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Autopsy-Determined Atherosclerosis in Elite US Military Special Operations Forces

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ABSTRACT

Background: Autopsy studies of trauma fatalities have provided evidence for the pervasiveness of atherosclerosis in young and middle-aged adults. The objective of this study was to determine the prevalence of atherosclerosis in elite US military forces. **Methods:** We conducted a retrospective study of all US Special Operations Command (USSOCOM) fatalities from 2001 to 2020 who died from battle injuries. Autopsies were evaluated from Afghanistan- and Iraq-centric combat operations for evidence of coronary and/or aortic atherosclerosis and categorized as minimal (fatty streaking only), moderate (10–49% narrowing of ≥1 vessel), and severe (≥50% narrowing of ≥1 vessel). Prevalence of atherosclerosis was determined for the total population and by subgroup characteristics of age, sex, race/ethnicity, combat operation, service command, occupation, rank, cause of death, manner of death, and body mass index (BMI). **Results:** From the total of 388 USSOCOM battle injury fatalities, 356 were included in the analysis. The mean age was 31 years (range, 19–57 years), and 98.6% were male. The overall prevalence of coronary and/or aortic atherosclerosis was 17.4%. The prevalence of coronary atherosclerosis alone was 13.8%. Coronary atherosclerosis was categorized as minimal in 1.1%, moderate in 7.6%, and severe in 5.1%. Of those with atherosclerosis, 24.2% were <30 years old, 88.7% were from enlisted ranks, and 95.2% had combatant occupations. When BMI could be calculated, 73.5% of fatalities with atherosclerosis had a BMI ≥25. **Conclusions:** Autopsy-determined atherosclerosis is prevalent in elite US military Special Operations Forces despite young age and positive lifestyle benefits of service in an elite military unit.

KEYWORDS: *atherosclerosis; elite US military forces; coronary atherosclerosis; aortic atherosclerosis*

Introduction

Premature cardiovascular disease mortality rates—deaths among 25- to 64-year-old adults—have remained relatively constant over the past 10 years following a four-decade era of steady decline.[1] Among young 18- to 59-year-old adults hospitalized over the past decade for a first acute myocardial infarction, prevalence rates for modifiable cardiovascular risk factors were found to be high, with 92% having one or more documented risk factors and 70% having two or more.[2] Prevalent risk factors among these young adults include hypertension (58%), dyslipidemia (57%), smoking (53%), diabetes (27%), and obesity (18%).

Military and civilian autopsy studies of atherosclerosis in trauma fatalities have provided evidence of initial onset of cardiovascular disease at an early age.[3-7] The prevalence of atherosclerosis in US military trauma fatalities was noted to be 77% during the Korean conflict,[3] 45% in the Vietnam conflict,[5] and 12% in the initial years of conflict in Afghanistan and Iraq.[6] This last study also associated the prevalence of atherosclerosis to medical record documentation of cardiovascular risk factors to include dyslipidemia (50%), hypertension (44%), and obesity (22%).

Service in elite military units promotes healthy practices and affords the opportunity to adopt and maintain positive lifestyle changes considered to be protective from the development and progression of cardiovascular disease. Regular exercise, emphasis on healthy nutrition, and routine monitoring of medical readiness parameters are benefits of service within US military Special Operations Forces.

Because stress exposure has been implicated as a cardiovascular risk factor,[8] service within elite military units can also have potential negative consequences. For military populations, particularly those who experience combat and combat injury, stress may play a crucial role in the development of atherosclerosis. Recent studies have shown that severity of combat injury has been associated with the subsequent development of hypertension, diabetes, and cardiovascular disease in Afghanistan and Iraq veterans.[9-11] Notable was the correlation that for every 5-point increase in injury severity score, there was a commensurate increase in the rate of these diseases.[9] Also

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important was that combat exposure increases hypertension risk, and combat injury exacerbates this risk.[10]

A multidisciplinary mortality review and analysis of battle-injured fatalities was recently conducted on elite US military Special Operations Forces.[12] Injury survivability was reported as a probability gradient based on anatomic injuries in an ideal setting of all required medical resources being immediately available and with appropriate medical care optimally administered initially and throughout the continuum of care. Among the battle-injured population, injury survivability was reported as potentially survivable or survivable in 25.7% and nonsurvivable in 74.3%. In that review, the contributions of non-trauma effects, such as atherosclerosis and other comorbidities, were not examined.

