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Cardiac Arrest During Long-Distance Running Races

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IMPORTANCE More than 29 million participants completed marathons and half-marathons in the US between 2010-2023, approximately 3 times the number from 2000-2009. Contemporary long-distance race-related cardiac arrest incidence and outcomes are unknown.

OBJECTIVE To determine the incidence and outcomes of cardiac arrests during US marathons and half-marathons between 2010-2023 from a record of race finishers and a comprehensive review of cases from media reports, direct contact with race directors, USA Track & Field claims, and interviews with survivors or next of kin.

DESIGN, SETTING, AND PARTICIPANTS Observational case series from the Race Associated Cardiac Event Registry; cohort data from US marathon and half-marathon runners from January 1, 2010, to December 31, 2023. Case profiles were reviewed to determine etiology and factors associated with survival. Incidence and etiology data were compared with historical reference standards (2000-2009).

EXPOSURE Recreational long-distance running (marathon and half-marathon distance).

MAIN OUTCOMES Incidence proportions of sudden cardiac arrest and death.

RESULTS Among 29 311 597 race finishers, 176 cardiac arrests (127 men, 19 women, 30 sex unknown) occurred during US long-distance running races. Compared with 2000-2009, cardiac arrest incidence remained unchanged (incidence rate, 0.54 per 100 000 participants [95% CI, 0.41-0.70] vs 0.60 per 100 000 [95% CI, 0.52-0.70], respectively). However, there were significant declines in cardiac death incidence (0.20 per 100 000 [95% CI, 0.15-0.26] vs 0.39 per 100 000 [95% CI, 0.28-0.52]) and case fatality rate (34% vs 71%). Cardiac arrests remained more common among men (1.12 per 100 000 [95% CI, 0.95-1.32]) than women (0.19 per 100 000 [95% CI, 0.13-0.27]) and during the marathon (1.04 per 100 000 [95% CI, 0.82-1.32]), compared with the half-marathon (0.47 per 100 000 [95% CI, 0.38-0.57]). Among runners for which a definitive cause of cardiac arrest could be determined (n = 67/128 [52%]), coronary artery disease rather than hypertrophic cardiomyopathy was the most common etiology. Decreased cardiopulmonary resuscitation time and an initial ventricular tachyarrhythmia rhythm were associated with survival.

CONCLUSIONS AND RELEVANCE Despite increased participation in US long distance running races, cardiac arrest incidence remains stable. There has been a marked decline in cardiac arrest mortality, and coronary artery disease was the most common etiology among cases with sufficient cause-related data. Effective emergency action planning with immediate access to defibrillation may explain the improvement in survival.

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Editorial
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Supplemental content

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Since 2010, there have been approximately 29.3 million finishers of marathon and half-marathon races in the US, approximately 3 times the number from 2000-2009.[1] The growing popularity of distance running has been paralleled by significant expansion in the number of available races. Increases in participation and race availability have been accompanied by the emergence of data clarifying the nature of cardiovascular pathology among endurance athletes.[2-4] Rising participation rates coupled with heightened awareness of potential cardiac risks associated with long-distance running races have generated intensification of race course medical coverage and emergency action planning.

Initial findings from the Race Associated Cardiac Event Registry (RACER) included a low overall cardiac arrest incidence rate, the identification of male marathon runners as the highest-risk subgroup, a dominant cardiac arrest etiology of hypertrophic cardiomyopathy, and an overall cardiac arrest case fatality rate of 71%.[1] Since that time, there have been advancements in cardiac case ascertainment techniques, consideration of changes in the demographics of race participants, the introduction of molecular autopsies, and more widespread availability of both bystander cardiopulmonary resuscitation (CPR) and automated external defibrillators (AEDs). The collective impact of these factors is unknown, and the contemporary incidence, etiologies, and outcomes of race-related cardiac arrest, including the potential impact of the COVID-19 pandemic, are uncertain. This follow-up study from the RACER consortium was performed to address these areas of scientific uncertainty.

Key Points

Question What is the contemporary incidence of cardiac arrest and death among marathon and half-marathon runners in the US?

Findings In this case series and cohort study from the Race Associated Cardiac Event Registry, the incidence of cardiac arrest during marathons and half-marathons has remained relatively stable since 2010, compared with 2000-2009. The risk of dying from cardiac arrest during long-distance running races has decreased by approximately 50% compared with 2000-2009.

Meaning Effective emergency action planning during marathons and half-marathons, inclusive of immediate access to defibrillation, has likely led to significant improvements in cardiac arrest outcomes, equivalent to settings with publicly accessible automated external defibrillators.

Methods

Study Overview and Design

RACER is a prospective observational case series of US marathon and half-marathon runners with a primary goal of defining the incidence proportion (using the denominator of the total number of race participants as the cohort), outcomes, and etiologies of cardiac arrest during long-distance running races. This study followed the Strengthening the Reporting of Observational Studies in Epidemiology reporting guideline.[5] Cardiac arrest case data comprising the RACER database (2000-2023) were acquired using a targeted multistep algorithm that uses public search engines as previously described[1] and summarized below. For this second analysis (2010-2023), additional case ascertainment resources not available during the first RACER study period (2000-2009)[1] were also used, including publicly accessible, comprehensive networks of race director contact information and the USA Track & Field (USATF) cardiac arrest claims database, as detailed below. The different data sources were used to build the case series rather than to cross-validate information between different sources of information.

