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Aviation Accident Risk for Airmen with Aphakia and Artificial Lens Implants

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16. Abstract

Airmen with aphakia and intraocular (IOL) implants who, on a case-by-case basis, may obtain a waiver for a medical certificate, have been previously associated with higher aviation accident rates when compared to the total civil airman population. This study analyzes the accident frequencies of these civil airmen for a 4-year period (1982-95). Medical records were evaluated for all certified airmen who carried FAA-specific pathology codes for aphakia and artificial lens implants during the study period. Aviation accident and active airman population frequencies were obtained from FAA databases. The entire population of aphakia and IOL airmen and those < 50 years of age had significantly higher ($p < .50$) accident rates than the corresponding non-aphakic airman population. Aeromedical certification considerations of the study findings are discussed. Further investigations into additional confounding factors between the aphakic and non-aphakic populations are recommended.

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AVIATION ACCIDENT RISK FOR AIRMEN WITH APHAKIA AND ARTIFICIAL LENS IMPLANTS

INTRODUCTION

Vision changes as one ages. Changes in refraction and ocular light transmission typically appear in the age range 34-45 years, while those changes in the retinal and neural system usually become more evident about age 55-65 (1). Presbyopia, macular degeneration, and glaucoma are examples of vision conditions that become more common with aging (2).

Elderly pilots are becoming a larger percentage of the total civil airman population. In 1966, pilots over 50 years of age made up only 9.5% of the civil airman population. Twenty years later, in 1986, this age group comprised 22% of that population (3). As the frequency of elderly pilots has increased, the prevalence of visual impairment in the civil airman population has also increased (4)(5).

Cataract, a condition in which there is a loss of transparency of the crystalline lens or its capsule, is the third leading cause of blindness in the United States (6) and is often associated with the aged. Aphakia, a condition in which the crystalline lens has been extracted, is usually a result of the removal of a cataractous lens. The relationship of age to aphakia is well established, and was again verified in a recent study on aphakia prevalence in the civil airman population (7). There are three ophthalmic devices normally employed to correct aphakia: spectacles, contact lenses, and artificial or intraocular lens (IOL) implants.

Aphakic spectacles have many optical deficiencies and are not recommended for flight operations (8). Although superior to spectacles, contact lenses used to correct aphakia have their own deficiencies. Poor compliance is a problem with rigid (hard) lenses (9). Soft contact lenses are difficult for the patient to see, poorly handled by older aphakics, and their wearers are more prone to infections and more susceptible to the development of contact lens solution sensitivities.

In the last decade, IOL implantation has become the primary therapeutic modality for the correction of aphakia in the United States. In 1980, approximately 396,000 cataract procedures were performed in the United States and 30% of these surgeries included the implantation of an IOL (10). In 1988, nearly one million cataract operations were performed in the United States and 90% of these surgeries included the implantation of an IOL (6). In 1990, approximately 1.385 million cataract surgeries were done in this country and 98% of these included the implantation of an IOL (11). Cataract surgery accounts for about 40% of all eye operations in the United States (12) with a success rate for contemporary cataract surgery of better than 98% (13). During this period, there have been notable advances in cataract surgical procedures and in designs and materials used by ophthalmic surgeons for IOL implantation which have provided the impetus for early medical intervention. A recent Federal Aviation Administration (FAA) study confirmed the

increased prevalence of IOL use in the civil airman population during the period 1982-85 (14).

In the FAA's Guide for Aviation Medical Examiners (AME), the examining physician may issue a medical certificate to a third-class (private pilot) aphakic applicant who meets designated visual criteria and is otherwise healthy. However, first- (air transport pilot) and second-class (commercial pilot) airman applicants who have had cataract surgery are deferred issuance of a certificate and their applications are submitted for further consideration by the FAA. A waiver can be issued for such applicants (15), on a case-by-case basis, after review of a complete ophthalmological evaluation.

Aviation accidents associated with defective vision in civil airmen have been the subject of numerous studies by the FAA (16, 17, 18, 19, 20, 21, 22, 23). Two of these studies by Dille and Booze addressed aphakia and artificial lens implants (21,22). While one of the studies found a statistically significant elevation in the accident rates for these pilots in relation to that of the total airman population (21), the other study reported only that the accident rates for the aphakia and artificial lens implant groups were higher than the rate for the total airman population (22). Due to the small accident population in relation to the large overall airman population, this later study did not have enough power to test whether these differences were statistically significant. The authors recommended that a longer term study be performed in the hopes of determining whether accident rates for pilots having these medical conditions were significantly higher than those of a normal pilot population.