However, atherosclerotic changes were observed in the autopsy reports of these Special Operations Forces. Thus, the current study was conducted to assess and report the overall prevalence of autopsy-determined atherosclerosis in this unique population and to correlate findings with other observed characteristics, including injury survivability.

Methods

We conducted a retrospective study of all USSOCOM fatalities who died from battle injuries incurred during combat operations between September 2001 and July 2020. Fatalities were evaluated for autopsy-determined atherosclerosis. This study was approved by the Research Regulatory Compliance Division, US Army Institute of Surgical Research.

Fatality data were obtained from the Armed Forces Medical Examiner System (AFMES). All battle-injured fatalities in the US military undergo a comprehensive autopsy examination conducted by a board-certified forensic pathologist assigned to AFMES. The findings of the examination, including a detailed cardiovascular assessment, are incorporated into the autopsy report. To facilitate the cardiovascular assessment, the aorta was opened longitudinally, and the coronary arteries were serially cross-sectioned while remaining attached to the heart. Of note is that prior to 2007, the decedent's height and weight were measured but not always included in the autopsy report. Additionally, AFMES autopsy reports do not consistently include information on race or medical history and medications. Thus, data on race/ethnicity were obtained from the Defense Enrollment Eligibility Reporting System as self-identified and reported by the service member. Although evidence of medical intervention is documented in autopsy reports for acute trauma care, these data elements were not included in this study. Fatalities with extensive traumatic injury (e.g., blast, burns) to the cardiovascular system that prevented examination of coronary and aortic vessels were excluded from the study.

Consistent with previous military autopsy studies, a priori classifications of severity were assigned to atherosclerotic lesions prior to analysis and defined as minimal (fatty streaking only), moderate (10–49% luminal narrowing of ≥1 vessel), and severe (≥50% narrowing of ≥1 vessel). Atherosclerotic lesions documented in the autopsy report were classified accordingly.

Descriptive characteristics for fatalities included age, sex, race/ethnicity, combat operation, service command, military occupational specialty, rank, cause of death, injury survivability, and BMI. Age was grouped as <25 years, 25 to 29 years, 30 to 39 years, and ≥40 years. Race/ethnicity was grouped as White non-Hispanic, Black non-Hispanic, Hispanic, Asian/Pacific Islander, and Other. Combat operations included Enduring Freedom, Iraqi Freedom, New Dawn, Inherent Resolve, and Freedom's Sentinel. Service commands in USSOCOM include Air Force Special Operations, Marine Corps Forces Special Operations, Naval Special Warfare, and US Army Special Operations. Military occupational specialty was categorized as either combatant or support personnel. Military rank was categorized as either enlisted or officer. Cause of death was categorized as blast injury, gunshot wound, or blunt/multiple injury. Injury survivability was categorized as potentially survivable-survivable or nonsurvivable. BMI was categorized as <25.0, ≥25.0, or unable to determine.

Case counts, total coronary and aortic atherosclerosis prevalence, any coronary atherosclerosis prevalence, and 95% confidence intervals (CIs) were tabulated. Nonparametric significance testing was conducted using the Mann-Whitney test for age differences and exact tests for categorical variables. Boxplots for age and BMI were also examined. Bootstrapped, age-adjusted logistic regression, with 1,000 resamples, was used to analyze the association between BMI categories, military occupation, and atherosclerosis. Analyses were performed using SPSS Statistics version 26 (IBM).

