A 25-Year Analysis of Athlete Mortality in the United States: Causes, Trends, and the Role of Resource Disparities

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Background: Despite advancements in preparticipation physical examinations and cardiovascular evaluations, sport-related mortality persists. This study assesses athlete mortality over 25 years, stratifying data by sport, state, cause of death, socioeconomic factors, and age.

Hypothesis: Most athlete mortality would be due to sudden cardiac death (SCD) and occurred in contact sports in low-resource communities.

Study Design: Descriptive epidemiology study.

Level of Evidence: Level 3.

Methods: A retrospective search of athlete deaths occurring during games or practice from 1999 to 2024 was conducted using an online search engine (https://www.google.com/). Inclusion criteria required deaths to be related directly to athletic activity. Unrelated cases were excluded. The socioeconomic status of athletes was determined through the area deprivation index (ADI). Poisson regression was used to compare mortality rates with respect to sport type and region.

Results: A total of 593 athlete deaths were recorded, with a mean age of 16.2 years (range, 5-43). Most deaths occurred in male athletes (92%), at the high school level (70%), and during football participation (65%). Cardiovascular events were the leading cause of death (51%), followed by neurological causes (18%), and exertional heat stroke (11%). Mortality was highest during practice (69%) and was significantly more frequent in rural areas ($P < 0.001$). States with the highest mortality rates had an average national ADI of 67.8, indicating moderate socioeconomic deprivation, while states with the lowest mortality rates had an average ADI of 43.8. Exertional heat stroke accounted for 87.5% of deaths in football and was most prevalent in the South Atlantic region ($P < 0.001$).

Conclusion: Football had the highest rate of all-cause athlete mortality, driven by cardiovascular events, traumatic brain injuries, and exertional heat stroke. Mortality was disproportionately higher in rural areas during practice.

Clinical Relevance: Higher mortality rates correlated positively with greater socioeconomic deprivation, as indicated by ADI values.

Keywords: athlete mortality; heat stroke; socioeconomic disparities; sports safety; sudden cardiac death

Athlete mortality occurs across all levels of sports, including youth, high school, collegiate, and professional athletics. In an effort to increase player safety, approximately 30 million athletes under the age of 18 years undergo annual sports physical examinationss.[11] In recent years, growing attention has been brought to sudden cardiac death (SCD) among athletes.[2,3] Consequently, stringent screening guidelines, preparticipation physical examinations (PPE), and cardiovascular screening are performed routinely.[8,26] These guidelines include the National Collegiate Athletic Association

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(NCAA) requiring that all student-athletes and athletic personnel undergo PPE before participation in sports-related activities. However, these guidelines do not give a specific purpose for which the examination is done, nor do they require that the examination be completed or reviewed by a team physician.[23] The PPE includes a detailed medical history, with particular focus on both personal and family history of cardiovascular symptoms and disease. The physical examination portion focuses on identifying cardiovascular findings that increase risk for SCD.[19]

Common noncardiac causes of athlete mortality include exertional heat stroke, traumatic brain injury (TBI), and respiratory complications.[8] It is important to evaluate these causes as they are often related to sport-specific environments or mechanisms of injury. While previous studies have reported on the incidence of SCD in athletes, no study to date has focused on all-cause, sport-related, athlete mortality across various levels of competition in the United States (US).

The primary purpose of this study was to categorize and quantify the causes of athlete mortality over a 25-year period. The secondary purpose of the study was to evaluate resource allocation to each region where athlete mortality occurred, using the Area Deprivation Index (ADI)—a validated quantitative metric that measures the access to resources of a region.[16,28] We hypothesized that a majority of athlete mortality was due to SCD and occurred in contact sports in low-resource communities.

METHODS

Search Strategy

An online search engine (https://www.google.com/) was queried in October 2024 to locate publicized cases of athlete sport-related mortality from January 1, 1999 to September 30, 2024. The search strategy utilized the following keywords: "athlete death in-game," "athlete death during practice," and "athlete mortality in-sport," followed by the desired year. Another strategy was to start the search with the desired sport (football, basketball, soccer, baseball, etc), followed by "death in-sport/practice/game," and the desired year. Example search lines were: "Athlete death in-game 2024," "Football death in-sport 2023," and "Soccer mortality in-practice 2023." Additional details outlining the full search strategy are available in the Supplemental Information (available in the online version of this article).