Data contained in this RACER follow-up study represent the period beginning on January 1, 2010, and ending December 31, 2023. The prespecified data analysis period of 10 years was extended to include the COVID-19 pandemic and the return of organized long-distance running races in its aftermath. Eligible cardiac arrest cases occurred during US marathon (26.2 miles [42.195 km]) and half-marathon (13.1 miles [21.1 km]) races (from race start to finish or up to 1 hour of post-race recovery).[1,6,7] One additional case was a person who collapsed with full loss of consciousness on the race course and died in the hospital within several days due to multiorgan failure resulting from heat illness. The Emory institutional review board approved all aspects of this study, and procedures for informed consent are detailed below.

US Marathon and Half-Marathon Participation, 2010-2023

Running USA, a nonprofit running trade organization, provided annual marathon and half-marathon participation statistics. In contrast to the first RACER study, these data are internal and not public. Data were obtained and verified through Athlinks, an established running results database of official US recreational road race finishing times (including all certified marathons and half-marathons), and included the total number of finishing times in US marathons and half-marathons and self-reported runner sex/gender (male, female, nonbinary).

Identification of Races

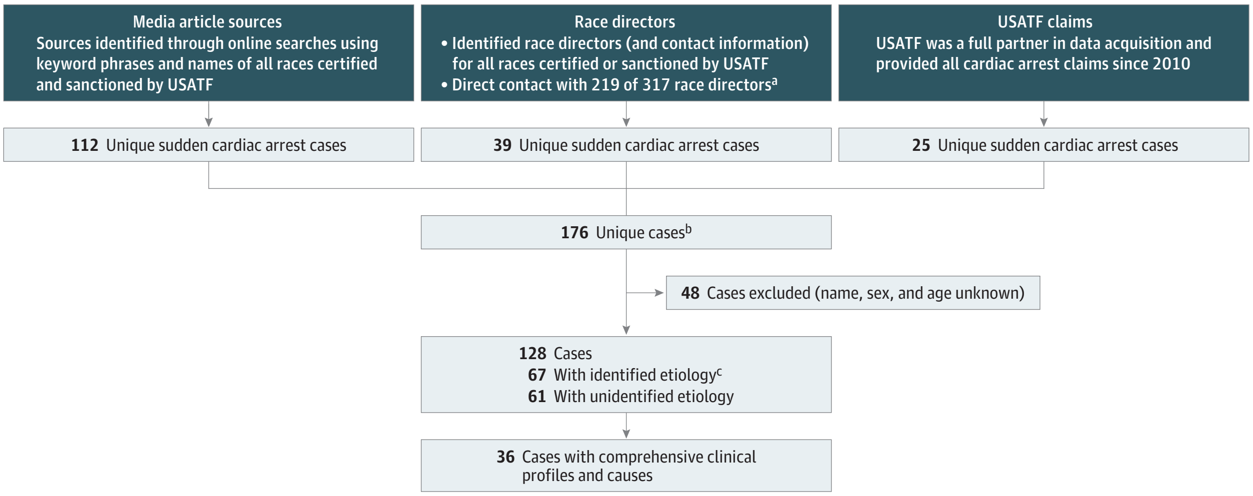
Marathons and half-marathons certified and sanctioned by the USATF were identified through extensive internet searches from relevant websites (https://marathonguide.com, https://www.halfmarathons.net). The USATF affirmed the accuracy of these identified marathons and half-marathons and provided names of additional eligible races. A total of 443 US marathons and half-marathons were included (eTable 1 in Supplement 1).

Identification of Cardiac Arrests

Cardiac arrest was defined as a pulseless unconscious state documented by a medical professional. Decedents were defined as persons not successfully resuscitated in the field or who died before hospital discharge. Survivors were defined as persons who were successfully resuscitated and subsequently discharged from the hospital.

Acknowledging the strength of numerous methods to identify cases,[8] we used 3 mechanisms (**Figure 1**). First, identical to the first RACER analysis,[1] intensive searches using public search engines (Google, Yahoo) were conducted. Specific keywords and phrases (*marathon death*; *marathon fatality*; *sudden cardiac death, marathon/half-marathon*; and *sudden cardiac arrest,*

Figure 1. Identification of Cardiac Arrests and Cohort Creation



USATF indicates USA Track & Field.

[a]Ninety-eight race directors did not respond to outreach or opted out of study assistance.

[b]N = 56 cases confirmed by 2 sources, none by all 3 sources.

[c]Confirmed etiologies by media report and comprehensive clinical profile (n = 36) or media report in isolation (n = 31).

marathon/half-marathon) were entered along with all 443 identified races and the specific years of interest. Cardiac arrest information, if available, including name, age, location, cause, and outcome (survival or death), was recorded. Second, new to this analysis, we attempted to contact all 317 respective race directors (many race directors oversee >1 race). Contacted race directors (219/317 [69%]) were asked (1) Were there cardiac arrests in your race(s) during 2010-2023; (2) If so, did the runner(s) survive; and (3) What year(s) did the event(s) occur. Last, also new to this analysis and through USATF, we identified cases filed as cardiac arrest claims between 2010-2023. USATF event organizers file incident reports for injuries occurring during USATF-sanctioned events. These claims, which included the year and outcome, are used in the mediation of actions between the injured party and the USATF insurance carrier.