The Federal Air Surgeon's request for continuing research on vision disorders related to aging, surgical intervention or other treatment as they affect airman performance, prompted the Vision Research Section, Civil Aeromedical Institute, in collaboration with the Aeromedical Certification Division, to perform a follow-up epidemiologic study on aphakia and IOL in civilian airmen and their association with aviation accidents during the study period 1982-85. The objective of this report is to present the results of our analysis of relative risk of accidents for pilots with and without the defined defects (aphakia and IOL) for the study period, 1982-85.

METHODS

1. A list was generated identifying civil airmen who were issued airman medical certificates between January 1, 1980, and December 31, 1985, and who carried one or both of the FAA-specific pathology codes 134 (aphakia) and 160 (artificial lens implant) in FAA computer files.

2. The medical records of these airmen were reviewed and a Vision Defect Database, of known demographic and medical data on these aphakic airmen, was constructed from the medical examination records and FAA computer files.

3. The Aviation Standards National Field Office, Operations Systems Branch (AVN-124), generated a list from the Accident/Incident Data Systems for the period of January 1, 1982, to December 31, 1985, of all airmen who were involved in civil aviation aircraft accidents (i.e., Accident Database).

4. A list of known aphakic airmen (n = 3460) during the study period was provided to AVN-124. This list was matched against the Accident/Incident Data Systems database for the time period of January 1, 1982, to December 31, 1985, which identified those aphakic airmen involved in civil aviation aircraft accidents (i.e., Aphakic Accident Database), which included fatal accidents.

5. The Aphakic Accident Database was compared with the Vision Defect Database to ensure all the identified aphakic airmen with accidents were aphakic, with or without an IOL, at the time of their accident and active at the end of the accident year. (Note: Active refers to the current status of the airman's medical certificate. Airmen are considered active until their certificate expires. FAA aeromedical certification guidelines consider an airman to be active for a period of 24 months after the month in which the certificate is issued. A certificate remains active even with the death of the airman from aviation-related or nonaviation-related causes.)

6. The aphakic accident reports were reviewed to determine the ascribed causal role in the accident, and the likelihood of vision or eye pathology being a factor.

7. The Data Services Division (AAC-300):
   a) Stratified all active airmen in the Consolidated Airman Information System (CAIS) database by effective class of medical certificate (Note: FAA aeromedical regulations stipulate that an airman may be first- or second-class medically certified and the time lapse since examination would reduce the "effective status" to a lesser class.) and age (< 50 or ≥ 50 years) as of the end of each study year.
   b) Stratified all airmen with accidents by effective class of medical certificate and age as of the end of each study year.
   c) Stratified all aphakic airmen from the Vision Defect Database by pathology (aphakia and IOL), by effective class of medical certificate and age as of the end of each study year.

8. Accident rates per 1,000 airmen were calculated for three major populations, total airman (aphakic and non-aphakic), aphakic airman (aphakia with and without IOL), and IOL airman (aphakia with IOL). These populations were then stratified by age and class. These rates were calculated for each calendar year and for the composite 4-year study period. Significance was determined by using the Chi-Square statistic (X^2c), or the Fisher Exact 2-Tailed Test, when appropriate.

RESULTS

There were 12,883 aviation accidents that occurred during the study period. When these accidents were cross-referenced to the CAIS database, 1,889 (14.7%) were deleted due to non-readable information in the pilot certificate number field, incorrect pilot certificate or social security numbers, and changes in the control data, for a total of 10,994 identifiable accidents. When the airmen involved in these 10,994 accidents were stratified by effective class of medical certificate held at the end of each year of the study, 1,832 (14.2%) airmen were deleted for the following reasons: not active at the time of the accident or at the end of the year; active at the time of the accident but not at the end of the year; not active at the time of the accident but active at the end of

TABLE 1. TOTAL ACTIVE AIRMEN BY AGE GROUP AND YEAR

CATEGORY	1982	1983	1984	1985	CUMMULATIVE FREQUENCIES 1982-85
APHAKIA:					
< AGE 50	465	488	516	516	1,985
≥ AGE 50	1,284	1,457	1,620	1,775	6,136
TOTAL	1,749	1,945	2,136	2,291	8,121
IOL:					
< AGE 50	106	135	179	217	637
≥ AGE 50	558	785	996	1,206	3,545
TOTAL	664	920	1,175	1,423	4,182
TOTAL AIRMEN:					
< AGE 50	608,960	586,289	573,746	551,161	2,320,156
≥ AGE 50	159,382	162,016	165,554	165,316	652,268
TOTAL	768,342	748,305	739,300	716,477	2,972,424

the year: and doubtful determination of effective class of medical certificate and age, leaving a total of 9,162 (71.1%) airmen with aviation accidents.

