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Original Article

The Incidence of Desaturation during Anesthesia in Adult and Pediatric Patients: A Retrospective Study

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We investigated the incidence of desaturation during general anesthesia in preoperatively hypoxic (<92%), and nonhypoxic (≥92%) pediatric (n=1,090) and adult (n=5,138) patients. We plotted the patients' SpO_2 value time-courses and assessed desaturation in 6,228 patients. The crude overall incidence (95%CI) for desaturation was 11.1% (9.4-13.1) in the pediatric patients and 0.9% (0.6-1.2) in the adults. The crude incidence of desaturation in the hypoxic pediatric patients was 2.5 times the risk in the nonhypoxic patients: risk ratio (RR) 2.5 (1.8-3.5), $p<0.001$. The risk of desaturation in the hypoxic adult patients was 20.1 times the risk in the nonhypoxic adult patients: RR 20.1 (10.3-39.2), $p<0.001$. When the patients were separately stratified by American Society of Anesthesiologists Physical Status (ASA-PS) and by age, the directly adjusted risk-ratio (RRs) showed that the hypoxic pediatric patients had 1.8 and 1.6 times the risk in the nonhypoxic pediatric patients: ASA-PS adjusted RRs 1.6 (1.8-2.2), $p<0.001$; age-adjusted RRs 1.8 (1.3-2.5), $p<0.001$, and the hypoxic adult patients had 13.8 times the risk in the nonhypoxic adult patients: RRs 13.8 (6.9-27.6), $p<0.001$. A pulse-oximeter check before the start of general anesthesia could ensure timely preparation to avoid intraoperative desaturation.

Key words: desaturation incidence, pulse oximetry, general anesthesia, adult, pediatric

The prevention of desaturation is an essential component of anesthesia practice. Oxygen saturation detected by pulse oximetry is a trustworthy and cost-effective measure of the body's oxygenation [1], and it has been studied extensively using various criteria [2-9]. Factors that influence the safe delivery of anesthesia such as associated risk factors [2,3] concerning intraoperative desaturation have been revealed. A wide range of the incidence of desaturation have been reported — from 0.5% [4] to 67% [5] — but the previous studies focused mainly on healthy populations, such as those with American Society of Anesthesiologists Physical Status classification (ASA-PS) 1 and 2 [6,7], and patients who underwent elective [4,8] and non-cardiac [9] surgeries.

Although studies carried out in specific populations limit the potential confounding between studied variables and outcomes [10], the use of specific populations also limits the generalization of the study results [11]. It is thus important to understand desaturation in all patients. The speculation that desaturation is more frequent in ill patients is reasonable, and but this has been only speculation until confirmation is obtained. The

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time-course of desaturation or SpO_2 values during anesthesia induction is also not known.

The monitoring of patients by pulse oximetry has proven benefits [12-14], and it is recommended by major organizations such as the World Health Organization (WHO) [15] as a minimum standard monitoring device for anesthesia [16,17]. A pulse oximeter is also the single device mentioned in the WHO surgical safety checklist to be used before the induction of anesthesia [18]. A pulse oximeter is clearly a valuable tool in the operating theater. In terms of its application in the immediate preoperative period, it is fair to say that an acceptable pulse oximetry reading of a patient about to be anesthetized affords the anesthesia team some degree of reassurance about the patient's general well-being. In the same way, a less than acceptable reading could forewarn of potential intraoperative incidents.

Here we conducted a retrospective study of adult and pediatric patients who presented for surgery to be conducted under general anesthesia. We sought to (1) determine the incidence of desaturation in general pediatric and adult patients, (2) plot the SpO_2 timelines during the observed periods, and (3) assess any association between pre-operative low SpO_2 and the occurrence of desaturation during anesthesia. We reasoned that a low SpO_2 before general anesthesia would increase the risk for intraoperative desaturation, and we therefore hypothesized that the incidence of desaturation would be higher in preoperatively hypoxic patients compared to nonhypoxic patients.

Patients and Methods

This retrospective cohort was treated at Okayama University Hospital during the 1-year period from January 1 to December 31, 2014, after approval by the Okayama University Institutional Review Board (IRB) (approval no. 1512-002). The IRB waived the requirement for written informed consent, based on the retrospective nature of the study. All patients who received general anesthesia for any type of surgery offered at this institution were included in the study. The patients who received sedation and mask-only anesthesia, patients who underwent a surgery lasting <45 min, and patients who received only regional anesthesia were excluded from the study.