Cardiac Arrest Causes and Clinical Profiles of Runners

Cardiac arrest causes were determined with methodology similar to that of the first RACER analysis.[1] First, all available media reports were reviewed for clear, identifiable causes in identified cases (n = 67). Additional search keywords included the name of the runner (if available). Etiologies were recorded if the reported diagnosis was definitive. For example, "hypertrophic cardiomyopathy," "anomalous coronary arteries," or "heat stroke" as stated causes in media reports were acceptable. "Coronary artery disease," "acute plaque rupture," and/or "coronary stent placement" in media reports were recorded as coronary artery disease. If media reports clearly disclosed that diagnostic testing or autopsy was inconclusive (autopsy-defined sudden arrhythmic death),[9] we recorded the etiology as unexplained. Unclear reported diagnoses, such as "heart attack," were not recorded. Second, for all publicly reported names, we searched for mailing addresses (including email) for survivors or next of kin. Letters including a formal study description, opt-out form, medical release form, and study staff contact information for consenting respondents, were sent. Respondents (n = 36) were queried about the cardiac arrest cause and details, demographic information, running/exercise history, and personal/family medical history. Information regarding emergency care, autopsy report (if applicable), and other pertinent medical records was obtained. Etiologies were matched to the respective media report(s) for the individual to affirm accuracy. Final cardiac arrest causes were adjudicated by 2 study investigators (J.H.K., A.L.B.). Last, new to this analysis, we established a Facebook page (established September 2023), which led to 1 person who experienced race-related cardiac arrest contacting the study team for a subsequent interview.

Statistical Analysis

Incidence proportions for cardiac arrest (also stratified by sex and race distance) and death were calculated as the number of events divided by the number of participants for the stated time interval, and 95% CIs for event rates were derived using Poisson distribution. An additional sensitivity analysis was performed to calculate the incidence proportion of cardiac arrest and death using only cases for which media reports were available (n = 165/176) (eTable 2 in Supplement 1). Sex was missing in 30 cases and race distance in 10 cases (marathon/half-marathon occurred on same day and course). In these cases, variables were assigned based on observed differences in the prevalence of sex and race distance in the total cohort (eTable 3 in Supplement 1). With regard to sex, for which men were approximately 86% predominant, sensitivity analyses were then conducted in which women were estimated at 25% and 50% of the missing cases. With regard to race distance, for which the half-marathon was approximately 70% predominant, a sensitivity analysis was conducted in which half-marathon was estimated at 50% (eTable 4 in Supplement 1). Poisson regression

Table 1. Baseline Characteristics of US Marathon and Half-Marathon Participants, 2010-2023, and Summary of Cardiac Arrests

Characteristics	Participants, No. (%)
Race participants	n = 29 311 597
Male	13 046 223 (44.5)
Female	15 871 153 (54.2)
Nonbinary	394 221 (1.3)
Marathon	6 806 683 (23.2)
Half-marathon	22 504 063 (76.8)
Cardiac arrests	n = 176
Deaths	59/176 (34)
Confirmed cardiac arrests[a]	
Men	127/146 (87)
Women	19/146 (13)
Marathon	66/166 (39.8)
Half-marathon	100/166 (60.2)

[a] Case numbers include only confirmed cases. N = 30 cases with sex unknown and n = 10 races with race distance unknown.

was used to compare cumulative incidence rates across separate time intervals between 2010-2023, between full and half-marathon, and between men and women, using the number of participants in the corresponding time interval as the offset.

To identify factors associated with survival or death, we analyzed a subset of individuals with available individual-specific data. Continuous variables are presented as means (SDs) and categorical variables as proportions. Cardiopulmonary resuscitation time and initial cardiac rhythm were individually associated with the outcome; thus, risk ratios for these variables were estimated using Poisson multivariable regression with standard error estimated via sandwich/robust variance estimator, which was used to correct for variance misspecification in Poisson regression (assumes equal variance and mean). All statistical analyses were performed using R version 4.3.1 (R Foundation). $P \leq .05$ was considered statistically significant.

Results

Cardiac Arrest and Death

US marathon and half-marathon finishers between 2010-2023 totaled 29 311 597 (**Table 1**). Among 176 cardiac arrests (1 per 166 667 participants, 0.60 per 100 000 [95% CI, 0.52-0.70]), there were 59 deaths (1 per 500 000 participants 0.20 per 100 000; 95% CI, [0.15-0.26]) and 117 survivors (66%) (**Figure 2**). Sensitivity analyses inclusive of only cases with media reports demonstrated similar cardiac arrest proportions (eTable 2 in Supplement 1). Cardiac arrest proportions were stable between 2010-2014 (0.54 per 100 000 [95% CI, 0.41-0.68]) and 2015-2019 (0.58 per 100 000 [95% CI, 0.45-0.73]) but increased significantly in 2020-2023 (0.81 per 100 000 [95% CI, 0.58-1.10]). In contrast, case fatalities were lower during 2015-2023 (25% [95% CI, 17%-36%]) compared with 2010-2014 (48% [95% CI, 32%-68%]) ($P = .01$). Compared with historical data from 2000-2009,[1] the absolute case fatality proportion during 2010-2023 was significantly decreased (71% vs 34%, $P < .001$).

