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Otic barotrauma from air travel

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Abstract

Otic barotrauma occuring during air travel involves traumatic inflammation of the middle ear, caused by a pressure difference between the air in the middle ear and the external atmosphere, developing after ascent or more usually descent. The pressure difference occurs because of failure of the eustachian tube to equilibrate middle ear and atmospheric pressures. It is a common problem, presenting with ear fullness, otalgia and deafness. Severe cases may result in tympanic membrane perforation and even round window membrane rupture. Of three randomized controlled trials, one showed that oral pseudoephedrine decongestants reduced otalgia in adults with recurrent ear pain during air travel, whilst another found that oral pseudoephedrine did not decrease in-flight ear pain in children. The third trial showed that oxymetazoline decongestant nasal spray, taken 30 minutes before descent, did not produce a statistically significant reduction in symptoms of barotrauma in adults with recurrent ear pain during air travel. We review the causes, prevention and treatment of this condition.

Keywords: Barotrauma; Altitude; Middle Ear; Eustachian Tube

Introduction

Otic barotrauma suffered during air travel, otherwise known as aerotitis media, is defined as an acute or chronic traumatic inflammation of the middle ear caused by a pressure difference remaining between the air in the middle ear and the surrounding environment, after ascent or more usually descent. The pressure difference occurs because of failure of the eustachian tube to equilibrate middle-ear and atmospheric pressures. The reduction of air pressure at high altitude is the major aetiological factor in air travel barotrauma. The condition is a common problem, presenting with ear fullness, otalgia and deafness. Severe cases may result in tympanic membrane perforation and even round window membrane rupture.

The first description of the condition was given in 1783 by J A C Charles, a French physicist, who, after becoming the first man to make a free ascent in a hydrogen balloon, complained of severe pain in his right ear during descent.[1]

Incidence

Barotrauma is the most prevalent medical problem associated with airplane travel and has been a causal factor in aviation accidents.[2] When asked about ear problems during previous flights, 28 out of 43 (65 per cent) children and 166 out of 363 (46 per cent) adults reported discomfort or pain.[3] For a single flight, the incidence of otalgia among passengers is 26–55 per cent in children[3,4] and 20 per cent in adults.[3] The incidence of barotrauma in 'healthy' military aircrews ranges from 1.9 to 9 per cent.[2,5] In one study, of the 13 out of 50 children who reported ear discomfort on a single flight, 31 per cent (4/13) experienced it during takeoff and ascent, compared with 85 per cent (11/13) who experienced it during descent and landing.[4] The huge number of passengers travelling by air worldwide gives an idea of the number of people potentially at risk.

Pathophysiology

Ascending

In a modern aircraft at cruising altitude, the cabin is pressurized to raise the air pressure to approximately three–quarters that of the ground atmospheric pressure. Therefore, as an aircraft ascends the atmospheric pressure decreases and the gas in the middle ear expands in accordance with Boyle's law. If the eustachian tube is not opened by, for example, swallowing, then the middle ear gas, with a relatively positive pressure, will continue to expand until the tympanic membrane is pushed laterally to its limit, an effect which can be seen with an otoscope during flight.[6] At a pressure differential of 15 mmHg, the eustachian tube (if functioning properly) passively opens and vents off the positive pressure air, thereby equalizing the ambient and

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middle-ear pressures. This process of passive venting is rarely a problem on ascent and occurs at about every 122 m (400 ft) of increasing altitude.[7] However, ear discomfort and pain can occur if there is eustachian tube dysfunction.[4]

Descending

As an aircraft descends, the atmospheric pressure increases back to 'normal' and therefore the gas in the middle ear contracts, again in accordance with Boyle's law. Now the eustachian tube behaves differently in descent as compared with ascent, in that air does not normally enter the middle ear passively and this is why aerotitis media tends to be more common and severe with descent. Muscular activity must open the auditory tube and this is usually achieved easily by swallowing or yawning. The tube can also be opened by some degree of overpressure applied at the nasal end, as in Valsalva's manoeuvre. These manoeuvres become increasingly difficult if the pressure differential between the middle ear and atmosphere is allowed to increase during descent. At a pressure differential of 60 mmHg (i.e. the ambient pressure is 60 mmHg greater than the middle-ear pressure) fullness of the middle ear occurs and passengers experience discomfort. A pressure differential of around 80 mmHg closes the soft nasopharyngeal end of the tube with a force greater than that which can be developed by the muscles that open the tube. At this stage the tube will stay 'locked' and any attempts to equalize the pressure become futile.[7] Beyond this point, the pathophysiological changes of barotrauma will occur. Performing Valsalva's manoeuvre at this stage may become counter-productive by magnifying the already increasing overpressure in the nasopharynx. The pressure differential at which tube-locking occurs is variable, and will depend on the intrinsic strength of the tubal dilator muscles in any particular individual.[6]

Rupture of the tympanic membrane. If the pressure differential reaches 100–500 mmHg the tympanic membrane ruptures, which usually relieves the pain and pressure but may cause severe sequelae such as deafness, vertigo and vomiting.[7] King[8] reported a tympanic membrane rupture incidence of 4.2 per cent in 897 ears with barotrauma. Many perforations will heal spontaneously.

