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# Is this baby fit to fly? Hypoxia in aeroplanes

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**Abstract**

During air flight, cabin pressurisation results in a reduced fraction of inspired oxygen to 0.15. Healthy children desaturate by around 4% and remain asymptomatic. However children under the age of 1 year are more susceptible to hypoxia, especially if they were born preterm, and even more so if they are survivors of chronic neonatal lung disease. Pre-flight testing with a 'fitness to fly' test is available in some tertiary respiratory centres. The British Thoracic Society 2004 guideline currently recommends supplemental oxygen be given if the child's oxygen saturation falls below 90% during the test, although 85% may be a more appropriate cut off level.


## 1. Background

Air travel is so popular that over one billion people fly on commercial aeroplanes each year, and the figure is increasing all the time. Many parents expect to take their infants on planes, and nurses and midwives on postnatal wards are often asked whether this is safe, and how old must the baby be before they can fly. This article considers the issue of whether it is safe for babies to be exposed to the hypoxia experienced during air flight. Full accounts of other medical issues (for example risk of infection, thromboembolic disease, effects on the middle ear etc.) have been published by the Aerospace Medical Association in 2003 [1] and more specifically for children by the Canadian Paediatric Society in 2007 [2]. In addition, the British Thoracic Society have published evidence-based guidelines on managing passengers with respiratory disease planning air travel, and this includes a section on fitness to fly in childhood [3].

## 2. Air flight and hypoxia

At sea level, the fraction of inspired oxygen ($FiO_2$) in air is 0.21. Commercial aeroplanes fly at an altitude of 30–40,000 ft (9000–12,000 m), which would result in an $FiO_2$ of only 0.04. To combat this, the aircraft cabin is pressurised so that the passengers are at the equivalent of 5–8000 ft (1500–2400 m) which means that they are breathing air with an equivalent $FiO_2$ of 0.15–0.17. US Federal Aviation Regulations specify that cabins must not be pressurised to above 8000 ft (around 560 mm Hg), and if the cabin altitude rises above this, emergency oxygen masks are automatically deployed. Aircraft could be maintained at a sea level pressure (760 mm Hg) but this would reduce the energy available for other aircraft systems, increase fuel consumption and reduce the working life of the aluminium airframes [4].

Serious effects of altitude hypoxia do not usually arise until the atmospheric pressure drops to the equivalent of 10–12,000 ft (3000–3600 m) [5]. There is great individual variability and Mount Everest at 29,035 ft (8850 m) has been climbed without supplemental oxygen. However time for acclimatisation is obviously not available during air flight. Breathing air containing 15–17% $O_2$ can cause hypoxia in

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predisposed individuals. In addition, the air extracted from outside the plane at high altitude is extremely dry, this means humidity inside the plane ranges from 10 to 20% which can dry out airway secretions [6]. This issue becomes even more important with an increased respiratory rate (compensatory hyperventilation) that may occur in the presence of relative hypoxia.

Lee et al. studied 80 healthy children aged 6 months to 14 years during 8–10 h flights between Hawaii and Taiwan [7]. At sea level, mean oxygen saturation ($SaO_2$) was 98.5% and mean heart rate 105/min; after 3 h flight it was 95.7% and 105/min, and after 7 h 94.4% and 108/min. The $SaO_2$ results were marginally higher in the children under 2 years of age. No acclimatisation was noted and $SaO_2$ was lower when the children were sleeping (e.g. mean 93.4% *vs* 94.8% at 7 h measurement). Another study measured oxygen saturation by pulse oximetry on the ground and then during a flight in 84 passengers, ten of whom were 10 years or younger [8]. The mean (range) $SaO_2$ was 97% (93–100%) at ground level which fell to a mean of 93% (85–98%). Over half the passengers had $SaO_2$ of 94% or less during the flight and there was no difference between short and long haul flights. They found no significant change in heart rates.

## 3. Why are infants particularly susceptible to hypoxia?

A study of 67 healthy full term infants aged 29–54 days showed their baseline $SaO_2$ (measured by pulse oximetry) ranged from 97 to 100% (median 99.8%) [9]. 81% infants had short episodes of desaturation to 80% or less (occurring a median of 0.9/h) with a median duration of 1.2 s, and 97% were less than 4 s. The same group studied 66 preterm infants born at a gestational age of 25–36 weeks (median 34 week) when they had reached term [10]. Their baseline $SaO_2$ ranged from 89 to 100% (median 99.4%). However desaturations were more frequent (median 5.4/h and longer (median 1.5 s) than the term infants [10]. Ex-preterm babies also exhibited more apnoeic pauses and periodic breathing than term infants.