Cardiac Arrest Incidence by Sex and Race Distance

A total of 127 men, 19 women, and 30 individuals with unknown sex (n = 26/30 presumed men, n = 4/30 presumed women) experienced cardiac arrest. Cardiac arrest proportion was higher among men (1.12 per 100 000 [95% CI, 0.95-1.32]) compared with women (0.19 per 100 000 [95% CI, 0.13-0.27], $P < .001$) (Figure 2). Sensitivity analyses still affirmed higher risk among men (eTable 3 in Supplement 1). Among male marathon runners, cardiac arrest proportion increased in 2020-2023 (2.79 per 100 000 [95% CI, 1.73-4.26]) compared with 2010-2014 (1.65 per 100 000 [95% CI, 1.08-2.42]) and 2010-2019 (1.43 per 100 000 [95% CI, 0.88-2.21]). Overall, cardiac arrest proportion among male marathon runners was 1.80 per 100 000 (95% CI, 1.39-2.28).

Cardiac arrests occurred in 100 half-marathons and 66 marathons. Race distance could not be determined for 10 cardiac arrest cases (n = 7 presumed half-marathons, n = 3 presumed marathons). Cardiac arrest proportion was higher during marathons (1.04 per 100 000 [95% CI, 0.82-1.32]) compared with half-marathons (0.47 per 100 000 [95% CI, 0.38-0.57], $P < .001$) and in sensitivity analyses (Figure 2; eTable 4 in Supplement 1).

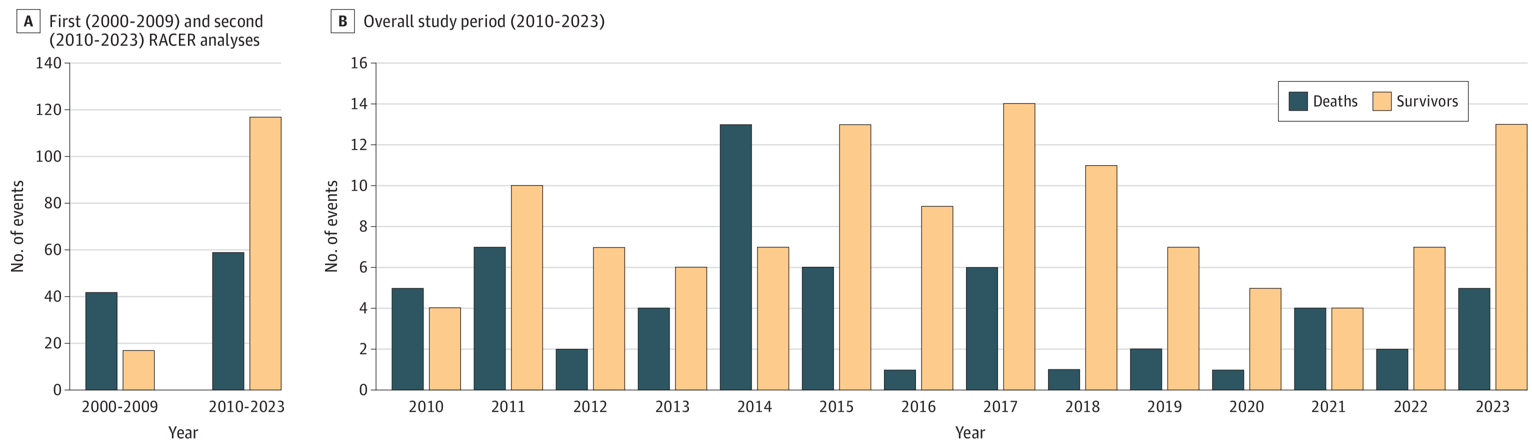
Cardiac Arrest Etiologies

Of 176 cardiac arrests, 48 were unidentified (no name, age, or sex) individuals. Among 128 identified individuals with available information (n = 77 survivors and n = 51 decedents), survivors were older (mean, 47.6 [SD, 15.1] vs 34.4 [SD, 12.9] years, $P < .001$), but there were no differences comparing survivors and decedents by sex (91% male and 9% female vs 84% male and 16% female, $P = .39$) or race distance (60% half-marathon and 40% full marathon vs 59% half-marathon and 41% full marathon, $P > .99$). The etiology of cardiac arrest was available in 67 cases (52%) (**Table 2**). The most common cause was coronary artery disease (27/67 [40%]; 25/27 survivors [93%]), followed by unexplained (17/67 [25%]; 8/17 survivors [47%] and 9/17 decedents [53%]). Hypertrophic cardiomyopathy was uncommon (5/67 [7%] with 3 survivors [1 survivor with additional myocardial bridging] and 2 decedents). Exertional heat stroke accounted for 4 of 67 cardiac arrests (6%), with 3 decedents and 1 survivor (also with incidental myocardial fibrosis).

