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Sudden Death in Young Adults: A 25-Year Review of Autopsies in Military Recruits

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Background: **Sudden death among military recruits is a rare but devastating occurrence. Because extensive medical data are available on this cross-sectional and diverse population, identification of the underlying causes of sudden death may promote health care policy to reduce the incidence of sudden death.**

Objective: **To determine the causes of nontraumatic sudden death among a cohort of military recruits.**

Design: **Retrospective cohort study using demographic and autopsy data from the Department of Defense Recruit Mortality Registry.**

Setting: **Basic military training.**

Patients: **All nontraumatic sudden deaths from a monitored 6.3 million men and women age 18 to 35 years.**

Measurements: **Descriptive analysis, crude mortality rates of causes of sudden death, and frequency of events as a function of cause of death.**

Results: **Of 126 nontraumatic sudden deaths (rate, 13.0/100 000 recruit-years), 108 (86%) were related to exercise. The most common cause of sudden death was an identifiable cardiac abnormality (64 of 126 recruits [51%]); however, a substantial number of deaths remained unexplained (44 of 126 recruits [35%]). The predominant structural cardiac abnormalities were coronary artery abnormalities (39 of 64 recruits [61%]), myocarditis (13 of 64 recruits [20%]), and hypertrophic cardiomyopathy (8 of 64 recruits [13%]). An anomalous coronary artery accounted for one third (21 of 64 recruits) of the cases in this cohort, and, in each, the left coronary artery arose from the right (anterior) sinus of Valsalva, coursing between the pulmonary artery and aorta.**

Limitations: **This cohort underwent a preenlistment screening program that included history and physical examination; this may have altered outcomes.**

Conclusions: **Cardiac abnormalities are the leading identifiable cause of sudden death among military recruits; however, more than one third of sudden deaths remain unexplained after detailed medical investigation.**

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See editorial comment on pp 882-884.

Sudden death in healthy persons is uncommon and is usually due to previously undetected cardiovascular disease (1, 2). Most sudden deaths among apparently healthy young athletes occur during exertion and are most often caused by cardiac abnormalities (3–5). Gardner and colleagues (6) reported that 60% to 78% of exercise-related deaths in U.S. military personnel during 1996–1999 were attributable to a cardiac cause. Among young adults (persons 17 to 34 years of age), 50% of exercise-related deaths were attributable to preexisting heart disease (6). Maron and colleagues (7, 8) identified 158 sudden deaths in U.S. athletes younger than 35 years of age from 1985 through 1995 and found that 85% had a cardiovascular cause. In this and other studies of young athletes, hypertrophic cardiomyopathy, coronary artery anomalies, and cystic medial necrosis with a subsequent ruptured aorta were commonly associated with sudden death (3, 7, 9, 10). Uncommon causes of cardiac death in persons who exercise include myocarditis, floppy mitral valve, aortic stenosis, aortic dissection, and sarcoidosis (3, 11). Phillips and colleagues (12) identified 19 sudden cardiac deaths from 1965 through 1985 during Air Force basic military training at Lackland Air Force Base, Texas, the only training site for Air Force basic military training. The most frequent underlying cause of these deaths was myocarditis (42%), followed by coronary anomalies (16%).

The frequency of sudden death in athletes younger than 35 years of age is not clearly defined (13). Regardless of frequency, sudden death in young adults garners disproportionate attention from the media and raises important issues of legal liability (5). Deaths occurring during basic military training are of particular concern because they occur despite a preenlistment health screening program and have a substantial effect on the structure of basic training. The medical screening, conducted at a Military Entrance Processing Station, consists of a personal (but not family) medical history questionnaire and physical examination. The physical examination includes a clinical evaluation; blood and urine testing; and measurements of blood pressure, pulse, height, and weight. Cardiovascular screening is limited to heart auscultation. Electrocardiography is performed only if any abnormalities are identified.