Okayama University Hospital is a teaching hospital with operating theaters equipped for common and specialized surgeries, including organ transplants. In general, when the patient arrives at the operating theater, the process begins by signing in the patient to the operating theater, confirming the patient's identity, ensuring that consent for the surgery has been obtained, and a check of the surgical procedure and site of the surgery before the start of anesthesia. Anesthetic drugs for patients ≤ 15 years old included sevoflurane 5-8%, oxygen 50-100%, propofol 3-5 mg/kg, and rocuronium 1 mg/kg, when appropriate. The anesthetic drugs given to patients >15 years old were propofol 1-2 mg/kg, either remifentanil 0.3-0.5 μg/kg/min or fentanyl 2-4 μg/kg, oxygen, and a choice of either sevoflurane or desflurane, as appropriate. A pulse oximeter (AY-920P, Nihon-Kohden, Tokyo; or Radical-7®, Masimo, Irvine, CA, USA) with specific age- and size-appropriate sensors and electronic-charting features was used during the anesthesia of all patients.

Data collection and assessment. All data for this study were extracted from a main database, which receives (from the operating theater) all monitor readings and electronic (e^-) anesthesia records during surgical anesthesia, in real time. We extracted the data with the guidance of the expert staff in charge of the e-database. For every anesthetized patient, the anesthetist enters the patient's details into the anesthesia e-database inside the operating theater before anesthesia commences. This anesthesia e-database is linked to all patient-monitoring devices, which are connected to the main database. The main database stores the average oxygen saturation (SpO_2) value detected at 1-min intervals by the pulse oximeter that is attached to the monitored patient.

Our search obtained the patients' identification number, date of procedure, sets of oxygen SpO_2 readings from the first time the SpO_2 appears on the monitor (first minute) over a period of 45 min, demographic (age, sex, body mass index [BMI] and ASA-PS) data, and the sites and duration of surgical procedures. Since a patient could have presented for surgery more than once, one recorded procedure on the database was counted as one patient; although desaturation could recur after a previous event subsided, we only counted one desaturation event from each patient.

We considered the 92% level SpO_2 value as normal SpO_2 in this study, and we also used this value as the cut-off for the classification of patients into the hypoxic

and nonhypoxic groups, due to the location of this value at the oxygen dissociation curve [19, 20].

Patient selection and outcome. We classified the patient data into the pediatric (≤ 13 years old) and adult (> 13 years old) groups. We then divided the pediatric and adult groups into 2 subgroups according to their first recorded SpO_2 % (starting SpO_2) on arrival inside the operating theater. Patients with a first recorded SpO_2 < 92% were classified as the hypoxic subgroup; patients with a first recorded SpO_2 ≥ 92% were classified as the nonhypoxic subgroup. The outcome of interest was desaturation, which was defined for the 2 (adult and pediatric) hypoxic patient subgroups as an SpO_2 decrease of ≥ 1% from the starting SpO_2 value, for a minimum of 180 sec. In the nonhypoxic patients, desaturation was defined only if a patient's SpO_2 fell to < 92% and remained below this level for a minimum of 180 sec.

Data analysis. We analyzed the patients' data using Excel 2010 (Microsoft, Redmond, CA, USA) and OpenEpi ver. 3.01 (www.openepi.com). We used Student's *t*-test to compare the means of the baseline variables age, BMI, and anesthesia time for significant variability between the hypoxic and nonhypoxic subgroups. We assessed the ASA-PS variable between the hypoxic and nonhypoxic subgroups by Wilcoxon rank test for unpaired data. We adjusted for variables proven by Student's *t*-test and Wilcoxon rank test to be significantly different between the hypoxic and nonhypoxic subgroups among the pediatric patients and the adult patients by stratifying the data to that variable.

We divided the ASA-PS classes into 2 subgroups: low-risk (ASA 1, 1E, 2, and 2E) and high-risk (ASA 3, 3E, 4, 4E, 5, and 5E). The pediatric patients were also divided by age into four subgroups: infant (0-1 year old), toddler (2-3 years old), preschooler (4-6 years old), and school age (7-13 years old). We stratified the pediatric data into ASA-PS (the 2 strata), and age (the 4 strata) separately in order to assess the individual effect of each variable on the crude risk ratio. To assess the combined effect of ASA-PS and age, we simultaneously stratified the data for them, with each of the pediatric group's two ASA-PS subgroups with the 4 age-subgroups as sub-strata, so that there were eight total strata. The adult group was stratified by ASA-PS only, so that the adult data had 2 total strata. The pediatric and adult strata were entered into OpenEpi 2 × 2 contingency tables set at 95%CI, which outputted risk-based estimates and adjusted incidence ratios with Breslow-Day tests. A p-value < 0.05 was considered significant.

