MEDDOCS Open Access Publisher

ISSN: 2637-9627

Annals of Pediatrics

Open Access | Research Article

Can the Introduction of a Preoxygenation Routine Reduce the Incidence of Desaturation During Induction in Children?

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Received: Dec 08, 2020

Accepted: Jan 26, 2021

Published Online: Jan 30, 2021

Journal: Annals of Pediatrics

Publisher: MedDocs Publishers LLC

Online edition: http://meddocsonline.org/

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Keywords: General anesthesia; Anesthesia induction; Children; Hypoxemia; Intubation; Pre-oxygenation; Patient compliance.

Abstract

Objective: Preoxygenation aims to maximize the pulmonary oxygen reserve to prolong the period of safe apnea during induction. In pediatric anesthesia, adequate preoxygenation is not always possible since young children are often reluctant to accept the face-mask. This study aimed to evaluate the effects of introducing a best-possible preoxygenation routine in a pediatric anesthesia unit.

Methods: We performed a prospective observational study of two cohorts of a total of 375 children. We analyzed the number, duration and depth of desaturation events before and after the implementation of routine preoxygenation, with special focus on patient compliance and quality.

Results: Twelve out of 190 (6.3%) vs seven out of 185 (3.8%) children had episodes of SpO_2 <90% in inductions without and with preoxygenation, respectively. Only two desaturations lasted more than 60 s. Especially toddlers tolerated preoxygenation poorly resulting in low quality.

Conclusion: Deep and prolonged desaturation during induction is rare in a pediatric anesthesia unit without cardiac surgery. The overall benefit of routine preoxygenation is still unclear in this setting.

Introduction

The rationale for preoxygenation is to reduce the risk of hypoxemia during induction. Hypoxemia develops earlier and progresses faster in pediatric patients than in adults during apnea [1]. When SpO_2 drops below 90%, hypoxemia develops rapidly because of the steep decline in PaO_2 due to the sigmoid shape of the dissociation curve of oxyhemoglobin [2-4]. Deep desaturation, when the oxygen saturation falls below 70%, increase mortality and the risk for dysrhythmias, hemodynamic adverse effects and hypoxic brain injury [5,6].

Three recent large studies have increased the awareness of respiratory events in pediatric anesthesia. A study from 2004 including data from 24 165 anesthetics showed that the incidence of perioperative respiratory adverse events was 15% in a general pediatric population and doubled in the infant population (patients aged ≤1 year) [7]. In the pan-European APRICOT study, the incidence of perioperative respiratory adverse events was 3.1% (2.9-3.3) [8]. An observational study focusing on the incidence of desaturation during induction based on electronic

Cite this article: Edfast PJ, Frykholm P. Can the Introduction of a Preoxygenation Routine Reduce the Incidence of Desaturation During Induction in Children?. Ann Pediatr. 2021; 4(1): 1052.

anesthesia records reported an 11.1% incidence in a pediatric population. In the latter study, desaturation was defined as an SpO_2 drop below 92% lasting a minimum of 3 consecutive minutes [9].

Furthermore, the role of preoxygenation in the prevention of desaturation in children is not well characterized. When our pediatric unit decided to introduce a preoxygenation routine we therefore took the opportunity to study the incidence of desaturation before and after the change of routine.

The primary aim of this study was to investigate the value of preoxygenation in pediatric anesthesia by comparing the incidence of oxyhemoglobin desaturation during induction of anesthesia in non-preoxygenated patients and preoxygenated patients. Our hypothesis was that preoxygenation decreases the risk of desaturation during induction of anesthesia in children.

Secondary objectives include the assessment of the efficacy of the best-possible preoxygenation technique preoxygenation duration and quality, compliance to the procedure (tolerability) as well as co-factors such as induction method or airway plan that could be associated with increased risk of desaturation.

Methods

This study was designed as a prospective cohort study at a tertiary center pediatric anesthesia unit. The regional ethics committee waived written informed consent since the study was an audit of a quality improvement project (Uppsala Regional Ethics Committee registration number 2018/269). All children scheduled for elective surgery under general anesthesia were eligible for the study. Exclusion criteria were age >17 years and patients with tracheostomy and face-mask only airway.