Cardiovascular diagnoses that prompt rejection for enlistment include valvular heart diseases, coronary artery disease, symptomatic arrhythmia, persistent resting sinus tachycardia, documented ventricular arrhythmias, left bundle-branch block, Mobitz type II second-degree and third-degree atrioventricular block, the Wolff–Parkinson–White syndrome, hypertrophy or dilatation of the heart, cardiomyopathy (including myocarditis or pericarditis), history of heart failure, all congenital anomalies except for corrected patent ductus arteriosus, and hypertension. Disqualification for cardiac or vascular system abnormalities is very rare. In 2000, approximately 55 of almost 365 000 enlisted

Context

Sudden nontraumatic death in military recruits may offer insight into the causes and prevention of sudden death in young adults.

Contribution

Among 6.3 million military recruits age 18 to 35 years, sudden nontraumatic death occurred at a rate of 13.0 per 100 000 recruit-years. Over half of the 126 autopsied decedents had an identifiable cardiac abnormality; one third had an anomalous coronary artery. More than one third of deaths had no explanation.

Cautions

This study had no control recruits who did not die suddenly.

Implications

Sudden nontraumatic death among military recruits occurs rarely. Whether more intensive screening would effectively prevent sudden death is unknown.

–The Editors

applicants (0.15%) to military service were found to be unfit for military service because of cardiac or vascular disqualification.

The duration of basic military training and the graduation requirements vary among the military services. In general, however, basic training may include basic rifle marksmanship; hand grenade, bayonet, and hand-to-hand combat training; unarmed combat training; physical fitness tests (that is, pushups, sit-ups, and a timed run); obstacle courses; live-fire exercises; foot marches (3, 5, 8, 10, and 15 kilometers); and field training exercises.

Efforts to understand and prevent the rare, but tragic, occurrence of sudden death among these young adults depend on active surveillance of the population and accurate determination of mortality rates. However, published information on cause-specific mortality in this population is limited to isolated case reports (14–18), and population-based studies focused on a single military service (19) or specific cause of death (12, 20). To provide surveillance data specifically for recruit deaths, the Armed Forces Institute of Pathology implemented the Department of Defense Recruit Mortality Registry (DoD-RMR) in the Medical Mortality Surveillance Division at the Office of the Armed Forces Medical Examiner. This registry contains reports of every recruit death and autopsy. Recruit deaths described in the publications mentioned previously were included in the DoD-RMR. Descriptive analyses of nontraumatic and traumatic causes of recruit mortality derived from the DoD-RMR have been published elsewhere (21, 22). In the current study, we used data from the DoD-RMR to determine the cause of nontraumatic sudden death among military recruits over a 25-year period (1977 through 2001).

METHODS

The Institutional Review Board of Brooke Army Medical Center approved this study. Nontraumatic recruit deaths were identified through the DoD-RMR. The registry reflects a review of military personnel records and investigative reports, death certificates and autopsies, and Armed Forces Institute of Pathology consultations and toxicology studies. The DoD-RMR considers a death to be a recruit death if the fatal incident occurred at a military training site before completion of initial training while the recruit was in an enlisted status in the Air Force, Army, Marine Corps, or Navy (22, 23). Of the nontraumatic recruit deaths that occurred from 1977 through 2001, cases were eligible for this study if they were categorized in the DoD-RMR as idiopathic deaths or deaths due to the following causes: cardiac, exertional heat illness, vascular, asthma, and all exercise-related deaths not elsewhere classified. We obtained demographic data and details about the circumstances of the fatal incident from the DoD-RMR because clinical histories were not consistently available from pathology reports from the military treatment facilities or civilian hospitals where these deaths were initially evaluated. The inclusion criteria for this study were a nontraumatic death with an available autopsy report for pathologic confirmation of the cause of death.

We used the DoD-RMR to obtain and manually review records from each case that met the inclusion criteria. Cases were classified as sudden (cardiac, noncardiac, or idiopathic) and nonsudden. Sudden death was defined as an event resulting in death or terminal life support within 1 hour of the inciting event. Deaths were defined as cardiac in origin if the decedent had pathologically confirmed heart disease with clinical circumstances defined as potentially cardiac in origin. Idiopathic sudden death was defined as any sudden death unexplained by preexisting disease and without identifiable cause on postmortem examination.

