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Transnasal humidified rapid-insufflation ventilatory exchange (THRIVE) in children: a randomized controlled trial†

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Abstract

Background. Transnasal humidified rapid-insufflation ventilatory exchange (THRIVE) was introduced to adult anaesthesia to improve the safety of airway management during apnoea before intubation. The objective of our study was to determine whether THRIVE safely prolongs apnoeic oxygenation in children.

Methods. This was a randomized controlled trial in 48 healthy children, with normal airways and cardiorespiratory function, in age groups 0–6 and 7–24 months, 2–5 and 6–10 yr old, presenting for elective surgery or imaging under general anaesthesia. All children were induced with sevoflurane, O_2, and N_2O, followed by muscle relaxation with rocuronium, and standardized preoxygenation with bag-and-mask ventilation. The control arm received jaw support during apnoea, whereas the THRIVE arm received jaw support during apnoea and age-specific flow rates. The primary outcome was to demonstrate that children allocated to THRIVE maintain transcutaneous haemoglobin saturation at least twice as long as the expected age-dependent apnoea time in the control group.

Results. Both study arms (each n=24) were similar in age and weight. The apnoea time was significantly shorter in the control arm: average 109.2 (95% CI 28.8) s in the control arm and 192 s in the THRIVE arm (0–6 months), 147.3 (95% CI 18.9) and 237 s (7–24 months), 190.5 (95% CI 15.3) and 320 s (2–5 yr), and 260.8 (95% CI 37.5) and 430 s (6–10 yr), respectively. Average transcutaneous haemoglobin saturation remained at 99.6% (95% CI 0.2) during THRIVE. Transcutaneous CO_2 increased to a similar extent in both arms, with 2.4 (95% CI 0.5) mm Hg min^{-1} for the control arm and 2.4 (95% CI 0.4) mm Hg min^{-1} for the THRIVE arm.

Conclusion. Transnasal humidified rapid-insufflation ventilatory exchange prolongs the safe apnoea time in healthy children but has no effect to improve CO_2 clearance.

Clinical trial registration. ACTRN12615001319561.

Key words: apnoeic oxygenation; hypoxia; nasal high flow; patient safety; preoxygenation; tracheal intubation

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Editor's key points

- Transnasal humidified rapid-insufflation ventilator (THRIVE) is effective in minimizing hypoxia after induction of apnoea in adults, but it is not clear whether or it is so in children.
- In a randomized controlled study, the authors assessed whether or not THRIVE prolonged the time to hypoxia during apnoea in children.
- THRIVE would be effective in delaying hypoxia during apnoea after induction of anaesthesia in children.

Hypoxia remains the leading cause of anaesthesia-related morbidity and mortality in children, and complications during intubation are directly related to the presence of difficult airways and the number of attempts required.[1–3] In a newly described technique, transnasal humidified rapid-insufflation ventilatory exchange (THRIVE), nasal high-flow oxygen insufflation successfully prolonged the apnoeic oxygenation time post-induction, enabling unhurried intubation in adults with expected difficult airways and cardiorespiratory compromise.[4] The onset of desaturation in apnoeic children occurs much faster than in adults and is known to be age dependent.[5] Children have a smaller functional residual capacity than adults,[6] have a greater metabolic demand, generating a higher CO_2 output,[7] and have a greater tendency for airway collapse.[8,9] Therefore, the time frame to establish a safe airway in infants and children is much shorter than in adults. A recent Australian prospective study of all emergency intubations occurring in a tertiary paediatric emergency department (ED) showed that only 78% of intubation attempts were successful at the first attempt, with 14% having an adverse desaturation event.[10] With an increasing number of intubation attempts, there is an increase in severe desaturation and significant increase in adverse events.[11,12] Prolonging the safe apnoeic oxygenation time would in theory improve outcome and reduce adverse events. The purpose of this proof-of-concept study, using a randomized controlled trial design, was to demonstrate that THRIVE prolongs the safe apnoeic oxygenation time in infants and children. Additionally, we aimed to investigate CO_2 clearance during THRIVE. We hypothesized that THRIVE allows at least twice the safe apnoeic oxygenation time compared with the control group.