During a three-month period, elective anesthesia inductions at the pediatric surgery unit were observed and documented by at least one of the authors. The documentation included information regarding induction (Intravenous, Sevoflurane or Sevoflurane $^{+}N_2O$), airway (endotracheal tube or laryngeal mask), preoxygenation duration, quality and tolerability (if preoxygenated) and lowest measured SpO_2 during induction. The rates of desaturation at two severity levels (SpO_2 <90% and SpO_2 <80%) were determined. All observations were done from the start of preoxygenation until a definitive airway was confirmed and SpO_2 restored to > 90%. The saturation curve was continuously monitored by the observer. Transient low values when the sensor had insufficient contact, or the pulsations were unsteady in amplitude or frequency were excluded as artifacts.

During the first six weeks, preoxygenation was used infrequently according to local routine. After six weeks of data collection, the anesthesiologists were instructed to preoxygenate every patient prior to anesthetic induction for at least one minute, as effectively as they thought appropriate even if the patients were non-cooperative. The preoxygenation quality parameter recorded by the observer ranged from 0-4; 0: No preoxygenation, 1: O_2 flowing >5cm from the patient, 2: O_2 flowing <5 cm from the patient, 3: Face mask with skin contact but without response in $EtCO_2$ and 4: Tight-fitting face mask with response in $EtCO_2$. The preoxygenation tolerability parameter ranged from 0-3; 0: Not at all, verbally and physically averting, 1: Verbally averting, 2: Generally accepts the face mask, 3: Easily accepts the face mask. The anesthesia team was instructed to place the facemask as close to the face as they thought appropriate for the individual child, while not to causing undue discomfort or distress.

Measurements and equipment

Saturation was measured with the integrated pulse oximeter of the Philips IntelliVue MX800® with a Masimo RD SET DCI-P® pediatric reusable SpO_2 sensor placed on any finger. The saturation curve and numerical values were continuously observed by the researcher. Small infants and neonates were equipped with an additional pulse oximeter: Masimo Radical-7®, with a Masimo wrap-around style sensor placed around the metatarsals. The additional pulse oximeter was an extra safety measure routinely used for neonates and infants and was not used in the study unless the primary pulse oximeter had lost contact or other issues resulting in measurement errors. The primary pulse oximeter in neonates and small infants was placed on a hand, usually with a Masimo wrap-around style sensor.

Anaesthesia methods

All children are evaluated pre-operatively for cardio-pulmonary, airway and aspiration risk factors. Infants are almost never given premedication, but toddlers and pre-school children (age 1-5) are routinely given a low dose of oral midazolam, 0.3 mg kg-1, while older children only on request. All patients arrive in the operating room with at least two sites with local anesthesia cream (EMLA, Aspen Nordic). Primary mask induction with sevoflurane or intravenous induction with propofol 3 – 5 mg kg^{-1} after i.v. cannulation is according to the discretion of the attending anesthesiologist, if possible involving the child´s opinion. If i.v. induction is chosen, sevoflurane is added to deepen the anesthesia after the child has lost consciousness.

Statistical methods

The sample size was originally ascertained from an estimated incidence of desaturation during induction of anesthesia to 1%, alpha= 0,05, a small effect size (0.1) and a power of 80% which resulted in 323 subjects per cohort. Due to time limitations and an under-estimated incidence the sample size was reduced to 200 anesthetics in each cohort. All statistical analyses were performed using TIBCO Statistica™. Multivariate regression analysis was done for the variables preoxygenation, age, airway, and sex with desaturation set as the dependent variable and odds ratios were calculated.

Results

We recruited a total of 395 children for the study; 198 inductions performed without and 187 with preoxygenation, respectively. Ten patients were excluded (Figure 1). In the 190 inductions conducted without preoxygenation, 12 (6.32%) desaturations were observed. In the cohort with preoxygenated patients the corresponding number was 7/185 anesthetics (3.78%), (no significant difference). In the multivariate analysis of risk factors for desaturation, we found an influence of age (Odds ration 0,83 (95% CI 0.73-0.94)) and airway plan intubation vs LMA (OR 4.45 (95% CI 1.73-11.4), but no effect of sex or duration of preoxygenation.

