

# A 5-Year Analysis of Aviation Medical Examinations in South Korea

Ji Soo Kim; Bok Soon Han; Young Hwan Kwon; Juwon Lim

- INTRODUCTION:** Little has been studied to promote aviation health in South Korea. The aim of this study was to analyze the results of aviation medical examinations conducted in South Korea over the past 5 yr and, in doing so, provide evidence for establishing a health promotion, disease prevention plan.
- METHODS:** Subjects of the study consisted of applicants who underwent aviation medical examinations from January 1, 2016, to December 31, 2020.
- RESULTS:** Over the past 5 yr, the total number of aviation medical examinations in South Korea has shown an annual increase of more than 10%. In the presence of the COVID-19 pandemic in 2020, the number of aviation medical examinations, both renewal and initial, for all types of licenses, except renewal aviation medical examinations for the ATCL, decreased. Disqualification rates were generally higher in initial examinations than in renewal examinations. The examination results for license renewal showed the ATPL disqualification rate to be the highest at 3.5 per 1000 pilots per year in their 50s, with cardiology cases being the most common reason for disqualification, followed by ophthalmology cases and psychiatry cases. Diagnostic categories for those disqualified after initial aviation medical examinations were similar, though ophthalmological causes were most common, followed by cases of psychiatry and neurology.
- CONCLUSION:** Main causes of disqualification in airmen and air traffic controllers were identified as the presence of cardiovascular, ophthalmic, and psychiatric diseases. The results of this study provide evidence for improving health promotion activity plans to manage risk factors of such diseases for aviation workers.
- KEYWORDS:** aerospace medicine, pilots, air traffic controllers, medical certificate, medical examination.

Kim JS, Han BS, Kwon YH, Lim J. A 5-yr analysis of aviation medical examinations in South Korea. *Aerosp Med Hum Perform.* 2022; 93(6):499–506.

The health of aviation workers, including airmen, is directly related to aviation safety. In particular, in-flight medical incapacitation that occurs without prior notice can impair aviation performance and threaten aviation safety. A previous study using the National Transportation Safety Board database identified fatal accidents during 2015 in the United States.<sup>24</sup> To ensure aviation safety, the International Civil Aviation Organization (ICAO) provides Standards and Recommended Practices for issuing licenses. South Korea has also established standards and procedures for aviation medical examinations in accordance with ICAO Standards and Recommended Practices.

Aviation medical examinations provide an opportunity for early detection and management of diseases, intended to prevent potential incapacitation and related consequences. According to the 2018 Aerospace Medical Certification Statistical Handbook,

the most commonly reported medical condition was hypertension with medication.<sup>21</sup> The need for promoting preventative mental health treatment and managing depressive symptoms has continued to be an issue.<sup>25</sup> However, to our knowledge, there have been no previous extensive reports regarding the results of aviation medical examinations in South Korea. The aim of this study was to analyze the results of aviation medical

From the International Healthcare Center; the Department of Occupational and Environmental Medicine, Kangbuk Samsung Hospital, Sungkyunkwan University School of Medicine; and the Aeromedical Center, Korean Air, Seoul, Republic of Korea. This manuscript was received for review in July 2021. It was accepted for publication in March 2022.

Address correspondence to: Juwon Lim, Ph.D., M.D., Seoul National University Hospital, Seoul, Republic of Korea; imvacsa@gmail.com.

Reprint and copyright © by the Aerospace Medical Association, Alexandria, VA. DOI: <https://doi.org/10.3357/AMHP.5973.2022>

examinations conducted in South Korea during a 5-yr period (2016–2020) and, in doing so, obtain a better understanding to establish a health promotion, disease prevention plan for aviation workers.

## METHODS

### Subjects

Subjects of the study consisted of applicants who underwent the aviation medical examination conducted by an aviation medical examiner (AME) between January 1, 2016, and December 31, 2020.

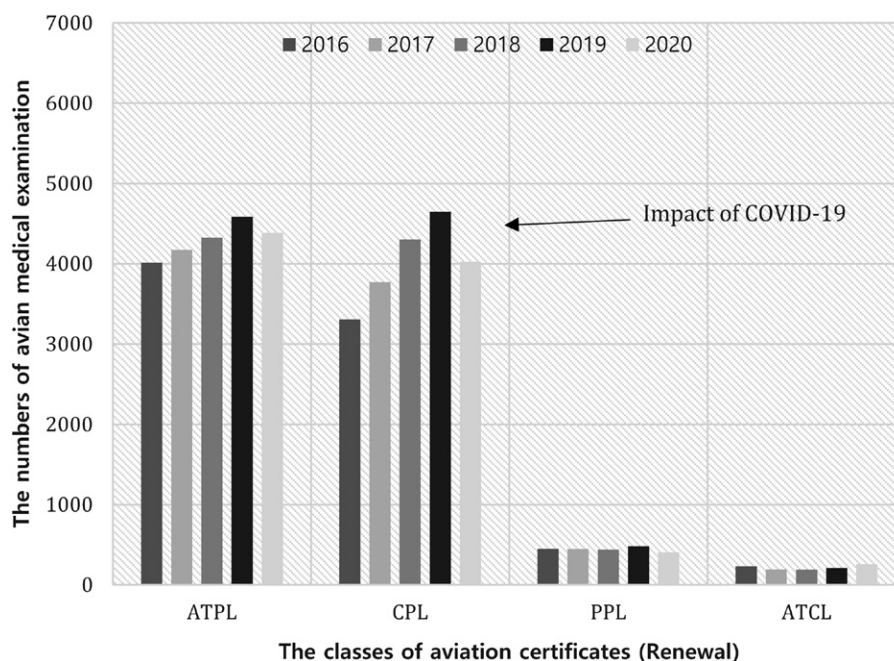
### Procedure

Aviation medical examinations are carried out for the purpose of obtaining a license (initial) or renewing the Air Transport Pilot License (ATPL), Commercial Pilot License (CPL) and Private Pilot License (PPL), or Air Traffic Controller License (ATCL). The AME is obligated to submit the results of the aviation medical examination to the Aerospace Medical Association of Korea monthly. The association then reviews the suitability of the airman medical certificate issuance. A decision assessed to be fit refers to a case that meets the aviation medical examination criteria. Special issuance refers to a case in which the experience and ability of an applicant for aviation medical examination partially fails to meet a certain criterion; if it is deemed necessary, the airman medical certificate can be issued by limiting the scope of aviation duty, shortening the validity period, or imposing conditions such as medical checkups. A disqualifying medical condition refers to a case that does not meet the aviation medical examination standards.<sup>15</sup>

