Upper Respiratory Infections and Barotrauma Among Commercial Pilots

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BACKGROUND: Health incapacitation is a serious threat to flight safety. Therefore, a study conducted 10 yr ago examined the incidents of ear-nose-throat (ENT) barotrauma and upper respiratory infection (URI) among commercial pilots and found that a large number continued to carry out their duties despite the risk of incapacitation. Now, 10 yr later, this new study examines if the attention to URIs has improved.

METHOD: This study was conducted at the Danish Aeromedical Centre over the course of 1 yr with 463 valid respondents to a questionnaire on URIs and ENT barotrauma. These respondents were compared to 940 respondents answering the same questionnaire 10 yr prior in the same setting.

RESULTS: This study shows a significant increase in the number of pilots flying despite signs of an URI from 42.8 to 50.1% and in the number of pilots using decongestant medicine from 43.3 to 59.5%. The proportion of pilots experiencing one or more ENT barotraumas has also increased from 37.4 to 55.5% for barotitis media and from 19.5 to 27.9% for barosinusitis.

CONCLUSION: Half of all pilots in this study fly despite signs of an URI. This is a significant increase and shows that after 10 yr an URI is still not considered a valid reason for reporting in sick despite international aeromedical recommendation. Based on these findings, the study recommends that awareness of the risk of flying with an URI be increased.

KEYWORDS: aviation, barotitis, barosinusitis, ear, sinus, occupational health, sudden incapacitation, flight safety.

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This study is a follow-up of a 2005 study on Danish commercial pilots ("Upper respiratory infections and barotraumas in commercial pilots: a retrospective survey"[26]). We compared the acceptance of Danish commercial pilots to flying with upper respiratory infections (URIs) and risk of barotrauma with a similar cohort 10 yr earlier. A hazard to aviation is incapacitation of a pilot due to any reduction in medical fitness to a degree or nature that is likely to jeopardize flight safety.[9,22]

Pressure changes, such as those arising during flight, can result in barotitis media and/or barosinusitis, defined as injury sustained from failure to equalize the pressure differential between an air-containing space with that of the surrounding environment.[29] This can be exacerbated when the person has an URI while flying due to the inability to equalize pressure during rapid changes of atmospheric pressure during ascent and descent.

Otic barotrauma is known to be an adverse effect of barometric pressure fluctuations during altitude changes and one of the most common causes of acute incapacitation among aircrew.[26] This condition is also known as 'acute otitic barotrauma' or 'aerotitis media' or 'barotitis media.'[5] It is a fairly common aeromedical condition.[27,28] Barotitis media is an injury to the middle ear caused by a difference between barometric pressure in the middle ear and the ambient pressure. Normally, the Eustachian tube maintains equal pressure on both sides of the eardrum by allowing external pressure to enter the middle ear. If the Eustachian tube is not functioning properly due to an infection, scarring, or other pathological conditions, it may restrict airflow and result in a relative negative pressure in the middle ear. Very severe pressure differentials could result in damage to the middle ear, e.g., pain, hearing loss, hemorrhaging, perforation, etc.[12] Kanick and Doyle have presented a

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physiological model of barotrauma development in a normal middle ear during flight.[11] Their model shows the increased risk of barotitis media posed by URIs when flying. Similarly barosinusitis is an acute or chronic injury of one or more of the sinuses caused by a pressure differential between the air inside the sinus and that of the ambient atmosphere,[16] potentially leading to severe pain and epistaxis.[21]

At cruising altitude, a plane has a cabin barometric pressure of around three-quarters that of the ground atmospheric pressure.[20] When ascending, the decreasing cabin pressure causes the gas in the middle ear to expand in accordance with Boyle's law. This relatively positive pressure continues to expand until the pressure differential reaches 15 mmHg, when the Eustachian tube passively opens and vents off positive pressure air. Therefore, equalizing the middle ear pressure normally does not cause problems during ascent, but an URI or stenosis can make it necessary to use increased pressure to open the Eustachian tube even when ascending.[1]