We plotted the SpO_2 time course with the average SpO_2 value of all patients in each patient subgroup for

Table 1 Demographic data for the pediatric and adult patient groups

	Pediatric (≤13-year-old) group			Adult (>13-year-old) group		
Variable[1]	Hypoxic n = 269	Nonhypoxic n = 821	p[2]	Hypoxic n = 74	Nonhypoxic n = 5,064	p[2]
Age, years	1.8 (2.9)	5.1 (4.2)	< 0.001	55.2 (20.7)	57.2 (18.1)	0.33
ASA-PS EI	3 (3, 4)	2 (2, 3)	< 0.001	2 (2, 3)	2 (2, 3)	< 0.001
Em	3 (2, 3)	3 (3, 3)	0.32	2 (2, 3)	3 (3, 4)	< 0.001
BMI, (kg/m^2) Female	19.1 (4.2)	20.8 (7.2)	0.10	23.3 (6.1)	23.3 (9.8)	0.90
Male	19.4 (5.4)	21.2 (6.1)	0.09	24.3 (9.5)	22.9 (6.2)	0.30
A/Time[3] (min)	348 (312)	300 (233)	0.05	297 (232)	312 (245)	0.56
Top 3 operation sites, n (%)	Cardiac 125 (46.5%)	Head & Neck 178 (21.7%)	—	Lower abdomen 31 (41.9%)	Lower abdomen 1,078 (21.3%)	—
	Head & Neck 15 (5.6%)	Cardiac 160 (19.5%)	—	Joints 20 (27.0%)	Joints 897 (17.7%)	—
	Joints 0 (3.7%)	Joints 89 (10.8%)	—	Chest & Medias 17 (23.0%)	Head & Neck 857 (16.9%)	—

ASA-PS, American Society of Anesthesiologists-Physical Status classification; A/Time, anesthesia time; BMI, body mass index; Cardiac, cardiac-related surgeries; Chest & Medias, chest and mediastinum; EI, elective surgery; Em, emergency; Joints, hip, spine and limbs, [—]: not tested.

[1]Age, ASA-PS, BMI, and Anesthesia time are average (SD); ASA-PS includes median (IQR).

[2]By two-tailed distribution Student's *t*-test for variables (age, BMI, A/time); by two-tailed Wilcoxon test for unpaired data (ASA-PS).

[3]From the start of anesthesia induction to extubation.

each 1-minute interval of the observation period. Since a large number of patients with SpO_2 values of ≥92% would raise the average despite the presence of low SpO_2 readings (which could mask observable findings), we plotted the data of the patients who experienced desaturation separately from those of the patients who did not experience desaturation.

Results

Our data search provided 12,488 sets of patient data; 6,228 of the sets were eligible for the present analysis. Patient records that were excluded were duplicate patient records and extensive missing data records. There were 1,090 pediatric patients and 5,138 adult patients. Hypoxic (n=269) and nonhypoxic (n=821) pediatric patients were identified, and hypoxic (n=74) and nonhypoxic (n=5,064) adult patients were identified. During the operative-anesthesia period analyzed, a total of 165 patients (121 pediatric and 44 adult patients) experienced desaturation.

Table 1 summarizes the demographic data for the pediatric and adult patient groups. Between the hypoxic and nonhypoxic subgroups of pediatric patients, the patient age and ASA-PS class differed significantly. Between the hypoxic and nonhypoxic adult patients, only the ASA-PS class differed significantly. Fig. 1-4 illustrate the age and ASA-PS distribution of the pediatric and adult patients, respectively. The majority (n=708, 65%) of all pediatric patients and the majority (n=4, 254, 68%) of all adult patients were in the low-risk ASA-PS classification.

The pediatric patients. In the pediatric group, 55 patients in the hypoxic subgroup and 66 patients in the nonhypoxic subgroup experienced desaturation during the observation period. Twenty-three patients (8.6%) in the hypoxic subgroup and 60 patients (7.3%) in the nonhypoxic subgroup underwent emergency surgeries. All of the hypoxic and nonhypoxic pediatric patients who experienced a desaturation event (n=121) underwent cardiac-related surgeries.

Table 2 summarizes the characteristics of hypoxic and nonhypoxic patients who experienced desaturation. The overall incidence of desaturation in the total pediatric group was 11.1% (9.4-13.1). The crude incidence (95%CI) in the hypoxic subgroup (20.5%, 16.0-25.7) was 2.5 times higher (RR=2.5, 1.8-3.5; $p<0.001$) than the incidence in the nonhypoxic subgroup (8.0%, 6.4-10.1) during the observation period.

