Aircraft Cabin Pressurization and Concern for Non-Arteritic Anterior Ischemic Optic Neuropathy

Samir Nazarali; Henry Liu; Maleeha Syed; Terry Wood; Samuel Asanad; Alfredo A. Sadun; Rustum Karanjia

BACKGROUND: Cabin pressurization is the process by which aircraft maintain a comfortable and safe environment for passengers flying at high altitudes. At high altitudes, most patients can tolerate changes in pressurization; however, passengers at high risk of hypoxia may experience ischemic events. The purpose of this study was to evaluate variations in pressurization of commercial aircraft at cruising altitude and describe its relevance in relation to patients with non-arteritic anterior ischemic optic neuropathy (NAION).

METHODS: Altimeters were used to measure altitude and cabin altitude at cruising altitude aboard 113 commercial flights, including 53 narrow-body and 60 wide-body aircraft.

RESULTS: Cabin altitude ranged from 4232 ft to 7956 ft at cruising altitudes ranging from 30,000 ft to 41,000 ft. The mean cabin altitude for all flights was 6309 ± 876 ft. Narrow-body aircraft had a significantly higher mean cabin altitude (6739 ± 829 ft) compared to wide-body aircraft (5929 ± 733 ft). For all flights, the mean cruising altitude was 35,369 ± 2881 ft with narrow-body aircraft cruising at a lower altitude of 34,238 ± 2389 ft compared to wide-body aircraft at 36,369 ± 2925 ft. Newer generation aircraft had a mean cabin altitude of 6066 ± 837 ft, which was lower than the mean cabin altitude of older aircraft (6616 ± 835 ft).

DISCUSSION: Innovation in flight design has offered the ability for aircraft to fly at greater altitudes while maintaining lower cabin altitude. Those at high risk of hypoxia-induced complications may consider aircraft type when air travel is required.

KEYWORDS: NAION, cabin pressurization, cabin altitude, commercial flight.

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Cabin pressurization is used to maintain a higher pressure than the surrounding atmosphere, ensuring passenger safety and comfort. Ideally, physiological cabin pressurization would approximate sea level pressure of 760 mmHg.[5] However, according to the U.S. Federal Aviation Administration, conventional commercial aircraft must be able to pressurize their cabins to not exceed 8000 ft (2438 m) above sea level.[11] This decreases the risk for hypoxia, altitude sickness, and barotrauma. Most aircraft are pressurized at levels between 6000 and 8000 ft (1829 to 2438 m). Pressurization is limited by structural and mechanical considerations. Higher pressurization (closer to sea level) may not be desirable due to increases in energy consumption and stress on the fuselage, thus competing with the demands of the aircraft's other systems.[14]

At high altitudes, hypobaric exposures can occur on commercial aircraft. Arterial oxygen saturation remains stable until altitudes of approximately 8200 ft (2499 m) and exponentially decreases to 65% by 21,500 ft (6553 m).[4] Normally, changes in oxygenation on board pressurized aircraft have minimal effects on most passengers; however, patients with cardiopulmonary diseases and compromised arterial oxygen saturation are less able to tolerate reductions in inspired oxygen pressure and may be susceptible to a variety of ischemic conditions, including ocular ischemic events.[5]

From the Department of Ophthalmology & Visual Sciences, University of Alberta, Edmonton, Canada; the Faculty of Medicine, University of Ottawa, Ottawa, Canada; Doheny Eye Centre UCLA, David Geffen School of Medicine at UCLA, and the Doheny Eye Institute, Los Angeles, USA, and The Ottawa Hospital Research Institute, The Ottawa Hospital, Ottawa, Canada.

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Address correspondence to: Samir Nazarali, Department of Ophthalmology & Visual Sciences, Faculty of Medicine and Dentistry, University of Alberta, 2319 Active Treatment Centre, 10240 Kingsway Avenue NW, Edmonton, Alberta, Canada T5H 3V9; samir3@ualberta.ca.