The Ministry of Land, Infrastructure, and Transport operates an Airmen Medical Certificate Management system to electronically store and process data of airman applicants, aviation medical examinations, and airman medical certificates.<sup>23</sup> The data for this study were obtained from official sources of the AMCM system. These included the age of applicants, current license status and type, affiliated organization, and diagnosis. Also, the final decision of the examination, which is determined by the advisory committee, and the reason for decision were used in the analysis of this study. Data were not inclusive of coexisting diagnostic categories that may have also contributed to the final decision and, therefore, only one diagnostic category was used per applicant. All diagnoses are recorded in the database using the MOLIT manual, which is inclusive of the *International Classification of Diseases, 10<sup>th</sup> Revision (ICD-10)* codes from the World Health Organization. This study was approved by the Seoul National University Hospital Institutional Review Board (IRB number: E-2105-144-1221). Because the database was officially provided and anonymized according to strict confidentiality guidelines prior to distribution, the requirement for informed consent was waived.

### Statistical Analysis

Statistical analyses were carried out using the STATA 16 program (StataCorp LLC, College Station, TX, USA). Pearson's Chi-squared test was used to calculate the statistical significance for each diagnostic category. Odds ratios and 95% confidence intervals were obtained by logistic regression analyses. We used  $P < 0.05$  as the level of significance. In addition, since age distribution differed according to license type, the disqualification rate was adjusted according to age.



**Fig. 1.** Number of aviation medical examinations for airmen medical certificates (renewals) according to license type from 2016–2020.

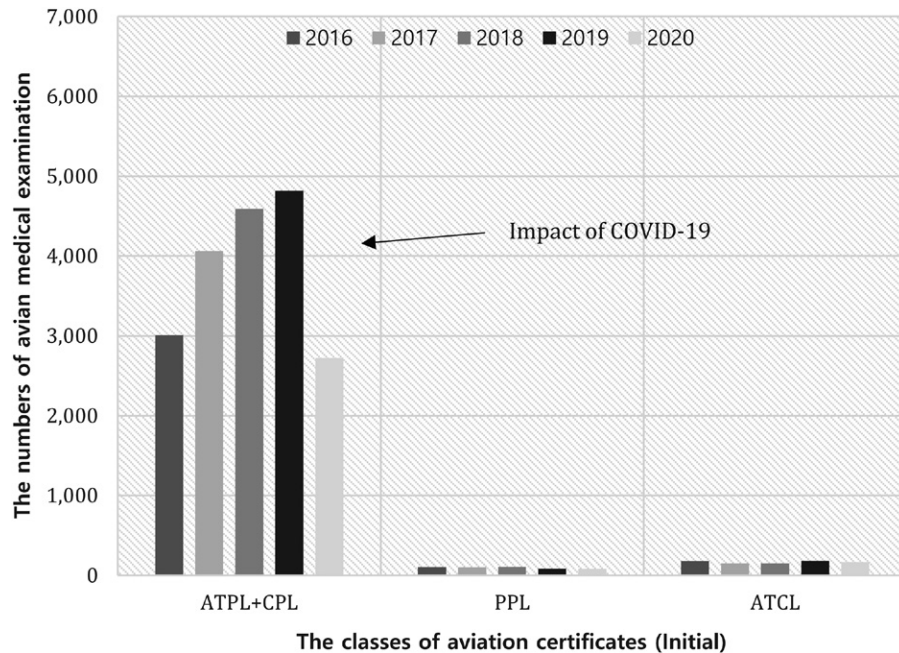
## RESULTS

During the 5-yr period, the number of aviation medical examinations, renewal and initial in total, increased by more than 10% annually: 11,290 cases in 2016; 12,893 cases in 2017; 14,107 cases in 2018; 15,007 cases in 2019; and 12,041 cases in 2020 (Fig. 1, Fig. 2).

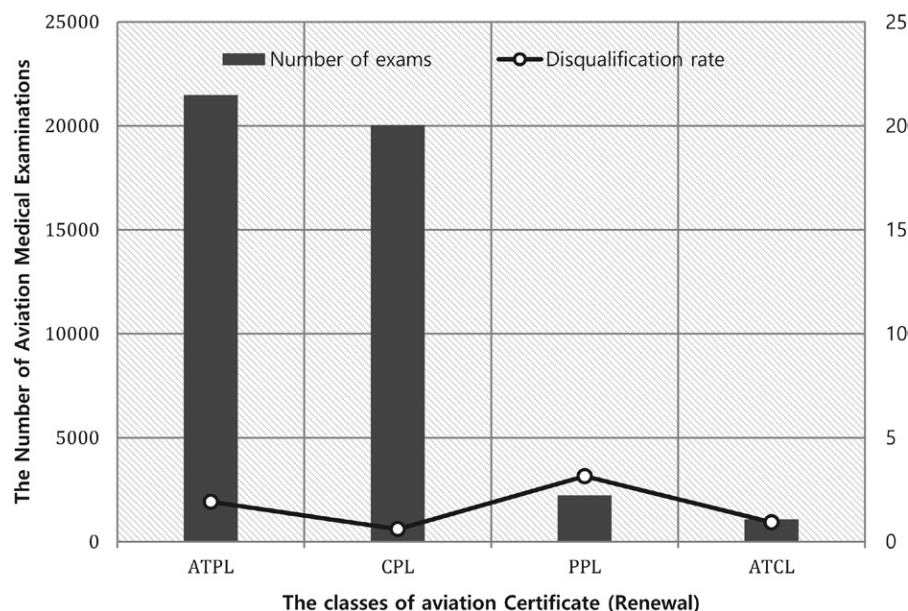
In the presence of the COVID-19 pandemic in 2020, the number of aviation medical examinations, both renewal and initial, for all types of licenses, except renewal aviation medical