Inclusion/Exclusion Criteria

Cases were included if symptom onset leading to athlete mortality occurred during sports-related activity (ie, games or practice), or if death resulted from symptoms that originated during such activity and persisted. Cases were excluded if the cause of death was unrelated to sports participation.

Data Verification

Searches were performed by 3 independent reviewers and cross-referenced to ensure there were no duplicate cases. Disputes were then resolved by a fourth independent reviewer. The included cases were then verified against reported data from the National Center for Catastrophic Sport Injury Research (NCCSIR).[22] Cases were also verified by a panel of board-certified physicians to confirm the cause of death and relation to sport per inclusion and exclusion criteria. Cases that were not also found in the NCCSIR database were excluded. The urbanization status of the location of death was determined using data from the US Census.[34]

Database Creation

Data regarding each death were recorded in a database and included the athlete's reported name, date of incident, cause of death, age, race, sex, sport played, level of sport (youth, high school, college, professional), environment (game or practice), state and city where incident occurred, address of institution they played for (when applicable), and the state and national ADI of the institution they played for. The most common cause of death (heat stroke) was further stratified by various US regions. The rate of the most common cause of death (heat stroke) in football players was determined using US census data of football participants in each state across our 25-year sample.[24,31]

ADI Calculation

The ADI is a validated, quantitative metric that evaluates the socioeconomic conditions and access to resources in a region. This calculation was used due to its extensive validation as well as a specific focus on socioeconomic disadvantage. Other calculators, such as the Social Vulnerability Index (SVI), are calculated at the census tract level, which could miss important variations in socioeconomic conditions that can be captured by the ADI's smaller look at the census block group level.[1,29] ADI is calculated based on 4 main categories: income, education, employment, and housing quality. ADI values for a given US census block group are presented as a state decile (0-10) and national percentile (0-100). An ADI value closer to 0 indicates an affluent area with minimal deprivation, a value in the 5th decile and 50th percentile indicates an average level of deprivation, and values >5 and >50 indicate higher levels of socioeconomic deprivation.[16,28] In this study, the athlete's home institution address was used to calculate ADI. The home institution is where each athlete practices and competes a majority of the time. This location would be where screening and safety training protocols would be implemented. Therefore, each athlete's respective ADI was calculated by entering these addresses into the "Neighborhood Atlas" database.[16]

Statistical Analysis

Mortality rates were calculated separately for each sport and US Census region over the study period. The general US population was used as the denominator to calculate death rates from 1999

to 2024. The general US population obtained from US Census data was used to allow for standardization of the population across states and years. For sports with available participation data, specifically football, basketball, and soccer, the athlete participation numbers were obtained from publicly available reports and used to compute sport-specific mortality rates between 2010 and 2023—the timeperiod for which sports-specific data were available. To compare mortality rates across sports and years with available participation data (2010-2023), Poisson regression models were constructed using SAS Version 9.4 (SAS Institute). The number of athlete deaths served as the dependent variable, and the athlete participation count for each sport was included as an offset term to account for differing exposure levels. Sport type (football, basketball, soccer) and year were included as independent variables, with year treated as a categorical covariate. Relative risk (RR) between sports was calculated with soccer as the reference group, as it had the lowest mortality rate per million participants and provided a baseline for comparison of adjusted rate ratios.

To compare mortality rates across sports and geographic regions, Poisson regression models were constructed using SAS Version 9.4 (SAS Institute). The number of deaths served as the dependent variable, with the general population count used for population size. Independent variables included sport type, geographic region, and year (treated as a categorical variable). RR was also calculated to compare rural versus urban athlete deaths for each sport, with the general population of rural and urban areas used for population size. The RR of exertional heat stroke-related deaths among football players was calculated by region using the population of players in those regions. The South Atlantic region served as the reference group because it had the highest mean number of deaths during the study period.

A simple linear regression was performed with year as a continuous independent variable and athlete deaths per 100 million participants as the dependent variable. The coefficient of determination (R^2) was calculated to quantify the proportion of annual variance in deaths explained by time. This analysis was conducted solely for descriptive purposes and was distinct from the Poisson regression models used to evaluate mortality rates across sports and regions.