Runners With Comprehensive Clinical Profiles

Comprehensive etiologies were available for 36 people (19 survivors, 17 next of kin) (**Table 3**). Among coronary artery disease cases (n = 9), both acute plaque rupture and stable disease were reported. For autopsy-defined sudden arrhythmic death (n = 7),[9] samples were sent for postmortem genetic testing in 4 of 7 cases, and 3 demonstrated variants of uncertain significance in cardiomyopathy genes. Postmortem toxicologic testing revealed the presence of stimulants (caffeine, amphetamines, and/or pseudoephedrine) in 4 decedents (n = 3 unexplained, n = 1 arrhythmogenic cardiomyopathy). Descriptive characteristics, including the location of cardiac arrests, are reported in the eTable 5 in Supplement 1. Bystander CPR was performed in all 36 cardiac arrests, and AED unavailability (n = 3 [8%]) occurred only among decedents. In multivariable analysis, increased CPR time (risk ratio, 1.2 [95% CI,

Figure 2. Cardiac Arrest and Death Totals Also Stratified by Sex and Race Distance, and Incidence Estimates for Cardiac Arrest and Death During Marathons and Half-Marathons in the US



	2000-2009	2010-2023	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Sudden cardiac death and survivor case totals[a,b]																
Total death	42	59	5	7	2	4	13	6	1	6	1	2	1	4	2	5
Total survivors	17	117[c]	4	10	7[c]	6[c]	7[c]	13[c]	9[c]	14[c]	11[c]	7	5	4	7[c]	13[c]
Sudden cardiac arrest totals by sex and race distance																
Total	59	176	9	17	9	10	20	19	10	20	12	9	6	8	9	18
Men	51	127[d]	7	16	7	7	12	12	6	16	4	7	6	7	5	15
Women	8	19[d]	0	1	0	1	5	2	2	1	3	1	0	1	1	1
Imputed cases (men, women)	NA	26, 4	2, 0	0, 0	1, 1	2, 0	3, 0	4, 1	2, 0	2, 1	5, 0	1, 0	0, 0	0, 0	3, 0	1, 1
Marathon	40	66[d]	5	7	3	3	7	6	3	8	4	0	2	5	3	10
Half marathon	19	100[d]	4	10	4	6	11	13	6	11	7	9	4	3	5	7
Imputed cases (marathon, half-marathon)	NA	3, 7	0, 0	0, 0	0, 2	0, 1	1, 1	0, 0	1, 0	0, 1	0, 1	0, 0	0, 0	0, 0	1, 0	0, 1
All marathon and half-marathon race participants, No. per 100 000[e]																
Total	108.7	239.1	20.00	22.37	24.69	26.35	27.63	26.73	25.93	23.96	22.65	22.27	6.85	10.29	15.78	17.62
Marathon-total No.	39.5	68.07	5.4	5.76	5.37	5.85	5.98	5.61	5.51	5.20	5.22	5.11	1.83	2.62	4.03	4.59
No. of men, No. of women	24.09, 15.41	37.25, 28.58	3.03, 2.12	3.21, 2.25	2.99, 2.18	3.26, 2.44	3.27, 2.50	3.04, 2.36	2.34, 3.01	2.84, 2.18	2.87, 2.19	2.87, 2.08	1.01, 0.77	1.51, 1.06	2.32, 1.63	2.69, 1.81
Half marathon-total No.	69.22	225.05	14.60	16.62	19.33	20.49	21.64	21.11	20.42	18.76	17.43	17.16	5.03	7.67	11.75	13.03
(No. of men, No. of women)	33.23, 35.99	93.19, 130.13	5.94, 8.56	6.72, 9.79	7.88, 11.35	8.06, 12.30	8.40, 13.11	8.45, 12.48	8.18, 12.02	7.68, 10.92	7.35, 9.94	7.48, 9.55	2.18, 2.71	3.48, 4. 14	5.33, 6.36	6.06, 6.90
Incidence of sudden cardiac arrest, No. per 100 000 (95% CI)			2010-2019										2020-2023			
Total sudden cardiac arrest	0.54 (0.41-0.70)	0.60 (0.52-0.70)	0.56 (0.47-0.66)										0.81 (0.58-1.10)			
Marathon[f]	1.01 (0.72-1.38)	1.04 (0.82-1.32)	0.91 (0.67-1.20)										1.61 (1.00-2.46)			
Half-marathon[f]	0.27 (0.17-0.43)	0.47 (0.38-0.57)	0.45 (0.36-0.56)										0.53 (0.33-0.82)			
Male sex[g]	0.90 (0.67-1.18)	1.12 (0.95-1.32)	1.04 (0.85-1.25)										1.46 (1.03-2.03)			
Female sex[g]	0.16 (0.07-0.31)	0.19 (0.13-0.27)	0.19 (0.12-0.28)										0.20 (0.06-0.46)			
Incidence of sudden cardiac death, No. per 100 000 (95% CI)	0.39 (0.28-0.52)	0.20 (0.15-0.26)	0.19 (0.14-0.26)										0.24 (0.12-0.42)			

NA indicates not applicable; RACER, Race Associated Cardiac Event Registry.