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Flight induced ocular pathology is an interesting area for continued research. Thus far, single reports have shed light onto the possibility of flight induced ischemic optic neuropathy.[13,15] These reports hypothesize that ischemic optic neuropathy resulted from thromboembolic or hypoxic mechanisms induced by prolonged flights. The former is believed to lead to occlusion of short nutrient vessels supplying the optic nerve, while the latter from decreased blood oxygen and elevated CO_2 levels from depressed cabin ventilation and pressure. Both cases provide insight on the significant effects that flight can have on certain patients at risk of ischemic injury.

Non-arteritic ischemic neuropathy (NAION) is a condition characterized by sudden onset of painless vision loss. Patients may also complain of other visual limitations, including deficits to color vision, depth perception, and visual fields. Small vessel circulatory insufficiency of the optic nerve is the most widely recognized cause of NAION; however, the exact mechanism by which ischemia occurs is uncertain. Similar to systemic small vessel disease, diabetes, hypertension, and dyslipidemia are risk factors for NAION. The Ischemic Optic Neuropathy Decompression Trial showed 60% of patients with NAION had at least one vasculopathy-related risk factor.[7] Other suggested risk factors for NAION include sleep apnea, vasospasm, severe anemia, generalized hypoperfusion, and nocturnal hypotension. Unfortunately, there is no proven effective treatment for NAION. Although conditions at high altitudes could theoretically impact optic nerve perfusion, few cases exist in the literature documenting NAION during flight travel.

Cottrell et al. conducted the first systematic evaluation of cabin altitude and pressure on commercial aircraft.[5] Their data demonstrated a significant difference in pressurization between newer aircraft types relative to older types. More recent data suggest that commercial aircraft over the past decade are operating at even higher cabin altitudes (corresponding to less oxygen saturation). In a review of 200 U.S. commercial flights by Hampson et al., the highest cabin pressures were documented on mainline commercial aircraft compared to regional and turboprop aircraft, which typically fly at lower altitudes.[12] Peak cabin altitude also increased linearly with flight distance up to 1200 km before plateauing. Moreover, 10% of the aircraft from their study reached cabin altitudes greater than 8000 ft (2438 m), exceeding the recommended Federal Aviation Administration guidelines and resulting in lower arterial oxygen saturation.

Adverse health effects associated with air travel have been described, especially those of the cardiovascular and respiratory systems. Muhm et al. conducted a randomized controlled study using hypobaric chambers to simulate altitude exposure.[14] The study estimated an average reduction of 4% in oxygen saturation during a flight's ascent from sea level to 8000 ft in healthy acclimatized adults. While these mild hypoxemic conditions were not associated with adverse symptoms of sensory or psychomotor disturbances typical of acute mountain sickness, it did, however, result in passenger discomfort beyond 3 h. This is often a consequence of a marked reduction in alveolar oxygen tension associated with high altitudes. Dillard and colleagues also conducted a simulated altitude study whereby patients with severe COPD were monitored in an altitude chamber at 8000 ft, resulting in decreased arterial oxygen tension to clinically significant levels.[8]

Roubinian and colleagues conducted a prospective observational study on the incidence and severity of hypoxemia in passengers with pulmonary hypertension during commercial flights and found that hypoxemia occurred in a quarter of patients.[17] Of the 34 participants, 9 experienced oxygen desaturation (oxygen saturation $< 85\%$) and 13 reported symptoms during flight, including chest pressure/tightness, light-headedness, dyspnea, or palpitations. Oxygen desaturation was found to be correlated with cabin pressures $>$ 6000 ft (1829 m), ambulation, and flight duration.