Rupture of the inner-ear window. There have been a number of cases of rupture of the oval or round window membrane occurring in flight.[9–11] A history of barotrauma with vomiting, tinnitus, vertigo, imbalance and the presence of a sensorineural deafness suggests a rupture leading to a fistula. This can be proved at tympanotomy and successfully closed by means of a fat graft.[6]

Despite cabin pressurization bringing the ambient pressure up to three-quarters that of ground air pressure, a descent from the typical cruising altitude of most commercial aircraft is sufficient to create an 80 mmHg gradient.[5] Dickson and King[12] found that the severity of barotrauma sustained in flight is related to the rate of descent from altitude and hence to the rate of pressure change. Certain aircraft, such as the Boeing 737, have a relatively greater rate of pressure change during descent than others (e.g. the Boeing 747, DC-10 and Airbus 310) and this results in a greater risk of barotrauma.[13]

TABLE I

CAUSES OF FAILURE OF PRESSURE EQUILIBRATION DURING FLIGHT

Sleeping during descent
Eustachian tube dysfunction
– Anatomical abnormality
– Previous eustachian tube dysfunction
– Oedema
– Rhinitis
– Upper respiratory tract infection
– Chronic middle-ear disease
– Pregnancy

Causes of failure of pressure equilibration

Failure of pressure equilibration during flight may be caused by poor function of the eustachian tube due to any condition that narrows the lumen of the tube by oedema, increases the amount or viscosity of the mucus coating the tubal membrane, or impairs the ability of the tube to open. Some of the commoner causes are listed in Table I. Commonest among these are the effects of coryza and allergic or vasomotor rhinitis. Congenital and traumatic malformations of the nasal skeleton, as well as gross malocclusion of the teeth and jaws, may also impair eustachian tube function.[6] Each episode of barotrauma causes mucous membrane oedema and tubal system deterioration, further compromising the middle ear so that one attack of barotrauma predisposes to another.[14]

Are children more prone to barotrauma?

Children may be more prone to otic barotrauma[3] due to a number of factors. Anatomic differences in their eustachian tubes, an increased frequency of viral upper respiratory tract infections, and adenoidal tissue either mechanically blocking the eustachian tube orifice or acting as a focus of infection, may all contribute to eustachian tube dysfunction. In addition, many children are unable to perform Valsalva's manoeuvre and this may further increase the likelihood of in-flight barotrauma.[3]

Glue ear would appear to be protective against barotrauma. In a study observing 24 ears with an effusion in 14 children during a flight, no earache developed in the affected ears, presumably because the middle ear had become a fluid-containing space and therefore did not function under the physical laws governing gas-filled spaces. Three ears had air–fluid levels and it would be reasonable to presume that these ears would not be similarly protected as they had some air in the middle ear. However, all three remained asymptomatic. Interestingly, two patients did develop otic barotrauma in the contralateral 'normal' ear, which probably had borderline eustachian tube dysfunction at the time of the flight.[15]

Pathology

When there is a sustained negative pressure in the middle ear serous fluid is produced by the mucous glands in the middle ear in an effort to equalize the pressure.[16] Sufficient negative pressure may exist to cause the rupture of blood vessels from the surrounding vasculature, resulting in a haemotympanum, or in severe cases, bulging and perforation of the tympanic membrane.[17] Histological changes seen with barotrauma range from congestion of the mucous membrane to oedema, bleeding into the mucosa of the middle-ear space, seromucinous effusion and polymorph infiltration.[18] Teed's classification of barotrauma to the ear[19] is shown in Table II.

Clinical symptoms and signs

Symptoms of mild barotrauma include a sensation of ear blockage, followed by pain and a conductive hearing loss. Clinical signs include tympanic membrane retraction, congestion and haemorrhage, haemorrhage or effusion in the middle ear, and tympanic membrane perforation.[17,19] Resolution of symptoms may take as long as four weeks, depending on the severity of the injury and subsequent treatment.[20] A history of barotrauma with vomiting, tinnitus, vertigo, imbalance and the presence of a sensorineural deafness suggests a perilymph fistula.

