Negative pressure in the middle ear in children after nitrous oxide anaesthesia

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A study was conducted to measure the pressure in the middle ear in healthy children, following nitrous oxide anaesthesia.

Premedication with chloral hydrate and scopolamine orally was similar in all patients and awake patients received thiopentone 4–5 mg·kg^{-1} for induction of anaesthesia. All received nitrous oxide (66 per cent) in oxygen and halothane or isoflurane as required. Exposure to nitrous oxide varied from 17–100 minutes, mean 47 minutes.

All patients developed negative pressure in one or both ears in the first day following anaesthesia. This is a higher incidence than previously reported and may be explained by the inability of children to equilibrate negative middle ear pressure via the eustachian tube.

Many children complain of difficulty hearing in the first 24 hours after nitrous oxide anaesthesia. An increase in middle ear pressure during anaesthesia with nitrous oxide has been described by many investigators.[1–5] Complications including rupture of the tympanic membrane, graft displacement, stapes displacement, haemotympanum and temporary or permanent hearing impairment, have been attributed to this increased pressure.[1,3,6,7] Several investigators have also noted development of negative middle ear pressure following the discontinuation of nitrous oxide[1,3,8] and in at least one instance rupture of the tympanic membrane was caused by the negative pressure developed.[5,9] However, systematic study of middle ear pressures has not been reported in children.

We examined the effect of nitrous oxide on middle ear pressure after anaesthesia in 22 paediatric patients who had normal healthy ears.

Key words
ANAESTHETICS, GASES: nitrous oxide; EAR: middle; ANAESTHESIA: paediatrics.

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Methods

Twenty-two paediatric patients, aged 2–17 years, mean 9.3 (SD ± 5.1) were studied. Approval had been obtained from the hospital research advisory committee and informed parental consent was given. Patients were eligible for the study if they were classified ASA physical status I or II, had no history of ear disease and were undergoing a surgical procedure not involving the ears or airway. A normal preoperative tympanogram was required for admission to the study. Using the criteria of Drake-Lee and Casey,[4] a normal tympanogram was defined as giving a characteristic sharply defined peak using an impedance audiometer, with a middle ear pressure between −100 and +25 decaPascal (daPa). Middle ear pressures were measured with a Madsen Electronics 25330 Impedance Audiometer.

The theoretical basis of impedance audiometry has been described elsewhere and its accuracy confirmed and accepted.[1,7,10] In brief, the impedance audiometer functions by forming an air-tight seal in the external auditory canal. A pure tone is emitted while the pressure in the external canal is varied stepwise from −300 daPa to +200 daPa and

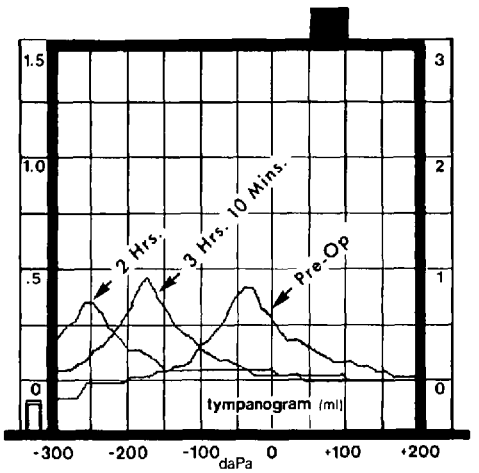

FIGURE 1 Three tympanograms from the same patient, the first preoperatively, the next two hours postoperatively and the last three hours ten minutes postoperatively. Middle ear pressure is obtained by dropping a perpendicular from the peak of the curve and the intersection on the horizontal axis indicates the pressure (daPa).

measurements of reflected sound are made at each pressure. When the pressure in the middle ear and the external auditory canal are equal, the tympanic membrane is free to vibrate. At this point of minimal impedance, the pressure in the middle ear is assumed to equal the known pressure generated in the external auditory canal. A curve is constructed by plotting impedance against pressure. Figure 1 shows tympanograms obtained preoperatively and at two hours and three hours ten minutes postoperatively. All patients were premedicated with chloral hydrate 40 $mg \cdot kg^{-1}$ and scopolamine 0.008 $mg \cdot kg^{-1}$ orally. Following induction with thiopentone (2.5 per cent) 4–5 $mg \cdot kg^{-1}$ anaesthesia was maintained with 66 per cent nitrous oxide in oxygen and halothane or isoflurane in a low concentration. Supplemental narcotics were given as required. Exposure to nitrous oxide varied from 17–100 minutes, mean 47 minutes.