RESULTS

Demographic Data

A total of 583 cases of athlete mortality were recorded from January 1, 1999 to September 30, 2024. Mean age at the time of death was 16.2 ± 3.2 years (range, 5-43). There were significantly more cases of male (n = 547) than female (n = 47; $P < 0.001$) mortality. Athlete death occurred most often in high school athletes, with 413 (69.6%) cases recorded. Cases also occurred more commonly in practice (69%). Of the cases that occurred in-game, a larger proportion occurred during home games (43.5%) compared with away games (23.7%), with 32.8% of cases lacking documented location information. Further demographic data can be found in Table 1.

Table 1. Demographic data

	Total	
	n	%
Total	593	100.0
Age, years		
≤12	47	7.9
13-15	166	28.0
16-18	292	49.2
19-21	61	10.3
22-25	17	2.9
≥26	8	1.3
Unknown	2	0.3
Sex		
Female	46	7.8
Male	547	92.2
Race		
Black	224	37.8
White	238	40.1
Asian	6	1.0
Hispanic	42	7.1
Other	1	0.2
Unknown	82	13.8
Level of competition		
Youth	78	13.2
High school	413	69.6
Collegiate	94	15.9
Professional	8	1.3
Environment		
Game	186	31.4
Home	81	43.5
Away	44	23.7
Location not provided	61	32.8
Practice	407	68.6

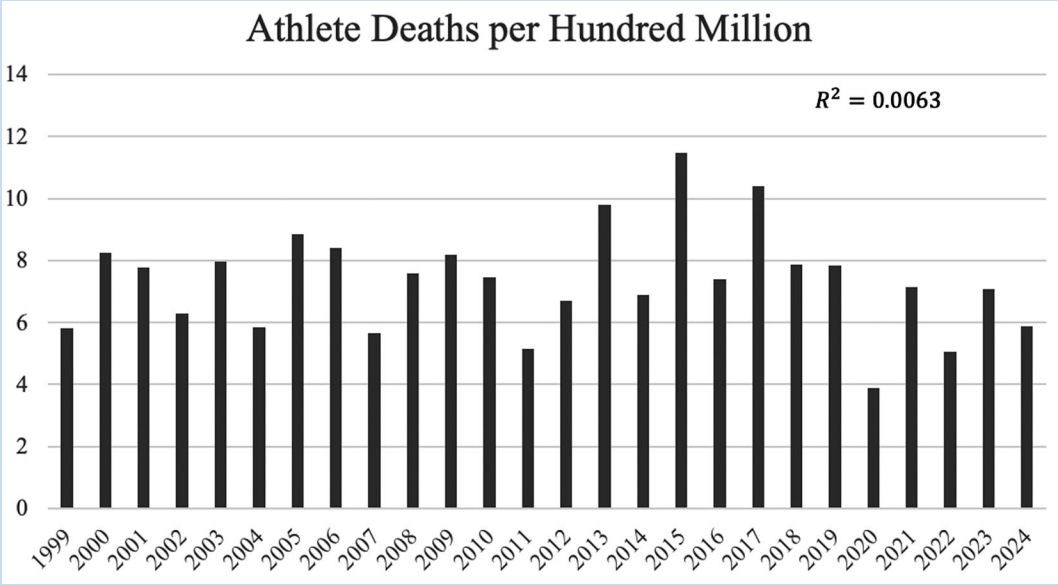

Figure 1. Total athlete deaths each year relative to US population.