Crude mortality rates are presented as deaths per 100 000 recruit-years (calculated by multiplying numeric death rates [number of deaths/number of recruits] by average training period expressed in years). The average training period was 8 weeks for the Army and the Navy, 6 weeks for the Air Force, and 11 weeks for the Marine Corps. We obtained population data from the Defense Manpower Data Center. Of the cases that made up this series, 5 have been discussed in detail in previous case reports (14–18), and 26 have had their sickle-cell status reported (without detailed discussion of causes of death) (12, 20, 22). We calculated CIs for mortality rates by using the Rothman binomial method (24), and we calculated *P* values for comparisons by using the Mantel–Haenszel method (25). We considered *P* values less than 0.05 to be significant. Statistical analysis was performed by using JMP Professional 5.0.1 (SAS Institute, Inc., Cary, North Carolina).

Table 1. **All-Service Nontraumatic Sudden Death Rates for Recruits by 5-Year Categories, 1977–2001**

Years	Sudden Deaths, *n*	Population × 10^5	Rate (95% CI)*
1977–1981	37	16.5	14.6 (10.6–20.1)
1982–1986	37	15.3	15.7 (11.4–21.7)
1987–1991	20	12.7	10.2 (6.6–15.8)
1992–1996	13	9.3	9.1 (5.3–15.5)
1997–2001	19	9.1	13.6 (8.7–21.2)
Total	126	62.9	13.0 (10.9–15.5)

* Calculated by multiplying the numeric death rate by 6.5 (reflecting the average of 8 weeks of basic military training for all services combined) and expressed per 100 000 recruit-years.

RESULTS

The DoD-RMR contains 277 deaths identified from among 6.3 million recruits from 1977 through 2001. No recruit was noted to have preentry cardiovascular disease, and postmortem toxicology reports showed no evidence of illicit drug use. A family history of premature death or cardiovascular disease is not routinely gathered on initial-entry service members. Autopsy reports were available for 148 (97%) eligible nontraumatic deaths. The 126 sudden nontraumatic cases form the basis of the current study. The median age of the recruits was 19 years (range, 17 to 35 years), and 111 (88%) were male. The rate of nontraumatic sudden death was 13.0 per 100 000 recruit-years, a figure that did not vary significantly over the 25-year study period (**Table 1**). Approximately half (64 of 126 recruits) of the nontraumatic sudden deaths were due to an identifiable cardiac abnormality, and slightly more than one third (44 of 126 recruits) were idiopathic (**Table 2**). A temporal relationship to exertion was noted in 86% (108 of 126 recruits) of events. There were 18 noncardiac sudden deaths: 6 from coagulopathy and hemorheologic causes (3 sickle-cell crises, 2 episodes of pulmonary embolism, and 1 internal hemorrhage), 5 from intracranial hemorrhage, 4 from pulmonary causes (respiratory distress due to asthma [$n = 2$], sarcoidosis [$n = 1$], and alveolar hemorrhage [$n = 1$]), and 3 from exertional rhabdomyolysis or heat stroke.

The most common cardiac causes of sudden death were coronary artery pathology (39 of 64 recruits [61%]), myocarditis (13 of 64 recruits [20%]), and hypertrophic cardiomyopathy (8 of 64 recruits [13%]) (**Table 3**). There were 21 anomalous coronary arteries, all of which were the left coronary artery arising from the right (anterior) sinus of Valsalva, with a course between the pulmonary artery and aorta. Of those with this finding, 19 were men and 2 were women; the median age was 19 years (range, 17 to 31 years). Twelve recruits were white, 8 were African American, and 1 was Native American. Of these 21 deaths, premortem symptoms (chest pain, dyspnea, or syncope) were noted in the autopsy reports of 11 (52%) cases. Additional details regarding 1 of these deaths were published as a case report (18).