Advances in technology, particularly in jet engine design, have facilitated larger passenger aircraft with the capacity to cruise at higher altitudes. Higher cruising altitudes, coupled with the same amount of cabin pressurization relative to lower cruising altitudes, has a direct impact on blood oxygen saturation. At sea level, optimal arterial oxygen pressure is 98 mmHg, which is reduced in an unpressurized aircraft to $<$ 72 mmHg at 32,000 ft (9754 m), and reduced even further to $<$ 55 mmHg at 42,000 ft (12,802 m). Additionally, aircraft can ascend at speeds upwards of 5000 ft/min (1524 m/min), increasing the risk of rapid relative hypoxia.[3] Nevertheless, Federal Aviation Regulations mandate that the rate of climb of the cabin be limited to 500 ft/min (152 m/min), while the maximum rate of descent of the cabin altitude be 300 ft/min (91 m/min).

The advent of composite materials within aircraft fuselage has enabled flight at greater altitudes while maintaining lower cabin altitudes, allowing for higher arterial oxygen saturations. This is of great significance as the literature continues to suggest the potential for altitude-induced health events even below cabin pressures of 8000 ft.[1] Given the risks of low oxygen saturation and the advances in new composite fuselage technology, the purpose of this study was to determine the pressurization on commercial jet aircraft during flight. We also outline the possibility for altitude-induced ocular ischemia, particularly NAION, a condition associated with the hemodynamic alterations involved in flight travel.

METHODS

Altimeters (Protrek PAW1300 altimeter, Casio, Tokyo, Japan) were used to measure commercial aircraft pressurization at cruising altitude. The following information was collected for each flight: type of aircraft, cruising altitude, and cabin altitude. The altimeters' accuracy was verified in the Rocky Mountains, at altitudes of up to 8000 ft (2438 m) and were found to be within 20 ft of posted altitudes. Data was collected by three trained individuals, all using the same altimeter. Altitude and maximal cruising altitude were determined from flight data provided by the pilot or the onboard information system. All readings were taken in real time. A total of 113 flights were measured, including 53 narrow-body aircraft and 60 wide-body aircraft (**Table I**). Single-aisle aircraft with a fuselage cabin

Table I. Distribution of Flight Data Across Narrow and Wide-Body Aircraft and Newer and Older Aircraft ($N = 113$).

TYPE & GENERATION OF AIRCRAFT	NO. OF FLIGHTS
Narrow	
Older	
A319/A320/A321	25
B737	7
MD80	5
B757	5
Newer	
SJ100	2
E170/175/E190	7
CRJ900	2
Wide	
Older	
B767	3
B747	5
Newer	
A330/340	13
B777/772	23
B787	2
A350	9
A380	5

diameter of 10–13 ft were considered narrow-body, while twin-aisle aircraft with a fuselage width of 16–20 ft were considered wide-body. Aircraft were also analyzed based on the date of aircraft type certification (Table I). Aircraft developed in 1990 or later were identified as newer aircraft.

All data are expressed as means ± SD (**Table II**). Independent Student's *t*-tests and Mann-Whitney *U*-tests were performed for statistical analysis. Results of the nonparametric tests are reported. Spearman's correlation was performed to assess the relationship between altitude and cabin altitude. Two-tailed P-value < 0.05 was considered significant. A separate subgroup analysis was performed on newer types of aircraft, B787 and A350. The fuselages of these aircraft are composed of composite materials, which permit maintenance of lower cabin altitude while flying at higher altitudes.

RESULTS

Seven types of narrow-body and seven types of wide-body aircraft were studied (Table I). Cabin altitude ranged from 4232 ft to 7956 ft (1290 to 2425 m) at cruising altitudes ranging from 30,000 ft to 41,000 ft (9144 to 12,497 m). Spearman's correlation of altitude and cabin altitude was $R^2 = 0.312$, $P = 0.001$.

A comparison between cabin altitude at different cruising altitudes for narrow vs. wide body aircraft is shown in **Fig. 1**.

Table II. Comparison of Flight Altitude and Cabin Altitude Across Aircraft Types.

	NO.	FLIGHT ALTITUDE (ft)	MEAN CABIN ALTITUDE (ft)
All flights	113	35,369 ± 2881	6309 ± 876
Narrow	53	34,238 ± 2389	6739 ± 830
Wide	60	36,368 ± 2924	5929 ± 734
Older	50	34,840 ± 2452	6616 ± 834
Newer	63	35,796 ± 3130	6066 ± 837

Values are expressed as mean ± SD (ft).