Airmen from the Vision Defect Database (n = 3460) were cross-referenced to the CAIS database. A total of 43 airmen were deleted due to error messages in one of the identification fields (e.g., social security number, pilot certification number, etc.), leaving a total of 3,417 known aphakia and IOL airmen during the study period.

Aphakic airmen with accidents during the study period were cross-referenced to the CAIS database. One airman was deleted from the study (active at the time of accident, but was not active at the end of the year), leaving a total of 41 aphakic airmen involved in accidents and active at the end of the accident year.

The frequency of the total, and aphakia and IOL airmen by age groups (< 50 and ≥ 50) and by year is presented in Table 1. As expected, in the aphakia and IOL airman

TABLE 2. ACCIDENT FREQUENCIES BY AGE GROUP AND YEAR

CATEGORY	1982	1983	1984	1985	CUMMULATIVE FREQUENCIES 1982-85
APHAKIA:					
< AGE 50	2	1	3	7	13
≥ AGE 50	7	8	5	8	28
TOTAL	9	9	8	15	41
IOL:					
< AGE 50	1	0	2	4	7
≥ AGE 50	3	3	4	7	17
TOTAL	4	3	6	11	24
TOTAL AIRMEN:					
< AGE 50	1,885	1,730	1,722	1,578	6,915
≥ AGE 50	538	562	603	544	2,247
TOTAL	2,423	2,292	2,325	2,122	9,162

populations there are substantially more airmen ≥ 50 years of age. In the total airman population, the larger population is those airmen < 50 years of age.

The accident frequency of the total, and aphakia and IOL airmen by age groups and by year is presented in Table 2. In the aphakia and the IOL airman populations, the ≥ 50 age groups had more accidents than < 50 age groups, while the reverse was true in the total airman population.

TABLE 3. ACCIDENT RATES PER 1,000 AIRMEN BY AGE GROUP AND YEAR

CATEGORY	1982	1983	1984	1985	CUMMULATIVE RATES 1982-85
APHAKIA:					
< AGE 50	4.3	2.1	5.8	13.6	6.6
≥ AGE 50	5.5	5.5	3.1	4.5	4.6
TOTAL	5.1	4.6	3.7	6.5	5.0
IOL:					
< AGE 50	9.4	0.0	11.2	18.4	11.0
≥ AGE 50	5.4	3.8	4.0	5.8	4.8
TOTAL	6.0	3.3	5.1	7.7	5.7
TOTAL AIRMEN:					
< AGE 50	3.1	3.0	3.0	2.9	3.0
≥ AGE 50	3.4	3.5	3.6	3.3	3.4
TOTAL	3.2	3.1	3.1	3.0	3.1

The accident rate per 1,000 airmen of the total, and aphakia and IOL airmen by age groups and by year is presented in Table 3. Aphakia and IOL accident rates were significantly higher ($p < .002$ and $p < .0031$, respectively), in comparison to that of the non-aphakic airman populations. It is important to note that although aphakia and IOL airmen have higher total accident rates than the total airman population, aphakic airmen (with or without IOL) were responsible for only approximately 1.4 accidents per 100,000 airmen in the total airman population.

In the total airman population, the ≥ 50 age group had a significantly ($p < .0001$) higher accident rate than the < 50 age group. However, similar comparison of the aphakia and IOL populations indicated no significant difference ($p > .366$ and $p > .079$, respectively) between accident rates for the two age categories.