examinations for the ATCL, decreased. Compared to 2019, the greatest decrease (43%) was seen in the number of initial examinations to obtain ATPL and CPL licenses; in contrast, renewal examinations for the ATCL increased 22%. In total, the number of initial aviation medical examinations decreased 42% while the number of renewal aviation medical examinations decreased 9%.

During 2016–2020, the proportion of cases for the ATPL and CPL accounted for the majority of both renewal and initial aviation medical examinations (92.6% and 93.6%, respectively).

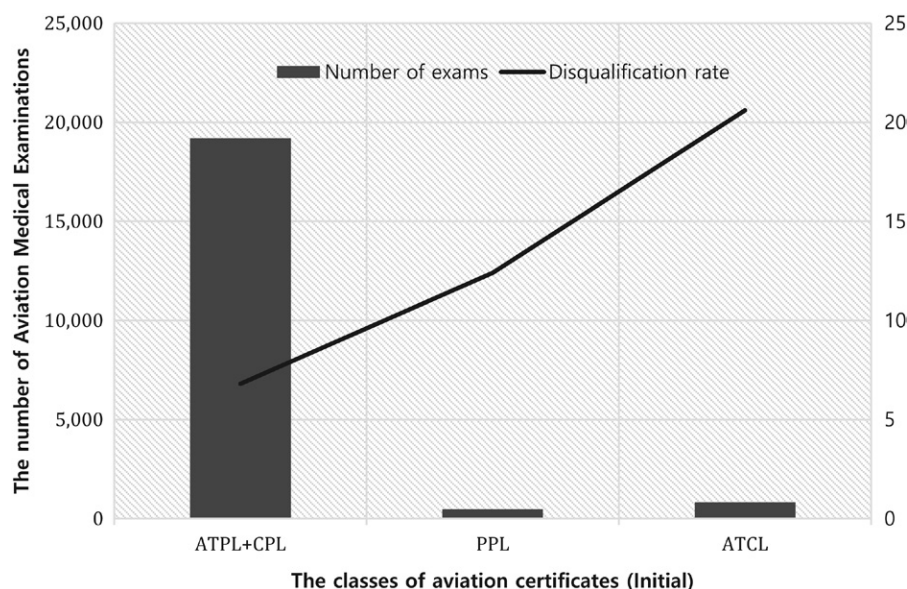


**Fig. 2.** Number of aviation medical examinations for airmen medical certificates (initial) according to license type from 2016–2020.



**Fig. 3.** Total number of aviation medical examinations for airmen medical certificates (renewals) and disqualification rates according to license type from 2016–2020.





**Fig. 4.** Total number of aviation medical examinations for airmen medical certificates (initial) and disqualification rates according to license type from 2016–2020.

The proportion of examinations for the PPL was higher in renewal than in initial examinations (5.0% and 2.4%, respectively), while the proportion of examinations for the ATCL was higher in initial than in renewal examinations (2.4% and 4.0%, respectively) (**Fig. 3, Fig. 4**).

Disqualification rates were generally higher in initial examinations than in renewal examinations. The highest rate (20.6) was observed for initial examinations to obtain the ATCL, contrasting from 0.93 (1 disqualification case out of 1079 examinations) for the same license in renewal examinations.

For license renewal, the average disqualification rate per 1000 pilots per year was statistically significant in the ATPL group ( $P = 0.005$ ,  $P = 0.003$ ,  $P = 0.039$  for those ages between 20 and 29, 50 and 59, and 60 and above, respectively). Those between 40 and 49 yr of age accounted for the majority (42.0%) of examinations. Among the ATPL applicants judged to be disqualified, the 50s age group accounted for the largest share at 54% (**Table I**). However, the rate of disqualification per 1000 pilots was the highest (19.2) in the 20s age group. No pilots in the 30s age group were disqualified. Specifically, the rate of disqualification per 1000 pilots by age group remained 1.0 in the 40s age group and increased to 3.2 in the 50s and 2.6 in the 60s age group ( $P = 0.003$  and  $P = 0.039$ , respectively). Main diagnostic categories for disqualification in renewal examinations were cardiovascular, followed by ophthalmology, for ATPL. Cardiovascular diseases such as myocardial infarction and coronary artery diseases and ophthalmological cases of visual field defect and failure of visual acuity test were more common causes of disqualification (**Table AI** online, <https://doi.org/10.3357/AMHP.5973sd.2022>). Disqualification due to psychiatric issues pertained to anxiety.

Regarding examinees for renewal of the CPL and PPL, most were below 40 (60.1%) and 30 (60.5%) yr of age, respectively.

Among the disqualified CPL applicants, the 30s and 40s age group accounted for the largest share at 31% and 46%, respectively. The rate of disqualification per 1000 pilots was 0.3 and 1.5 in the 30s and 40s age group, respectively. In the PPL applicants judged to be disqualified, the 20s and 30s age group accounted for the majority at 57% and 43%, respectively. The rate of disqualification per 1000 pilots was 3.0 and 3.9 in the 20s and 30s age group, respectively. There was no statistical significance between the 20s and 30s age group ( $P = 0.731$ ). Disqualification cases for renewal of the CPL and the majority (57%) of PPL included ophthalmological causes such as visual field defect; however, CPL disqualification cases also consisted of hypertension and ECG abnormalities without submission of additional information.