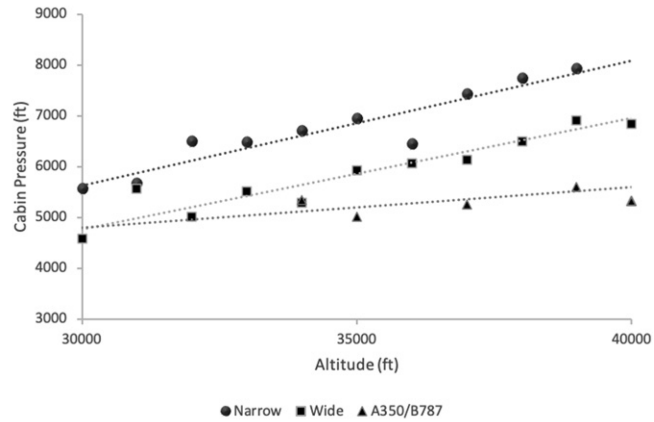

Fig. 1. Comparison of cabin altitude at different flight altitudes for narrow and wide body aircraft ($N = 113$). Narrow: Slope = 0.25, R^2=0.88; Wide: Slope = 0.22, R^2=0.92; B787/A350: Slope = 0.08, R^2=0.51.

The mean cabin altitude for all 113 flights was 6309 ± 876 ft. Narrow-body aircraft had a significantly higher mean cabin altitude (6739 ± 829 ft) compared to wide-body aircraft (5929 ± 733 ft) ($P < 0.0001$, $z = -5.525$, Mann-Whitney *U*-test) (Table II). For all flights the mean altitude was 35,369 ± 2881 ft with narrow-body aircraft cruising at a lower altitude of 34,238 ± 2389 ft compared to wide-body aircraft at 36,369 ± 2925 ft ($P < 0.0001$, $z = -4.075$, Mann-Whitney *U*-test).

With respect to service date, newer generation aircraft had a mean cabin altitude of 6066 ± 837 ft, which was lower than the mean cabin altitude of older aircraft (6616 ± 835 ft). Cabin altitudes were significantly different between newer and older generation aircraft ($P = 0.0002$, $z = 3.780$, Mann-Whitney *U*-test), along with cruising altitudes with mean altitudes of 35,907 ± 3043 ft for newer aircraft and 34,698 ± 2522 ft for older aircraft ($P = 0.038$, $z = -2.079$, Mann-Whitney *U*-test) (**Fig. 2**).

Analysis of the newest generation of aircraft, B787 and A350, showed a mean cabin altitude of 5510 ± 529 ft at a mean altitude of 38,828 ± 2451 ft, which is the lowest of all analyzed groups. Variability among aircraft model at similar altitudes 30,000–34,999 ft (9144–10,667.7 m) and 35,000–41,000 ft (10,668–12,497 m) is presented in **Table III**.

DISCUSSION

The present study analyzed the internal pressurization at cruising altitude of 113 flights in 14 different aircraft types. Wide-body and newer generation aircraft demonstrated significantly lower mean cabin altitude compared to narrow-body and older generation aircraft, respectively. Additionally, the newest types of aircraft studied, B787 and A350, were found to cruise at the lowest mean cabin altitude of all groups. Cabin altitudes on all flights remained within the best practice guideline of 8000 ft (2438 m).

Case reports have revealed the risks of flight-induced ischemic optic neuropathy.[13,15] These reports have suggested that ischemic optic neuropathy may result from thromboembolic or hypoxic mechanisms induced by prolonged flights.