When the plane descends, the cabin pressure increases until it returns to sea level. During descent a person must voluntarily act to open the Eustachian tubes to equalize pressure.[12] This can be done by performing a Valsalva maneuver, yawning, swallowing, or by blowing the nose.[8] An average person swallows every 60 or 75 s,[1] so under normal conditions, pressures can be equalized during descent, but if the ability to open the Eustachian tube is compromised, symptoms of barotrauma can result. Symptoms of acute barotrauma can range from pain and hemorrhage from the ears and/or nose to severe vertigo and sensorineural hearing loss.[15] The sensorineural hearing loss could be permanent.[29] Dizziness arising from differential external pressures between the left and right middle ears is so-called alternobaric vertigo.[18] Alternobaric vertigo is characterized by a strong rotatory vertigo resulting from pressure differentials between the contralateral middle ear cavity that stimulate the proximate vestibular end organs asymmetrically.[29] Lundgren and Malm have underlined the correlation between URIs, difficulties in pressure equalization of the middle ears, and alternobaric vertigo, and have stressed the risk connected with alternobaric vertigo when flying.[19] According to Wicks, alternobaric vertigo nearly always occurs when there is difficulty in clearing the ears. In his article "Alternobaric vertigo: an aeromedical review," Wicks described seven cases of alternobaric vertigo in which all (100%) had URIs at the time.[30]

Rupture of the tympanic membrane can occur at a pressure differential of 100–500 mmHg and can relieve the pain, but have sequelae such as vertigo and vomiting. Rupture of the round and oval window membrane has also been observed.[7,12,20] Perilymphatic fistulas (with uncharacteristic vertigo, hearing impairment, and tinnitus[23]) are a rare, but also possible consequence of flying with an URI.[14,25] The severity of symptoms relates to the rate of pressure change while descending.[19,20]

In 2005, the study "Upper respiratory infections and barotraumas in commercial pilots: a retrospective survey" examined the incidents of ear-nose-throat (ENT) barotrauma and URI among aircrew.[26] The study showed that among some commercial pilots URIs were not considered a valid reason to report in sick and Rosenkvist et al. strongly recommended attention to flight safety and the risks of vertigo and ENT barotrauma when commercial pilots fly with an URI.[26]

Now, 10 yr later, this study examines whether the recommendations have been followed. The study assessed self-reported ENT infections and the incidence of barotrauma among commercial pilots. The percentage of pilots who flew with an URI and the number who use decongestant medicine in these cases were examined. The percentage of pilots incapacitated before takeoff was also explored. Furthermore, the survey also enquired into the onset of signs of barotrauma. All results were compared to the previous study to evaluate the development of ENT barotrauma among commercial pilots and the attitude toward flying with an URI. The aim of this study was to examine whether the recommendation from 2005 has been adopted, and whether there has been change in the behavior of flying with an URI during the last 10 yr.

METHODS

This study focused on active commercial pilots under 65 yr of age. As a pilot who has attained the age of 65 yr should not act as a pilot of an aircraft engaged in commercial air transport,[4] all respondents over 65 yr were excluded (11 pilots). In the original study from 2005, pilots over 65 yr were not excluded. In order to have comparable datasets, respondents over 65 yr were excluded in the 2005 dataset also (eight pilots). Consequently, a few recalculated results of the 2005 dataset mentioned in this publication deviate slightly from the original publication.

Pilots were included in the study if they were in possession of a class 1 license (commercial pilot license or airline transport pilot license). Private pilots, military pilots, and other aircrew were excluded, as the focus of this study was on commercial pilots with regards to flight safety and in comparison with results of the dataset from 2005.

The questionnaire (**Table I**) was designed specifically for the study in 2005, validated in that study, and reused in this 2014–2015 study. The questions pertained to symptoms and signs of URI and barotrauma in relation to flying with an URI. Besides background questions on age, sex, and type of license, the pilots were asked about allergies, number of URIs per year, number of sinusitis cases, and of barotitis media and barosinusitis throughout their career. Pilots were asked to recall their number of URIs over the preceding year, while reports of barotrauma were based on incidences throughout their whole professional life, as the number of barotraumas were expected to be much lower than the URIs. Furthermore, pilots were questioned on the use of decongestant medication in relation to flying duties, and they stated whether they had reported themselves sick prior to a scheduled flight when they had signs of an URI. If the pilots had experienced barotrauma, they were asked if they had experienced a feeling of incapacitation prior to the flight in question and what the cabin altitude was at the time of onset of the barotrauma-related signs. The

Table I. Summary of Items in the Questionnaire.