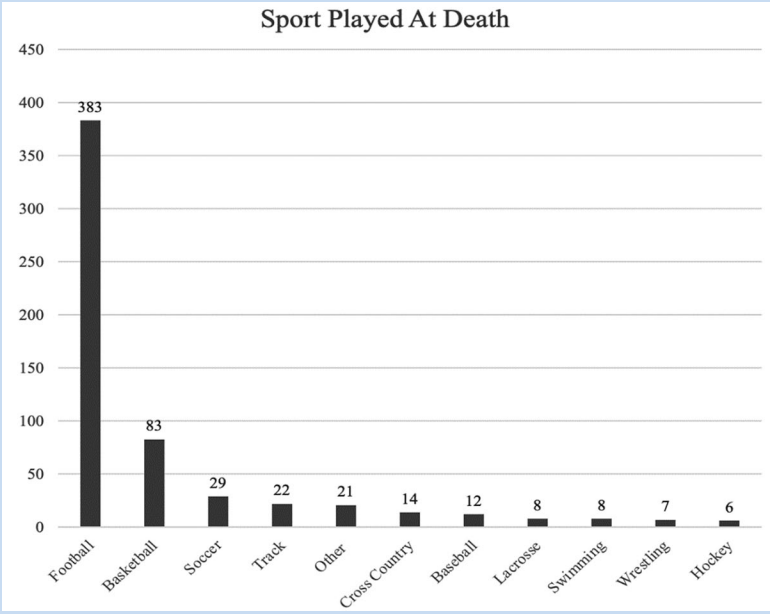

Figure 2. Sport played at time of death. Listed under 'Other': cheer (3), dance (1), field hockey (1), flag football (4), golf (1), marathon (1), mixed martial arts (1), polo (1), rowing (1), tennis (3), volleyball (2), water polo (2).

Cases Stratified by Year

The year with the highest total sport-related deaths was 2015, with 37 cases. The year with the lowest number of sport-related deaths was 2020, with 13 cases. Linear regression analysis demonstrated no significant temporal trend in athlete mortality between 1999 and 2024, with the year explaining <1% of the variation in annual deaths (R^2 = 0.0063). This indicates that the rate of athlete mortality has remained relatively stable over the 25-year period. A breakdown of yearly sport-related athlete deaths per 100 million is found in Figure 1.[30,36]

Sport Played

Football accounted for the largest number of athlete deaths in the database, with 383 (65%) cases of sport-related mortality, followed by basketball, with 83 (14%) cases, and soccer, with 29 (5%) cases. Further breakdown by specific sports played is detailed in Figure 2.

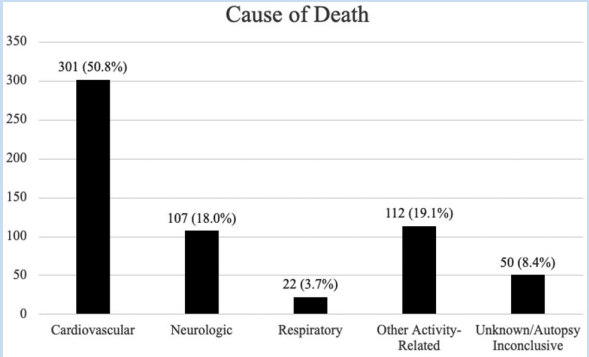

Figure 3. Cause of death among athletes.

Cause of Death

The most common cause of death was due to cardiovascular causes in 301 athletes (51%). In 50 cases (8.4%), the cause of death was unable to be determined due to an inconclusive autopsy report or the absence of a reported cause of death in news articles and obituaries. Further breakdown of the causes of death is shown in Figure 3.

Cardiovascular death was due to the following causes: sudden cardiac death, 285 (94.68%); commotio cordis, 14 (4.65%); aortic dissection, 1 (0.33%); and carotid artery dissection, 1 (0.33%) (Figure 4).

Neurologic causes of death were further stratified into the following categories: TBI, 83 (77.6%); spinal injury, 11 (10.3%); brain aneurysm, 5 (4.7%); seizure, 3 (2.8%); stroke, 2 (1.9%); arteriovenous malformation, 2 (1.9%); and brain hemorrhage, 1 (0.93%) (Figure 5).

Other sport-related causes of death were stratified into the following categories: exertional heat stroke, 65 (10.96%); sickle cell crisis, 29 (4.89%); internal organ damage, 6 (1.01%); hyponatremia, 4 (0.67%); drowning, 3 (0.51%), lightning strike, 3 (0.51%); blunt force trauma, 1 (0.17%); laceration to neck, 1 (0.17%); and traumatic diaphragm rupture, 1 (0.17%). Respiratory causes of death were further stratified into the following categories: asthma, 13 (2.19%); pulmonary embolism, 8 (1.34%); and anaphylaxis, 1 (0.17%).

Data Analysis

Football accounted for the highest number of athlete deaths, representing more than half of all reported cases across all sports, and had the greatest mortality rate when standardized per million participants. Across a 14-year sample of available data, football had an average of 2.40 ± 0.66 (SD) (95% CI, 2.047-2.746) athlete deaths per million participants.[31] Football also had more deaths per million participants than both soccer ($P < 0.001$) and basketball ($P < 0.001$). There was also a significantly higher number of deaths in basketball than in soccer ($P < 0.001$) (Table 2). After adjusting for population size, Poisson regression analysis demonstrated that football athletes had a markedly higher risk of sport-related death compared with soccer (adjusted RR, 69.6; 95% CI, 51.7-93.6; $P < 0.001$). Basketball athletes also demonstrated an elevated risk (adjusted RR, 1.83; 95% CI, 1.23-2.71; $P = 0.002$) compared with soccer. Overall, football posed the greatest adjusted risk of athlete mortality, followed by basketball, whereas soccer demonstrated the lowest rate of sport-related deaths per million participants.