In the separate adjustment for ASA-PS shown in Table 3, the Breslow-Day test was undefined (p=NaN, *i.e.*, not a number), and thus we could not interpret the combined stratum-specific risk ratios with the Mantel-Haenszel (MH) method (RR_{MH}). Instead, we used the directly adjusted risk ratio (RR_s), which showed a reduction of 36% from the crude RR (ASA-PS-RR_s=1.6, 1.8-2.2, $p=0.005$). In the separate adjustment for age, the Breslow-Day test could not reject the null hypothesis that the stratum-specific risk-ratios were homogenous ($p=0.18$), and thus the MH-adjusted

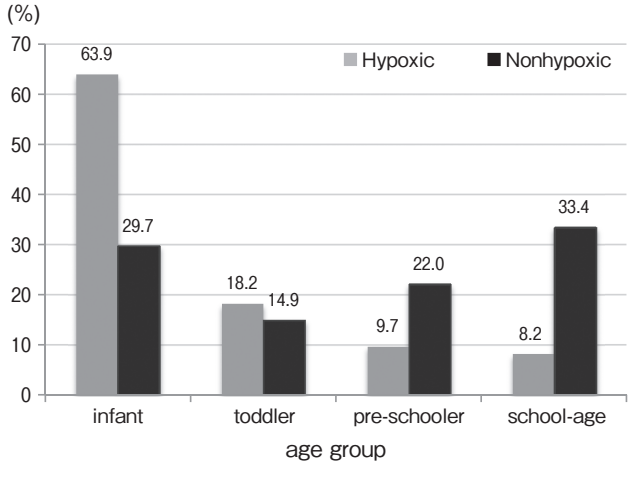

Fig. 1 The age-group distribution of the hypoxic and nonhypoxic pediatric patients. Percent of the total hypoxic patients. Percent of the total nonhypoxic patients.

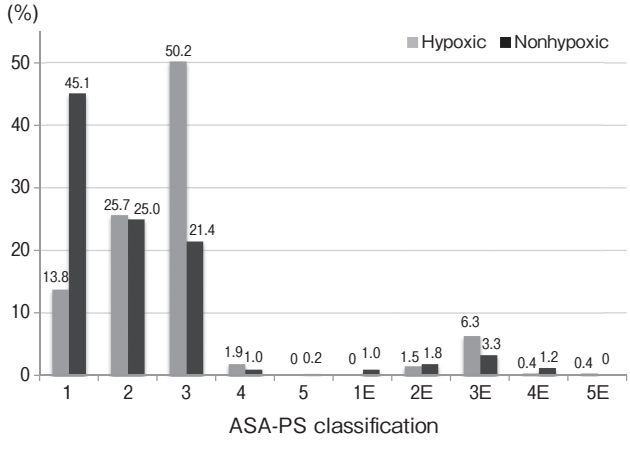

Fig. 2 The ASA-PS distribution of the hypoxic and nonhypoxic patients in the pediatric group. Percent of the total hypoxic patients. Percent of the total nonhypoxic patients.

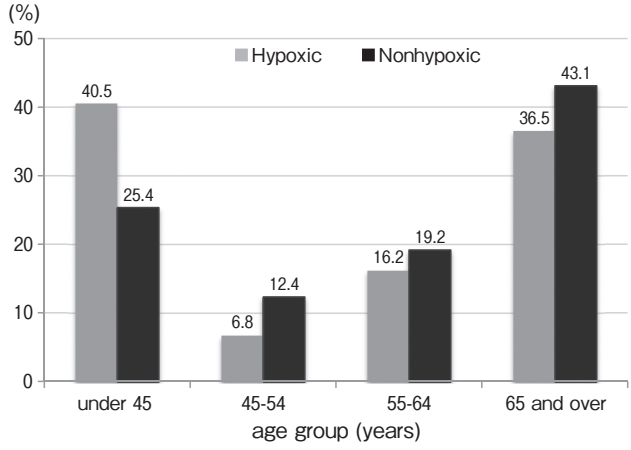

Fig. 3 The age-group distribution of the hypoxic and nonhypoxic adult patients. Percent of the total hypoxic patients. Percent of the total nonhypoxic patients.

