Prevalence of Cardiovascular Abnormalities in Pilots Involved in Fatal General Aviation Airplane Accidents

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Introduction: Cardiovascular disease in general and coronary heart disease in particular remains the leading cause of morbidity and mortality in developed countries. Coronary artery disease is of concern in aviation because of its potential to cause sudden in-flight incapacitation. The purpose of this study was to analyze the cardiovascular abnormalities in pilots involved in fatal general aviation airplane accidents. ***Method:*** A comprehensive review was performed of all cardiovascular abnormalities detected during autopsies conducted on pilots involved in fatal fixed-wing general aviation aircraft accidents in the U.S. from 1996–1999. Data was obtained from the database maintained at Civil Aerospace Medical Institute in Oklahoma City. ***Results:*** An analysis of 534 autopsy reports revealed presence of cardiovascular abnormalities in 234 pilots (prevalence rate 43.82%). Coronary artery stenosis had a prevalence rate of 37.64%. There were 41 pilots who had evidence of severe atherosclerosis of the left coronary artery. This was significantly associated with stenosis of the right coronary and circumflex arteries. There was a statistically significant relation between coronary atherosclerosis and advancing age. ***Discussion:*** Although the overall prevalence of coronary atherosclerosis is lower than previously reported, evidence of severe atherosclerosis was found in a relatively high percentage of pilots and may be a cause for concern. The findings have implications for aircrew health education and primary prevention programs. There is also a need for more standardized data collection.

Keywords: cardiovascular disease, coronary artery disease, aircrew.

AT THE END of the 20th century, cardiovascular diseases (CVD) including coronary heart disease (CHD) accounted for one of every 2.5 deaths in the U.S. (1). An estimated 61.8 million Americans have some form of CVD (1). The prevalence of the disease has been shown to increase with age and to be higher among middle-aged men (34.2%) than women (28.9%) (1). Although the cardiovascular mortality rate in the U.S. has been declining by approximately 2–3% for the last 15 yr (2), CHD remains the single leading cause of death (1).

CVD in general, and CHD in particular, has the potential of causing sudden cardiac death (SCD). SCD is defined as natural death due to cardiac causes, heralded by abrupt loss of consciousness within 1 h of the onset of acute symptoms (22). Pre-existing heart disease may or may not have been known to be present, but the time and mode of death are unexpected. The most widely used estimate is 250,000 SCDs annually (1), a figure that represents 50% or more of all cardiovascular deaths in the U.S. There are two ages of peak incidence of sudden death: between birth and 6 mo of age, and between 45 and 75 yr of age (6). In the adult population, the incidence of SCD due to CHD increases as a function of advancing age. CHD can often remain asymptomatic with SCD being the first presentation of the disease (14).

Coronary Heart Disease and Aviation

CHD has been a cause for concern in aviation, ever since the first published aircraft accident subsequent to a pilot's fatal heart attack occurring during flight in 1937 (3). Certain studies, such as the "1000 Aviator" project in 1978 and 1979, reported a lower mortality rate for cardiovascular diseases for aircrew than would be expected from an unselected U.S. male civilian population (8,17). In 1985, Holberg (13) reported a decreased overall incidence of acute myocardial infarction (MI) in U.S. Navy pilots, but showed a relationship of increasing cardiac risk and age. However, autopsy studies have not shown differences in significant CHD in pilots of both civilian and military aircrew compared with age-matched control subjects. These studies have reported a 10–20% prevalence of significant (50%–75%) stenosis of one or more coronary arteries (28,29,30).

CHD is of concern in aviation safety because of its potential to cause in-flight incapacitation. Incapacitation due to CHD may be slow or abrupt in onset and subtle or complete in its manifestation. The aviation community has been immensely concerned with the issue of in-flight incapacitation. This concern for the possibility of sudden in-flight incapacitation has governed the development of medical standards both for screening for a medical disorder as well as evaluation of medical conditions before resuming flying. Incapacitation in general aviation (GA) is of much greater concern

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to regulatory authorities, since the likelihood of an accident following in-flight incapacitation is usually greater when there is no co-pilot.

The causes of in-flight incapacitation in civil and military pilots are varied and include acute coronary events (18,21,26), new onset idiopathic epilepsy, gastrointestinal illnesses, and physiological problems such as spatial disorientation and hypoxia (26). Despite the fact that less than 1% of all air accidents occur as a consequence of in-flight incapacitation (21), pilots receive extensive health risk assessment, because sudden incapacitation in the air is costly in terms of life and aircraft (7,18). In the civilian pilot population, which is generally older compared with the military, acute coronary events are responsible for a large number of sudden incapacitation (18,21), usually occurring in men over age 40.