All reported cases of desaturation are shown in (Table 1&2). The incidence of desaturation ≥30 s was 1.1% (2 cases) in the cohort without preoxygenation and (2.2%) (4 cases) in the preoxygenation cohort, respectively. There were 3 (1.6%) *vs*. 5 (3%) cases of deep desaturation (SpO_2<80%) in the non-preoxygenation and preoxygenation cohorts, respectively. The mean lowest measured saturation during induction was 96.1% (6.2) for the cohort without preoxygenation and 97.9% (4.8) for the cohort with preoxygenation.

Preoxygenation duration, quality and tolerability

The duration of preoxygenation was measured from the start of preoxygenation until a hypnotic drug (propofol, thiopentone or sevoflurane) was administered. The mean duration was 79.5 ± 45.5 SD seconds. The instruction was to obtain an effective preoxygenation with a duration >60 seconds, but in 39 cases (21%) preoxygenation was performed <60 seconds. The shortest preoxygenation lasted 30 seconds.

Values from the Preoxygenation Quality Parameter (PreQ) displayed in Table 3 indicate that it was possible to preoxygenate with acceptable quality in most cases (80% of the cases had a PreQ ≥3). A substantial portion (36%) of the patients aged 1-3 years were preoxygenated with oxygen flowing from a facemask <5 cm from mouth and nose, but without skin contact.

The number of children who tolerated the preoxygenation poorly (PreT ≤1) was similar in age groups <1 years and 1-3 years (52% and 48% respectively) but only 6% in age group >3 years (Table 5). Most children tolerated preoxygenation reasonably well (Table 5). Children who tolerated the preoxygenation well were older (mean age 8.93 ± 5.22) than those who tolerated the mask poorly (mean age 2.06 ± 1.96).

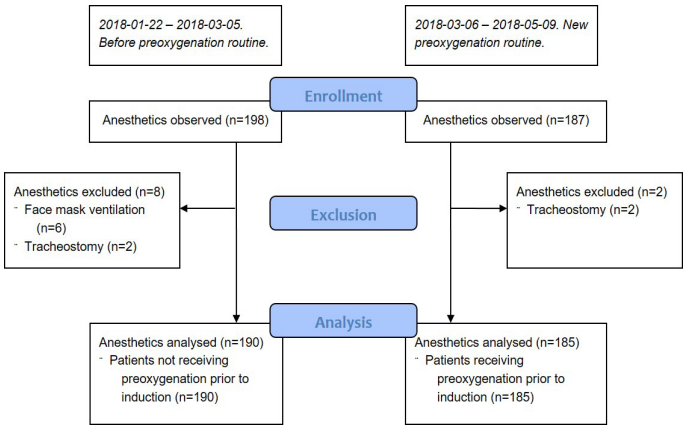

Figure 1: Consort diagram.

Table 1: Cases with desaturation in the no preoxygenation cohort.

Sex	Age (yrs)	Airway	Induction agent	SpO_2 <90 (s)	SpO_2 <80 (s)	Sat_{min}	Comments*
M	0.08	LMA	Sevo + N_2O	70	60	56	Difficult face mask ventilation. OTA.
M	0.35	TT	Sevo	15	0	83	Failed intubation. Second attempt successful.
M	0.45	TT	Sevo	5	0	88	
M	1.6	LMA	IV	5	0	89	
M	1.82	TT	Sevo	130	65	40	Video laryngoscope with introducer. Third attempt successful.
M	2.7	LMA	IV	5	0	88	
M	3.18	LMA	IV	10	5	76	
M	4.1	TT	IV	10	0	88	
F	4.11	TT	IV	10	0	82	
M	7.12	LMA	IV	10	0	86	
M	11.5	TT	IV	20	0	86	Distressed child, refused face mask during IOA.
M	13.7	LMA	IV	10	0	86	
Mean age (yrs): 4.23 ± 4.42 SD							

* In cases without comments the airway was successfully inserted at the first attempt.

Table 2: Cases with desaturation in the preoxygenation cohort. PreD – duration of preoxygenation, PreQ – quality of preoxygenation.