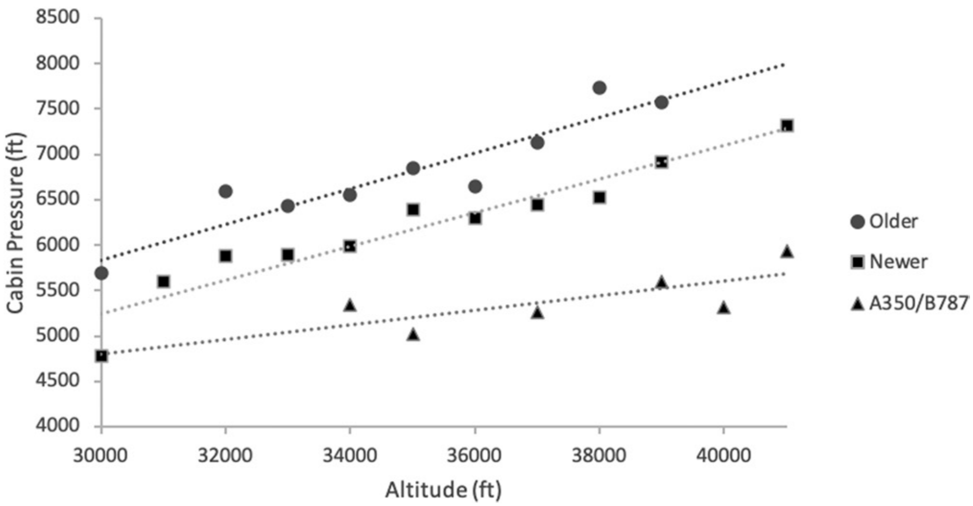

Fig. 2. Comparison of cabin altitude at different flight altitudes (ft) for newer and older generation aircraft (*N* = 113). Older: Slope = 0.17, R^2=0.80; Newer: Slope = 0.19, R^2=0.91; B787/A350: Slope = 0.08, R^2=0.51.

The thromboembolic mechanism would require a thrombotic source, which if on the venous side such as in a deep vein thrombosis, would also require a shunt from the venous to arterial circulation before occluding the vascular supply of the optic nerve. This is less likely than the idiopathic hypoxic variant of NAION, which is thought to occur as a result of hypotension or aberrant autoregulation-induced hypoxia.[2] In turn, NAION may also result from decreased blood oxygen and increased carbon dioxide from reduced cabin ventilation and pressure.

A review of the literature demonstrated a recent case of NAION occurring during in-flight travel conditions. Distefano and Lam[9] documented a case of a 41-yr-old pilot who experienced graying out of his vision while performing G-force maneuvers in an A10 fighter jet. He was left with a superior paracentral visual field deficit; his clinical exam was most consistent with NAION.[9] The patient had also experienced two other episodes of NAION while on the ground. Given the two episodes on the ground, it can be suggested that the patient was already predisposed to NAION prior to engaging in the G-force maneuvers and its associated ischemic changes. The case outlines the possibility for flight-induced optic nerve ischemia and the importance of considering NAION in susceptible individuals exposed to frequent hypoxic environments at high altitudes such as pilots.

Studies conducted by De Bats et al. demonstrated the relationship between NAION and hypoxia intolerance from an inadequate physiological response to high altitudes.[6] An insufficient ventilatory response leads to hemoglobin desaturation and a compensatory increase in blood pressure. The authors present a case of a patient at high altitudes who developed bilateral NAION, which is typically a unilateral disease. Upon further investigation, hypoxia intolerance testing was positive, as a greater than 15% hemoglobin desaturation [from normoxic (98%) to hypoxic (80%)] and a 22-mmHg increase in blood pressure in hypoxia (195/88 mmHg) was seen. The notion of "disc at risk" is well known in ophthalmology as an anatomical configuration that predisposes some patients to NAION.[2] An extreme case of the "disc at risk" is optic nerve drusen. These crystals take up space in the nerve, thus limiting the physical space in the nerve for circulatory and neuronal components. Optic nerve crowding, as seen in a "disc at risk" in conjunction with the known hypoxia increased cerebral and optic nerve edema, theoretically would increase the likelihood of NAION. Indeed, there is a case report of an 11-yr-old child, well outside the normal age demographics for NAION, with bilateral optic disc drusen who developed bilateral NAION after climbing to 11,000 ft (3353 m).[3] In turn, duration of exposure and exertion in hypoxic conditions can be a potential trigger for those at risk of NAION. The occurrence of NAION following long-haul flights or high mountain stays may be warranted for further clinical investigation. In addition, patients with unilateral NAION should be made aware of this association, which has implications for taking long haul flights, especially on aircraft which are pressurized to higher altitudes (lower oxygen partial pressure). This also applies to the 6–10% of the general population who are hypoxia intolerant for other medical reasons.