Results

Of the total 388 USSOCOM battle-injured fatalities that occurred during the study period, 32 fatalities were excluded (14 lacked documentation, 13 had extensive traumatic injury, 5 had the heart removed for donation prior to autopsy). Of the remaining 356 fatalities, the mean age was 31 years (range, 19 to 57 years), 83.4% (297/356) were white non-Hispanic, and 98.6% (351/356) were male. Table 1 details the prevalence of atherosclerosis overall and by study population characteristics.

The overall prevalence of coronary or aortic atherosclerosis was 17.4% (95% CI, 13.8–21.7%) and in males was 17.7% (95% CI, 14.0–22.0%) because none of the five females had atherosclerosis. The prevalence of any coronary atherosclerosis was 13.8% (95% CI, 8.8–21.8%). Coronary atherosclerosis was categorized as minimal in 1.1% (95% CI, 0.4–3.0%), moderate in 7.6% (95% CI, 5.2–10.9%), and severe in 5.1% (95% CI, 3.2–7.9%). By race/ethnicity, prevalence of atherosclerosis was highest in white non-Hispanics at 19.5% (95% CI, 15.4–24.5%).

The overall distribution of age between individuals with and without atherosclerosis is depicted in Figure 1A. Of fatalities with atherosclerosis, 24.2% (15/62) were <30 years old, 88.7% (55/62) were from enlisted ranks, and 95.2% (59/62) had combatant occupations. Fatalities with atherosclerosis (mean [standard deviation (SD)] age, 35.0 [7.3] years) were 5.5 years older than those without (mean [SD] age, 29.5 [5.5] years; $p < .001$). No difference in prevalence was seen between the <25-year and 25-to-29-year age groups; however, the 30-to-39-year and ≥40-year age groups had approximately 2 to 3 and 6 times the prevalence, respectively, of either or both younger age groups combined. Of fatalities with atherosclerosis <30 years old (range, 23–29 years), 40.0% had minimal, 40.0% had moderate, and 20.0% had severe disease. Of fatalities ≥30 years old (range, 30–57 years), 23.4% had minimal,

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TABLE 1 *Prevalence of Coronary and/or Aortic Atherosclerosis in US Special Operations Command Battle-Injured Fatalities, September 2001 to July 2020 (N=356)*

Characteristics	No. of Fatalities With Atherosclerosis/Total No.	Atherosclerosis Prevalence, % (95% CI)
Total	62/356	17.4 (13.8, 21.7)
Any coronary atherosclerosis	49/356	13.8 (8.8, 21.8)
Atherosclerosis severity		
Minimal, aorta only	13/356	3.6 (2.1, 6.2)
Minimal, coronary (No. with aorta)	4/356 (1 with aorta)	1.1 (0.4, 3.0)
Moderate, coronary (No. with aorta)	27/356 (7 with aorta)	7.6 (5.2, 10.9)
Severe, coronary (No. with aorta)	18/356 (2 with aorta)	5.1 (3.2, 7.9)
Age, y		
<25	5/57	8.8 (3.4, 18.3)
25–29	10/124	8.1 (4.2, 13.7)
30–39	33/148	22.3 (14.5, 26.7)
≥40	14/27	51.9 (28.8, 62.6)
Sex		
Female	0/5	0.0 (n/a)
Male	62/351	17.7 (14.0, 22.0)
Race/ethnicity		
White, non-Hispanic	58/297	19.5 (15.4, 24.5)
Black, non-Hispanic	1/14	7.1 (1.0, 37.3)
Hispanic	2/28	7.1 (1.8, 24.6)
Asian/Pacific Islander	1/9	11.1 (1.5, 50.2)
Other*	0/8	0.0 (n/a)
Combat operation		
Enduring Freedom (Sep 2001–Dec 2014)	33/229	14.4 (10.4, 19.6)
Iraqi Freedom (Mar 2003–Aug 2010)	19/84	22.6 (14.9, 32.8)
New Dawn (Sep 2010–Dec 2011)	0/0	0.0 (n/a)
Inherent Resolve (Jun 2014–Jul 2020)	1/8	12.5 (1.7, 54.0)
Freedom's Sentinel (Jan 2015–Jul 2020)	9/35	25.7 (13.9, 42.6)
Service command		
Air Force Special Operations	1/13	7.7 (1.1, 39.3)
Marine Corps Forces Special Operations	2/19	10.5 (2.6, 33.9)
Naval Special Warfare	7/59	11.9 (5.7, 22.9)
United States Army Special Operations	52/265	19.6 (15.3, 24.9)
Military occupational specialty		
Combatant	59/319	18.5 (14.6, 23.2)
Support	3/37	8.1 (2.6, 22.4)
Rank		
Enlisted	55/314	17.5 (13.7, 22.1)
Officer	7/42	16.7 (8.1, 31.1)
Cause of death		
Blast injury	34/153	22.2 (16.3, 29.5)
Gunshot wound	23/154	14.9 (10.1, 21.5)
Blunt/multiple Injury	5/49	10.2 (4.3, 22.4)
Injury survivability		
Potentially survivable–survivable	18/98	18.4 (11.9, 27.3)
Nonsurvivable	44/258	17.1 (12.9, 22.2)
Body mass index**		
<25.0	9/76	11.8 (6.3, 21.3)
≥25.0	25/127	19.7 (13.6, 27.6)
Unable to determine	28/153	18.3 (12.9, 25.3)