[a] All cases were identified by media reports except those identified through USA Track & Field. [b] Includes cases identified by race director. [c] Includes cases identified by USA Track & Field. [d] Case number presented represents the confirmed cases and not inclusive of the imputed cases. [e] Participant totals include men, women, and nonbinary. [f] In the 10 cases with unknown race distance, in the specific years with unknowns, race distance was assigned based on race distance-difference observations in the other 166 cases. [g] In the 30 cases with unknown sex, in the specific years with unknowns, sex was assigned based on sex-difference observations in the other 146 cases. Additional sensitivity analyses were also performed.

Table 2. Confirmed Etiologies of Cardiac Arrest and Death for Identified Runners During US Marathons and Half-Marathons, 2010-2023 (N = 67/128, 53%)

Diagnosis	No. (%) Survivors (n = 45)	No. (%) Decedents (n = 22)
Coronary artery disease	25 (56)[a,b]	2 (9)[a,b]
Unexplained/autopsy-defined sudden arrhythmic death[c,d]	8 (18)[a]	9 (41)[a]
Anomalous coronary artery	3 (7)[a]	2 (9)[a]
Anomalous coronary artery[e]	1 (2)[a]	0
Aortic stenosis	1 (2)[a]	0
Bicuspid aortic valve	1 (2)[a,b]	0
Brugada syndrome	1 (2)[a]	0
Hypertrophic cardiomyopathy	1 (2)[a]	2 (9)[a]
Hypertrophic cardiomyopathy[f]	1 (2)[a]	0
Possible hypertrophic cardiomyopathy[g]	1 (2)[a]	0
Spontaneous coronary artery dissection	1 (2)[a]	0
Heat stroke[h]	1 (2)[a]	0
Heat stroke	0	3 (14)[a]
Dilated cardiomyopathy	0	1 (5)[a]
Arrhythmogenic cardiomyopathy	0	1 (5)[a]
Fibromuscular dysplasia	0	1 (5)[a]
Hyperkalemia	0	1 (5)[a]

[a] Participant(s) identified through media reports.

[b] Participant(s) identified through race directors.

[c] Unexplained cases among survivors came after comprehensive clinical evaluations generally consisting of 12-lead electrocardiogram, cardiac imaging, coronary imaging, exercise testing, electrophysiological testing, and/or genetic testing and still without a definitive cause.

[d] Autopsy-defined sudden arrhythmic death came after autopsies had completely normal cardiac findings, nonspecific cardiac findings (incidental mild myocardial fibrosis), or abnormal cardiac findings deemed unlikely to be directly related to the outcome (bicuspid aortic valve without severe valve calcification and degeneration and no aortopathy).

[e] Anomalous coronary artery origin with an additional myocardial bridge.

[f] Hypertrophic cardiomyopathy with an additional myocardial bridge.

[g] Possible hypertrophic cardiomyopathy included mild left ventricular hypertrophy (13-mm wall thickness), lack of apical wall thickness tapering, and presence of myocardial fibrosis.

[h] Exertional heat stroke with additional, unexplained myocardial fibrosis.

Percentages are respective for identified survivors or decedents.

1.1-1.4] per 5 minutes; *P* = .001) and an initial rhythm of pulseless electrical activity/asystole (risk ratio, 2.5 [95% CI, 1.4-4.6]; *P* = .003) were independently associated with death.

Discussion

These data indicate that proportions of cardiac arrest incidence among long distance runners have been relatively stable over the last 2 decades (2000-2009: 1 per 185 185[1] and 2010-2019: 1 per 172 413) but have increased slightly since 2020 (1 per 123 457). Cardiac arrest risk among men and at the marathon distance remains higher compared with women and half-marathons, respectively. Among the highest-risk demographic, male marathon runners,[1] the cardiac arrest incidence proportion was stable between 2010-2019 (1 per 64 516) compared with 2005-2009 (1 per 49 261) but has also increased since 2020 (1 per 35 482). Despite relative stability in cardiac arrest risk over time, risk of cardiac death during marathons and half-marathons has declined markedly by approximately 49% (1 per 256 410 vs 1 per 500 100) since 2010.[1] The predominant cause of cardiac arrests is coronary artery disease, which is most common among older runners, and not hypertrophic cardiomyopathy. Appreciating that the demographics of race participants appear constant over time, these results suggest that improvements in emergency action planning, particularly universal application of bystander CPR and near-immediate deployment and use of AEDs, have positively affected outcomes of cardiac arrest during long-distance racing.

These findings provide several new insights into race-related cardiac arrests. Cardiac arrest risk estimates (1 per 166 667 participants), which include the higher-risk demographics of men (1 per 89 286) and the marathon race distance (1 per 96 154), are still lower when compared with an analogous athletic population, recreational triathletes (1 per 57 471 participants).[10] Triathlons, in addition to the unique stresses of swimming, typically involve high-intensity exercise surges compared with more consistent moderate-intensity efforts during long-distance running. The importance of exercise intensity as a determinant of cardiac arrest risk is supported by the observation in this study that most cardiac arrests occurred during the last quartile of races, when runners often increase intensity when approaching the finish line. Aligned with prior RACER data,[1] this risk was highest among male marathon runners with ischemic heart disease. These observations suggest that primary cardiac preventive care among older, recreational distance runners may be inadequate and an important area of consideration in the clinical setting.