Among the applicants for initial examination for ATPL and CPL judged to be disqualified, the 20s and 30s age group accounted for 82% and 18%, respectively (**Table II**). The rates of disqualification per 1000 pilots for the respective age groups were highest at 7.7 and 6.7, respectively.

For those disqualified after initial aviation medical examinations for ATPL and CPL together, ophthalmological causes were most common [80 applicants (61%)], followed by cases of neurology (10%) and psychiatry (8%) (**Table AII** online, <https://doi.org/10.3357/AMHP.5973sd.2022>). Ophthalmological diseases, among diagnostic categories, had the highest disqualification rate of 4.2 per 1000 pilots. The most common diagnosis under the ophthalmological category was strabismus followed by visual field defect. Depression was the most common diagnosis for disqualification due to psychiatric issues. Similarly, ophthalmological diseases had the highest disqualification rates in PPL as well as ATCL; cases of strabismus and visual field defect were present as well as depression.

**Table 1.** Number of Aviation Medical Examinations for Airmen Medical Certificates, Disqualification Rates of Aviation Medical Examination, and Diagnostic Categories of the Disqualifications According to License Type (Renewal) from 2016–2020.

CLASSES	AGE GROUPS	NUMBER OF EXAMS	NUMBER OF DENIALS	PERCENT OF TOTAL DENIALS	AGE-SPECIFIC DENIAL RATE*	OR (95% CI)**	P-VALUE
ATPL	≤29	52	1	2%	19.2	19.6 (2.4–158)	0.005
	30–39	2125	0	0%	0.0		
	40–49	9026	9	22%	1.0	1	0.003
	50–59	6863	22	54%	3.2	3.2 (1.5–7.0)	
	≥60	3416	9	22%	2.6	2.6 (1.0–6.7)	
	Total	21,482	41	100%	1.9		
CPL	≤29	2379	2	17%	0.8	1	0.276
	30–39	12,223	4	33%	0.3	0.4 (0.1–2.1)	
	40–49	4004	6	50%	1.5	1.8 (0.6–8.8)	
	50–59	1020	0	0%	0.0		
	≥60	420	0	0%	0.0		
	Total	20,046	12	100%	0.6		
PPL	≤29	1345	4	57%	3.0	1	0.731
	30–39	776	3	43%	3.9	1.3 (0.3–5.8)	
	40–49	57	0	0%	0.0		
	50–59	21	0	0%	0.0		
	≥60	26	0	0%	0.0		
	Total	2225	7	100%	3.1		
ATCL	≤29	290	0	0%	0.0		
	30–39	242	0	0%	0.0		
	40–49	341	1	100%	2.9		
	50–59	169	0	0%	0.0		
	≥60	37	0	0%	0.0		
	Total	1079	1	100%	0.9		
NUMBER OF DENIALS, PERCENT OF TOTAL DENIALS, DENIAL RATE (N, %, RATE)							
DIAGNOSTIC CATEGORIES***	ATPL	CPL	PPL	ATCL	TOTAL		
Cardiology	16, 39%, 0.7	2, 17%, 0.1	0, 0%, 0	0, 0%, 0	18, 30%, 0.4		
Ophthalmology	9, 22%, 0.4	1, 8%, 0	4, 57%, 1.8	0, 0%, 0	14, 23%, 0.3		
Psychiatry	4, 10%, 0.2	1, 8%, 0	1, 14%, 0.4	1, 100%, 0.9	7, 11%, 0.2		
Malignancy	4, 10%, 0.2	2, 17%, 0.1	0, 0%, 0	0, 0%, 0	6, 10%, 0.1		
Neurology	4, 10%, 0.2	2, 17%, 0.1	0, 0%, 0	0, 0%, 0	6, 10%, 0.1		
Respiratory	1, 2%, 0	2, 17%, 0.1	1, 14%, 0.4	0, 0%, 0	4, 7%, 0.1		
Otorhinolaryngology	2, 5%, 0.1	0, 0%, 0	0, 0%, 0	0, 0%, 0	2, 3%, 0		
Others	1, 2%, 0	2, 17%, 0.1	1, 14%, 0.4	0, 0%, 0	4, 7%, 0.1		
Total	41, 100%, 1.9	12, 100%, 0.6	7, 100%, 3.1	1, 100%, 0.9	61, 100%, 1.4		

\*Age-specific disqualification rates per 1000 airmen applicants; \*\*OR and 95% CI were obtained by logistic regression analysis; \*\*\*only one main diagnostic category was used for one applicant. Coexisting diagnoses did not contribute to categorization.

ATPL: air transport pilot license, CPL: commercial pilot license, PPL: private pilot license, ATCL: air traffic controller license, OR: odds ratio, CI: confidence interval.

## DISCUSSION

In this study, the results of aviation medical examinations were analyzed for aviation workers including airmen, and the scope of cases was extensive over the course of 5 yr. Analyses were performed based on the type of license and whether examinations were initial or for renewal of respective licenses.