*American Indian, Alaskan Native, and declined to report.
**Calculated as weight in kilograms divided by height in meters squared. Two fatalities had a BMI <18.5, and 16 fatalities had a BMI ≥30.

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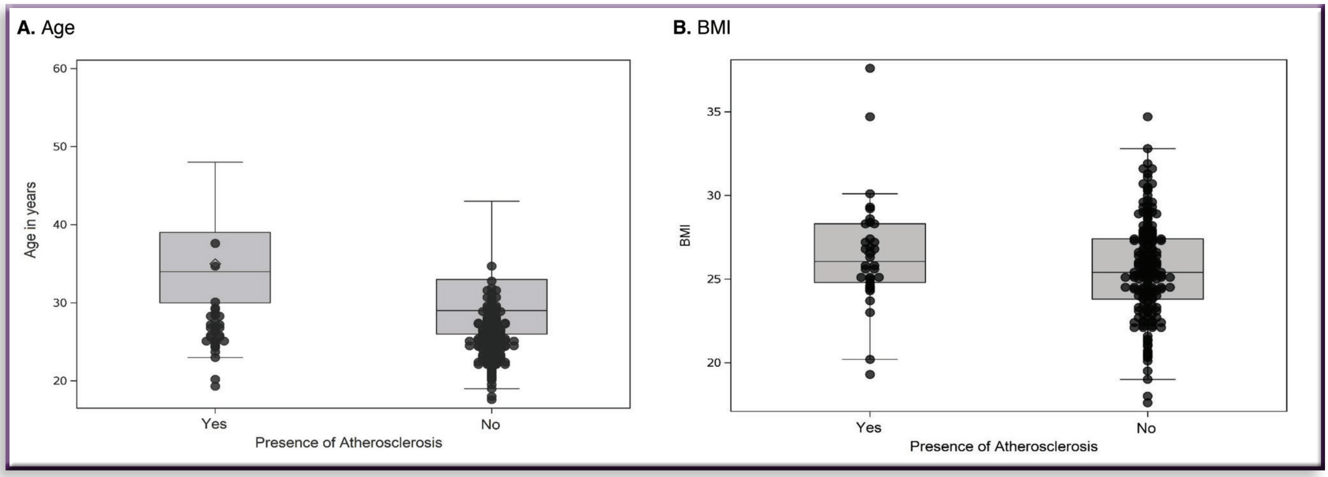
FIGURE 1 *Box plots of distribution of* **(A)** *age and* **(B)** *body mass index (BMI) between individuals with and without atherosclerosis.*



44.7% had moderate, and 31.9% had severe disease. Additionally, white non-Hispanic males ≥30 years old were found to have an atherosclerosis prevalence of 29.5% (43/146), of which 76.7% (33/43) had moderate or severe disease.