Reasons for the slight increase in cardiac arrest incidence proportion after 2020 are unknown. Clinical myocarditis after SARS-CoV-2 infection among competitive athletes is not common.[11-13] Myocarditis was not observed in this study as the cause of cardiac arrest among cases with clinical profiles available (n = 12) between 2020 and 2023. While speculative, a plausible explanation may be decreased health care utilization during the COVID-19 pandemic, which affected many generally healthy people,[14] leading to reduced detection and treatment of occult cardiovascular disease. As long-distance race participation continues to approach prepandemic levels, it is unknown how clinical characteristics and medical and running histories of marathon and half-marathon participants have changed. Ongoing longitudinal epidemiologic assessments with consideration of race participant characteristics warrant further attention.

These data provide hypothesis-driving insights into the risk of cardiac death during long distance running races and the importance of race medical planning. Among runners analyzed in RACER from 2000-2009, 58% and 48% of individuals experiencing cardiac arrest received bystander CPR and on-scene AED use, respectively.[1] In contrast, between 2010-2023 and among runners with complete clinical profiles available for review, immediate bystander CPR was provided to all, and there was near-universal use of AEDs. Critical aspects of medical race planning include CPR education and the strategic placement of AEDs along the race courses

Table 3. Confirmed Etiologies of Cardiac Arrest or Death in US Marathon and Half-Marathon Runners With Comprehensive Clinical Profiles (N = 36)

Participant No.	Age range, y	Sex	Autopsy findings and/or cardiac arrest cause	Additional clinical and/or autopsy findings
Participants who died				
1	50-55	Male	Coronary artery disease	Acute 100% occlusion/acute plaque rupture of prior saphenous vein graft to posterior descending artery
2	45-50	Male	Dilated cardiomyopathy	No postmortem samples sent for genetic tests No coronary artery disease Left ventricular mass 500 g with no myocardial necrosis
3	45-50	Male	Hyperkalemia (7.2 mEq/L)	Normal cardiac imaging findings and coronary anatomy
4	40-45	Male	Arrhythmogenic cardiomyopathy	Fatty infiltration in the right ventricular myocardium Toxicology results positive for pseudoephedrine
5	35-40	Male	Coronary artery disease	Right coronary artery stenosis: 70%-80% Left anterior descending artery stenosis: 40%-50% First diagonal stenosis: 90%-95% No thromboses (stable coronary artery disease)
6	30-35	Male	Autopsy-defined sudden arrhythmic death	No cardiac findings by autopsy
7	30-35	Male	Exertional heat stroke	Race temperature, 72 °F; 100% humidity
8	25-30	Male	Autopsy-defined sudden arrhythmic death	No cardiac findings by autopsy
9	25-30	Male	Autopsy-defined sudden arrhythmic death	Nonspecific myocardial fibrosis on microscopic examination of the right ventricle (no fibrofatty infiltration, not believed consistent with overt cardiomyopathy and results of genetic testing negative)
10	25-30	Male	Hypertrophic cardiomyopathy	Septal left ventricular hypertrophy with evidence of left ventricular outflow tract obstruction
11	25-30	Male	Autopsy-defined sudden arrhythmic death	Notable cardiac finding on autopsy: bicuspid aortic valve (minimal calcified, no associated aortopathy) Variant of uncertain significance (*DSG*) Toxicology positive for caffeine
12	25-30	Female	Coronary anomaly (high takeoff of left coronary ostium with slit-like orifice)	Myocardial fibrosis in left coronary distribution
13	20-25	Male	Autopsy-defined sudden arrhythmic death	No cardiac findings by autopsy Variant of uncertain significance (*CACNB2*) Toxicology positive for amphetamines
14	20-25	Male	Autopsy-defined sudden arrhythmic death	No cardiac findings by autopsy Variant of uncertain significance (*PRDM16* and *SLC4A3*)
15	20-25	Female	Autopsy-defined sudden arrhythmic death	No cardiac findings by autopsy Toxicology positive for pseudoephedrine and caffeine Prior routine LDL-C: 240 mg/dL (6.22 mmol/L)
16	20-25	Male	Exertional heat stroke	Race temperature, 30 °C (86 °F) Collapse near end of marathon, multisystem organ failure
17	20-25	Male	Autopsy-defined sudden arrhythmic death	No cardiac findings by autopsy
Participants who survived				
1	65-70	Male	Coronary artery disease	99% proximal left anterior descending artery stenosis with thrombus (acute plaque rupture)
2	60-65	Male	Coronary artery disease	Diffuse multivessel coronary artery disease including severe left main and left anterior descending artery disease with thrombus (acute plaque rupture)
3	60-65	Male	Hypertrophic cardiomyopathy and left anterior descending artery myocardial bridge	Maximum left ventricular septal wall thickness of 20 mm with myocardial fibrosis in region of hypertrophy
4	60-65	Male	Coronary artery disease	Percutaneous intervention performed, unknown if acute plaque rupture vs stable disease
5	55-60	Male	Unexplained	Prior remote history of atrial flutter status after ablation Left anterior descending artery with ostial 50%-60% stenosis, fractional flow reserve of 0.94
6	55-60	Male	Severe aortic stenosis	Rheumatic heart disease
7	55-60	Male	Coronary artery disease	80% mid-left anterior descending artery stenosis and 99% mid obtuse marginal stenosis (stable disease)
8	55-60	Male	Coronary artery disease	Acute 100% occlusion of proximal left anterior descending artery with thrombus (acute plaque rupture)
9	55-60	Male	Coronary artery disease	Percutaneous intervention performed, unknown if acute plaque rupture vs stable disease
10	55-60	Male	Unexplained	40%-50% left anterior descending artery stenosis
11	45-50	Male	Severe aortic stenosis/bicuspid aortic valve	None
12	45-50	Female	Coronary artery disease	Acute 100% occlusion of proximal left anterior descending artery (acute plaque rupture)
13	35-40	Male	Spontaneous coronary artery dissection	None