In South Korea, from 2016 to 2020, the total number of aviation medical examinations carried out for renewal of ATPL, CPL, and PPL over the 5-yr period was 21,482, 20,046, and 2225, respectively. In the presence of the COVID-19 pandemic in 2020, the number of renewal aviation medical examinations decreased, which the exception of renewal examinations for the ATCL. This may have been due to the alleviations or exemptions instated by ICAO for license renewal to eligible applicants. Corresponding disqualification rates for renewal of ATPL,

CPL, and PPL were 1.9, 0.6, and 3.1 per 1000 airmen. This is a considerably lower rate compared to that of other countries. According to the results of the U.S. Federal Aviation Administration's aviation medical examination, the annual disqualification rate for aviation pilots from 1987 to 1988 was 6.5 per 1000 pilots.<sup>3</sup> Among European countries, according to a paper published in Norway, the disqualification rate from a total of 12,552 examinations for CPL during 2006–2010 was 6.8 per 1000 pilots.<sup>10</sup> In France, disqualification rates in 1993 and in 2003 were 5.0 and 6.0, respectively, the main reason being related to cardiovascular diseases. There are several possible reasons why the disqualification rate in this study was lower than that of previous studies. Early detection and continuous management of risk factors for diseases in pilots may have lowered the prevalence of diseases in South Korea.<sup>14</sup> In addition, pilots with serious illnesses may have avoided undergoing

**Table II.** Number of Aviation Medical Examinations for Airmen Medical Certificates, Disqualification Rates of Aviation Medical Examination, and Diagnostic Categories of the Disqualifications According to License Type (Initial) from 2016–2020.

CLASSES	AGE GROUPS	NUMBER OF EXAMS	NUMBER OF DENIALS	PERCENT OF TOTAL DENIALS	AGE-SPECIFIC DENIAL RATE	OR (95% CI)	P-VALUE
ATPL + CPL	<29	15,288	108	82%	7.1	1	
	30-39	3458	23	18%	6.7	0.9(0.6-1.5)	0.792
	40-49	306	0	0%	0.0		
	50-59	138	0	0%	0.0		
	60-	9	0	0%	0.0		
	Total	19,199	131	100%	6.8		
PPL	<29	364	2	33%	5.5	1	
	30-39	61	2	33%	32.8	6.1(0.8-44.4)	0.072
	40-49	30	0	0%	0.0		
	50-59	21	2	33%	95.2	19.1(2.5-142.7)	0.004
	60-	7	0	0%	0.0		
	Total	483	6	100%	12.4		
ATCL	<29	797	17	100%	21.3		
	30-39	20	0	0%	0.0		
	40-49	3	0	0%	0.0		
	50-59	0	0	0%	0.0		
	60-	4	0	0%	0.0		
	Total	824	17	100%	20.6		
Total	<29	16,449	127	82%	7.7	1	
	30-39	3539	25	16%	7.1	0.9(0.6-1.4)	0.683
	40-49	339	0	0%	0.0		
	50-59	159	2	1%	12.6	1.6(0.4-6.7)	0.492
	60-	20	0	0%	0.0		
	Total	20,506	154	100%	7.5		
NUMBER OF DENIALS, PERCENT OF TOTAL DENIALS, DENIAL RATE (N, %, RATE)							
DIAGNOSTIC CATEGORIES***	ATPL + CPL	PPL	ATCL	TOTAL			
Cardiology	4, 3%, 0.2	0, 0%, 0	0, 0%, 0	4, 3%, 0.2			
Ophthalmology	80, 61%, 4.2	5, 83%, 10.4	13, 76%, 15.8	98, 64%, 4.8			
Psychiatry	11, 8%, 0.6	1, 17%, 2.1	3, 18%, 3.6	15, 10%, 0.7			
Malignancy	5, 4%, 0.3	0, 0%, 0	0, 0%, 0	5, 3%, 0.2			
Neurology	13, 10%, 0.7	0, 0%, 0	0, 0%, 0	13, 8%, 0.6			
Respiratory	9, 7%, 0.5	0, 0%, 0	0, 0%, 0	9, 6%, 0.4			
Others	9, 7%, 0.5	0, 0%, 0	1, 6%	10, 6%, 0.5			
Total	131, 100%, 6.8	6, 100%, 12.4	17, 100%, 20.6	154, 100%, 7.5			

\*Age-specific disqualification rates per 1000 airmen applicants; \*\*OR and 95% CI were obtained by logistic regression analysis; \*\*\*only one main diagnostic category was used for one applicant. Coexisting diagnoses did not contribute to categorization.

ATPL: air transport pilot license, CPL: commercial pilot license, PPL: private pilot license, ATCL: air traffic controller license, OR: odds ratio, CI: confidence interval.

aviation medical examinations, although there is no evidence to support this. The low disqualification rate may also be due to the “healthy worker effect” in pilots, which was shown to be accompanied by a lower prevalence of obesity and smoking, as shown in a previous study.<sup>9</sup>

The ATPL disqualification percentage was the highest in the 50s age group, at 3.2 per 1000 applicants. Increased incapacitation with age has been previously reported; pilots in their 60s were five times more likely to be incapacitated than pilots in their 40s.<sup>11</sup> The annual incapacity rate was 0.25% among 16,145 UK/Joint Aviation Requirements professional pilot license holders in 2004.<sup>4</sup> In renewal examinations, the presence of cardiology-related diseases was the most common [18 cases (30%)] reason for disqualification. Several studies have shown cardiovascular diseases to be a major cause of in-flight incapacitation.<sup>2</sup> Specifically, myocardial infarction and coronary artery disease were major causes of grounding;<sup>3</sup> this coincides with the results of causes for disqualification in renewal

examinations in our study. Therefore, it is important to identify pilots at risk for any in-flight cardiovascular events.