For combat operations, atherosclerosis was most prevalent in Operation Freedom's Sentinel, followed by Operation Iraqi Freedom. By Service command, atherosclerosis was most prevalent in US Army Special Operations Forces. Prevalence of atherosclerosis was greatest in those whose cause of death was from blast injury at 22.2% (95% CI, 16.3–29.5%), as well as in those found to have potentially survivable-survivable injuries at 18.4% (95% CI, 11.9–27.3%). Prevalence of atherosclerosis was also higher in combatants at 18.5% (95% CI, 14.6–23.2%) compared with support personnel at 8.1% (95% CI, 2.6–22.4%). Age-adjusted odds of atherosclerosis were higher for combatants versus support personnel (odds ratio [OR], 3.29; 95% CI, 0.91–11.91; $p = .06$; Table 2).

Height, weight, or both were not documented in 108 autopsy reports. Extensive traumatic injury prevented calculation of BMI for an additional 45 fatalities. When BMI could be calculated, 73.5% (25/34) of fatalities with atherosclerosis had a BMI ≥25. However, overall, the distribution of BMI did not differ between individuals with and without atherosclerosis, as demonstrated by Figure 1B. Age-adjusted odds of atherosclerosis were higher for BMI ≥25 compared with BMI <25 (OR, 1.58; 95% CI, 0.67–3.70; $p = .30$) but did not differ from individuals in whom BMI was unable to be determined (OR, 1.01; 95% CI, 0.43–2.41; $p = .98$; Table 2).

Discussion

Premature cardiovascular disease remains a leading cause of death in the US,[1] with identified risk factors that include hypertension, dyslipidemia, smoking, diabetes, and obesity. Underpinning these risk factors is the considerable influence of physical inactivity and suboptimal nutrition. Given that Special Operations Forces are renowned for their physical fitness,[13] healthy nutrition practices,[14] and human performance programs,[15,16] most would expect a relatively low prevalence of atherosclerosis.

In contrast to this theory was the 17.4% overall prevalence of atherosclerosis found in our study of elite military Special Operations Forces, which was higher than the 12.1% prevalence previously reported for total US military fatalities during the Afghanistan and Iraq conflicts.[6] Additionally, a previous review of 614 USSOCOM fatalities who died from battle and non-battle deaths while performing duties between 2001 and 2018 identified 6 individuals (mean age, 39 years) who died directly as a result of acute myocardial infarction with underlying severe coronary artery disease.[17] Of these six individuals, one died during training and five while deployed in support of combat operations.

A limitation of our study was the inability to analyze cases by known risk factors, such as hypertension, dyslipidemia, smoking, and diabetes. If autopsy reports were matched with medical history, as was previously done by Webber et al.,[6] this could reveal characteristics and behaviors that outweigh the positive lifestyle aspects of service in an elite unit. Although we found 73.5% of Special Operations fatalities with atherosclerosis had a BMI ≥25, the odds of cardiovascular disease risk did not differ by BMI categories in age-adjusted analysis (<25 vs. ≥25, $p = .30$, vs. UTD, $p = .98$).

Individuals in elite tactical units are required to maintain higher levels of fitness to successfully perform their occupational demands. Therefore, a higher BMI is less likely to represent any degree of obesity and is more likely secondary to an increase in muscle mass among individuals in these units. A review of studies on individuals in elite tactical units found the collective to lean toward a mesomorphic build, with average BMI of 26 but average body fat percentage of 15%, as well as higher fitness measures across multiple domains.[13] Our study population was composed of elite and highly active personnel with BMI profiles that are associated with lower cardiovascular disease risk compared with those of total military forces[18] and the civilian population.[19]