Measurements were made in both ears when the patients were stable in the recovery room and repeated at 1–2 hourly intervals as their clinical course permitted. Patients who were discharged from hospital on the day of surgery were examined until the time of separation and inpatients were examined on the first and second day postoperatively.

Results

One hundred and forty-two measurements were obtained in 22 patients. Figure 2 shows pressures recorded (daPa) on the vertical scale and time (hours) on the horizontal axis.

All patients developed a negative pressure in one or both ears during the period of the study. Fourteen of the patients (64 per cent) developed a pressure lower than −200 daPa and most of these developed pressures of −300 daPa, the lower limit of the audiometer (see Table).

Discussion

An increase in middle ear pressure during nitrous oxide anaesthesia has been documented by many investigators. Reports of decreased middle ear pressures after nitrous oxide anaesthesia have also been recorded. Davis *et al.*[1] measured middle ear pressures for 50 minutes after nitrous oxide administration and found that pressures declined towards

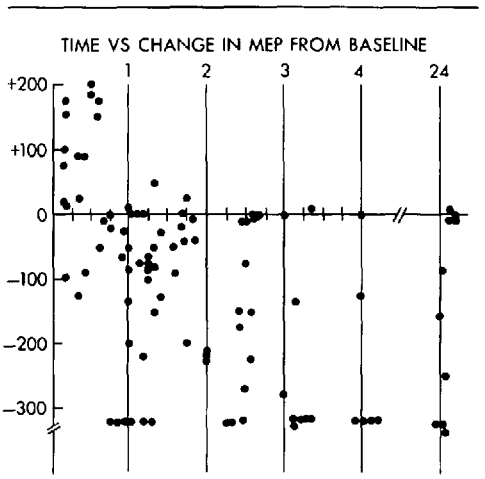

FIGURE 2 All middle ear pressure measurements are recorded. The horizontal axis is divided in hourly intervals, beginning with the discontinuation of nitrous oxide. Measurements taken between four and 48 hours postoperatively are recorded on the line marked 24 (hrs). Pressures are in daPa. Atmospheric pressure is 0 and the range of pressure is from +200 to −300 daPa. All pressures equal to or greater than 300 daPa are recorded as 300 daPa.

TABLE Results

	Maximum negative pressure reached (daPa)		*Change in pressure from baseline daPa*	
Patient	*Right ear*	*Left ear*	*Right ear*	*Left ear*
1	300	250	−320	−270
2	200	250	−180	−210
3	0	75	0	−75
4	20	40	−20	−40
5	175	200	−150	−225
6	40	10	−40	−10
7	0	10	0	−10
8	50	85	−60	−95
9	50	300	−50	−270
10	140	180	−90	−80
11	225	300	−200	−275
12	175	200	−150	−200
13	300	300	−325	−300
14	300	300	−300	−250
15	300	300	−300	−275
16	0	300	0	−300
17	300	300	−275	−275
18	300	300	−300	−300
19	50	75	−125	−150
20	250	250	−200	−220
21	0	40	−25	−65
22	300	300	−300	−300

normal preoperative values. Patterson and Bartlett[3] commented that one patient in their study developed a middle ear pressure of $-285\ mmH_2O$, 70 minutes after cessation of nitrous oxide. Perrault *et al.*[5] noted a pressure of $-450\ mmH_2O$, which caused tympanic membrane rupture, 30 minutes after discontinuing nitrous oxide.

Our results show development of low middle ear pressures, in normal paediatric patients, is much more common than may have been previously suspected. In fact all patients in our study developed middle ear pressures below atmospheric pressure in the first postoperative day.