Disqualification rates were generally higher in initial examinations than in renewal examinations. Diagnostic categories for those disqualified after initial aviation medical examinations were similar to that of renewal examinations. However, the majority of initial applicants (64%) were disqualified due to ophthalmological diseases. In renewal examinations, visual field defect was the major cause of disqualification; in initial examinations, there were also several cases of strabismus, color blindness, and post-refractive surgery. Visual impairment has become an increasingly important health and safety concern for pilots due to aging. Therefore, identifying and preventing age-related eye diseases in pilots is an important component of aviation safety. Not only age but also a history of eye problems is associated with increased incidence of vision disorders.<sup>19</sup> In South Korea, post-refractive surgery was the most common single ocular disease behind a

special issuance.<sup>8</sup> Refractive surgeries such as laser-assisted subepithelial keratectomy (LASEK) and laser in-situ keratomileusis (LASIK) are permitted, if there are no sequelae, in the Korean aviation medical examination, and the proportion of young pilots who have undergone surgery has been increasing. However, implantable collamer lenses, even with increased intraocular pressure, can impair the vision and cause loss of in-flight control; pilots are prohibited from flying if this surgery has been performed. Therefore, careful history-taking of previous refractive surgery is necessary for AMEs, and those wishing to pursue becoming pilots should be informed before undertaking refractive surgeries, as they have been shown to be causes for disqualification from initial examinations in our study. In addition, it is necessary to analyze the cause of ophthalmic problems and prevent development of eye diseases unsuitable for in-flight conditions. Visual field defects that develop slowly tend to be recognized only after significant progression. Hence, a system to track the degree of visual impairment, rather than solely screening for visual impairment that do not meet standards, is needed.

Types of psychiatric diseases in disqualification differed between initial and renewal applicants; depression was more common than anxiety in initial applicants. A previous systemic review regarding pilot mental health revealed that the prevalence of depression in commercial airline pilots ranged from 1.9 to 12.6%.<sup>17</sup> One cross-sectional study found that 4.1% of pilots had suicidal thoughts within the past 2 wk.<sup>25</sup> Pilots can experience depression and mental illness as often as the general population; however, the concern of underreporting persists. Moreover, commercial airline pilots may experience occupational stressors such as circadian rhythm disturbances, sleep disorders, and fatigue, increasing the risk of developing mental illnesses. Still, some pilots manage their mental illnesses on their own without seeking medical help for fear of disqualification or stigma. Therefore, both prevention and management of mental healthcare is just as important, as is regular aviation medical examinations for the purpose of license issuance or renewal.

Despite the COVID-19 pandemic, renewal examinations for the ATCL increased 22% in 2020. The disqualification rate of applicants for the ATCL was the lowest (0.9 per 1000 controllers) among renewal examinations, but the highest (20.6) among initial examinations. Applicants for the ATCL have been noted to be tense, stressed, and experience excessive use of voice.<sup>13</sup> Health problems of these applicants have been identified, including vocal discomfort, hoarseness, high blood pressure, lack of physical activity, overweight, excessive body fat, lack of social relationships, and sleep deprivation.<sup>16,22</sup> Although these are noncommunicable diseases, they may substantially impair performance, and the relatively high disqualification rate in initial medical examinations suggests intervention may be needed even before license issuance.

In South Korea, efforts are being made to prevent mental illness and protect personal information regarding mental health. However, policies and laws that require mandatory reporting and those that reprimand nonreporters with

deteriorating mental conditions are likely to backfire. For mental health promotion, not only is systematic management and improvement of cultural awareness regarding psychiatric patients necessary, but also the introduction of information and communications technology in the psychiatric field. More than half of the digital therapeutics developed or currently under development in the psychiatric domain use cognitive behavior therapy-based therapeutics. Such digital therapeutics are undergoing development for various diseases such as diabetes and asthma as well as depression and sleep disorders.

The six malignancies that caused disqualification in this study pertained to renal cancer, gastrointestinal stromal tumor, lung cancer, prostate cancer, and testicular cancer. Airline pilots and cabin crew are occupationally exposed to higher levels of cosmetic and ultraviolet (UV) radiation than the general population, but the association between cosmetic and UV radiation and the risk of developing diseases such as melanoma has not yet been established. Some studies reported pilots to have about twice the incidence of melanoma compared to that of the general population because of UV radiation.<sup>7,20</sup> However, no disqualification due to melanoma was detected in this study, which may be due to differences in ethnicity. There have also been reports on the higher incidence of prostate cancer in pilots in comparison to that of the general population.<sup>6,18</sup> In this study, there was one case of disqualification due to prostate cancer. Further cohort studies and research are necessary to determine the association between malignancy and the aviation environment. AMEs can strive for early detection of particular types of cancer in airmen, in regards to their working environment, through regular checkups.

The topic of cosmic radiation is also of continued interest to aviation workers and the airlines. Exposure to ionizing radiation has been associated with cancer. However, this issue is directly related to airline management and economic feasibility. In 2018, the average exposure dose of Korean Air flight pilots was 2.32 mSv and the highest, 5.65 mSv; this continues to increase.<sup>1</sup> A material engineering approach to this issue may suffice than efforts to regulate the annual total exposure to radiation. However, to date, there has been no commercialized solution due to results limited to laboratory studies.<sup>26</sup>

Aviation workers are required to maintain a higher level of health for aviation safety than the general population. Aviation workers not only require personalized preventive activities, regular checkups, and health promotion management as that of the general population, but also need customized care regarding managing jet lag, fatigue, and exposure to cosmic radiation. Although aviation medical examinations aim to detect health abnormalities and manage risk factors in aviation workers, annual examinations have a limit in detecting such risk factors. The importance of continuous health promotion and disease prevention have been emphasized increasingly worldwide. However, most existing methods are not cost-effective. With the development of digital healthcare based on information and communications technology, a platform for aviation workers can be used to achieve plausible, cost-effective health care outcomes.<sup>5,12</sup> Aviation specialists or AMEs can prescribe digital



coaching (digital health applications, digital therapeutics) to aviation workers so they can periodically self-manage their health. Through this platform, AMEs can provide a care-continuum that is comprehensive for chronic illnesses and the health care needs of aviation workers. The Canadian Aviation Regulations, for example, is currently using telemedicine for eligible applicants of civil aviation medical examinations and certificate renewals.