CHD, thus, assumes importance in aviation for various reasons. Firstly, as a disease itself, it needs to be addressed by primary and secondary prevention strategies as applicable to any population, so that the decreasing trends in the incidence and mortality of CHD can be maintained. Second, the knowledge of the extent of the prevalence of the disease can direct or influence policies with respect to routine medical examination of pilots. Third, CHD is, and will likely remain the leading medical condition to influence all safety decisions with respect to the likelihood of in-flight medical incapacitation.

Unfortunately, there have been no reported studies for almost two decades on the prevalence of CVD among pilots. Population characteristics of disease are influenced and modified by various intervention strategies and it is essential that policies and decisions be based on the most current data of the disease burden in the population. The purpose of the present study, therefore, was to analyze the cardiovascular abnormalities in general, and coronary atherosclerotic changes in particular as observed and documented in autopsies conducted on GA pilots involved in fatal fixed-wing airplane accidents between 1996 and 1999.

METHODS

Autopsies on pilots involved in fatal civil aviation aircraft accidents in the U.S. are conducted by the local medical authorities under whose jurisdiction the accident occurs. These reports are then forwarded by the Regional Flight Surgeons to the Federal Aviation Administration's (FAA) Civil Aerospace Medical Institute (CAMI) in Oklahoma City. These autopsy reports were analyzed for pilots involved in fatal fixed-wing airplane accidents operating under Code of Federal Regulations (CFR) Title 14, Part 91 from 1996 to 1999. A total of 559 autopsies of pilots involved in 498 accidents were analyzed. For the corresponding period, there were 1121 fatal GA accidents, yielding an autopsy rate of about 44%.

Booze et al. (4), in their analysis of post-mortem coronary atherosclerosis changes in GA pilots, successfully used a three-category system which accommodated expressions of mild, moderate, and severe as follows:

Grade I (mild): <33% luminal occlusion
Grade II (moderate): 33–66% luminal occlusion
Grade III (severe): >66% luminal occlusion

The same classification system was used for this study. Terms such as "few atheromatous plaques," "no significant atherosclerosis," and "minimal or mild atherosclerosis" were placed into the Grade I category. When it was stated in the report that moderate or severe atherosclerosis was present with no figures quoted, they were placed in Grade II and Grade III, respectively. Whenever the pathologist used combinations such as minimum-moderate or moderately severe, the upper category was recorded. A similar rationale was used for percentage figures, for example 60–70% occlusion was recorded as Grade III (using 70%). In all cases, the numerical figure took priority over the descriptive term, for example, moderate atherosclerosis with 30% occlusion was recorded as Grade I.

The following categories of information related to cardiovascular disease/pathology were selected from the autopsy data for analysis in our study. Stenosis of the left, right, and circumflex coronary arteries, coronary stenosis general, coronary histology and graft, and aorta and coronary calcification were included for analysis. The category of coronary artery stenosis (general) appears to have been used when there was a generalized atherosclerosis in almost all the arteries. The category of coronary histology was interpreted as representing all other changes related to the cardiovascular system excluding those of atherosclerosis and calcification that were documented during autopsy.

RESULTS

Cause of Death

Of the 559 cases, blunt trauma, implying polytrauma was attributed as the primary cause of death in 86.0% (n = 481) of the cases. The next highest were thermal burns (3.9%, n = 22), and drowning in 3.6% (n = 20) of the cases. Exsanguination and inhalation of smoke and toxic gases were each responsible for 2.0% (n = 11) of the cases. Cardiovascular (CVS) disease was considered as the primary cause of death in six cases (1.07%). See Wiegmann and Taneja (31) for a global analysis of the injuries contained in this database.

Of the six cases in which CVS was considered as the primary cause of death by the medical examiner, in four of them incapacitation (heart attack) was cited as a cause by the National Transportation Safety Board (NTSB) investigators. Coronary stenosis was present in these cases ranging from 20% to 100%, with evidence of thrombus in one. On the other hand, there were five cases which mentioned acute MI/thrombus/clot on autopsy which could have occurred just prior to the accident. In only one of these, incapacitation was cited as a cause by the investigators.

Prevalence of Cardiovascular Abnormalities and Coronary Artery Atherosclerosis

Of the 559 autopsies analyzed for this study, 25 indicated that the body was fragmented and no organ/viscera may have been available for examination. There

TABLE I. DISTRIBUTION OF CORONARY ARTERY STENOSIS.