Methods

Study design

This was a prospective randomized controlled trial in infants and children undergoing general anaesthesia, measuring the length of apnoeic oxygenation time using THRIVE.

Study setting

The study took place in a Department of Anaesthesia in a tertiary university teaching paediatric hospital.

Subjects

The subjects were infants and children aged up to 10 yr presenting for elective surgical or medical imaging procedures requiring general anaesthesia. Perioperative risk assessment was carried out according to a recent publication by von Ungern-Sternberg and colleagues.[13] Only children with healthy lungs, heart, and airways (no recent airway infection or history of asthma, reactive airways, or any other lung disease), ASA I or II, non-obese, with normal airway assessment (specifically, with no known upper airway obstruction, such as adenotonsillar hypertrophy), and suitable for inhalation induction were included. Eligible children for the study were screened from the daily activity of the anaesthetic department, and parents were approached for consent before surgery. The study was approved by the institutional review board (HREC/15/QRCH/158) and registered in the Australian New Zealand Trials registry (ACTRN12615001319561). A report to the ethics committee regarding safety and progress was given after 10 and then 20 children enrolled. Children were randomized 1:1 to either the THRIVE or the control arm immediately after recruitment and also stratified to age 0–6 months, 7–24 months, 2–5 yr, and 6–10 yr. Randomization was accomplished by using opaque sealed envelopes and a computer-generated sequence per age group (https://www.sealedenvelope.com).

Induction of anaesthesia and monitoring

Anaesthesia was induced by inhalation of oxygen 40%, nitrous oxide 60%, and up to 4–8% sevoflurane depending on response and age at the discretion of the anaesthetist, by conventional facemask and T-piece or semi-closed circle system. I.V. access was established and the ability to ventilate the lungs ascertained via bag-and-mask technique. Fentanyl 1 μg kg^{-1} and rocuronium 0.6 mg kg^{-1} were administered to achieve muscle relaxation. Sevoflurane and nitrous oxide were discontinued, fractional inspired O_2 was increased to 100%, and anaesthesia was maintained with a propofol i.v. infusion (with or without a bolus) at the discretion of the anaesthetist. Bag-and-mask ventilation using a PEEP of 5 cm H_2O was continued for 3 min to maintain transcutaneous haemoglobin saturation (Sp_{O_2}) 100%, aiming for expired oxygen ($P_{E'O_2}$) >90% and end-tidal carbon dioxide ($P_{E'CO_2}$) 35–45 mm Hg. Transcutaneous carbon dioxide ($tcCO_2$) monitoring (SenTec OxiVenT System, Therwil, Switzerland) was applied on the forearm and continuously monitored. Further standard monitoring included heart rate, Sp_{O_2} averaged to 5 s, and ECG.

Control arm

Children allocated to the control arm received jaw support after preoxygenation to ensure an open airway. The oxygen mask was then taken off the child's face and thus oxygen delivery discontinued. The apnoea time in the control group was defined as the time from discontinuation of assisted ventilation at end-tidal O_2 90% until a reduction in Sp_{O_2} from 100 to 92% and was recorded in seconds. Once Sp_{O_2} reached 92%, bag-and-mask ventilation in 100% oxygen was recommenced, and after Sp_{O_2} increased again to 100%, the laryngoscopy view was noted and the airway secured.

THRIVE intervention arm

Children allocated to the THRIVE intervention arm received jaw support after preoxygenation with bag-and-mask ventilation. Immediately after ceasing assisted ventilation, the age-appropriate nasal prongs were applied and weight-specific high flow rates delivered using the Optiflow THRIVE™ system (Fisher & Paykel Healthcare, Auckland, New Zealand). The flow rates applied were as follows: 0–15 kg, 2 litres kg^{-1} min^{-1}; 15–30 kg, 35 litres min^{-1}; 30–50 kg, 40 litres min^{-1}; and >50 kg, 50 litres min^{-1}. A blinding of the intervention was technically not feasible. In the intervention arm, once the apnoea time exceeded twice the published anticipated apnoea time[14] (Table 1), ventilation was resumed with bag and mask irrespective of whether the Sp_{O_2} had changed or not.