In Cottrell's study from three decades ago, newer aircraft types resulted in higher altitude exposures compared to older aircraft models.[5] However, our study demonstrated a linear increase in cabin altitude with increasing altitude for narrow and

Table III. Variability in Aircraft Model by Aircraft Altitude.

ALTITUDE 30,000–34,999 ft	NO. OF FLIGHTS	ALTITUDE 35,000–41,000 ft	NO. OF FLIGHTS
A319/320/321	14	A319/320/321	11
A330/340	7	A330	6
A350	1	A350	8
A380	1	A380	4
B737	2	B757	3
B757	2	B772/777	16
B772/B777	7	B747	5
B767	1	B737	5
CRJ100	2	B767	2
E170/175/190	5	B787	2
MD80	5	E170/175/190	2
SJ100	2		

wide body aircraft relative to older and newer aircraft types. These findings are consistent with a study conducted by Hampson et al. reporting similar findings.[12]

Aircraft pressurization is important for adequate arterial oxygenation in humans. Alveolar oxygen tension levels reach 65 mmHg at 8000 ft corresponding to 60 mmHg in arterial oxygen tension, while at sea level the tension level is between 75 to 100 mmHg. This decrease in arterial oxygen content can be tolerated in healthy patients, but can result in significant hypoxemia in patients with vascular conditions and pre-existing baseline reductions in oxygen saturation. In the United States, crewmembers must be provided with supplemental oxygen if the internal cabin altitude reaches 10,000 ft (3048 m; ambient Po_2 110 mmHg). However, the cutoff for supplemental oxygen for passengers remains at 15,000 ft (4572 m; Po_2 90 mmHg).[1] Given the various adverse physiological and cognitive effects associated with altitudes above 10,000 ft (Po_2 110 mmHg), the current U.S. Federal Aviation Regulations mandate that an aircraft must be able to maintain a cabin altitude no higher than that equivalent to an altitude of 8000 ft (2438 m; Po_2 118 mmHg).[10,11,16] However, pressure maintenance is at the expense of increased aircraft weight and fuel consumption. As a result, this upper limit remains a “best practice” guideline rather than a requirement. The present study has a few limitations to consider. The data set included a moderate sample of 113 flights of 14 different aircraft, with some aircraft only represented twice.

We offer the suggestion that those at high risk of hypoxia-induced complications, including those susceptible to NAION, who are frequently traveling consider wide-body and newer generation aircraft if possible. Although all flights studied maintained pressurization below suggested guidelines, the possibility for oxygen desaturation remains with current flight practices, especially for those at high risk.

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Authors and affiliations: Samir Nazarali, M.D., Department of Ophthalmology & Visual Sciences, University of Alberta, Edmonton, Canada; Henry Liu, M.D., Maleeha Syed, M.D., and Rustum Karanjia, M.D., Ph.D., Faculty of Medicine, University of Ottawa, Ottawa, Canada; Terry Wood, M.D., Samuel Asanad, M.D., Alfredo A. Sadun, M.D., Ph.D., and Rustum Karanjia, Doheny Eye Centre UCLA, David Geffen School of Medicine at UCLA, Los Angeles, USA; Henry Liu and Rustum Karanjia, The Ottawa Hospital Research Institute, The Ottawa Hospital, Ottawa, Canada; and Samuel Asanad, Alfredo A. Sadun, and Rustum Karanjia, Doheny Eye Institute, Los Angeles, USA.

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