Sudden Deaths in Young Competitive Athletes

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**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.\(^1\)\(^,\)\(^3\)\(^,\)\(^5\)\(^-\)\(^14\)

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**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\(^2\)\(^,\)\(^6\)\(^,\)\(^7\)\(^,\)\(^17\)\(^-\)\(^20\) and utilization of disqualification criteria,\(^4\)\(^,\)\(^11\) as well as availability of automated external defibrillators for secondary prevention.\(^3\)\(^,\)\(^21\) 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.
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.\textsuperscript{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 Burrell’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, 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, and 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 training\textsuperscript{11} (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, histologic, and toxicologic 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 pathologic materials were selectively requested and analyzed.

Of the 1866 sudden death events, 1049 (56%) were judged to have 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 participants was assembled from the records of several sports organizations, including the National Federation of State High School Associations (41,291,690),\textsuperscript{26} the National Collegiate Athletic Association (2,288,407),\textsuperscript{27} the National Junior College Athletic Association (278,780),\textsuperscript{27} and the National Association of Intercollegiate Athletics (285,411) for high school and college athletes. The number of participants was converted to the number of participants with the correction factors suggested by Van Camp et al\textsuperscript{9} (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, skating, boxing, and team 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, football, soccer, 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.\textsuperscript{12,28} (Figure 2). Coronary artery anomalies of wrong sinus origin...
were next in frequency (119 cases [17%]). Several other cardiovascular diseases each accounted for ≥6% of the total, with the most common of these being myocarditis (41 cases [6%]), arrhythmogenic right ventricular cardiomyopathy (30 [4%]), 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 reported 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 ≥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 ($n=281$...
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 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). 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...
constitute a unique medical issue with substantial societal impact given the youthful age and apparent good general health of the victims, and are also relevant to the controversy surrounding the most efficacious and practical approach to preparticipation cardiovascular screening of large populations of athletes.

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,

### Table. Demographics of Sudden Death in Young Athletes

<table>
<thead>
<tr>
<th>Sport</th>
<th>Male, n (%)</th>
<th>Female, n (%)</th>
<th>Race, n</th>
<th>Cause of Death, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gender</strong></td>
<td>Male, n (%)</td>
<td>Female, n (%)</td>
<td>White</td>
<td>Black</td>
</tr>
<tr>
<td>Football</td>
<td>565 (30)</td>
<td>1 (0.2)</td>
<td>280</td>
<td>80</td>
</tr>
<tr>
<td>Basketball</td>
<td>405 (22)</td>
<td></td>
<td>142</td>
<td>20</td>
</tr>
<tr>
<td>Soccer</td>
<td>115 (6)</td>
<td></td>
<td>81</td>
<td>20</td>
</tr>
<tr>
<td>Baseball</td>
<td>111 (6)</td>
<td></td>
<td>95</td>
<td>11</td>
</tr>
<tr>
<td>Motor vehicle racing‡</td>
<td>104 (6)</td>
<td></td>
<td>102</td>
<td>0</td>
</tr>
<tr>
<td>Track and field</td>
<td>96 (5)</td>
<td></td>
<td>74</td>
<td>22</td>
</tr>
<tr>
<td>Wrestling</td>
<td>69 (4)</td>
<td></td>
<td>56</td>
<td>4</td>
</tr>
<tr>
<td>Boxing</td>
<td>56 (3)</td>
<td></td>
<td>21</td>
<td>19</td>
</tr>
<tr>
<td>Swimming§</td>
<td>46 (2)</td>
<td></td>
<td>43</td>
<td>1</td>
</tr>
<tr>
<td>Cross country</td>
<td>38 (2)</td>
<td></td>
<td>30</td>
<td>6</td>
</tr>
<tr>
<td>Hockey</td>
<td>29 (1.5)</td>
<td></td>
<td>28</td>
<td>1</td>
</tr>
<tr>
<td>Horse riding¶</td>
<td>27 (1.4)</td>
<td></td>
<td>21</td>
<td>1</td>
</tr>
<tr>
<td>Softball</td>
<td>22 (1.2)</td>
<td></td>
<td>19</td>
<td>0</td>
</tr>
<tr>
<td>Marathon</td>
<td>20 (1.1)</td>
<td></td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>Lacrosse</td>
<td>19 (1.0)</td>
<td></td>
<td>18</td>
<td>1</td>
</tr>
<tr>
<td>Skiing¶</td>
<td>19 (1.0)</td>
<td></td>
<td>19</td>
<td>0</td>
</tr>
<tr>
<td>Triathlon</td>
<td>17 (0.9)</td>
<td></td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>Rugby</td>
<td>16 (0.9)</td>
<td></td>
<td>13</td>
<td>2</td>
</tr>
<tr>
<td>Martial arts</td>
<td>15 (0.8)</td>
<td></td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td>Others#</td>
<td>14 (0.8)</td>
<td></td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>Rowing</td>
<td>11 (0.6)</td>
<td></td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Cycling</td>
<td>10 (0.5)</td>
<td></td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>Tennis</td>
<td>10 (0.5)</td>
<td></td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Volleyball</td>
<td>10 (0.5)</td>
<td></td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Gymnastics</td>
<td>9 (0.5)</td>
<td></td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Surfing</td>
<td>9 (0.5)</td>
<td></td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Figure skating</td>
<td>2 (0.1)</td>
<td></td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Golf</td>
<td>2 (0.1)</td>
<td></td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td>1866</td>
<td></td>
<td>1692</td>
<td>174</td>
</tr>
</tbody>
</table>

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).
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 origin20,29 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 resources2,17 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. Cardiomyopathies, which paradoxically has been reported as the most common cause of sudden death in young athletes within the Veneto region of northeastern Italy.2\textsuperscript{10,11}

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\textsuperscript{18,19,24,25} and the importance of disqualification standards.\textsuperscript{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

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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


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 from cardiovascular causes were included in this analysis. The registry included athletes of all ages and from all sports. The majority of deaths occurred during sports activities, with the highest rate of deaths occurring during competitive sports activities. The most common cause of death was hypertrophic cardiomyopathy, followed by congenital coronary artery anomalies. The registry also included data on the demographics and underlying cardiac conditions of the athletes. Over the 27-year period, the rate of sudden death in competitive athletes has remained relatively stable, with a slight increase in the rate of death among female athletes. The registry also included data on the effectiveness of preparticipation screening and the use of automated external defibrillators in preventing sudden death. Overall, the registry provides important information on the epidemiology of sudden death in competitive athletes and the impact of preparticipation screening and other interventions on preventing these deaths. 

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