1	Age	_____years
2	Gender	M/F
3	Type of license	PPL, CRL/ATPL*
4	Allergies (state type)	_____
5	Active flying	_____years
6	Estimated number of URI per year	0, 1, 2, __number if > 2
7	Estimated number of sinusitis cases in total	0, 1, 2, __number if > 2
8	Problems equalizing ear pressure in connection with active flying	0, 1, 2, __number if > 2
9	Problems equalizing sinus pressure in connection with active flying	0, 1, 2, __number if > 2
10	Do you stay at home when you have an URI?	Yes/No
	If no, do you take decongestant medication?	Yes/No
11	Fill out the remainder of the form if you reported problems equalizing ear or sinus pressure in connection with active flying.	
11a	Did you feel incapacitated prior to actual flight?	Yes/No
11b	Cabin altitude at onset of symptoms	_____Feet
11c	Flight phase at onset of symptoms	Ascending/Descending/ Level
11d	Type of aircraft	____Type of aircraft

flight phase of the onset of the barotrauma-related signs was requested—climbing, level, or descending flight—as was the type of aircraft.

The research question was explored through the design of a follow-up study, but not with an identical cohort. This study was conducted in the same manner as the previous study in 2005, using the same design and the same questionnaire, and was carried out in the same setting at the Danish Aeromedical Centre. This is where pilots come to have their aeromedical certification validated and, during these visits, the questionnaire was handed out by the secretaries and filled out by the pilots before each medical check.

To ensure flight safety, pilots with a commercial multicrew pilot license under 60 yr of age visit the Danish Aeromedical Centre once a year for a medical check, and when over 60 yr every 6 mo.[3,4,9] The present study was conducted over a longer period of time (12 mo, from the 25th of February 2014 to the 25th of February 2015) than the previous study (6 mo). The 12-mo period was chosen to maximize the number of respondents and to prevent including any pilot twice, as the validity of class 1 medical certificates is limited to 12 mo for the commercial multicrew pilot license under 60 yr.[9] All questionnaires filled out by respondents between 60 and 64 yr were controlled for duplications by comparing age, gender, types of allergies, and type of aircraft (23 questionnaires in total with the reference numbers 15, 73, 98, 112, 119, 124, 129, 239, 280, 307, 338, 351, 360, 381, 389, 408, 450, 475, 494, 497, 509, 513, and 514; all questionnaires by respondents 65 yr and above were excluded). Four questionnaires (two by two) could have been duplications and, therefore, the two possible duplicates were excluded (questionnaires 307 and 509 could have been filled out by the same person, as could questionnaires 15 and 119; consequently, questionnaires 119 and 307 were excluded).

Anonymity was secured by letting the pilots respond to the questionnaire with no ID reference in the waiting room and then leaving it in one of the two boxes set up in the clinic. It was important to conduct the study anonymously to minimize potential fears that information given would influence the economic situation or career of the respondents. Later on, each questionnaire was assigned a reference number when added to the database.

All statistical calculations were carried out using Microsoft Excel 2008 for Mac, version 12.2.3 (Microsoft Corporation, New York), and the Statistical Package for Social Sciences software, 2010, version 19 (IBM SPSS, Armonk, NY). An alpha-level of 0.05 was used. Both parametric and nonparametric statistics were used depending on whether data was binominal, following a normal distribution or not. An independent sample *t*-test was used to compare the results from 2005 to the results in 2015 when data was binominal. For other data Kolmogorov-Smirnov and Shapiro-Wilk tests were used to assess whether the distribution was normal and, if not, the *P*-value was calculated using the Mann-Whitney *U*-test, a nonparametric test.

As the protocol for the study was submitted to the Ethics Committee of Copenhagen in 2005 and as this study was based on a questionnaire and no biological material was included, no new approval was needed for the new study in 2014–2015. The reference number from the Ethics Committee of Copenhagen is H-4-2014-Fsp 30.

Table II. Overview of Results from 2005 and 2014–2015 and the *P*-Value of the Null Hypothesis (That the Results Are Identical in the 2 yr of Research).