TABLE 4. SUMMARY OF STATISTICAL TESTS FOR PATHOLOGY AND AGE

CATEGORY	ODDS RATIO	95% CONFIDENCE INTERVAL	CHI-SQ (Yates)	P-VALUE	FISHER 2 -TAIL TEST
Total Aphakia	1.64	(1.19 < OR < 2.26)	9.61	0.00193	
Total IOL	1.87	(1.22 < OR < 2.83)	8.79	0.00303	
< Age 50 Aphakic	2.21	(1.22 < OR < 3.89)	7.36	0.00669	
< Age 50 IOL	3.72	(N/A)	N/A		0.00336
Note: Above populations are compared with like non-aphakic populations.					
≥ Age 50 Total Airman vs < Age 50 Total Airman	1.16	(1.10 < OR < 1.21)	35.60	0.00000	
≥ Age 50 Aphakia vs < Age 50 Aphakia	0.70	(0.35 < OR < 1.42)	0.82	0.36654	
≥ Age 50 IOL vs < Age 50 IOL	0.43	(N/A)	N/A		0.07950

Although both the < 50 and ≥50 age groups in both the aphakia and IOL populations had higher accident rates than similar age categories in the total airman population, only the < 50 aphakic and IOL populations had significantly ($p < .007$ and $p < .004$, respectively) higher accident rates than their counterparts in the non-aphakic airman population.

The statistical test results are summarized in Table 4.

Upon review of the FAA accident reports of airmen with aphakia or IOL, neither the presence of aphakia or IOL was ascribed a causal role, nor was any association to vision problems ascribed during any accident.

DISCUSSION

In our study, aphakia and IOL airmen have significantly higher accident rates/1,000 airmen than the rates for the non-aphakic airman population. For the defined defects, our accident rates are lower than those reported in Dille & Booze's 1979 and 1980-81 studies. However, direct comparison should be viewed with caution as the populations used to determine accident rates for the two studies are different. While we determined aphakia and IOL populations by direct review of the airman medical records, Dille and Booze determined their populations by pathology codes medically assigned by the FAA, several of which were found to be miscoded during our review process. In addition, we reviewed individual medical records to ensure all airmen involved in accidents had aphakia or an IOL at the time of the acciden and were active both at the time of the accident and at the end of the calendar year.

Age is considered significant in air carrier operations (e.g., in the U.S. the retirement age for air carrier pilots is 60 years), however there is no mandatory upper age limit for general aviation pilots. When analyzed by age categories, total civil airmen ≥ 50 years of age had significantly higher accident rates than those airmen < 50 years of age. This supports the association of age with increased accident risk that has been previously observed (16, 24, 25). Booze found that age-specific accident rates for older airmen increased approximately four times that of younger airman (24). Others have reported a linear increase in accident rate with increasing age (16, 25).

Aphakia and IOL airmen < 50 and ≥ 50 years of age had higher accident rates per 1,000 airmen than that for the same age categories in the total airman population. However, the differences between the non-aphakic airman population versus the aphakia and IOL airman populations were significant in airmen < 50 years of age and non-significant for the older age category. In other words, although there are substantially fewer aphakia and IOL airmen < 50 years of age, these younger airmen were involved in significantly more accidents than non-aphakic airmen of the same age category. We postulate that younger airmen may be "physiologically" impaired by aphakia, but do not have the "psychological" impairment that the aged often accept. As various sensory-motor functions, including vision, begin to deteriorate, the aged may exercise greater caution and reduced exposure to hazards. This finding may be significant since medical intervention for cataracts and the implantation of IOLs in the United States are being done on progressively younger patients. Additionally, the lack of significant differences in the accident rates of the ≥ 50 aphakia and IOL airmen compared to those of the < 50 aphakia and IOL airmen suggest that medical impairment rather than age may be a more important factor to aviation accident risk. These findings support Dougherty and Harper's (17) conclusion that the increased risk of accidents associated with age was actually associated with frequency of physical defects accumulating with age, rather than age itself.

An aircraft accident is defined as an occurrence associated with the operation of an aircraft which takes place between the time any person boards an aircraft with the intention of flight until such time as all such persons disembarked, in which any person suffers death or serious injury, or in which the aircraft receives substantial damage (26). Such events are rare, and the use of accidents as a performance measurement associated with a medical condition is limited by the low frequency of reported occurrences. Aircraft incidents, defined as occurrences

involving the operation of one or more aircraft in which the hazard or potential hazard to safety is involved, but are not classified as an accident due to degree of injury and/or extent of damage (27), may be a better performance measurement. However, many cases are not reported and other incidents are not a direct result of piloting an aircraft.