(continued)

Table 3. Confirmed Etiologies of Cardiac Arrest or Death in US Marathon and Half-Marathon Runners With Comprehensive Clinical Profiles (N = 36) (continued)

Participant No.	Age range, y	Sex	Autopsy findings and/or cardiac arrest cause	Additional clinical and/or autopsy findings
14	35-40	Male	Unexplained	Variant of uncertain significance (*SCN5A*)
15	30-35	Male	Unexplained	None
16	25-30	Male	Exertional heat stroke	Additional small region of mid-myocardial fibrosis in the inferior left ventricular wall No inducible arrhythmias with exercise testing
17	25-30	Male	Coronary anomaly (anomalous origin of right coronary off left sinus of Valsalva and left anterior descending artery myocardial bridge)	None
18	25-30	Female	Coronary anomaly (anomalous origin of left coronary off right sinus of Valsalva)	None
19	20-25	Male	Possible hypertrophic cardiomyopathy	Mild left ventricular hypertrophy (1.3-cm wall thickness) with failure of apical tapering and mild mid-myocardial fibrosis in the septal and basal inferolateral wall Variant of uncertain significance (*PLEKHM2*) Bicuspid aortic valve Mild aortic root enlargement (4.2 cm)

Abbreviation: LDL-C, low-density lipoprotein cholesterol.

based on the likelihood of cardiac events. Remarkably, during long-distance races, which often have large and complex geographic footprints, the chance of cardiac arrest survival has increased from 29% (2000-2009)[1] to 66% (2010-2023), which is comparable to other settings with publicly accessible AEDs, including airports,[15,16] casinos,[17] and high schools/universities.[18,19]

In this study, cardiac arrest etiology could be confirmed in 52% of identified individuals (n = 67/128) (Table 2), which was nearly identical to RACER analyses from 2000-2009 (n = 31/59 [53%]).[1] The most common cause of cardiac arrest was coronary artery disease, which was associated with both acute plaque rupture and stable, demand ischemia.[1,20-22] Unexplained cardiac arrest, after comprehensive clinical testing (survivors) or autopsy (autopsy-defined sudden arrhythmic death,[23] decedents), was the second most common cause which parallels numerous contemporary sudden death registries of competitive athletes.[7,24,25] Postmortem genetic analyses revealed variants of uncertain significance in 3 cases. Future widespread use of molecular autopsies is necessary for enhanced understanding of genetic contributions to sudden death. Hypertrophic cardiomyopathy was no longer a common etiology, perhaps a consequence of prior case ascertainment bias in the 2000-2009 analyses. With an estimated disease prevalence of approximately 1 per 500,[26] these findings suggest that cardiac risk in patients with hypertrophic cardiomyopathy who are engaged in long-distance running may not be as high as previously reported. Last, the significance of positive stimulant toxicology in 4 decedents is unknown. A recent study reported temporal association between cardiac arrest in patients with ion channelopathies and ingestion of energy beverages.[27] In this study, this was an unexpected observation that warrants consideration in the counsel of runners prior to recreational racing.

Limitations

This study has several limitations. First, the case ascertainment methodology was not identical to RACER 2000-2009[1] because this study included additional methodologies that did not exist before 2010. This may have affected the comparison to epidemiologic trends between 2000-2009 and potentially masked a decline in cardiac arrest incidence. However, the methodology expanded to account for the significant growth of recreational long-distance running and stable cardiac arrest incidence rates across both RACER analyses, including our sensitivity analyses, suggest comparable epidemiologic data. In addition, case fatalities were all associated with media reports, similar to prior RACER analyses. Second, race finishing times were used as surrogates for participants. Thus, some runners may have been counted more than once, leading to underestimation of true cardiac arrest risk. This same limitation was present in RACER 2000-2009 analysis,[1] suggesting comparable incidence proportion estimates. Last, only approximately 50% of cardiac arrest etiologies could be reported, and complete clinical profiles could not be ascertained. Although these same limitations were present in the RACER 2000-2009,[1] and age and sex were similar between those with and without complete information, there is the potential for selection bias.

The incidence of cardiac arrests during long-distance running races has been relatively stable over the last 2 decades. However, the risk of cardiac death has markedly declined since 2010. This finding suggests that concerted efforts to improve emergency action planning, inclusive of immediate access to defibrillation, have led to significant improvements in outcomes. Atherosclerotic coronary disease currently represents the most common cause of cardiac arrest. Future emphasis on primary cardiac prevention in long distance runners may positively affect outcomes.

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