Investigations

Tympanometry

In a study addressing whether tympanometry could predict if a patient would develop barotrauma on flying, 80 subjects were tested prior to and after exposure to decreased ambient pressure in a hypobaric chamber simulating pressure changes during a flight. Of the nine ears exhibiting abnormal pre-pressures, only one subsequently exhibited barotrauma following the hypobaric experience. The authors suggested that testing prior to altitude exposure is of no value in identifying those individuals who will suffer from barotrauma during flight and postulated that this may be because tympanometry only reflects eustachian tube patency at an instant and is not a true test of eustachian tube function.[21] A tympanogram performed immediately after Toynbee's test (swallowing with nose pinched closed) showing no increase in negative pressure may suggest eustachian tube dysfunction with a predilection to barotrauma.[13]

Imaging

Nakashima *et al.*[22] looked at the cochlear aqueduct widths on computed tomography scans of eight patients with inner-ear barotrauma but found no significant difference in the widths between the affected and non-affected sides. Three affected sides had no identifiable jugular fossa and the authors suggested a possible relationship may exist between inner-ear barotrauma and poor development of the jugular fossa.

TABLE II

TEED'S CLASSIFICATION OF MIDDLE-EAR BAROTRAUMA

Grade 0:	Normal
Grade 1:	Retraction with redness in Schrapnell's membrane and along the manubrium
Grade 2:	Retraction with redness of the entire ear drum
Grade 3:	Same as grade 2 plus evidence of fluid in the tympanum or haemotympanum
Grade 4	Perforation of the ear drum

Prevention

The simplest way to prevent aerotitis media is to avoid air travel when symptoms of an upper respiratory tract infection are present.[7] When actually flying, preventative measures can either aid the opening of the eustachian tube or optimize patency of the tube. During descent, equilibration of the middle-ear pressure has to be repeated at least three to four times due to the pressure gradient, in order to prevent the risk of otic barotrauma.[23]

Simple measures

Opening of the eustachian tube and pressure equilibration for many patients is usually easily achieved by swallowing, jaw movements, yawning or chewing, while other passengers need to perform Valsalva's manoeuvre several times during descent and some passengers fail even by these means to equilibrate their middle-ear pressures.[3] Using a warm, wet towel over the external ear to decrease 'ambient' pressure during descent has also been advocated.[4] For infants, bottle-feeding during descent, commenced when adults perceive the need to clear their ears, is a useful strategy to prevent infants from crying, presumably due to barotitis.[24]

Valsalva's manoeuvre

Valsalva's manoeuvre, described by Antonio Valsalva in 1704, involves forcible expiration with the lips and nostrils closed, thereby raising the air pressure in the nasopharynx, which forces air along the eustachian tubes. All frequent flyers should be familiar with this procedure.[7] It should be noted that, while Valsalva's manoeuvre is employed commonly in flight to clear the ears, it can cause syncope on occasion by way of pooling of blood in the venous system and stimulating pulmonary stretch reflexes which can induce arrhythmias.[25]

Frenzel's manoeuvre

Frenzel's manoeuvre[26] for ventilating the middle ear involves trying to say 'k' repeatedly while voluntarily closing the nose, mouth and glottis (as when preparing to lift a heavy weight). It has the advantage that it can be performed in any phase of respiration and is independent of intrathoracic pressure, thus avoiding the risk of syncope, which is critical for pilots. However, it is a technique that often has to be taught and is therefore not as common amongst passengers as Valsalva's manoeuvre.

Ear plugs

Patients are now able to obtain Cirrus ear plugs (Cirrus Healthcare Products, Sandwich UK), which contain a CeramX™ filter that regulates the air pressure change in the ear canal, allowing a more gradual change and thereby apparently allowing a suboptimally functioning eustachian tube time to 'catch up' with external pressure changes on descent.

Otovent

Stangerup *et al.*[3] looked at middle-ear pressure equilibration using the Otovent. This is a balloon-like device that is inserted into one nostril and inflated whilst the contralateral nostril is closed, thereby effectively working like a Valsalva's manoeuvre. They found that in children and adults there was a statistically significant greater increase in middle-ear pressure when using the Otovent in comparison with Valsalva's manoeuvre. However, an actual reduction of barotrauma when using the Otovent was not shown. These authors recommended autoinflation using the Otovent set in children and also in adults with problems clearing their ears during flight descent in order to prevent painful ear conditions.

Systemic decongestants

Numerous sources recommend prophylactic and therapeutic use of oral or topical nasal decongestants to prevent and treat middle-ear barotrauma.[17] Pseudoephedrine causes adrenergic vasoconstriction which results in reduction of tissue hyperaemia and oedema, and shrinkage of swollen mucosal membranes. These effects are well documented for the nasal passages and presumably occur in other areas of the respiratory tract, including the eustachian tube.[27] Therefore, pseudoephedrine should improve or maintain eustachian tube patency and allow equilibration of middle-ear pressures.[28]

