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Altitude-associated intraocular pressure changes in a gas-filled eye

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Abstract

Purpose: Intraocular gases are commonly used in vitreoretinal surgery. Patients are routinely advised against air travel before the complete absorption of intraocular gas. Consequently, reports on air travel in patients with large intraocular gas bubbles are highly unusual. Here, we report the intraocular pressure changes of a patient ascending to an altitude of 2,600 feet in a helicopter with a 50% fill perfluoropropane (C₃F₈) gas bubble in his left eye.

Methods: Case report and literature review

Results: A 61-year-old male patient underwent pars-plana vitrectomy for a rhegmatogenous retinal detachment, with fluid-gas exchange using 16% C₃F₈. With a 50% fill bubble in the left eye, the patient took a short helicopter trip ascending to a maximum altitude of 2,600 feet. Before take-off, IOP in the operated eye was 14 mmHg. The average increase in IOP was 10.8 mmHg per 1000 feet of ascent, with a maximum recorded IOP of 42 mmHg. The patient denied both ocular pain and loss of vision, but did report changes in the appearance of the gas bubble meniscus at 2,100 feet.

Conclusion: Short term low altitude air travel may be tolerated by some patients with intraocular gas in situ. Further studies are required to define the conditions by which patients with gas bubbles may fly safely.

Summary statement

The authors describe the intraocular pressure variations of a patient ascending to an altitude of 2,600 feet in a helicopter with a 50% fill perfluoropropane gas bubble in his left eye.

Keywords

air-travel; altitude; intraocular gas; intraocular pressure

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Background

Internal tamponade of the retina with injection of intraocular gases, primarily sulphur hexafluoride (SF₆) or perfluoropropane (C₃F₈), is a commonly performed technique in vitreoretinal surgery.^{1,2} As the absorption of intraocular gases follows first-order kinetics, small volumes of gas may be present for several weeks after surgery.^{3,4} Due to the risk of potentially harmful elevations in intraocular pressure (IOP), air travel is discouraged in patients with intraocular gas in situ.⁵ These recommendations are based on data from experimental animal models,^{6,7} as well as human studies conducted in hypobaric chambers with intraocular gas volumes of <20%.^{8,9} Notably, there is a lack of consensus between investigators, with some reporting that eyes with small volumes of intraocular gas (<10%) will tolerate the decreased atmospheric pressure of air travel without dangerous spikes in IOP,^{7,9,10} and others stating that any volume of intraocular gas is unsafe.^{8,11,12} Furthermore, there are very few published reports of altitude-associated changes in IOP with volumes of intraocular gas >20%.¹³ Here we report the IOP variations of a patient ascending to an altitude of 2,600 feet in a helicopter with a 50% fill C₃F₈ gas bubble in his left eye.

Case presentation

A 61-year-old male patient diagnosed with rhegmatogenous retinal detachment underwent pars plana vitrectomy, with injection of 16% C₃F₈ gas into the left eye. The surgery was performed at our facility in Boston, Massachusetts (altitude of 19 feet above sea level). Past ophthalmic history was remarkable for lattice degeneration and presbyopia. The patient had no history of elevated IOPs. Past medical history was notable for hypertension and hypercholesterolemia. The patient's regular medications included hydrochlorothiazide, valsartan, rosuvastatin and aspirin.

One month following the surgery, the patient expressed a desire to take a short-duration, low-altitude helicopter flight. The risks of the journey were explained in detail, and the patient provided informed consent. During the helicopter flight, the patient was continuously monitored for ocular pressure, pain and visual impairment by one of the authors (DGV). IOP was evaluated by Tono-Pen (Reichert Technologies, Depew, NY) prior to take-off, and was rechecked periodically throughout the journey. Flight parameters that were recorded included journey duration and altitude. Duration of ascent was 14 minutes to a maximum altitude of 2,600 feet, with the descent taking a further 20 minutes.

Gas bubble volume prior to take-off was 50%. The bubble size was not monitored objectively in-flight. The patient was questioned regularly during the flight as to whether any subjective change to the size of the bubble could be appreciated, by assessing the level of the fluid/gas interface. The patient denied any subjective changes to the appearance of the gas bubble until an altitude of 2,100 feet, at which time an apparent increase in the size of the bubble was reported, with the meniscus of the gas bubble exhibiting a "flatter curvature". IOP measurements at various altitudes are presented in Figure 1. Notably, the IOP values in both eyes were identical before and after the flight (13 mmHg OD and 14 mmHg OS). The average increase in IOP in the left (operated) eye was 10.8 mmHg per 1000 feet of ascent,

and the average increase in IOP in the right (non-operated) eye was 1.5 mmHg per 1000 feet. Maximum recorded IOPs were 42 mmHg in the left eye, and 17 mmHg in the right.

Discussion

Altitude-associated changes in the volume of intraocular gas bubbles can be explained by Boyle's law ($P_1 V_1 = P_2 V_2$). Decreases in absolute intraocular pressure (atmospheric pressure + IOP) are observed as altitude increases, due to the falling surrounding atmospheric pressure.⁶ Concurrently, and in accordance with Boyle's law, the intraocular bubble expands. Using a rabbit model, Lincoff and colleagues have demonstrated that the recorded fall in absolute intraocular pressure lags slightly behind the drop in atmospheric pressure.⁶ Moreover, the investigators demonstrated that the larger the volume of intraocular gas, the greater this lag. The delay in pressure equilibration causes the elevated IOP readings that are observed with increases in altitude.