In addition to tangible reduction in disease, Webber et al.[6] also proposed potential artifactual variations in methodology (e.g., inclusion versus exclusion of fibrous thickening as atherosclerosis) and expectation bias (e.g., special versus routine performance of autopsies) to explain differences in autopsy-determined atherosclerosis seen in US military fatalities from the Korean and Vietnam conflicts versus the Afghanistan and Iraq conflicts.[3,5,6] Selection bias was also described to account for possible differences between earlier conflict conscripts versus more recent conflict all-volunteer forces,[6] with the latter having potentially healthier cardiovascular profiles

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TABLE 2 *Results of Bootstrapped, Age-Adjusted Logistic Regression Analysis of Body Mass Index and Occupational Specialty Associations With Coronary and/or Aortic Atherosclerosis in US Special Operations Command Battle-Injured Fatalities, September 2001 to July 2020 (N=356)*

Characteristics	Age-Adjusted Military Occupation OR (95% CI); *p*-value	Age-Adjusted Body Mass Index OR (95% CI); *p*-value
Age	1.15 (1.10, 1.21); <.001	1.15 (1.10, 1.21); <.001
Military occupational specialty		
Combatant	3.29 (0.91, 11.91); .06	
Support (ref)		
Body mass index*		
<25.0 (ref)		
≥25.0		1.58 (0.67, 3.70); .30
Unable to determine		1.01 (0.43, 2.41); .98

*Calculated as weight in kilograms divided by height in meters squared. Two fatalities had a BMI <18.5, and 16 fatalities had a BMI ≥30.

and the benefit of increased survival from advancements in battlefield trauma care.

Data from our USSOCOM population show a similar age-specific prevalence of atherosclerosis compared with the previous autopsy study of fatalities from conflicts in Afghanistan and Iraq by Webber et al.[6] However, notable are differences in prevalence for risk factors between USSOCOM fatalities and total US military force fatalities, specifically in respect to BMI and occupational specialty. A BMI of ≥25 was associated with increased prevalence of atherosclerosis in both populations; however, for USSOCOM fatalities, the BMI was not a statistically significant discriminator between those with and without atherosclerosis. A possible explanation for this finding may be that of small sample size because only two USSOCOM fatalities had a BMI <18.5 and 16 had a BMI ≥30. Thus, the BMI distribution was more constrained between a BMI of 20 to 30, making it less likely to observe differences. Additionally, BMI may not accurately reflect body composition in this athletic population (greater skeletal muscle mass versus excess adipose tissue).

The difference in occupational specialty was more pronounced, as Webber et al.[6] observed a lower prevalence of atherosclerosis among personnel with combat (11.3%) versus noncombat (13.6%) occupations, and our data showed a higher prevalence among personnel with combat (18.5%) versus non-combat (8.1%) occupations. However, overlapping CIs did occur and are likely the result of the small sample size of noncombat personnel. In age-adjusted analysis, the odds of atherosclerosis were three-fold higher in combatants versus support personnel, with a p value of .06. It is difficult to make inferences from this observation because combat occupation activities in the USSOCOM environment occur at a higher operational tempo and in general incur a larger amount of risk and, presumably, stress.

Data absent from this analysis that could provide biologically plausible explanations for this observation include smoking, smokeless tobacco, sleep deprivation, performance-enhancing supplements, dietary factors, stressful environments, and physical exposures, particularly during high-intensity training and while on combat operations. Nutrition and nutritional supplement information available to Special Operations Forces has largely been inferred from studies on traditional sports and athletes. Although human physiology is fundamentally the same, the circumstances and context of combat training and operations are unique.[14] Thus, physical training and combat environment intensity and frequency, as well as the consumption of multiple combinations and varying quantities of performance-enhancing supplements, are factors that should be further explored to determine atherosclerosis impact and protection versus risk. Such information would not only better inform decisions made by individuals but would also better inform leaders, commanders, and policy. This may be particularly important as the military evaluates and treats patients with low testosterone or assesses the future utility of testosterone supplementation to increase lean body mass during short-term severe energy deficit.[20]