Mortality Stratified by State

The overall national rate of athlete mortality over the 25-year study period was 1.83 per million people.[20,35] The 5 states with the highest mortality per million people over the 25-year study period were: Mississippi (4.44), Kansas (4.24), Georgia (3.86), West Virginia (3.85), and Oklahoma (3.48). The 5 states with the lowest mortality per million people over the 25-year study period were: New Mexico (0.50), Utah (0.72), New Hampshire (0.76), Connecticut (0.85), and Arizona (0.95). Finally, Alaska, Hawaii, Delaware, and Wyoming all recorded zero athlete deaths. Further information on cases of athlete death in each state is shown in Figure 6.

ADI and Urbanization Status

The average national ADI of the 5 states with the highest rates of athlete mortality was 67.8, indicating a moderately high level of deprivation. Conversely, the average national ADI of the 5 states with the lowest rates of athlete mortality was 43.8, indicating a relatively lower level of deprivation. Population urbanization data were also evaluated to ascertain whether each case of athlete mortality occurred in an urban or rural area. This data was based on US Census data and showed that 304 (51.3%) athlete deaths occurred in urban areas, while 289 (48.7%) athlete deaths occurred in rural areas.[34]

Further breakdown of each major sport's proportion of deaths in urban versus rural areas is found in Table 3. When urban and rural athlete deaths are compared on a per million basis using the national populations of urban and rural areas, more athlete deaths occur among rural athletes.

Rate of Exertional Heat Stroke Death in Football Athletes

Of athletes whose cause of death was exertional heat stroke, 87.5% were football players. The South Atlantic region was found to have the highest rate of death from exertional heat stroke, with 1.16 deaths per 10,000 football players. Further data for each region can be found in Table 4.

DISCUSSION

The most important finding of this study was that football had the highest incidence of all-cause, sport-related, athlete mortality over the past 25 years, with a significantly higher number of deaths than any other sport, including when adjusting per 100 million participants. With this result, we hope that more focus is given to PPE and other interventions for football in particular.

Cardiovascular causes, primarily SCD, made up >50% of deaths recorded in our study. Increasing knowledge of SCD in

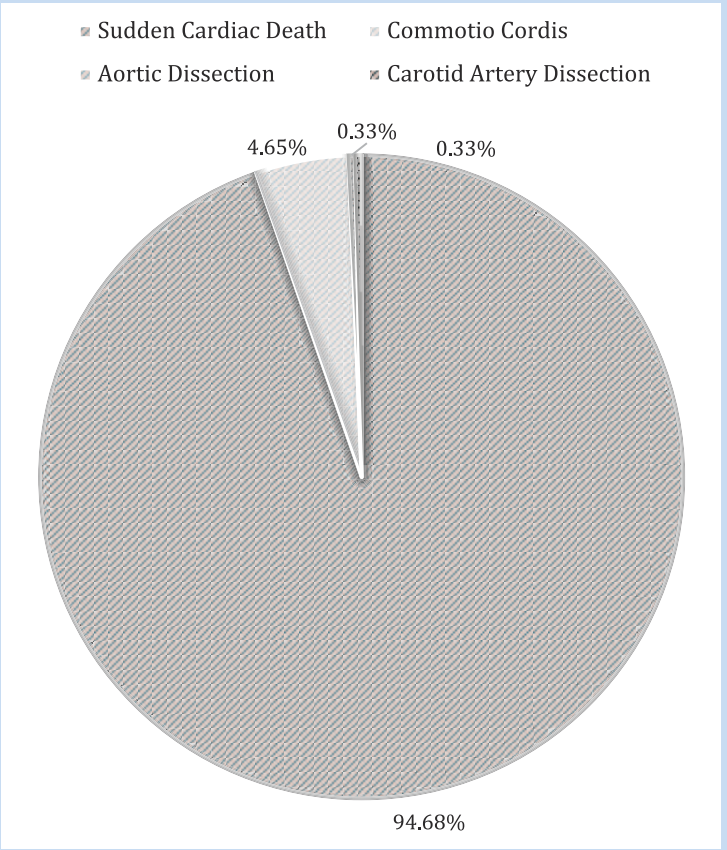

Figure 4. Cardiovascular death by type.