There were 44 cases of idiopathic sudden death despite a detailed investigation and a full autopsy. There were 38 cases related to exercise, and 12 were identified with sickle-cell trait. Among recruits with nontraumatic sudden death, sickle-cell trait was significantly associated with idiopathic sudden death compared with other causes of death ($P < 0.001$). Among recruits dying suddenly with hypertrophic cardiomyopathy, the mean (±SD) left ventricular mass was 481 ± 80 g and mean (±SD) left ventricular wall thickness was 2.0 ± 1.0 cm. On microscopic examination, 3 demonstrated myocyte hypertrophy, 1 demonstrated myocyte hypertrophy and disarray, and the remaining 4 had increased left ventricular mass alone without documented microscopic changes.

Premortem prodromal symptoms during training as a

Table 2. **Demographic Characteristics of Recruits with Nontraumatic Sudden Death during Recruit Training, 1977–2001**

	Total Recruits, *n**	Cardiac Deaths†		Idiopathic Deaths†		Noncardiac Deaths†		Total Deaths†	
		Deaths, *n*	Mortality Rate (95% CI)	Deaths, *n*	Mortality Rate (95% CI)	Deaths, *n*	Mortality Rate (95% CI)	Deaths, *n*	Mortality Rate (95% CI)
Age									
17–19 y	40.2	41	6.6 (4.90–9.0)	21	3.4 (2.2–5.2)	11	1.8 (1.0–3.2)	73	11.8 (9.4–14.8)
20–24 y	19.0	15	5.1 (3.1–8.5)	15	5.1 (3.1–8.5)	4	1.4 (0.5–3.5)	34	11.6 (8.3–16.3)
≥25 y	3.6	8	14.4 (7.3–28.5)	8	14.4 (7.3–28.5)	3	5.4 (1.8–15.9)	19	34.3 (22.0–53.6)
Sex									
Male	54.3	59	7.1 (5.5–9.1)	37	4.4 (3.2–6.1)	15	1.8 (1.1–3.0)	111	13.3 (11.0–16.0)
Female	8.5	5	3.8 (1.6–9.0)	7	5.4 (2.6–11.1)	3	2.3 (0.8–6.7)	15	11.5 (7.0–18.9)
Ethnic group									
Non–African American	50.3	41	5.3 (3.9–7.2)	20	2.6 (1.7–4.0)	10	1.3 (0.7–2.4)	71	9.2 (7.3–11.6)
African American	12.5	23	12.0 (8.0–17.9)	24	12.5 (8.4–18.6)	8	4.2 (2.1–8.2)	55	28.6 (22.0–37.2)
Total	62.9	64	6.6 (5.2–8.4)	44	4.5 (3.4–6.1)	18	1.9 (1.2–2.9)	126	13.0 (10.9–15.5)

* Expressed per 100 000 recruits; discrepancies in summing recruit accessions are due to rounding directly from the Defense Manpower Data Center's All-Service data.
† Mortality rates were calculated by multiplying the numeric death rate by 6.5 (reflecting the average of 8 weeks of basic military training for all services combined) and expressed per 100 000 recruit-years.

Table 3. **Nontraumatic Sudden Deaths with an Identifiable Cardiac Abnormality during Recruit Training, 1977–2001 (*n* = 64)**

Cardiac Abnormality	Sudden Deaths, *n* (%)*
Cardiomyopathy	23 (36)
Myocarditis	13 (20)
Hypertrophic cardiomyopathy	8 (13)
Idiopathic dilated cardiomyopathy	1 (2)
Right ventricular dysplasia	1 (2)
Coronary artery pathology	39 (61)
Anomalous coronary artery	21 (33)
Atherosclerotic coronary artery disease	10 (16)
Coronary artery hypoplasia	3 (5)
Coronary aneurysm	2 (3)
Intramyocardial coronary bridge	2 (3)
Coronary dissection	1 (2)
Miscellaneous cardiac findings	2 (3)
Bicuspid aortic valvular stenosis	1 (2)
Embolic myocardial infarction	1 (2)

* Some numbers have been rounded.

function of subclassification of cardiac death ($P = 0.007$) differed significantly. On review of the autopsy reports, almost one third (31%) of recruits with underlying coronary artery pathology who died suddenly and almost one quarter (22%) with underlying myocardial disease who died suddenly had documentation suggesting that the recruit had symptoms that may have been consistent with the underlying abnormality. This compares with less than 5% of patients with sudden idiopathic death (**Table 4**).