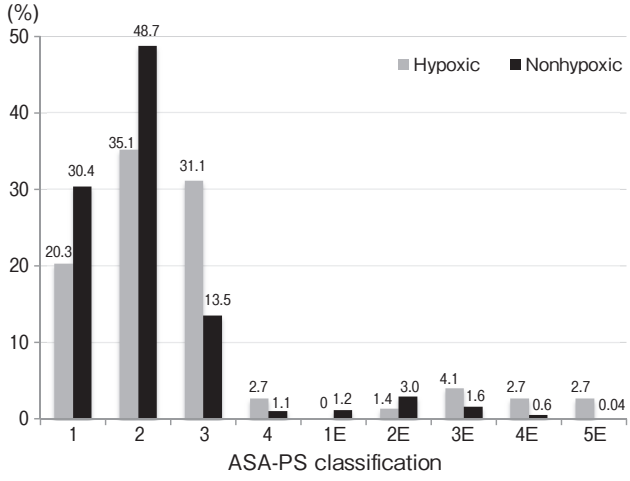

Fig. 4 The ASA-PS distribution of the hypoxic and nonhypoxic adult patients. Percent of hypoxic patients. Percent of nonhypoxic patients.

Table 2 Characteristics of the pediatric patients who experienced desaturation

	% of Total (n)	Age[1]	ASA-PS[2]
Hypoxic patients' underlying conditions:			
Total patients	100% (55)		
Cardiac catheterization[3]	32.7% (18)	3.2 (3.8)	3 (2–3)
Transposition of great arteries	23.6% (13)	1.4 (3.3)	2 (2–3)
Hypoplastic left heart syndrome	10.9% (6)	1 (1.1)	2 (2–3)
CHD for mediastinal drainage	10.9% (6)	0 (1.2)	3 (3–3)
Pulmonary hypertension sec. CHD	5.5% (3)	0 (0)	3 (2–3)
Pulmonary atresia	3.6% (2)	0 (0)	3 (3–3)
Patent ductus arteriosus	3.6% (2)	1 (0)	3 (3–3)
Cardiac valve defect	3.6% (2)	1 (0)	3 (3–3)
Tetralogy of Fallot	1.8% (1)	0	3
Aorto-pulmonary collateral arteries	1.8% (1)	4	3
Unspecified	1.8% (1)	0	3
Nonhypoxic patients' underlying conditions:			
Total patients	100% (66)		
Transposition of great arteries	16.7% (11)	3.6 (3.4)	3 (2–3)
CHD for cardiac catheterization	15.2% (10)	3.1 (2.3)	3 (3–3)
CHD for mediastinal drainage	10.6% (7)	0 (1.2)	3 (3–3E)
Ventricular septal defect (VSD)	7.6% (5)	0 (0.4)	3 (3–3)
Hypoplastic left heart syndrome	7.6% (5)	1.8 (1.3)	3 (3–3)
Patent ductus arteriosus	4.5% (3)	2.7 (2.3)	3 (3–3E)
Pulmonary hypertension sec. CHD	3.0% (2)	3.0 (4.2)	(2–4E)
Aorto-pulmonary collateral arteries	3.0% (2)	0 (0)	(2–5)
Pulmonary atresia	1.5% (1)	0	2
Aortic dissection	1.5% (1)	0	3
Atrio-ventricular septal defect	1.5% (1)	0	3
Interrupted aortic arch and VSD	1.5% (1)	0	2
TAPVR	1.5% (1)	0	3
Tetralogy of Fallot	1.5% (1)	0	3
CHD for valve replacement	1.5% (1)	2	3
CHD with pace-maker for battery replacement	1.5% (1)	7	3
CHD unspecified	19.7% (13)	2.5 (1.5)	3 (2–3)

CHD, congenital heart disease; TAPVR, total anomaly of pulmonary venous return.
[1]Data are average (SD). [2]Data are median (interquartile range). [3]Type of CHD unspecified for cardiac catheterization and mediastinal drainage.