Newborns and infants in the first year of life have an increased tendency to ventilation–perfusion mismatch making them particularly susceptible to hypoxaemic episodes, especially if they are ill or in the presence of airway hypoxia [5]. There are a number of factors that contribute to the greater risk of infants developing hypoxia: the presence of fetal haemoglobin (with oxygen dissociation curve shifted to the left); tendency to pulmonary vasoconstriction in presence of airway hypoxia; tendency to bronchoconstriction in the presence of airway hypoxia; relatively fewer alveoli; compliant rib cage; and smaller airway diameter [5]. In addition, in the first two months of life, infants may show a paradoxical inhibition of the respiratory drive causing apnoea/hypoventilation in response to hypoxia or infection [5].

## 4. The effects of hypoxia

Although the effects of chronic hypoxia and living at altitude are well established (reviewed by Samuels [5]), the effect on infants of shorter periods of hypoxia such as that experienced during air flight, is less well known. Hypoxia can cause apnoea and hypoventilation. Consequently the greatest concern is whether a period of hypoxia can lead to an acute life threatening event (ALTE) or actual sudden infant death. There have been case reports of sudden death following air flights [11] but it is generally believed that flying is safe for healthy children in the first year of life [12]. In practical terms, many millions of infants have flown and clearly not suffered either short or long term adverse effects from their periods of reduced oxygen saturations.

To gain a greater understanding of the effect of the aircraft level of hypoxia on healthy infants, Parkins et al. performed a study whereby 34 healthy infants (born at term) with a mean age of 3 months (range 1–6 months) were exposed to 15% oxygen for a mean of 6.3 h [11]. The exposure was discontinued if the saturations dropped to <80% for 1 min or more. Median baseline $SaO_2$ fell from 97.6% to 92.8% (median fall 4.9%); this was accompanied by a significant rise in heart rate. The individual response was unpredictable with no correlation between baseline room air $SaO_2$ and the extent of the subsequent fall. There was a reduction in the proportion of time spent in a regular breathing pattern, and a 3.5 fold increase in the time spent in periodic apnoea. Four out of 34 infants had a significant desaturation to <80% for 1 min or more (remaining asleep), and were withdrawn from the study at 1.9–5.2 h; one required supplemental oxygen for the next hour to maintain $SaO_2$ above 94%. Controversially, the authors concluded that air travel may be harmful to some infants.

## 5. Pre-flight testing: the 'fitness to fly' test

Normal saturations at sea level are a poor indicator of the ability to tolerate air flight, hence the need for a specific test where the inspired oxygen concentration is set at the