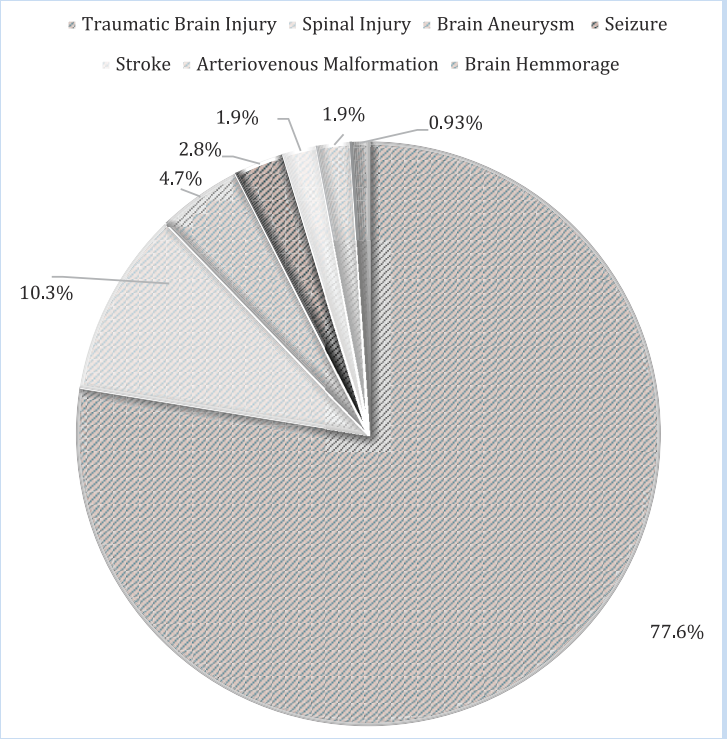

Figure 5. Neurologic death by type.

Table 2. Athlete deaths per million participants

Year	Football	Soccer	Basketball
2023	1.964	0.071	0.101
2022	1.481	0.000	0.107
2021	2.868	0.159	0.184
2020	0.990	0.080	0.072
2019	3.327	0.084	0.161
2018	2.907	0.088	0.289
2017	2.874	0.419	0.299
2016	2.190	0.084	0.269
2015	2.572	0.158	0.470
2014	2.676	0.000	0.087
2013	3.241	0.079	0.211
2012	2.412	0.000	0.084
2011	1.860	0.000	0.040
2010	2.190		0.040
	*$P < 0.001$; **$P < 0.001$	**$P = < 0.001$	

*Comparison with soccer group; ** comparison with basketball group.