Table 3 Pediatric group, separate stratification for ASA-PS and age

	Hypoxic		Non-hypoxic		Risk-based measures		
ASA-PS[1]	Desat /total	Incidence (95%CI)	Desat /total	Incidence (95%CI)	Risk-ratio	p^2	Overall incidence[3]
Low-risk	18/110	16.4 (10.5-24.5)	16/598	2.7 (1.6-4.3)	6.1 (3.2-11.6)	<0.001	4.8 (3.4-6.7)
High-risk	37/159	23.3 (17.3-30.5)	50/223	22.4 (17.4-28.4)	1.0 (0.7-1.5)	0.9	22.8 (18.8-27.3)
Crude	55/269	20.5 (16.0-25.7)	66/821	8.0 (6.4-10.1)	2.5 (1.8-3.5)	<0.001	11.1 (9.4-13.1)
Adjusted	Directly adjusted RR (95%CI): 1.6 (1.8-2.2); $p = 0.005$, MH-adjusted RR (95%CI): 1.6 (1.2-2.1); $p = 0.005$ Breslow-Day test for interaction of RR (chi square = 21.9); NaN						
Age, years	Desat /total	Incidence (95%CI)	Desat /total	Incidence (95%CI)	Risk-ratio	p^2	Overall incidence3
Infant	39/172	22.7 (17.0-29.5)	31/244	12.7 (9.1-17.5)	1.8 (1.2-2.7)	0.01	16.8 (13.5-20.7)
Toddler	11/49	22.5 (12.9-36.0)	19/122	15.6 (10.1-23.1)	1.4 (0.7-2.8)	0.39	17.5 (12.5-24.0)
Preschooler	2/26	7.7 (1.0-25.3)	11/181	6.1 (3.3-10.7)	1.3 (0.3-5.4)	>0.99	6.3 (3.6-10.5)
School age	3/22	13.6 (3.9-34.2)	5/274	1.8 (0.7-4.3)	7.5 (1.9-29.2)	0.03	2.7 (1.3-5.3)
Crude	55/269	20.5 (16.0-25.7)	66/821	8.0 (6.4-10.1)	2.5 (1.8-3.5)	<0.001	11.1 (9.4-13.1)
Adjusted	Directly adjusted RR: 1.8 (1.3-2.5); $p < 0.001$ MH-adjusted RR: 1.8 (1.3-2.5); $p < 0.001$ Breslow-Day test for interaction of RR (chi square = 4.841); 0.184						

Desat/total, No. of desaturation patients/total; NaN, not a number; RR, risk ratio; [1]Low risk = ASA 1, 1E, 2, 2E; High risk = ASA 3, 3E, 4, 4E, 5, 5E. [2]Two-tailed Fisher exact p-values; < 0.05 is considered significant. [3]Combined incidence of desaturation in the hypoxic and nonhypoxic patients. *Analysis on OpenEpi version 3.01.

RR (which was the same as the directly adjusted risk ratio) showed a 28% reduction from the crude RR (age-RR_S = 1.8, 1.3-2.5, $p < 0.001$).

Both the ASA-PS classification and the ages of the pediatric patients significantly confounded our pediatric crude estimate, so we simultaneously adjusted for both variables as shown in Table 4. In the simultaneous stratification, the stratum-specific risk ratios were not homogenous (Breslow-Day test p = NaN), and although an RR_{MH} was outputted (RR_{MH} = 1.5, 1.1-2.0, $p = 0.03$), we present it only to show that there was confounding with age and ASA-PS. In addition, the directly adjusted RR was undefined, and thus we present the stratum-specific risk ratios only, as shown in Table 4.

The stratum-specific risk ratios were high in the low-risk age subgroups, although only 2 strata reached statistical significance: the infant (RR = 4.2, 1.6-11.1, $p = 0.009$) and school-age (RR = 25.2, 2.4-265, $p = 0.03$) subgroups. In the high-risk toddler subgroup, being hypoxic before the start of general anesthesia showed a protective effect for desaturation during the observation period, although it did not reach statistical significance (RR = 0.8, 0.4-1.8, $p = 0.88$). The stratum-specific overall incidences of desaturation in the low-risk pediatric patients showed a descending trend, which was highest in the infant (8.4%, 5.1-13.5), toddler (7.5%, 3.7-14.4), and preschooler (4.8%, 2.3-9.4) patients and lowest in the school-age patients (1.2%, 0.2-3.5). This descending trend was not seen in the age groups of the high-risk patients, and was not seen in the separate age-adjusted stratification in Table 3.

Our comparison of the overall desaturation incidences of the age groups in the low-risk patients to that in the high-risk patients (Table 4) revealed a multiple-fold increase of the overall incidences from the low-risk to the high-risk groups. The high-risk infants' overall risk (23.1, 18.2-28.9) was a 2.8-fold increase from that in the low-risk infants; the high-risk toddlers' overall risk (33.9, 23.5-46) was a 4.5-fold increase from that is the low-risk toddlers; the high-risk preschoolers' overall risk (12.2, 4.9-26.0) was a 2.5-fold increase from that in the low-risk preschoolers, and the high-risk school-age patients' overall risk (13.2, 5.3-27.8) was an 11-fold increase from that in the low-risk school-age patients. The average (SD) duration of desaturation was 15.35 min (13.08) in the hypoxic subgroup and 15.89 min (12.04) in the nonhypoxic subgroup.