	2005 (*N* = 940)	2014-15 (*N* = 463)	*T*-TEST *P*-VALUE / *U*-TEST (MANN-WHITNEY) *P*-VALUE
Average number of URIs per year and range	1.62 (0–8)	1.81 (0–8)	0.001*
Average number of sinusitis in total and range	0.65 (0–11)	0.84 (0–27)	0.051*
Went flying despite signs of URI	42.8%	50.1%	0.010
Use decongestant medicine among pilots flying with an URI	43.3%†	59.5%‡	< 0.001
Pilots having experienced one or more barotitis media episodes in their career	37.4%	55.5%	< 0.001
Pilots having experienced one or more barosinusitis episodes in their career	19.5%	27.9%	< 0.001
Onset of signs of barotitis media during descent	90.6%	93.7%	0.178*
Incapacitated before flying	2.4%	3.2%	0.390

* No normal distribution by Kolmogorov-Smirnov and Shapiro-Wilk tests. *P*-value calculated by nonparametric Mann-Whitney *U*-test.
† *N* = 402.
‡ *N* = 232.

RESULTS

During a 6-mo period in 2005, 948 commercial pilots with a class 1 license answered a questionnaire regarding symptoms of URI and ENT barotrauma, and reported anonymously if they had been on duty with an URI. This study recalibrated the 2005 results by excluding 8 of the 948 received questionnaires because the respondents were 65 yr or above. The following recalculated results are based on the remaining 940 respondents. The 2005 study showed that 42.8% of the responding pilots continued work despite signs of an URI and, of this group, 43.3% reported taking decongestant medication. Of all pilots participating in the survey, 37.4% reported that they had experienced one or more barotitis media episodes, while 19.5% reported one or more barosinusitis incidents. Both types of barotrauma were mainly experienced during descent (90.6%).

From the 25th of February 2014 to the 25th of February 2015, 525 similar questionnaires were answered at the Danish Aeromedical Centre. Of these, 49 were excluded because the client had not been the holder of a class 1 license. Furthermore, 11 questionnaires were excluded because the respondent had reached the age of 65 yr, and 2 questionnaires were excluded because the respondent was between 60 and 64 yr and they could have been duplicates. The following results are based on the questionnaires filled out by the remaining 463 pilots and are compared to the results of the study from 2005.

The group of 463 pilots in 2015 included 445 men (96.1%) and 18 women (3.9%) with an average age of 45.3 yr (range: 19–64). The average years of flying experience of pilots in 2015 was 21.4 yr (range: 0–47). Of the pilots, 79.5% had more than 10 yr experience and could therefore potentially have been part of the study in 2005. The study in 2005 had a comparable group of pilots with 97.0% men and 3.0% women, an average age of 43.6 yr (20–64), and an average experience of 20.5 yr (0–49).

The mean number of URIs per year was 1–2 in 2015 (mean 1.81, range 0–8), similar to 2005 with 1–2 URIs per year as well (mean 1.62, range 0–8), although there was a statistical difference (**Table II**). The mean number of episodes of sinusitis per pilot year of flying experience was 0.84 (range 0–27). In 2005 this number was 0.65 (range 0–11). Neither the number of URIs nor the number of episodes of sinusitis had a normal distribution (Kolmogorov-Smirnov and Shapiro-Wilk tests both had a $P < 0.001$), so nonparametric tests were used. The analysis revealed that the mean numbers of URIs were significantly different in the two studies [Mann-Whitney $U(1414)$, $P = 0.001$], while the episodes of sinusitis were not statistically significantly different [Mann-Whitney $U(1414)$, $P = 0.051$]. Even if statistically different, the practical difference of URIs in the two studies is minimal.

The number of pilots flying despite signs of URI increased significantly over the 10-yr period from 42.8% in 2005 to 50.1% in 2015 [$t(1414) = 2.593$, $P = 0.010$]. Among the group of pilots flying despite signs of an URI ($N = 402$ in 2005 and $N = 232$ in 2015), the proportion using decongestant medication (nose drops) also increased from 43.3% in 2005 to 59.5% in 2015 [$t(632) = -3.972$, $P < 0.001$].

Looking at the pilots' health, there was a significant development in the number of pilots who experienced one or more barotitis media episodes. In 2015, it was found that 55.5% of the pilots had experienced one or more barotitis media episodes (range 0–54). This was a significant increase from the 37.4% (range 0–50) found in 2005 [$t(1414) = -4.094$, $P < 0.001$]. Likewise, the number of pilots having experienced one or more episodes of barosinusitis in their career had significantly increased over the 10-yr period from 19.5% (range 0–15) in 2005 to 27.9% (range 0–18) in 2015 [$t(1414) = -3.787$, $P < 0.001$].