Degree of Stenosis	Left	Right	Circumflex	General	Total (%)
Grade I: <33%	30	27	21	11	89 (34.49)
Grade II: 33–66%	39	20	10	07	76 (29.45)
Grade III: >66%	41	27	15	10	93 (36.04)
Total	110	74	46	28	258

were 234 autopsies out of the remaining 534 that had some cardiovascular abnormality (prevalence rate of 43.82%). Coronary artery stenosis (stenosis of the left, right, circumflex artery, coronary stenosis general and coronary calcification) was present in 201 of the 534, giving a prevalence of 37.64%.

Severity of Coronary Artery Stenosis

Stenosis of the left coronary artery was present in 110 of these autopsies. While 37.27% (n = 41) of these 110 cases fell in the category of Grade III (severe) atherosclerosis, 27% (n = 30) were considered mild/minimum or Grade I. Stenosis of the right coronary artery was documented in 74 autopsies. Of these 74 with stenosis of the right coronary artery, 36.48% (n = 27) had evidence of Grade III atherosclerosis. An equal number had Grade I (mild) atherosclerosis. Stenosis of the circumflex artery was present in 46 autopsies and showed evidence of less severe atherosclerosis, half of them being Grade I stenosis.

Presence of atherosclerosis in the left coronary artery was significantly associated with concomitant presence in the right coronary artery [χ^2(n = 234,1)=68.886, p < 0.001] and circumflex artery [χ^2(n = 234,1)=37.452, p < 0.001]. Atherosclerosis in the coronary arteries was significantly associated with age (see below). Data available from 201 autopsies that had stenosis of the left, right, and circumflex coronary artery along with the coronary stenosis general were combined to produce an estimate of the severity of disease. Of the 258 arteries that had stenosis, Grade III stenosis was seen in 36.04% (n = 93), whereas, 34.49%(n = 89) had Grade I stenosis (**Table I**).

Arterial Calcification

Coronary and aortic calcification was described in 78 and 48 autopsies, respectively. While it is difficult to ascribe the exact significance, it should presumably be considered as referring to advanced atherosclerotic changes in these blood vessels. There was more descriptive information available in this category. Of the 78 cases with coronary calcification, evidence of severe calcification was documented in 15% (n = 12) of the autopsies. Similar findings were observed under aortic calcification, where 13% (n = 9) of the 48 autopsies with aortic calcification were in the form of severe calcification (>66%).

Cardiac Histology, Graft, and Pacemaker

Coronary histology, better considered as cardiac histology, was another category of cardiovascular findings and reflects the changes observed histologically. There were 46 autopsy reports that had some findings recorded under this category. Cardiomegaly was observed in 36% (n = 18) of these 46 cases. Six cases had evidence of old myocardial infarction, whereas five had evidence of acute myocardial infarction, thrombus, or a clot. Two cases had cardiomyopathy.

There were six cases in which evidence of past coronary artery bypass graft surgery (CABGS) was present. A pacemaker was found in one. All the individuals who had CABGS were over 55 yr of age.

Age and Cardiovascular Abnormalities

There was a statistically significant relation between age and the presence of cardiovascular abnormalities [χ^2(n = 534, 8)=59.131, p < 0.001]. This relation was also observed between age and stenosis of the left [χ^2(n = 534, 8)=21.304, p < 0.01] and right coronary artery [χ^2(n = 534, 8)=24.600, p < 0.002], coronary stenosis general [χ^2(n = 534, 8)=18.100, p < 0.02], besides coronary calcification [χ^2(n = 534, 8)=31.696, p < 0.001].

The age distribution of the 234 pilots in whom cardiovascular abnormalities were documented is shown in **Fig. 1**. A total of 82.9% (n = 194) of these pilots were over 40 yr of age. Coronary artery atherosclerosis was also observed in 6 pilots who were 25 yr of age or younger. A large percentage of pilots who had evidence of double (47.1%) and triple vessel disease (35.1%) were over 61 yr of age. Also, of the 234 pilots with documented cardiovascular abnormalities during autopsy, 96.6% (n = 226) were males.