Discussion

We found that over a 25-year period, 86% of sudden nontraumatic deaths among military recruits were related to exercise. Although cardiac causes were attributed to half (51%) of the sudden deaths, the proportion of coronary artery anomalies was significantly higher than those identified in previous cohorts of sudden deaths in athletes, as well as in previous studies of military recruits (3, 4, 12).

Anomalous coronary anatomy is frequently described as the cause of sudden cardiac death; it accounts for 5% to 35% of causes of death in young persons although it is present in less than 0.3% to 0.8% of the population as a whole (26–30). We identified 21 cases with anomalous coronary arteries, all of which were the left coronary artery arising from the right (anterior) sinus of Valsalva, with a course between the pulmonary artery and aorta. Of these patients, 11 (52%) had a history of prodromal symptoms of chest pain, syncope, or dyspnea in the autopsy report. However, to avoid lost training days or disqualification from military service, the recruits may not have disclosed these symptoms before the fatal incident. This history is often not available to medical providers until the cause-of-death investigation has been completed. Basso and colleagues (31) reviewed registry data and found that in 27 sudden deaths in athletes due to anomalous coronary arteries, 12 of the athletes had undergone clinical evaluation before death, and 10 of these had had symptoms of either syncope or chest pain in the 2 years before death. Our finding that all anomalous coronary arteries were left main coronary arteries arising from the right coronary sinus is in concert with previous findings (32). Taylor and colleagues (32) reviewed records from 242 patients (0 to 87 years of age) with isolated coronary artery anomaly and reported that in the 140 cases in which the anomalous coronary artery originated in the aorta, the anomalous origin of the left main coronary artery from the right coronary sinus (49 of 140 [35%]) was most commonly associated with sudden death (32). Furthermore, most persons in whom the left main coronary artery arose from the right coronary sinus were younger than 30 years of age, and 50% were symptomatic before sudden death (32).

As previously published, screening with echocardiography identifies the anatomic but not the functional significance of anomalous coronary arteries (33, 34). Previous reports have suggested that the use of echocardiography be limited only to athletes when screening for anomalous origin of coronary arteries (33). However, in our cohort, at least half of military recruits with coronary anomalies had prodromal symptoms before sudden death, and half died within 1 month of initiating strenuous exertion (range, 6 to 78 days). Therefore, we recommend that screening for anomalous coronary arteries with an imaging technique (echocardiography, computed tomography, or magnetic resonance imaging) be strongly considered in any young patient initiating an exercise program who presents with symptoms that may be referable to cardiovascular disease. This is of particular importance given the high false-negative rate of electrocardiography and maximal stress testing in those with anomalous coronary arteries (31). Attempting to enhance current cardiovascular screening of asymptomatic personnel by using an imaging technique, while feasible in small populations of athletes (35–38), would be of unclear utility in a large military population. Echocardiographic screening in particular deserves additional study before widespread application as a screening tool to establish its ability to reduce events without excess cost or overdiagnosis of the extremes of normal physiology (39).

Table 4. **Prodromal Symptoms from Autopsy Reports of Nontraumatic Sudden Deaths in Recruits, 1977–2001***

Premortem Symptom	Coronary Artery Pathology (*n* = 39)	Myocardiopathic Abnormality (*n* = 23)	Idiopathic Death (*n* = 44)
Any symptom reported, *n* (%)	12 (31)†	5 (22)‡	2 (4)
Syncope, *n*	6	2	1
Chest pain, *n*	5	1	1
Dyspnea, *n*	4	1	–
Infection-related, *n*	1	2	–
Palpitations, *n*	–	1	–

* Symptoms in each column do not sum because some recruits had more than 1 prodromal symptom.
† $P = 0.002$ comparing coronary artery disease to idiopathic death.
‡ $P = 0.03$ comparing myocardiopathic abnormality to idiopathic death.