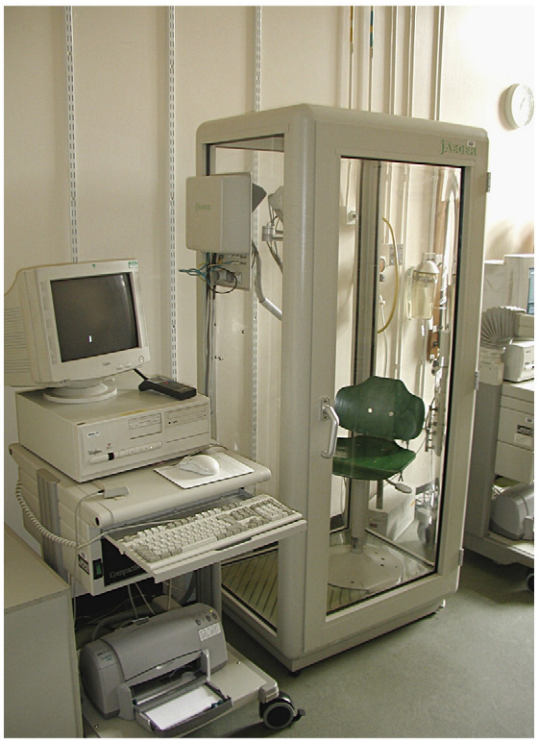

**Figure 1** Body box plethysmograph used for pre-flight testing.

level expected during flight [13]. Clearly this must be done safely in a controlled environment. The closest substitute would be sitting in a hypobaric chamber as that would reproduce both the reduction in atmospheric pressure as well as the reduction in inspired oxygen; however these chambers are not readily available in the health service. Dilliard et al. confirmed the reliability of the hypoxia inhalation test (breathing 15.1% oxygen through a mouthpiece for 15 min) comparing it to a hypobaric chamber (set at 8000 ft) both in healthy adults and adults with chronic obstructive pulmonary disease [14]. Oades et al. studied 22 children with cystic fibrosis before flights to the USA or the Alps. They found that inspiration of 15% oxygen in a hypoxia inhalation test was a better predictor of desaturation (in either the aeroplane or at 1800 m in the Alps) than spirometry or $SaO_2$ at sea level [15]. They found that spirometry and baseline $SaO_2$ tended to underestimate the desaturation risk in some patients.

Rather than wearing a facemask, which many people (particularly children) find uncomfortable, an alternative is to sit inside a sealed body plethysmograph (Fig. 1) in which the $FiO_2$ is reduced to 15% by adding nitrogen into the chamber over 5 min [16]. A pulse oximeter is used to measure the $SaO_2$ and heart rate, and the patient is observed throughout the test. $CO_2$ levels in the box do not exceed 0.5% and do not need to be monitored. If the patient is young, they can sit on their carer's lap inside the box. If the patient's $SaO_2$ drops to 85%, or below, oxygen is administered immediately and titrated until the $SaO_2$ is normal, and that informs the parents how much oxygen will be required during the flight. This is the method recommended in the British Thoracic Society (BTS) guidelines [3] and is how we currently perform the test at our centre.

Buchdahl et al. utilised this method to study 87 children aged 7–19 years with cystic fibrosis prior to intercontinental flights and compared results with in-flight pulse oximetry [17]. Ten children desaturated <90% at some point, but the pre-flight test hypoxia test predicted this in only two of them, although spirometry (forced expiratory volume in 1 s <50% predicted) was predictive in seven. Buchdahl et al. also reviewed their experience in 20 children under 5 years who had a variety of respiratory problems (and were too young to perform spirometry) [18]. The $SaO_2$ could take up to 20 min to stabilise (defined as a constant reading over 2–3 min) and baseline $SaO_2$ did not necessarily predict desaturation to <90%. Nine of the patients were ex-preterm infants (23–34 weeks gestation, median 27 weeks) and were tested aged 3–19 months (median 6 months). Eight of them had chronic neonatal lung disease (CNLD) and two were receiving supplemental oxygen over night. All nine patients desaturated, with a median $SaO_2$ of 99% dropping to a median of 92%.

Not all centres have access to a plethysmograph, therefore, the hypoxia inhalation test has also been carried out on infants using a facemask [13,19]. In a validation study, seven children aged 2–51 months (mean 10 months) had gas sampled continuously from under their nostrils whilst being administered high flow 14% $O_2$ (in nitrogen) via a facemask [19]. Although the median concentration entering the nose was 15.1%, two patients received only 13% and one received 16%. If the mask is not tight enough, room air entrainment occurs increasing the oxygen concentration delivered. The same department in Perth, Australia reported their data on 47 ex-preterm infants (23–36 weeks gestation, median 27 weeks) who had pre-flight testing at a median corrected age of 1.4 months [13]. They all had a history of neonatal lung disease, 32/47 had chronic neonatal lung disease but none were receiving supplemental oxygen. All infants had baseline $SaO_2$ >95% at sea level but despite this, 81% of the infants desaturated to less than 85% and were recommended to have supplemental oxygen on the plane. Median time for the $SaO_2$ to fall to 85% in those failing the test was 2 min. Baseline saturation did not predict outcome but age at testing was an important predictive factor with younger children more prone to significant desaturation. The authors suggested that all children with a history of neonatal lung disease and a corrected age under 3 months would require in-