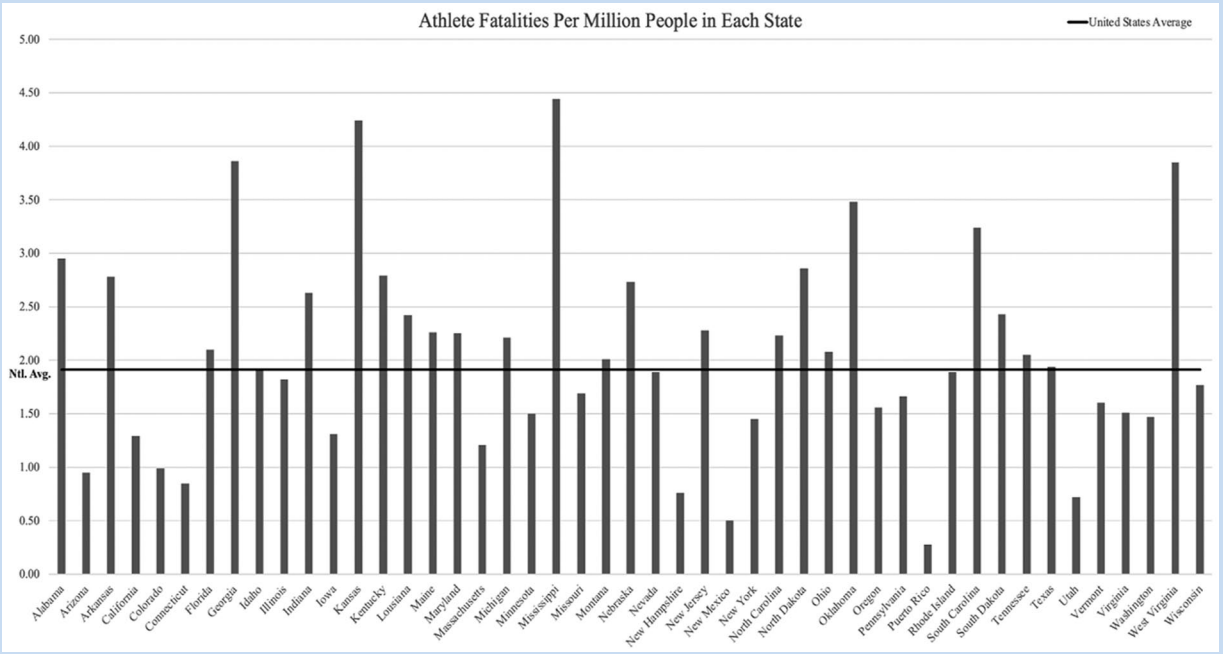

Figure 6. Athlete fatalities per million people in each state. Solid horizontal line, overall national rate of sport-related deaths among US athletes aged 12 to 25 years, calculated across the 25-year study period (1999-2024).

Table. 3 Rural and urban athlete death

	National population	Football		Basketball		Soccer	
		Deaths total	Deaths per million	Deaths total	Deaths per million	Deaths total	Deaths per million
Urban	254,679,763	187	0.73	43	0.17	15	0.06
Rural	61,862,372	196	3.17	40	0.65	13	0.21
RR, rural vs urban (95% CI)		4.32 (3.53-5.27); $P < 0.001$		3.83 (2.49-5.89); $P < 0.001$		3.57 (1.70-7.50); $P < 0.001$	

RR, relative risk.

Table 4. Region rate of exertional heat stroke death in football players

Geographic region (US states)	Heat stroke deaths in football athletes, n	Heat stroke deaths per 10,000 football athletes in each region	RR vs South Atlantic (95% CI)	*P* value
East North Central (WI, MI, IL, IN, OH)	6	0.33	0.28 (0.11-0.71)	0.008*
East South Central (KY, TN, MS, AL)	9	1.09	0.94 (0.43-2.08)	0.88
Middle Atlantic (NY, NJ, PA)	4	0.48	0.41 (0.14-1.22)	0.12
Mountain (MT, ID, WY, NV, UT, CO, AZ, NM)	1	0.14	0.12 (0.02-0.90)	0.03*
New England (ME, VT, NH, MA, RI, CT)	0	0	-	-
Pacific (WA, OR, CA, AK, HI)	3	0.22	0.19 (0.06-0.64)	0.006*
South Atlantic (MD, DE, WV, VA, NC, SC, GA, FL, PR)	19	1.16	1.00 (0.53-1.89)	>0.99
West North Central (ND, SD, MN, IA, KS, MO, NE)	6	0.62	0.53 (0.21-1.34)	0.18
West South Central (TX, OK, AR, LA)	8	0.39	0.34 (0.15-0.77)	0.01*

*Statistical significance.

athletes has led to the creation of organizations like Parent Heart Watch (PHW), which advocate for rigorous cardiovascular screening guidelines and increased levels of training for coaches and staff.[12,25,27] Individual states have also implemented legislation like the Smart Heart Act.[33] This requires that coaches and staff at all levels complete sudden cardiac arrest training, and that schools have an emergency action plan and provide a readily available automated external defibrillator on-site.[33] Other states have introduced programs such as the Safe Stars Initiative in Tennessee that recognize youth sports that adhere to high standards of safety, as well as provide resources and policies on increased safety standards.[32]