DISCUSSION

Cardiovascular diseases have been a significant cause of morbidity and mortality in the U.S. Evidence of CVD

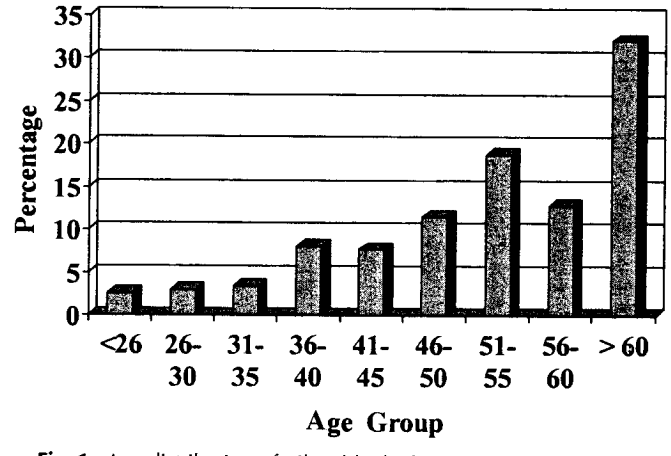

Fig. 1. Age distribution of pilots blocked across 5-yr age groups.

was present in 43.82% of the autopsies conducted on pilots involved in fatal aircraft accidents. Coronary artery disease (CAD) in the form of coronary artery stenosis was present in 37.64% of the pilots. Booze et al. (4) found evidence of CAD in 50.9% of the autopsies, whereas Pettyjohn and McMeekin (24) found CAD present to some extent at autopsy in about 87% of a 20–34-yr-old military group with 17% classified as moderate and severe. Mason (19) on the other hand found a prevalence of CAD amounting to 62% for a group of British military and civilian pilots killed while flying with 24% classified as having more than 50% luminal restriction. Mason (20) also points out that severe cardiac damage, a frequent feature of aircraft accidents, may have resulted in conservative interpretation and underestimation of the importance of coronary disease in fatal general aviation accidents.

CAD is defined as a more than 50% diameter stenosis in one or more of the coronary vessels (25). However, stenoses of $< 50\%$ also have major prognostic implications because these lesions most commonly lead to plaque rupture and acute MI. Sub-critical stenoses of $< 50\%$ are best characterized as non obstructive CAD. Lesions that produce stenoses of greater than 60% can cause flow limitations under conditions of increased demand (16). Data from stenosis of the left, right and circumflex coronary arteries were analyzed to give an estimate of the number of vessels involved. Single vessel disease was observed in 41.8% of the autopsies compared to 30.3% with evidence of triple vessel disease. Osswald (23) found triple vessel disease in 34.4% of his patients who had documented cardiac events, while 28.1% had single vessel disease. It is also worrisome that more than a third of the autopsies showed evidence of Grade III (severe) atherosclerosis or stenosis $> 66\%$. This differs significantly with the data reported by Booze et al. (4), who found evidence of severe coronary atherosclerosis in only 9.8% of pilots with coronary atherosclerosis. Perhaps, Booze et al. (4) had chosen the lower value of stenosis when a mixed figure was available and, therefore, had concluded that their data may possibly underestimate the severity of the disease. Non-standardization of reporting the cardiovascular disease at autopsy or differing age distribution of pilots in various studies could be possible reasons for this. The other explanation may be that, not discounting the different methodology used, this finding reflects a changing trend in the prevalence of severity of the disease and can be a cause for concern.

Sudden in-flight incapacitation of aircrew may result in loss of life and aircraft, and almost certainly in mission failure. While in-flight cardiac events are rare, the true frequency is probably underestimated (23), since identifying pilot incapacitation as a cause for an aircraft accident may be difficult or even impossible. CAD can be an important cause of sudden incapacitation or death even without prior history. In a study of cardiac events in asymptomatic USAF aviators over a 5-yr period, Osswald (23) found that 21% ($n = 8$) of cardiac events in previously asymptomatic aviators was SCD. In the present study there were six cases in which the medical examiner had considered cardiovascular disease as the primary mechanism of death. In four of these the National Transportation Safety Board (10) cited incapacitation (heart attack) as a cause. There was one report which was factual and thus no cause of accident/death annotated, however, autopsy can obviously provide vital input in this case. On the other hand, there were five cases where the medical examiner found evidence of acute MI/clot in the autopsy, but did not consider CVS as the primary cause of death. Blunt trauma was considered as the primary cause of death in these cases. The NTSB considered heart attack as the probable cause in only one of these four accidents. This points to the oft-encountered difficulty of determining the cause of death in accidents involving incapacitation and, even when there is evidence of acute myocardial infarction, blunt trauma may appear the more obvious cause of death.