**Table 1** Recent experience in pre-flight testing of ex-preterm infants aged under one year

| Gestational age (weeks) | Corrected gestational age weeks (months) | Pre-test $SaO_2$ (%) | Test minimum $SaO_2$ (%) | Result | Recommended supplemental oxygen for flight (l/min) |
|---|---|---|---|---|---|
| 28 | 28 (7) | 100 | 84 | Fail | 1.0 |
| 26 | 20 (5) | 98 | 83 | Fail | 0.5 |
| 24 | 15 (3) | 97 | 84 | Fail | 0.5 |
| 28 | 16 (4) | 99 | 81 | Fail | 0.5 |
| 35 | 20 (5) | 99 | 93 | Pass | Nil |
| 24 | 26 (6) | 94 | 84 | Fail | 1.0 |
| 26 | 28 (7) | 98 | 91 | Pass | Nil |
| 26 | 35 (8) | 97 | 91 | Pass | Nil |
| 26 | 35 (8) | 99 | 90 | Pass | Nil |
| 28 | 36 (9) | 100 | 92 | Pass | Nil |
| 28 | 16 (4) | 99 | 88 | Fail | 1.0 |
| 29 | 24 (6) | 100 | 92 | Pass | Nil |
| 30[a] | 12 (3) | 98 | 85 | Fail | 2.0 |
| 32 | 12 (3) | 98 | 95 | Pass | Nil |
| 28 | 20 (5) | 99 | 89 | Fail | 1.0 |
| 25 | 20 (5) | 96 | 80 | Fail | 1.0 |

[a] This patient also has a congenital cystic adenomatoid malformation.

flight oxygen, and that testing was indicated in all infants under 1 year corrected age. This does not necessarily apply to ex-preterm babies who had no respiratory problems.

Since this study was published, we started a new policy in the Neonatal Unit at Chelsea & Westminster Hospital whereby fitness to fly tests would be performed in all ex-preterm babies with a history of CNLD and a corrected age <1 year, whose parents were planning to fly with them. Inevitably we also tested some children with a history of neonatal ventilation but who did not reach the criteria of chronic lung disease. Over the past year, sixteen children have been tested and it was recommended that nine have supplemental oxygen for the flight (Table 1). Baseline $SaO_2$ was not predictive of the outcome.

## 6. Published guidelines

The BTS 2004 guidelines suggest that 'it is prudent to wait for one week after birth before allowing infants to fly to ensure they are healthy' [3], which is similar to the Aerospace Medical Association which suggests waiting one to two weeks after birth [1]. If an infant is oxygen-dependent (including ex-preterm babies with CNLD), and flying is imperative, the oxygen requirements should be titrated with a fitness to fly test. The BTS also suggests that if an infant has had neonatal respiratory problems, a hypoxic challenge should be considered, and they recommend the 'body box' method [16]. They recommend supplemental oxygen be given if the $SaO_2$ falls below 90%. They also recommend that ex-preterm infants who have a respiratory infection should probably not fly if they are still under the age of 6 months post-expected date of delivery. This latter recommendation is due to the increased risk of apnoeic episodes, especially with Respiratory Syncytial Virus infection [20].

The 2004 BTS recommendation that desaturating below 90% during a fitness to fly test is the cut off for who requires supplemental oxygen is not evidence-based, but an arbitrary consensus view. Indeed, in their initial 2002 guideline they took 85% as the cut off. The critical question which remains is whether it matters if the $SaO_2$ falls below 90% or even 85%. As discussed above, apart from the potential risk of ALTE [11] there seems to be little evidence to suggest that $SaO_2$ of 85–90% for a few hours is harmful. Chronic or intermittent hypoxia has been shown to adversely affect cognitive and behavioural outcomes, particularly in some children with congenital cyanotic heart disease and sleep-disordered breathing [21], but it is hard to imagine air travel itself can have a similar impact due to the relatively short periods involved.

In a recent study, a hypoxia test (14% oxygen for 20 min via a facemask) was performed in 34 healthy children and 35 children with a history of CNLD (all under 5 years old) [22]. In children under 2 years old, a cut off of 90% meant that 12/24 healthy children and 14/23 with CNLD 'failed' the test and would be recommended to have oxygen during the flight (all children older than 2 years passed). Using 85% as a cut off, only 1/24 healthy children and 6/23 with CNLD failed. This would suggest that the BTS 90% cut off is too high otherwise half of all healthy children would need extra oxygen in planes. Clearly this cannot be necessary, as there is a huge global experience showing that for many decades young children have flown without any respiratory problems.

Perhaps the compromise is to suggest that a cut off of 85% be used for mandatory supplemental oxygen, but if the child desaturated between 85 and 90%, oxygen only be given if the child has a viral cold at the time of flying. The problem with this latter recommendation is that oxygen needs to be arranged in advance, and since it cannot be predicted whether the child will have a cold, it will need to be available anyway. Certainly extra caution is necessary for long haul flights where it is inevitable the child will sleep. Short flights are likely to be less of a problem. The BTS may need to re-examine their recommended cut off in the light of a recent paper by Martin et al. [22]

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