The adult patients. In the adult group, 10 patients in the hypoxic subgroup and 34 patients in the

Table 4 Pediatric group, simultaneous stratification for ASA-PS and age

		Hypoxic		Non-hypoxic		Risk-based measures		
ASA-PS[1]	Age group[2]	Desat /total	Incidence (95%CI)	Desat /total	Incidence (95%CI)	Risk-ratio	p[3]	Overall incidence[4]
Low risk	Infant	9/47	19.2 (10.2–32.8)	6/131	4.6 (1.9–9.8)	4.2 (1.6–11.1)	0.009	8.4 (5.1–13.5)
	Toddler	5/29	17.2 (7.1–35.0)	3/77	3.9 (0.9–11.3)	4.4 (1.1–17.4)	0.07	7.5 (3.7–14.4)
	Preschooler	2/15	13.3 (2.5–39.1)	6/151	4.0 (1.6–8.6)	3.4 (0.7–15.2)	0.31	4.8 (2.3–9.4)
	School age	2/19	10.5 (1.7–32.6)	1/239	0.4 (0.0–2.6)	25.2 (2.4–265)	0.03	1.2 (0.2–3.5)
High risk	Infant	30/125	24.0 (17.3–32.2)	25/113	22.1 (15.4–30.7)	1.1 (0.7–1.7)	0.85	23.1 (18.2–28.9)
	Toddler	6/20	30 (14.3–52.1)	16/45	35.6 (23.2–50.2)	0.8 (0.4–1.8)	0.88	33.9 (23.5–46)
	Preschooler	0/11	0.0 (0.0–30.0)	5/30	16.7 (6.9–34.0)	0.0	0.38	12.2 (4.9–26.0)
	School age	1/3	33.3 (5.6–79.8)	4/35	11.4 (3.9–26.6)	2.9 (0.5–18.5)	0.71	13.2 (5.3–27.8)
	Crude	55/269	20.5 (16.0–25.7)	66/821	8.0 (6.4–10.1)	2.5 (1.8–3.5)	< 0.001	11.1 (9.4–13.1)
Adjusted	Directly adjusted RR: undefined, MH-adjusted RR: 1.5 (1.1, 2.0); $p = 0.03$ Breslow-Day test for interaction of RR: (chi-square undefined); NaN							

Desat/total, No. of desaturation patients/total patients in the subgroup; NaN, not a number.
[1]Low risk ASA-PS = ASA 1, 1E, 2, 2E, High risk ASA-PS = ASA 3, 3E, 4, 4E, 5, 5E.
[2]Infant = 0–1 year old, toddler: 2–3 years old, preschooler: 4–6 years old, school age: 7–13 years old.
[3]Two-tailed Fisher exact p-values.
[4]Combined incidence of desaturation in the hypoxic and nonhypoxic patients.
*Analysis on OpenEpi version 3.01

nonhypoxic subgroup experienced desaturation during the observation period. Eight patients (10.8%) in the hypoxic subgroup and 322 patients (6.4%) in the nonhypoxic subgroup underwent emergency surgeries. Of the total hypoxic and nonhypoxic adult patients that experienced desaturation (n = 44), 27 patients underwent emergency laparotomies, brain, lung, and laryngeal tumor resections, and 17 patients underwent cardiac-related surgeries.

Table 5 summarizes the characteristics of the hypoxic and nonhypoxic adult patients who experienced desaturation. The overall incidence of desaturation in the total adult group was 0.9% (0.6-1.2). The crude incidence in the hypoxic subgroup (13.5%, 7.3-23.3) was 20.1 times (RR = 20.1, 10.3-39.2, $p < 0.001$) the crude incidence in the nonhypoxic subgroup (0.7%, 0.5-0.9) during our observation period.

When the adult data were stratified to ASA-PS as shown in Table 6, the incidence of desaturation in the low-risk hypoxic patients (4.8, 0.5-16.7)) was 10.0 times (RR = 10.0, 2.4-41.5, $p = 0.04$) the incidence in the low-risk nonhypoxic patients (0.5, 0.3-0.7). Among the high-risk patients, the incidence in the hypoxic patients (25.0, 13.0-42.3) was 15.2 times (RR = 15.2, 6.9-33.7, $p < 0.001$) the incidence in the nonhypoxic patients (1.6, 1.0-2.8). The Breslow-Day test ($p = 0.616$) was not significant, and thus the adjusted risk-ratio showed that the hypoxic adult patients had 13.8 times the risk of desaturation compared to the nonhypoxic adult patients during our observation period ($RR_{MH} = 13.8$, 6.9-27.4, $p < 0.001$). The stratum-specific overall incidence for the adult patients was 2.5% (1.6-3.8) in the high-risk patients, a 5-fold higher risk than that in the low-risk patients (0.5%, 0.3-0.8). The average (SD) duration of desaturation was 18.89 min (13.30) in the hypoxic subgroup and 6.71 min (5.46) in the nonhypoxic subgroup.