Through this study, the main causes of being disqualified after undergoing aviation medical examinations were identified as diseases in cardiology, ophthalmology, and psychiatry. Health promotion activities should include measures to manage risk factors for such diseases. Preventive health care is important not only for attaining an individual's healthy lifestyle, such as diet control and exercising, but also for in-flight safety. In doing so, systematic support from both employers and the government is pivotal. The disqualifications from initially obtaining or renewing an aviation medical certificate observed in this study may not accurately represent the actual incidence of illness in aviation workers. In order to overcome this limitation, advancements in database development and utilization are also necessary.

## ACKNOWLEDGMENTS

*Financial Disclosure Statement:* The authors have no competing interests to declare.

*Authors and Affiliations:* Ji Soo Kim, M.D., and Juwon Lim, M.D., Ph.D., International Healthcare Center, Seoul National University Hospital, Seoul National University College of Medicine, Jongno-gu, Seoul, Korea; Bok Soon Han, M.D., Ph.D., Department of Occupational and Environmental Medicine, Kangbuk Samsung Hospital, Sungkyunkwan University School of Medicine, Jongno-gu, Seoul, Korea; and Young Hwan Kwon, M.D., Aeromedical Center, Korean Air, Gangseo-gu, Seoul, Korea.

## REFERENCES

- Ahn H-B, Kim K-W, Choi Y-C. A study on the reduction of cosmic radiation exposure by flight crew. *Journal of the Korean Society for Aviation and Aeronautics*. 2020; 28(1):1–6.
- DeJohn CA, Mills WD, Hathaway W, Larcher J. Cardiac inflight incapacitations of U.S. Airline pilots: 1995–2015. *Aerosp Med Hum Perform*. 2018; 89(9):837–841.
- Downey LE, Dark SJ. Survey reveals age and pathology trends for medically disqualified airline pilots. *Flight Safety Digest*. 1992; 11:1–6.
- Evans S, Radcliffe SA. The annual incapacitation rate of commercial pilots. *Aviat Space Environ Med*. 2012; 83(1):42–49.
- Eze ND, Mateus C, Cravo Oliveira Hashiguchi T. Telemedicine in the OECD: an umbrella review of clinical and cost-effectiveness, patient experience and implementation. *PLoS One*. 2020; 15(8):e0237585.
- Gudmundsdottir EM, Hrafnkelsson J, Rafnsson V. Incidence of cancer among licenced commercial pilots flying North Atlantic routes. *Environ Health*. 2017; 16(1):86.
- Hammer GP, Auvinen A, De Stavola BL, Grajewski B, Gundestrup M, et al. Mortality from cancer and other causes in commercial airline crews: a joint analysis of cohorts from 10 countries. *Occup Environ Med*. 2014; 71(5):313–322.
- Han BS, Kwon YH, Shin YY. Analysis of three years of airmen medical certificate for preparing aviation-related health promotion plan. *Korean J Aerosp Environ Med*. 2020; 30(1):40–49.
- Houston S, Mitchell S, Evans S. Prevalence of cardiovascular disease risk factors among UK commercial pilots. *Eur J Cardiovasc Prev Rehabil*. 2011; 18(3):510–517.
- Høva JK, Thorheim L, Wagstaff AS. Medical reasons for loss of license in Norwegian professional pilots. *Aerosp Med Hum Perform*. 2017; 88(2):146–149.
- Huster KM, Muller A, Prohn MJ, Nowak D, Herbig B. Medical risks in older pilots: a systematic review on incapacitation and age. *Int Arch Occup Environ Health*. 2014; 87(6):567–78.
- Keesara S, Jonas A, Schulman K. COVID-19 and health care's digital revolution. *N Engl J Med*. 2020; 382(23):e82.
- Korn GP, Villar AC, Azevedo RR. Hoarseness and vocal tract discomfort and associated risk factors in air traffic controllers. *Braz J Otorhinolaryngol*. 2019; 85(3):329–336.
- Kwon YH. Survey of medically disqualified airline pilots in Korea: 2015–2019. *Korean J Aerosp Environ Med*. 2020; 30(2):70–74.
- Matthews MJ, Stretanski MF. Pilot medical certification. *Treasure Island (FL): StatPearls*; 2021.
- Ming EE, Adler GK, Kessler RC, Fogg LF, Matthews KA, et al. Cardiovascular reactivity to work stress predicts subsequent onset of hypertension: the Air Traffic Controller Health Change Study. *Psychosom Med*. 2004; 66(4):459–465.
- Pasha T, Stokes PRA. Reflecting on the Germanwings disaster: a systematic review of depression and suicide in commercial airline pilots. *Front Psychiatry*. 2018; 9:86.
- Raslau D, Abu Dabrh AM, Summerfield DT, Wang Z, Steinkraus LW, Murad MH. Prostate cancer in pilots. *Aerosp Med Hum Perform*. 2016; 87(6):565–570.
- Rebok GW, Qiang Y, Baker SP, Li G. Age-related vision problems in commuter and air taxi pilots: a study of 3019 pilots, 1987–1997. *Aviat Space Environ Med*. 2007; 78(7):706–711.
- Sanlorenzo M, Wehner MR, Linos E, Kornak J, Kainz W, et al. The risk of melanoma in airline pilots and cabin crew: a meta-analysis. *JAMA Dermatol*. 2015; 151(1):51–58.
- Skaggs VJ, Norris AI. 2018 Aerospace medical certification statistical handbook. 2021. [Accessed 8 April 2022]. Available from: <https://rosap.ntl.bts.gov/view/dot/57232>.
- Sonati JG, De Martino MM, Vilarta R, da Silva Maciel E, Sonati RJ, Paduan PC. Quality of life, sleep, and health of air traffic controllers with rapid counterclockwise shift rotation. *Workplace Health Saf*. 2016; 64(8):377–384.
- User's manual. Application for airmen medical certificate. [Accessed 2021 May 20]. Available from: <https://www.esky.go.kr/MedCert.jsp>.
- Vuorio A, Budowle B, Sajantila A, Laukkala T, Junttila I, et al. Duty of notification and aviation safety—a study of fatal aviation accidents in the United States in 2015. *Int J Environ Res Public Health*. 2018; 15(6):1258.
- Wu AC, Donnelly-McLay D, Weisskopf MG, McNeely E, Betancourt TS, Allen JG. Airplane pilot mental health and suicidal thoughts: a cross-sectional descriptive study via anonymous web-based survey. *Environ Health*. 2016; 15(1):121. Erratum in: *Environ Health*. 2017; 16(1):129.
- Zheng B, Wang Z, Guo Q, Zhou S. Glass composite as robust UV absorber for biological protection. *Opt Mater Express*. 2016; 6(2):531–539.



