Control and Prevention; October 16, 2007.
35. Lightning fatalities, injuries, and damage reports in the United States. Section 3.1. National Lightning Safety Institute Web site. Available at: http://www.lightningsafety.com/nlsi_lls/fatalities_us.html. Accessed April 13, 2006.
36. Maron BJ, Haas TS, Doerer JJ, Thompson PD, Hodges JS. Comparison of cardiovascular disease mortality in young U.S. and Italian competitive athletes: which preparticipation screening strategy is really more effective? *Circulation*. 2008;118:S1083. Abstract.
37. International Olympic Committee Medical Commission. *Sudden Cardiovascular Death in Sport: Lausanne Recommendations: Preparticipation Cardiovascular Screening*. December 10, 2004. Available at: http://multimedia.olympic.org/pdf/en_report_886.pdf. Accessed April 17, 2007.

CLINICAL PERSPECTIVE

We have estimated the absolute number of sudden deaths in US competitive athletes from a large registry assembled over a 27-year period using systematic identification and tracking strategies. A total of 1866 athletes who died suddenly (or survived cardiac arrest), 19 ± 6 years of age, were identified throughout the United States from 1980 to 2006 in 38 diverse sports. Sudden deaths were predominantly due to cardiovascular disease (1049 [56%]) but also included deaths due to blunt trauma that caused structural damage (416 [22%]), commotio cordis (65 [4%]), and heat stroke (46 [2%]). Among the 1049 cardiovascular deaths, the highest number of events in a single year was 76 (2005 and 2006), with an average of 66 per year (range 50 to 76) over the last 6 years, many of which could not have been identified reliably by preparticipation screening (even with an ECG); 29% of deaths were among blacks, 54% of victims were in high school, 82% of the deaths occurred with physical exertion during competition/training, and only 11% were female. The most common cardiovascular causes were hypertrophic cardiomyopathy (36%) and congenital coronary artery anomalies (17%). In this national registry, the absolute number of cardiovascular sudden deaths in young US athletes was relatively low, with a rate of <100 per year. These data are relevant to the current debate surrounding preparticipation screening programs with ECGs and suggest the need for systematic and mandatory reporting of sudden deaths in athletes to a national registry.