The proportion of pilots reporting that signs of ENT barotrauma started during descent was not significantly different in 2015. It was found that 93.7% reported onset during descent, while the study in 2005 found the proportion to be 90.6% [Mann-Whitney $U(1414)$, $P = 0.178$]. Of those having experienced a barotrauma, 3.2% had felt some kind of incapacitation prior to the flight in question {not significantly different from the 2.4% in 2005 [$t(1414) = -0.860$, $P = 0.390$].

DISCUSSION

The main finding of this study is that despite signs of an URI and the risks of vertigo and barotrauma related to flying, a significant number of pilots nevertheless carried out their duties. ENT diseases (especially barotitis media and barosinusitis) contribute significantly to high altitude morbidity[24] and, according to a study in the U.S. Air Force, barotrauma is the most prevalent medical problem associated with airplane travel.[17] Furthermore, it has been shown that barotrauma has been a causal factor in aviation accidents.[20]

According to one of the requirements of the aviation authorities, the European Aviation Safety Agency [EASA, formerly the Joint Aviation Authorities (JAA)] noted in Commission Regulation (EU) No. 1178/2011 of 3 November 2011, MED.A.020, "Licence holders shall not exercise the privileges of their licence and related ratings of certificates at any time when they: (1) are aware of any decrease in their medical fitness which might render them unable to safely exercise those privileges…".[4] And according to EASA and the Civil Aviation Authority (CAA), an URI should be a reason for reporting unfit: "A significant, acute, or chronic infection of the oral cavity or upper respiratory tract is disqualifying. A fit assessment may be considered after full recovery."[2,6]

The 2005 study described an altered interpretation of the EASA requirements regarding URIs and flying[26] and urged airline companies and pilots to accept an URI as a valid reason for reporting illness. The 2015 results suggest that recommendations from the 2005 research have not been widely adopted by airline companies and pilots. A statistically significant increase of pilots carrying out their flying duties despite signs of an URI from 42.8 to 50.1% indicates that more pilots appear to be flying despite an URI.

Moreover, the 2015 study revealed a statistically significant increase of pilots using decongestant medicine (from 43.3 to

59.5%). The use of decongestant medicine is generally not allowed during duty.[26] This is not necessarily because of the medicine itself, but due to the diseases for which it is taken, which indicate that the pilot is not fit for flight.

Regarding the health of the pilots, it is concerning to see statistically significant increases of pilots having experienced barotrauma—barotitis media increased from 37.4 to 55.5% and barosinusitis increased from 19.5 to 27.9%. The 2005 study showed that pilots suffering from ENT barotrauma can become incapacitated to such a degree that they have to hand over the controls to their copilot.[26] Apart from the health issues related to barotrauma, another concerning aspect regarding flight safety is that alternobaric vertigo may potentially set in during critical phases of flight.

A possible reason for the statistically significant increase in the percentage of pilots working despite signs of an URI and the rise in the number of experienced barotrauma episodes could be found in the increased competition within the aviation industry and the increased stress on pilots.[10] In recent years, flight personnel in commercial airlines have experienced dramatic changes in their working conditions and the nature of commercial air transport.[9,10,22] The introduction of low-cost carriers has to some degree led the airline companies to change attitudes toward their employees and toward flight safety. Jorens et al. documents this in their recent report "Atypical Forms of Employment in the Aviation Sector": "Adhering to the economic objective sought by the employer is thereby gaining importance as opposed to maintaining a high safety threshold. This is furthermore corroborated by the fact that atypical forms of employment, which do not provide job security, additionally result in pilots and cabin crewmembers performing duties despite potentially feeling ill, as opposed to taking required sick leave."[10]

In addition, the report describes that only 53% of the employees in low cost carriers have a direct contract with the airline company.[10] When pilots are not permanently employed by the airline companies, they cannot obtain social rights and job security. This means that pilots might be working as self-employed pilots with very little or no insurance and financial support when sick.[10] The pilots in the present study were not asked which airline company they worked for to ensure anonymity, so we were not able to examine whether some of them were working under the above-mentioned conditions. This was a limitation of the current study and would be interesting to explore with future research.