While these organizations and laws exist, there are issues with initiating a national preparticipation cardiac screening. Some studies suggest that the current PPE question set has limitations and may not impact or improve athlete outcomes significantly.[5] From an economic standpoint, implementing nationwide electrocardiogram (ECG) screening for high school athletes would be costly, estimated at US $25 to $50 million a year.[28] Furthermore, some studies have shown diagnostic screening to be ineffective and inefficient, and the American College of Cardiology and American Heart Association advise against the use of ECG and echocardiography for screening of young athletes.[17,26] Diagnostic tests are often unable to distinguish

between physiologic cardiac remodeling and hypertrophic cardiomyopathy, therefore increasing the rate of false positive results and the number of athletes undergoing unnecessary testing.[21] Therefore, as conflicting evidence on this topic exists, the efficacy of a nationwide cardiac screening program to prevent SCD remains debatable.[10,17,21] As of now, the current recommendation is to use ECG and other advanced screening tools on the basis of the perceived risk of the athletes being tested, as well as the available infrastructure to do so.[4]

A key factor that differentiates this study from others is its additional focus on noncardiac causes of death. Other sport-related causes, such as exertional heat stroke and neurologic causes, made up 19.1% and 18% of recorded cases, respectively. The rate of exertional heat stroke death was notably higher in football players (87.5%). Football players in the South Atlantic and East South Central regions experience higher rates of exertional heat stroke deaths, likely due to the hot, humid climate, outdoor activity during peak heat, and the added strain of heavy protective gear.[2,18]

A Centers for Disease Control and Prevention study stated that the leading cause of athlete mortality in the US from 2005 to 2009 was exertional heat-related illness.[9] Regional climate in cases of exertional heat stroke has been studied and led to the development of wet bulb globe temperature guidelines, which indicate temperatures at which specific athletic activities should take place.[7,14] Despite existing guidelines, adherence to them is unclear. Additional measures are essential, especially in high-risk regions.

The most common neurologic cause of death was TBI. With >96% of cases of mortality from TBI linked to football, this is likely due to a sport-specific mechanism of injury. Specific cases of TBI in football can be caused by improper tackling techniques like "spear tackling," which is when a tackle is made with the player's head in a neutral or flexed position.[15] This can increase the risk of TBI occurrences and spinal cord injuries while also being an ineffective tackling form overall.[6,15] In addition, the use of inappropriate or outdated protective equipment has also been shown to increase occurrences of TBI.[13]

Previous studies have indicated that the evaluation of ADI in athlete mortality revealed disparities between populations.[3] Therefore, less access to resources may be a key factor leading to increased rates of athlete mortality. When stratified by state, the rate of athlete mortality was highest in Mississippi, Kansas, Georgia, West Virginia, and Oklahoma. These states had a combined average ADI of 67.8, indicating a moderately high level of deprivation. Conversely, the average national ADI of the 5 states with the lowest rates of athlete mortality was 43.8, indicating a relatively lower level of deprivation and a more socioeconomically advantaged area. This finding raises the question of whether a connection exists between athlete mortality and state access to resources.

Our study shows that a significantly higher rate of athlete deaths occurred in rural areas. Many of the states with higher ADIs and rates of athlete mortality also had larger rural populations. This finding is expected as state funding to schools is often partially based on US Census urbanization data,[34] which impacts how resources are allocated to school districts. As a result, rural areas with smaller populations may receive less funding and have limited access to athletic, medical, and emergency resources compared with urban regions with higher populations. These differences could contribute to longer transfer times to Level 1 trauma centers, potentially resulting in delays for athletes in receiving appropriate levels of care when they experience life-threatening events. While data on transport times were not available, this represents an important area for further investigation to better address and understand regional differences in athlete death.

Limitations

Our study relied largely on publicly available information. Therefore, it is difficult to determine how accurate the listed cause of death is in each case. Furthermore, cases were not included if there was no news article, autopsy report, or obituary publicly available. After initial searches using publicly available information, we used NCCSIR and found 63 additional cases. While ADI is a helpful tool to assess socioeconomic deprivation, it is limited by its inability to assess differences between people in a single US census block group. In addition, ADI was also unable to evaluate additional social determinants of health, such as access to transportation, access to nutritious foods, and health literacy.[4] Finally, our paper did not look at specific causes of sudden cardiac or neurologic deaths, which accounted for a majority of the cases in our study.

CONCLUSION

This study demonstrates that football has the highest rate of all-cause athlete mortality, primarily due to cardiovascular events, TBIs, and exertional heat stroke. A significantly higher rate of athlete mortality occurred in rural areas and during practices rather than games. Finally, evaluation of ADI revealed that states with higher rates of athlete mortality also had higher average ADI values, indicating greater levels of regional socioeconomic deprivation.

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