The rarity of aviation accidents is again demonstrated in our study. In the total airman population there were approximately 3.1 accidents per 1,000 airmen during the study period. The number of accidents contributed by either aphakia or IOL airmen to these accidents was minimal (about 0.014 per 1,000 airmen). The small number of aviation accidents makes statistical evaluation of association of stratified medical conditions to such events questionable. A coordinated airman health information and accident database system could greatly assist in any future correlation studies of aviation accidents to medical conditions by reducing the amount of lost data.

Human error has been found to cause or contribute to over half of all aviation accidents. Attempts to investigate human performance error, and vision performance in particular, in aircraft accidents face three major obstacles: such vision related accidents are rare events and difficult to identify; post-accident database information is often fragmentary or faulty; and potential liability associated with an accident can hinder the investigatory process (28). Neither aphakia nor IOL was ascribed a causal role upon review of the FAA accident reports, nor was any association with vision problems ascribed to any accident. Although upon close examination of these records some association of the accident with possible vision problems could be extrapolated either from environmental conditions present or the primary cause of the mishap, these are speculations and were not directly supported by the accident investigation team reports. Routine aircraft accident investigation, which seeks to determine the presence of physical problems and any association of the defect with the accident cause, may need to focus more closely on vision problems associated with aircraft accidents in order to truly identify causal relationships.

There are several aeromedical certification considerations indicated from our study, including:

1. The higher accident rates of the aphakia and IOL airmen suggest that epidemiological accident studies and clinical research on aviation stressor effects of these visually compromised airmen be continued. This research may be improved by a closer assessment of accident records to determine possible factors contributing to the accidents (e.g., time of day, phase of flight), which can be the foundation for considering various recommendations for reducing such accidents. The Vision Research Section plans to perform such an analysis of accidents involving aphakic airmen during our study period. Additionally, a system may be implemented that identifies aphakic airmen involved in accidents so that the evaluation by the accident investigator can focus on vision factors that may contribute to the accident.

2. Aphakia and IOL airmen in our study are not necessarily characteristic of airmen at any future time. Surgical techniques and ophthalmic materials are being constantly improved, as are changes in corrective device applications, which may improve the visual capabilities and safety of such pilots.

3. New medical applications to correct aphakia in the airman population should continue to be monitored.

4. No relaxation in the current aeromedical certification standards and review process is recommended at this time.

5. Future recommendations may consider the relative flight safety of airmen with multiple medical impairments.

6. Although no measurement of information processing skills, such as visual attention or cognitive function which the pilot possessed prior to the aircraft accident, is currently available, we have the capability to measure two functional variables (eye health and visual function) that contribute to the quality of visual information available to the pilot. These two variables, influenced by physiologic and environmental conditions, and the use of ophthalmic devices, can be monitored and optimized to improve visual efficiency and aviation safety.

In order to improve aviation performance and safety of the aged and the visually impaired, several programs are recommended for consideration and implementation:

1) The research community needs to develop basic information necessary for effective evaluation of the elderly and visually compromised airmen.

2) A medical or performance appraisal system should be developed to identify pilots considered to be at risk due to early or impending deterioration in health or performance. An appropriate measurement of piloting behavior (performance on a simulator) needs to be developed to evaluate pilot performance. And, as a result of an improved aircraft accident reporting system, a gauge of poor piloting skills (aircraft accident) can be used to validate such a performance test.

3) Aircraft design and maintenance needs to accommodate the capabilities and limitations of the older and medically impaired airmen.

4) Improved training and education of medically impaired airmen, whose conditions may adversely affect their ability to fly an aircraft, are needed.

CONCLUSIONS

The major findings of our study include:

1) Civil airmen ≥ 50 years of age had significantly higher accident rates than those airmen < 50 years of age.

2) Aphakia and IOL airmen had significantly higher accident rates than non-aphakic airmen.

3) Aphakia and IOL airmen < 50 years of age had significantly higher accident rates than non-aphakic airmen < 50 years of age.

Significant associations found with aphakia and IOL populations and aviation accidents should be cautiously interpreted. Our analysis could not directly attribute the causation of the observed higher frequency of aviation accidents to either aphakia and/or the use of an IOL. Therefore, it would be premature to suggest any change in current FAA aeromedical certification standards for airmen with aphakia and IOL. Further investigations into confounding factors between the aphakic and non-aphakic populations (e.g., flight hours, class of medical certificate held, type of aphakia) may provide further insight into possible visual problems in the cockpit.

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