Age distribution of the pilots in these data parallels the findings reported in literature (13,23). Holberg (13) while reporting the incidence of cardiovascular disease diagnosed among U.S. Navy pilots, found a significant relationship of increasing cardiac risk and age. Osswald (23) found a significant increase of cardiac events with age in USAF aviators. Our data confirm the above reported findings that age is a major determinant of the presence of coronary atherosclerosis as well as cardiovascular abnormalities in the population studied.

What are the implications of the finding that 82% of the pilots analyzed in this study were over 40 yr of age? Does it justify a screening procedure for CVD and, especially CHD, for pilots at this age? The medical examination required for general aviation flying (class III) does not require a screening EKG for confirming cardiovascular fitness. FAA requires a screening resting EKG at the age of 35 and annually after the age of 40 yr for issuance of a Class I medical certificate (9). There have been numerous studies on the role of resting EKG and even exercise EKG in detecting asymptomatic CAD, with exercise EKG being more reliable. A meta-analysis showed that the sensitivity and specificity of the exercise EKG for the detection of CAD were as high as 68% and 77%, respectively, in 147 consecutive published reports of patients who underwent angiographies and exercise testing (11). Considering the cost-benefit of introducing any new investigation, it is prudent to suggest that primary preventive strategies, especially aimed at selected age groups could produce the most cost-effective long-term benefits.

As a final note about the procedure used to classify CAD, the USAF classifies CAD aeromedically as Minimal Coronary Artery Disease (MCAD) and Significant Coronary Artery Disease (SCAD) (23). While MCAD refers to $< 40\%$ stenosis; SCAD refers to any single lesion greater than 40%, or gradable left main disease. The Armed Forces Institute of Pathology (4) uses a four-category classification system for coronary atherosclerosis as follows:

Grade I: $< 25\%$ luminal occlusion
Grade II: 26–50% luminal occlusion
Grade III: 51–75% luminal occlusion
Grade IV: $> 75\%$ luminal occlusion

All the above are attempts at classification and grading of disease for purposes of standardization, compar-

ison across databases, or even for risk stratification and decision making with regards to the flying status of an aviator. The classifications can sometimes induce a sense of complacency, especially with the lower grade disease. Several kinds of clinical observations over the last several years suggest that most MI result not from critical blockage but from lesions that produce stenoses that do not limit flow. It was observed that majority of acute occlusions actually occur in vessels with a previously identified stenosis of less than 50% on angiograms performed months to years earlier (2). The high-grade stenoses, when present, more frequently lead to acute myocardial infarction (2). However, because the non-critical stenoses by far outnumber the tight focal lesions in a given coronary tree, the lesser stenoses cause more infarctions, even though their individual probability of causing an MI is less than that of the high-grade stenoses. Therefore, it is imperative that the total prevalence of coronary atherosclerosis be considered whenever the prevalence of disease in aviator population is evaluated for purposes of risk intervention or the potential of in-flight incapacitation. Standardization of classification system is also needed for better interpretation and application of results of CAD research in aviation.

A comment should also be made concerning the overall completeness of the autopsy data used in this study. As mentioned earlier, the autopsy reports examined here were from 498 out of a possible 1121 fatal accidents occurring from 1996–1999, indicating an autopsy reporting rate of about 44%. Aviation authorities in the U.S. have expressed concerns about the low percentage of autopsy reports reaching CAMI, despite the existence of federal guidelines that state specific procedures for submitting these reports (5). Efforts should be directed to increase their rate of reporting because findings obtained from autopsies can provide vital information about crash forces besides the medical findings that can guide policy issues.

CONCLUSIONS AND RECOMMENDATIONS

CAD remains a leading cause of morbidity and mortality in the population. This study suggests that CAD is also a growing problem in the general aviation pilots. Population intervention strategies in combating CAD have proved successful in developed societies. Alterations such as the decrease in prevalence of cigarette smoking, the detection and treatment of hypertension, and reduction in serum cholesterol due to changes in diet and exercise have possibly influenced the rate of CAD (12). However, no program exists that specifically targets the pilot population. The success of these primary preventive strategies in the general population speaks for the priority with which these strategies could be reinforced through the system of aviation medical community. Cardiac risk detection and modification should become an integral part of the primary healthcare program of the pilot population. This could be reinforced by investigative techniques targeted at a subset identified as high cardiac risk population. Furthermore, it is essential that some standardized classification system be devised and agreed upon for identifying the atherosclerosis load during autopsies, so that prospective studies could evaluate and interpret data much more effectively.

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