In an accompanying paper in the late 1980s, Lincoff and colleagues demonstrated that decreases in cabin pressure that occur as an airplane ascends can be compensated for, without a symptomatic increase in measured IOP, for gas volumes up to 0.6 mL (approximately 10% of the volume of the eye).⁷ In addition, the authors described two patients with an estimated 1 mL of residual gas taking transatlantic flights in Boeing 747s without discomfort (usual cabin pressure equivalent to 7000 feet or less). The investigators propose that compensatory mechanisms including choroidal compression and scleral expansion provide intraocular space for the expanding gas.⁷ More recently, in a study of 12 patients at 4–6 weeks following pars plana vitrectomy with 15% C₃F₈ gas-fluid exchange, Noble and colleagues evaluated intraocular pressure changes in a hypobaric chamber simulating air travel.⁹ Although 6 of the patients had scleral buckles in place (which resulted in significantly lower peak IOPs compared to non-buckled eyes), the authors conclude that their results suggest that *all* patients with eyes containing small volumes of intravitreal gas and normal or baseline IOPs will tolerate typical air travel without the risk of dangerous elevations of IOP.⁹ Contrary to the findings from the above studies, the standard recommendation is that patients should not fly until intraocular gas has been fully absorbed.⁵

There are very few reports in the literature of altitude-associated IOP changes with intraocular gas volumes >20%. In 1994, Kokame and Ing published a case detailing the intraocular pressure changes in a patient with a gas bubble volume of 65% ascending to 3,000 feet.¹³ As with our report, the patient did not experience pain or decreased vision. Both cases also describe instantaneous changes in IOP with changes in altitude.¹³ The IOP increase per 1,000 feet of ascent in our study (10.8 mmHg) was very similar to that reported by Kokame and Ing. However, the patient described by Kokame and Ing received timolol 0.5% eye drops and 500 mg of acetazolamide prior to the flight, which is a potential confounding factor in their IOP measurements.¹³ Nevertheless, both cases report air travel at altitudes less than 3,000 feet being well tolerated by patients with relatively large volumes of intraocular gas.

In support of the current recommendation that patients with intraocular gas bubbles should avoid air travel, there are reports of patients with small gas fills experiencing significant

visual field loss^{12,14} and potentially pathogenic IOP elevations^{8,11} with air travel and simulated flight. The importance of a patient's past ophthalmic history is emphasized by a case reported by Muzychuk and colleagues, who describe a 64-year-old patient with glaucoma and a 10% fill C₃F₈ intraocular gas bubble following pneumatic retinopexy taking an international flight.¹² The patient described pain and complete loss of vision in the post-operative eye following take-off, that persisted until after landing. Upon review 2 weeks later, the patient's cup-disc ratio was observed to have increased from 0.3 to 0.5, and his optical coherence tomographic scan revealed a loss of nerve fiber layer thickness from an average of 97.0 µm before the flight to 85.6 µm afterward.¹² Gandorfer and Kampik also report two patients that experienced ocular pain and loss of vision during air travel in eyes with intraocular gas bubbles following pneumatic retinopexy.¹⁴ These cases clearly demonstrate that air travel can be risky with intraocular gas in situ, even at <20% fill,¹² and underscore the importance of taking into account both the factors concerning the individual (e.g. past ophthalmic history, baseline IOP, volume of intraocular gas etc.) as well as characteristics of the planned flight (duration, maximum altitude, type of aircraft).

Cabin pressurization is a critically important factor in determining of the risk of air travel, and warrants further discussion. Our case describes a subject ascending to an altitude of 2,600 feet in a helicopter without cabin pressurization. Similarly, the case reported by Kokame and Ing details IOP changes during a low-altitude flight in a private Cessna twin engine airplane without a pressurized cabin.¹³ In contrast with these cases, commercial aircraft cruise at considerably higher altitudes (typically 36,000–40,000 feet), and have cabin pressurization systems that protect passengers and crew from the physiological challenges associated with decreased environmental pressures. Thus, aircraft cruising at altitudes of 36,000–40,000 feet have an equivalent effective cabin altitude of 6,000–8000 feet above sea level. Indeed, regulations set by the Federal Aviation Administration in the US stimulate that cabin altitude should not exceed 8000 feet during normal operations.¹⁵ Recently however, aircraft have been manufactured to provide lower cabin altitudes with the goal of improving passenger comfort,¹⁶ with aircraft such as the Boeing 787 Dreamliner and the Airbus A350 being pressurized at less than 6,000 feet,¹⁷ and with modern light jets capable of maintaining sea level cabin pressures at normal cruising altitudes.¹⁸ Thus, flight characteristics can have a major impact on the risk of air travel, and should be considered when advising patients of the risks of flying. Most critically, however, we must acknowledge that attempts to inform patients fully regarding the risks of air travel with intraocular gas bubbles are at present limited by a scarcity of data.

Conclusions

This paper reports the IOP changes in a C₃F₈-filled eye at 50% volume ascending to 2,600 feet. The results suggest that low-altitude air travel may be well tolerated by some patients with relatively large volumes of intraocular gas. Furthermore, in an era of growing global air traffic and increased rates of vitreoretinal surgery involving intraocular gas injection,¹ this report highlights the need for additional studies to determine the safety of air travel with intraocular gas bubbles.

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Figure 1. Intraocular pressure (mm Hg) versus altitude (feet).

Solid black line shows pressure in left eye during ascent and dashed black line details pressure in left eye during descent. Solid grey line records pressure in right eye during ascent and dashed grey line shows pressure in descent.