Sex	Age (yrs)	Airway	Induction	PreD(s)	PreQ	PreT	SpO_2 <90 (s)	SpO_2 <80 (s)	Sat_{min}	Comments
M	0.02	TT	Sevo	60	4	3	40	10	75	Intubation successful on 2nd attempt
M	0.18	TT	IV	60	2	1	10	0	88	First intubation unsuccessful. Second attempt successful using video laryngoscope.
M	0.21	TT	Sevo	180	4	0	100	60	70	Intubation successful on 2nd attempt
M	0.26	LMA	Sevo	60	3	0	15	10	64	
M	0.36	TT	IV	210	3	3	20	10	70	3 unsuccesful intubation attempts. 3rd attempt with Glidescope® successful.
F	0.88	TT	IV	140	3	1	35	10	84	Difficult face mask ventilation.
M	14.7	LMA	IV	80	4	3	30	0	82	Regurgitation. Suction, recovery position.
Mean age (yrs): 2.37 ± 5.43 SD										

* In the case without comments the airway was successfully inserted at the first attempt.

Table 3: Preoxygenation Characteristics-Duration (PreD), Quality (PreQ) and Tolerability (PreT) expressed as absolute numbers (%) of children in each pre-defined category and mean values (SD) of the duration at the bottom of the first panel.

	<1 yrs n, (%)	1-3 yrs n, (%)	>3 yrs n, (%)	Total n, (%)
30-59 s	4 (19)	6 (17)	29 (23)	39 (21)
60-119 s	6 (29)	29 (80)	68 (53)	103 (56)
120-179 s	8 (38)	1 (3)	25 (19)	34 (18)
180-239 s	2 (9)	0 (0)	5 (4)	7 (4)
> 240 s	1 (5)	0 (0)	1 (1)	2 (1)
Mean duration ± SD (s)	106.2 ± 61.2	58.9 ± 17.9	79.8 ± 45.3	79.5 ± 45.5
Quality (PreQ)				
1	1 (5)	1 (3)	4 (3)	6 (3)
2	3 (14)	13 (36)	16 (13)	32 (17)
3	10 (48)	18 (50)	49 (38)	77 (42)
4	7 (33)	4 (11)	59 (46)	70 (38)
Tolerability (PreT)				
0	8 (38)	17 (47)	2 (2)	27 (14)
1	3 (14)	1 (3)	5 (4)	9 (5)
2	4 (19)	10 (28)	21 (16)	35 (19)
3	6 (29)	8 (22)	100 (78)	114 (62)

Discussion

Despite the benefits of preoxygenation in adults, it is currently not part of the standard procedure of elective anesthetic induction in children. A survey from 2012 reported that more than 25% of French pediatric anesthesiologists declared that they do not perform preoxygenation prior to anesthetic induction in children younger than 15 years [9]. There may be two main reasons that preoxygenation in pediatric anesthesia is not as widely performed as in adults: Firstly, children have smaller functional residual capacity and an almost fourfold higher metabolic rate (Resting Metabolic Rate (RMR) is 3.1 $kcal \cdot kg^{-1} \cdot h^{-1}$ in an infant, compared to 0.86 $kcal \cdot kg^{-1} \cdot h^{-1}$ in an adult (10,11)) resulting in a higher alveolar ventilation/Functional Residual Lung Capacity (FRC) ratio which implies that children would not, despite an optimal preoxygenation, benefit from it to the same extent as adults do. Secondly, effective and optimal preoxygenation requires a tight-fitting face-mask to make up a semi-closed ventilation system where full nitrogen washout can be obtained. A tight-fitting face-mask may stress the child and make it non-cooperative or even panicking which could lead to increased heart rate and blood pressure resulting in an increased oxygen consumption (VO_2) and a traumatized patient. This study included detailed observations of anesthesia inductions before and after a switch to routine preoxygenation >60 s prior to induction. The incidence of SpO_2 <90% was 6.32% in the cohort without preoxygenation *vs*. 3.78% with preoxygenation, but the difference was not statistically significant (p>0.2).

To our knowledge, this is the first study to evaluate the actual benefits of routine preoxygenation in pediatric anesthesia. It is difficult to obtain an effective preoxygenation in children (especially aged 1-3 years) and many pediatric patients are uncooperative during induction of anesthesia; studies report that one-third of children showed a distressed behavior at induction of anesthesia and one-quarter needed physical restraint [1,12,13].