Additionally, among fatalities with combat occupations, Webber et al.[6] reported an atherosclerosis prevalence of 11.3% (95% CI, 10.1–12.5%), while we found that USSOCOM fatalities had a significantly higher atherosclerosis prevalence of 18.5% (95% CI, 14.6–23.2%; p < .001). This finding could potentially be explained by the difference in age distribution between study populations: total US military forces (mean age, 25.9 years) versus an older Special Operations population (mean age, 31 years). Another possible explanation may be linked to differences in the intensity of exposure to stressful combat environments between Special Operations combatants and combatants in the total force, and between Special Operations combatants and Special Operations support personnel.[10]

Exposure to chronic psychological stress is believed to contribute to cardiovascular disease through pathophysiologic pathways, such as increased cardiac electrical instability and myocardial ischemia.[21] Strategies aimed at identifying and reducing psychologically stressful occupational factors are needed. This may be even more important among occupations with young and relatively healthy populations, such as USSOCOM, that are often presumed to have optimized other modifiable health behaviors, such as physical activity, nutrition, and overall fitness, but that have the potential to expose them to repeated psychological stress early in life. However, unlike European countries, the US does not generally acknowledge stress as a clinically meaningful risk factor for the development or progression of cardiovascular disease.[8]

Risk factors of hypertension, dyslipidemia, smoking, diabetes, and obesity have been well studied and followed by civilian, military, and veteran communities. However, combatant versus support personnel, males versus females, stress from combat, and nutrition and nutritional supplementation intake are all issues in the context of deployments and military service that warrant future investigation for atherosclerosis risk, morbidity, and mortality by the Department of Defense and the Department of Veterans Affairs. Additionally, because 18.4% of our study fatalities who died from potentially

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survivable–survivable injuries were found to have atherosclerosis, future study should also determine methods to evaluate the degree or combined effect such underlying disease comorbidity may have on injury survivability. This is particularly important because 88.4% of USSOCOM fatalities with potentially survivable or survivable injuries were found to have cardiovascular system stress via hemorrhage as a major component of the mechanism of death.[12]

Conclusions

Although fatalities in our study died from trauma and not from cardiovascular disease, this analysis can help identify preventive measures and future studies to better determine causality. Proactive and ubiquitous screening of military forces for risk factors and manifestation of premature cardiovascular disease should be considered and results analyzed. Data from individuals in autopsy studies could be matched with medical records and more detailed information on relative risk for hypertension, dyslipidemia, smoking, diabetes, and stress history examined.

Routine survey for other potentially more covert findings, such as degradation in athletic or mental performance, may help with early identification. A better understanding of etiologies contributing to these findings would benefit atherosclerosis prevention and mitigation strategies. Focused risk assessments should be refined and individualized throughout US Special Operations Forces human performance programs. Atherosclerotic disease development should be identified and closely monitored prospectively for progression.

Despite the advantages of age, healthy lifestyle, and the health-promoting community of elite US military Special Operations Forces, atherosclerosis was still found at autopsy. Efforts to mitigate the effects of well-studied behavioral health factors (e.g., smoking, diet) that contribute to atherosclerosis in this population must be intensified. Additionally, research and public health interventions must also study and target adverse occupational health factors to reduce the burden of cardiovascular disease in occupations otherwise dominated by young, active, relatively healthy populations.

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Disclaimer

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The authors have no disclosures.

Author Contributions

RSK and ELM conceived the study concept and design. All authors assisted in the acquisition, analysis, and interpretation of data. RSK, ELM, JTH, and JCJ contributed to the initial draft of the manuscript. All authors revised the manuscript for critically important intellectual content. All authors read and approved the final version of the manuscript to be published.

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- Prehospital Trauma Registry After-Action Reviews in Afghanistan
- Telemedicine Capabilities of Special Operations
- Targeted Intervention in Patients With mTBI
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