In this study, the percentage of nontraumatic sudden deaths attributed to "hypertrophic cardiomyopathy" was 6% versus 6.3% (8 of 126), which is lower than published series (2, 3, 7, 9). It is possible that we underdiagnosed hypertrophic cardiomyopathy. However, this seems unlikely because this is an autopsy series in which there was a notable lack of myofibrillary disarray on pathology reports and because direct measurements of maximal wall thickness were available. Although it may be suggested that these patients were too young to develop characteristic anatomic findings of ventricular hypertrophy, recent work by Maron and colleagues (40) found that ventricular thickness was highest in the youngest age group (18 to 39 years of age) and that thickness was reduced in persons older than 40 years of age (despite increasing flow gradient). In addition, it has been shown that the risk for sudden death is highest in those with the maximal wall thickness, also making underdiagnosis less likely in this series (41). It is also possible that in previous studies of athletes who died of sudden cardiac death, echocardiographic evidence of physiologic hypertrophy from athletic training was mistaken for hypertrophic cardiomyopathy. These deaths, then, may have been due to other, possibly arrhythmogenic, causes. Of similar concern in a series of this nature is the potential for previous exclusion of persons with hypertrophic cardiomyopathy by virtue of physical examination. However, this limitation would apply to all studies of this type, including those in athletes, unless it is presumed that athletes had never undergone a physical examination.

Examination of trends of sudden death due to myocarditis shows the value of these case series. Although histopathologic criteria for myocarditis change over time, it is more likely that alterations of previously close-living conditions of military recruits over the past few decades may have altered the natural course of echoviral, adenoviral, and coxsackieviral disease (12, 42). While there was no further definition of the causative agent of myocarditis, the decrease in cases since previous reports in this same population is encouraging.

Slightly more than one third (35%) of the sudden deaths in this series were classified as idiopathic, despite a full autopsy and detailed investigations at the time of each sudden death, as well as our own retrospective review. In several of the cases in our study, the autopsy report referred to a family history of premature sudden death; this suggests a congenital predisposition to malignant cardiac arrhythmia. The finding that 27% of idiopathic sudden death was associated with sickle-cell trait is concordant with a previous study of the recruit population from 1977 through 1981 (20). The military recruits studied by Kark and colleagues (20) are included in the DoD-RMR, and, as such, the similar reporting of an association between sickle-cell trait and sudden death does not necessarily further support an association.

The advantage of studying the recruit population is its diversity: It includes women, as well as ethnic and socioeconomic groups not ordinarily represented in athletic screening data. An equally important advantage is the control of the premortem environment (including factors such as the absence of recreational drug use), which may contribute to adverse cardiovascular outcomes (43, 44). However, preenlistment screening may have altered the cause of sudden death compared with the general population by excluding those at significant risk for sudden death (including persons with significant cardiac disease). The relationship with exertion must be noted with caution in this patient population, as basic entry military training strongly emphasizes a high degree of physical fitness and, depending on the service, may make up most of the time the recruit spends in training. However, as previously stated by Maron (45), "medical clearance" is not a promise that the athlete, or future military recruit, is free of potentially fatal cardiovascular disease. Thus, we need to acknowledge that, albeit potentially reduced, small risks remain for potentially fatal disease, even after a normal "screening examination."

Nontraumatic sudden death (13 deaths/100 000 recruit-years from 1977–2001) is relatively rare during basic military training. The primary causes of nontraumatic sudden recruit deaths are cardiac and idiopathic. In contrast to findings in other civilian and military populations, coronary artery anomalies, and not myocardial disease, are the most common cardiac abnormalities associated with sudden cardiac death in young adults (17 to 35 years of age) during basic military training.

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