We found no difference in the incidence of brief desaturations at induction, but the lowest recorded saturation was higher in the preoxygenation cohort. Interestingly, four children that were preoxygenated desaturated (SpO_2 <90%) at least 30 s versus only two in the no preoxygenation cohort. On the contrary, deeper desaturations lasting at least 60 s including SpO_2 values less than 80% occurred in two children without preoxygenation compared with only one in the preoxygenation cohort. We could speculate that the increased oxygen reserve while not preventing short desaturation episodes had an attenuating effect on the duration of desaturation when occuring, but the numbers are too small to draw any firm conclusions based on these observations, and the clinical significance of short episodes of desaturation may be debated. In fact, none of the desaturations observed were likely to cause neurologic or other injury. The multivariate analysis of cofactors showed an increased risk of desaturation during induction of anesthesia if the patient was to be intubated with an endotracheal tube compared to laryngeal mask. This may reflect that an LMA is established more rapidly than an ETT, but also that intubated patients may have more co-morbidity. We did not, however, record patient factors such as co-morbidity or type of surgery.

The risk of desaturation decreased with age, which is already well known from earlier studies [2] but we also observed an unexpected increased incidence of desaturation for boys *vs.* girls.

A goal of this study was to evaluate if routine preoxygenation of reasonable quality would be possible and useful in clinical practice anesthesiologists preoxygenated the patients to the extent they found reasonable without forcing or intimidating them. The results regarding preoxygenation duration, quality and tolerability showed that patients in the age category 1-3 years was the group that was preoxygenated with the poorest quality. Preoxygenation quality was lowest in toddlers - thirty-nine percent were preoxygenated with a mask that was not in contact with the skin. It is difficult to explain the preoxygenation procedure to a toddler, and the instruction was to not use undue force during the preoxygenation. Preoxygenation Tolerability (PreT) is likely to be influenced by how far the individual anesthesia provider was willing to go to achieve an adequate preoxygenation. A toddler may accept a detached face mask with flowing oxygen nearby but as soon as the mask approaches the face, some children are distressed and physically or verbally avert the mask during the whole preoxygenation procedure. This fact is supported by the Quality and Tolerability data in (Table 5) indicating that preoxygenation was effective in the majority of children >3 years and poor in about half of the children in the 1-3 year age group.

Previous studies have shown a correlation between distressed pediatric patients and negative post-operative outcomes not only immediately after the operation (emergence delirium, bed-wetting, increased analgesic requirements) but also during follow-up with negative effects such as nightmares, separation anxiety, eating disorders and increased fear of physicians [14,15]. Thus it is of utmost importance to weigh the possible benefit of preoxygenation in preventing hypoxia against the risk of increased stress during induction in some children.

Limitations

None of the patients in the preoxygenation cohort could be verified to have been fully or optimally preoxygenated (i.e. EtO_2= 90%) since end-tidal oxygen concentration was not an endpoint in the present study. In a sizeable proportion of especially younger children the preoxygenation quality was low and/or theoretically too short to maximize oxygen reserve. Furthermore, since preoxygenation with FiO_2 0.8 has long been the department's routine when there is an indication for preoxygenation, and the ventilators are set at this value by default, some children in the present study may have received FiO_2 0.8 although the study protocol stipulated FiO_2 1.0. The fresh gas flow may also have varied from 5 l/min to 10 l/min. However, the focus of the study was not the effect of optimal preoxygenation, but rather the effect of introducing a "good-enough" preoxygenation routine without unduly increasing stress during induction, which we think is more clinically relevant.

A further limitation is that we did not record individual premedication. Midazolam reduces the risk of distress during induction of anesthesia [13]. We do routinely premedicate toddlers with a low dose of oral midazolam 0.3 mg per kg, but never infants and only sporadically older children. The latter practice was not changed during the study period, and therefore the use of midazolam is unlikely to have influenced the difference between the groups but does decrease generalizability to hospitals with a more restrictive policy for midazolam premedication.

Finally, there is an uneven age distribution between the cohorts; the mean age is almost a year higher in the preoxygenation cohort, which might have an impact on the incidence of desaturation since younger patients are more likely to desaturate. It might also affect the proportions of the qualitative parameters of the preoxygenation- Preoxygenation Duration (PreD), Quality (PreQ) and Tolerability (PreT) since especially patients in the age group >3 years tend to get higher scores in all parameters just mentioned.

We conclude that deep and prolonged desaturation during induction is rare in a pediatric anesthesia unit without cardiac surgery. With the limitation that we did not strive to achieve a quantitative goal of EtO_2>0.9 in every child, the benefit of routine preoxygenation is unclear in this setting. Further studies would need larger sample sizes and perhaps take measures to optimize quality and efficacy.

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