The research in 2015 also showed that a small, but disconcerting percentage of pilots took off even though they felt incapacitated prior to the flight. Of the pilots, 3.2% were somewhat incapacitated prior to the actual flight, a rise since 2005, although not significantly different from that year.

Much effort has been put into higher aviation safety standards, from the strict security checks at airports to courses for pilots about human factors and limitations, multicrew coordination, increased requirements for passengers, and others.[13,26] Yet, it would appear that recommendations to avoid flying with conditions which may cause barotraumas and may pose a risk to aviation safety have not been consistently adopted, despite research and recommendations delivered 10 yr ago.

Compared to the present survey, the 2005 study had the advantage of having twice the number of respondents. In 2014–2015, twice the amount of time was spent gathering respondents, but only achieved half as many as in the first study. The reason for relatively fewer respondents in 2014–2015 is that regulations deciding where pilots should have their ENT examination performed were altered so that all aeromedical examiners can perform them today, while a visit at the Danish Aeromedical Centre was mandatory 10 yr back.[6] Furthermore, the bankruptcy of a large Danish airline company (Cimber Sterling) has forced a number of Danish pilots to move abroad for work, leading to fewer clients at the Danish Aeromedical Centre.

The fact that a visit at the Danish Aeromedical Centre is no longer mandatory could be a possible confounder. As pilots may be concerned about health issues affecting their status as a pilot, the attendants at the Danish Aeromedical Centre may only be the fittest of the pilots. This could possibly mean that even more pilots are working despite URIs than this study suggests. But whether the characteristics of those who choose to attend the Danish Aeromedical Centre are different from those who do not has not been examined and is a limitation of this study.

Although the mean number of URIs per year was statistically different, there was, as mentioned earlier, no difference in practice 10 yr later (both between one and two URIs per year). The number of episodes of sinusitis per pilot year of flying experience was not significantly different in the two studies. This indicates that ENT infections are not an important confounder of the results.

In this type of study, there is always the problem of recall bias. However, professional pilots tend to understate their problems and restrict their reporting,[26] which suggests that the true incidence of barotitis media and barosinusitis among professional pilots may in reality be even higher than indicated by this study. On the other hand, one should expect recall bias to be the same in the two studies, as they were conducted using the same setup. Therefore, the increase in incidents of barotrauma and pilots carrying out their duties despite signs of an URI is not likely to be affected by recall bias.

Of the pilots responding in 2015, 79.5% had more than 10 yr of professional experience, so therefore they could have been potentially included in the previous study. This could possibly have led to more awareness of symptoms after the first questionnaire about the issue. However, it is quite unlikely that this should be the reason for the increase, as one would generally not expect people to remember what questionnaires they answered 10 yr ago.

Another challenge concerning the 79.5% of respondents who could have been part of the first study is that the 2015 results on barotitis media and barosinusitis constitute the total number of such incidents throughout their career. This means that, for a quite large percentage of pilots participating in both studies, the number of ENT barotraumas before 2005 is also counted in the new research in 2015. This is obviously a

limitation of the study. Nevertheless, the study in 2015 shows that ENT barotraumas have been on the rise, which is not expected since URIs are a valid and mandatory reason for reporting in sick.

The question on when signs of barotrauma were experienced has been used as a way of validating the questionnaire. Data supports the theory that passive venting during ascent rarely causes problems,[30] while barotitis media tends to be more common and severe during descent. In 2015, 93.7% of those experiencing barotrauma did so during descent, which is not significantly different from 2005. The fact that barotitis sets in during a critical phase of flight further exacerbates the risk for flight safety.

This study has shown that pilots work more often when suffering from an URI than they did 10 yr ago and that ENT barotraumas have been on the rise during this period. This negative development could possibly have been caused by higher incentives not to report in sick due to changes in working conditions. Based on these findings, this study recommends strengthening the aviation industry's acceptance of an URI as a valid reason for reporting in sick and increasing the awareness of the risks flying with URIs pose to flight safety in order to ensure that risk of pilot incapacitation in flight remains as low as possible.

Knowledge of medical problems and health conditions that affect pilots in flight with potentially serious consequences for the pilot and passengers is extremely useful in relation to the regulatory aspects of pilot licensing and the development of appropriate, evidence-based aeromedical standards. It is recommended that the aeromedical certification system should continue to evolve with the developments in scientific research to ensure that the overall safety of the air transport system can be enhanced.

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