In a prospective, parallel, double-blind, randomized trial using adult volunteers with a history of recurrent ear discomfort during air travel, 96 patients received 120 mg pseudoephedrine and 94 received a placebo. Ear discomfort was present in 32 per cent of those receiving pseudoephedrine versus 62 per cent of the control group ($p = 0.001$). Adverse effects were minimal, including seven patients who experienced drowsiness. The authors conclude that treatment with 120 mg pseudoephedrine at least 30 minutes before flying appears to decrease the incidence of otalgia in adults with a history of recurrent ear pain during air travel.[20] On the other hand, in a trial involving children, pseudoephedrine was not found to decrease in-flight ear pain and was associated with drowsiness.[4] This may be related to the 1 mg/kg dose of pseudoephedrine given, which is a smaller dose per kilogram than the 120 mg administered to the adult subjects in the above studies. Contraindications to the use of pseudoephedrine include diabetes, thyroid disease, hypertension, heart disease, prostatism and current therapy with a monoamine oxidase inhibitor.

Topical nasal decongestants

Quick-acting sympathomimetic agents such as oxymetazoline hydrochloride decongest the nasal passages and may also reach the post-nasal space to allow the orifice of the eustachian tube to function more efficiently for pressure equalization. In the study mentioned above, using adult volunteers with a history of ear pain during air travel, symptoms of barotrauma were reported in 64 per cent of those receiving topical oxymetazoline nasal spray, in comparison to 71 per cent of those receiving a double placebo (capsule and spray), but this effect of oxymetazoline did not reach statistical significance.[28] The study involved dosage just 30 minutes before descent, which may not provide the optimal effect, and the delivery to the eustachian tube orifice may not have been adequate. Perhaps two puffs inhaled one hour before take-off and two puffs 30 minutes before descent would have been more effective.

Antihistamines

Passengers with allergies may benefit from the use of an antihistamine. The ability of antihistamines to dry and reduce mucosal oedema may be sufficient to reduce swelling and clear tenacious exudates from the eustachian tube orifice.[7] However, there is no scientific data at present to support their efficacy in preventing barotrauma.

Myringotomy/grommet

If a high-risk person finds it essential to fly, a myringotomy (with or without a grommet) can be performed to help avoid the problems associated with recurrent barotrauma.[17]

Laser eustachian tuboplasty

The relatively new technique of laser vaporization of the mucosa and cartilage on the posterior wall of the eustachian tube lumen, via either a transnasal or transoral approach, to improve eustachian tube function, may be beneficial to patients who experience barotrauma with air travel. However, further studies and long term results will be necessary to ultimately determine the merits of the procedure before widespread application of the technique.[29]

Treatment

Ear blockage sensations and otalgia that is severe or unremitting may initially be treated with systemic and topical decongestants as well as repeated attempts with Valsalva's manoeuvre. If symptoms persist then inflation with a Politzer's bag can be tried initially before moving on to a myringotomy with or without grommet insertion.[3]

Politzer's bag

A Politzer's bag is composed of a body (bulb), a distal nasal flange and an inlet port. With the patient seated, the contralateral naris is occluded whilst the flange of the Politzer bag is placed in the naris of the affected side. The patient is instructed to rapidly repeat aloud the letter 'k' while the hand-held bulb is compressed. Alternatively, the patient swallows small sips of water while the bulb is compressed. The device is capable of delivering multiple puffs of positive pressure, and 50 per cent of ear blockage sensations clear after a few minutes using this method.[7]

Myringotomy

A myringotomy may be needed if the patient is experiencing excruciating pain or an unrelenting ear blockage sensation. The procedure should produce dramatic relief, and most patients recover without sequelae.[7]

Summary: preventing barotrauma during air travel

On beginning ascent and descent, and certainly as soon as fullness in the ears is noted, passengers should begin simple measures to open the eustachian tube such as chewing, sipping fluids or yawning, as well as Valsalva's manoeuvre if necessary. These actions should be repeated every few minutes to stay ahead of the pressure differential. Passengers should therefore avoid sleeping at these times of pressure change.

When flying in a small plane with a limited number of persons on board, passengers who are experiencing ear blockage may ask the pilot to re-ascend, allowing them time to equalize their middle-ear pressures using Valsalva's manoeuvre before the plane resumes a slow descent.[7]

- **Otic barotrauma is the most common medical problem associated with flying**
- **This article reviews the causes, manifestations and treatment of otic barotraumas**

Treatment of any predisposing conditions should be optimized, for example by corticosteroid nasal sprays and antihistamines in patients with allergic rhinitis. In passengers who have recurrent problems or a predisposing condition, such as an upper respiratory tract infection, a systemic decongestant should be started one to two days before the flight. Other medications, such as antihistamines and topical nasal decongestants as well as the Otovent device and Cirrus ear plugs, may also be considered. Occasionally, a grommet is necessary prophylactically. The relatively new technique of laser eustachian tuboplasty may in the future benefit patients who experience otic barotrauma, but further studies are required.

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