## APPENDIX

**Table A1.** Diagnosis of Aviation Medical Examination Disqualifications for Renewal Airmen Medical Certificates from 2016–2020.

LICENSE	DIAGNOSTIC CATEGORIES	DIAGNOSIS	NUMBER	REMARK
ATPL	Cardiology	Myocardial infarction	6	
		Coronary artery disease	7	
		Valvular disease	1	Falsification
		Hypertrophic cardiomyopathy	1	Additional information not submitted
		Ventricular fibrillation	1	
	Ophthalmology	Visual field defect	3	
		Failure of visual acuity test	2	
		Glaucoma	1	
		Color Blindness	1	Additional information not submitted
		Cataract	1	Requiring treatment
	Psychiatry	Retinal detachment	1	Insufficient observation period
		Anxiety disorder	2	
		Delusional disorder	1	With paranoid personality
		Acute stress disorder	1	
	Malignancy	Renal cancer	1	Insufficient observation period
		GIST	1	Insufficient observation period
		Prostate cancer	1	Insufficient observation period
		Testicular cancer	1	Insufficient observation period
	Neurology	Brain hemorrhage	2	
		Cerebral infarction	1	
		Migraine	1	With visual disturbance
	Respiratory	Tuberculosis	1	
	Otorhinolaryngology	Sarcoidosis	1	
		Hearing loss	2	
	Others	Hyperthyroidism	1	Falsification
	Total		42	
CPL	Cardiology	Hypertension	1	Additional information not submitted
		ECG abnormalities	1	Additional information not submitted
	Ophthalmology	Visual field defect	1	
	Psychiatry	Pathological gambling	1	With alcohol addiction
	Malignancy	Renal cancer	1	Insufficient observation period
		Lung cancer	1	Undergoing treatment
	Neurology	Brain hemorrhage	1	
		Syncope	1	Of unknown origin
	Respiratory	Tuberculosis	1	
		Pneumothorax, bulla	1	
	Others	Behcet's disease	1	Undergoing treatment
		HIV infection	1	Falsification
	Total		12	
PPL	Ophthalmology	Visual field defect	3	
		Strabismus	1	
	Psychiatry	Panic disorder	1	
	Others	Crohn's disease	1	Undergoing treatment
	Total		6	
ATCL	Psychiatry	Bipolar disorder	1	
	Total		1	

ATPL: air transport pilot license, CPL: commercial pilot license, PPL: private pilot license, ATCL: air traffic controller license, ENT: ear nose and throat, ECG: electrocardiogram, GIST: gastrointestinal stromal tumor, HIV: human immunodeficiency virus.

**Table AII.** Diagnosis of Aviation Medical Examination Disqualifications for Initial Airmen Medical Certificates from 2016–2020.

LICENSE	DIAGNOSTIC CATEGORIES	DIAGNOSIS	NUMBER	LICENSE	DIAGNOSTIC CATEGORIES	DIAGNOSIS	NUMBER
ATPL	Ophthalmology	Strabismus	35				
& CPL		Visual field defect	15		Cardiology	Abnormal ECG	1
		Color blindness	6			Hypertension	1
		Postrefractive surgery	6			Valvular disease	1
		Glaucoma and visual field defect	7			WPW syndrome	1
		Poststrabismus surgery	4		Nephrology	IgA nephropathy	1
		Failure of visual acuity test	4			Proteinuria	1
		Retinal detachment	2			Renal failure	1
		Myopia	1		Others	Atopic dermatitis	2
	Psychiatry	Retinopathy	1			Hearing loss	1
		Depression	7			Hyperthyroidism	1
		Anxiety and depressive disorder	1			Disability of the arm	1
		Obsessive-Compulsive Disorder	1			Unknown diagnosis	1
		Panic disorder	1		Total		118
	Neurology	Epilepsy	2	PPL	Ophthalmology	Strabismus	1
		Moyamoya disease	2			Visual field defect	1
		AV malformation	1			Color blindness	2
		Abnormal EEG	2			Postrefractive surgery	1
		Autoimmune encephalitis	1		Psychiatry	Depression	1
		Dizziness	1		Total		6
		Head injury	1	ATCL	Ophthalmology	Strabismus	1
		Headache	1			Visual field defect	2
		Migraine	1			Color blindness	5
		Syringomyelia	1			Postrefractive surgery	3
	Respiratory	Pneumothorax, bulla	4			Poststrabismus surgery	1
		Tuberculosis	3			Cataract	1
		Bulla of the lung	1		Psychiatry	Depression	2
		Pneumothorax	1			Sleep disorder	1
	Malignancy	Brain tumor	1		Others	Exercise-induced Anaphylaxis	1
		Ewing's sarcoma	1		Total		17
		Leukemia	1				
		Osteosarcoma	1				
		Stomach Cancer	1				

ATPL: air transport pilot license, CPL: commercial pilot license, PPL: private pilot license, ATCL: air traffic controller license, ENT: ear nose and throat.  
 EEG: electroencephalogram; WPW syndrome: Wolff–Parkinson–White syndrome.