The proposed mechanism for development of reduced middle ear pressure is as follows.[9] On induction of anaesthesia, nitrous oxide, by virtue of its greater blood solubility, enters the middle ear more rapidly than nitrogen can be removed, causing an increase in pressure. As anaesthesia continues, nitrogen-containing gas is lost from the middle ear, largely by passive venting through the eustachian tube. Investigators who have followed middle ear pressure during nitrous oxide administration have noted a characteristic saw-tooth pattern in the pressure tracing as the middle ear repeatedly vents via the eustachian tube. At the end of the anaesthetic nitrous oxide has replaced some of the nitrogen in the middle ear and the longer the time the patient is exposed to nitrous oxide the greater is the loss of nitrogen from the middle ear. With the discontinuation of the anaesthetic, nitrous oxide is removed from the middle ear more rapidly than it is replaced by air, producing a negative pressure. As the flexible walls of the eustachian tube tend to collapse inwards, they do not equilibrate sub-atmospheric pressures as readily as pressures which are above atmospheric.

The development of negative middle ear pressures may have several important sequelae. Some patients suffer severe ear pain postoperatively. One patient in our study, a 15-year-old female who had extensive spinal surgery for scoliosis, three hours postoperatively complained of pain in her right ear which was more severe than pain from the operative site. Tympanograms showed a normal curve on the left and a middle ear pressure of −280 daPa on the right. Two hours later, the patient still complained of pain and the pressure in the right ear was less than −300 daPa. The patient was able to "pop" her ear several times on the evening of surgery, with resolution of the pain and the following day tympanograms of both ears were normal. Figure 1 shows sequential tympanograms obtained from another patient who showed a typical clinical course with negative pressure developing initially and a partial resolution with time. Secondly, the negative pressures developed may be associated with impaired hearing and middle ear injury. Singh and Kirk[8] found decreased hearing acuity in nine of 20 patients who developed negative middle ear pressures 24 hours after tonsillectomy and adenoidectomy. Waun *et al.*[7] noted conductive hearing loss of two weeks' duration and serous otitis in a patient following nitrous oxide anaesthesia and commented that "entrance of serous fluid into the middle ear may be caused by relatively small degrees of negative pressure." Tympanic membrane rupture has been reported as a result of highly negative middle ear pressure.[5] Thirdly, the alteration of pressure in the middle ear may cause stimulation of the vomiting centre.[12] Alexander *et al.* reported an incidence of nausea and vomiting significantly higher in patients who received nitrous oxide

compared with isoflurane or isoflurane and fentanyl anaesthesia.[11] One patient in our study vomited during measurement of his ear pressure which would support the role of the middle ear in causing emesis.

In conclusion, we have demonstrated the development of negative middle ear pressures is a common occurrence in normal children following nitrous oxide anaesthesia. Acute ear pain and temporary hearing dysfunction may be seen in such patients. The persistence of negative middle ear pressure occurs because the eustachian tube cannot permit atmospheric equilibration when middle ear pressure becomes sub-atmospheric. Children have a high incidence of respiratory tract infection with associated eustachian tube dysfunction, and may be at an increased risk of middle ear problems following nitrous oxide anaesthesia. The wisdom of using nitrous oxide in children with a history of ear problems or recent upper respiratory tract infection may be open to question.

Further research is required to determine the relationship between negative pressures developed in the middle ear, following nitrous oxide anaesthesia and secretory otitis media. In addition, the role of this alteration in middle ear pressure and its relationship to postoperative nausea and vomiting deserves further study.

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Résumé

Nous avons procédé à une étude dans le but d'évaluer le changement de pression dans l'oreille moyenne après une anesthésie au protoxyde d'azote.

Une prémédication oralle d'hydrate de chloral et de scopolamine a été donnée à tous les patients. Les patients éveillés ont recu du thiopentone 4–5 mg·kg^{-1} à l'induction de l'anesthésie. Le protoxyde d'azote (66 pour cent) associe à l'oxygen et l'halothane ou l'isoflurane ont été administrés à tous les patients selon leurs besoins. La durée d'administration du protoxyde d'azote varie de 17 à 100 minutes, avec une moyenne de 47 minutes.

Tous les patients ont développé une pression négative dans une ou les deux oreilles durant la première journée après l'anesthésie générale. Les résultats représentent une incidence accrue qui pourraient être expliquée par le manque d'adaptation chez les enfants à équilibrer la pression négative de l'oreille moyenne via les trompes d'eustache.