SpO_2 time-courses of the pediatric patients. The pediatric patients' average SpO_2 time-courses are illustrated in Fig. 5. Despite the low starting SpO_2, the hypoxic patients who did not experience desaturation (non-desaturation) rapidly improved from 77% to 90% in 7 min, with a small decrease but staying above 88% the remaining observation time. The hypoxic patients who experienced desaturation started around 84% with a maximum 3% brief increase and continued to maintain a value around the starting SpO_2 in the remaining observation period. The nonhypoxic patients who did not experience desaturation maintained an average of 99% saturation during the entire observation time, whereas the saturation of the nonhypoxic patients who experienced desaturation gradually dropped from 95% to 90% in 14 min, and the patients maintained an SpO_2

Table 5 Characteristics of adult patients who experienced desaturation

	% of Total (n)	Age[1]	ASA-PS[2]
Hypoxic patients' underlying conditions:			
Total patients	100% (10)		
Cardiac catheterization[3]	60 (6)	24.5 (14.8)	3 (2–3)
Atrial septal defect	20 (2)	54.0 (2.8)	(3–3E)
Aorto-pulmonary collateral artery	10 (1)	19.0	3
Mediastinal drainage[3]	10 (1)	22.0	3
Nonhypoxic patients' underlying conditions:			
Total patients	100% (34)		
Lung disease (cancer, inflammatory, COPD)	23.5 (8)	56.0 (16.8)	2 (2–2)
Atrial septal defect	14.7 (4)	56.8 (16.4)	2 (2–3)
Intra-cranial mass	5.9 (2)	36.5 (4.9)	(2–2E)
Parathyroid disease	5.9 (2)	65.5 (3.5)	(1–2)
Cardiac catheterization[3]	5.9 (2)	27.0 (15.6)	(2–3)
Pituitary disease	2.9 (1)	33.0	3
Laryngeal cancer	2.9 (1)	62.0	3
Ascending aortic aneurysm	2.9 (1)	60.0	3E
Intra-thoracic bleed	2.9 (1)	86.0	4E
Panperitonitis	2.9 (1)	73.0	3
Pancreatic cancer	2.9 (1)	79.0	2
Multiple fractures secondary to MVA	2.9 (1)	39.0	4E
Liver disease	2.9 (1)	51.0	3
Adrenal disease	2.9 (1)	65.0	3
Dysfunctional uterine bleeding	2.9 (1)	43.0	3
Ureteric tumor	2.9 (1)	74.0	2
Arthritis of knee joint	2.9 (1)	69.0	2
Unspecified	5.9 (4)	52.0 (17.0)	2 (1–3)

% of Total, % of total desaturation patients; MVA, motor vehicle accident. [1]Data are average (SD) to 1 decimal place. [2]Data are reported in median (interquartile range). [3]Unspecified CHD-type patients for cardiac catheterization and mediastinal drainage.

Table 6 Adult group, stratified by ASA-PS status

	Hypoxic		Nonhypoxic		Risk-based measures		
ASA-PS[1]	Desat /total	Incidence (95%CI)	Desat /total	Incidence (95%CI)	Risk-ratio	p^2	Overall incidence[3]
Low-risk	2/42	4.8 (0.5–16.7)	20/4,212	0.5 (0.3–0.7)	10.0 (2.4–41.5)	0.05	0.5 (0.3–0.8)
High-risk	8/32	25.0 (13.0–42.3)	14/852	1.6 (1.0–2.8)	15.2 (6.9–33.7)	<0.001	2.5 (1.6–3.8)
Crude	10/74	13.5 (7.3–23.3)	34/5,064	0.7 (0.5–0.9)	20.1 (10.3–39.2)	<0.001	0.9 (0.6–1.2)
Adjusted	Directly adjusted RR: 13.8 (6.9–27.6); $p<0.001$, MH-adjusted RR: 13.8 (6.9–27.4); $p<0.001$ Breslow-Day test for interaction of RR (chi square = 0.2518); $p=0.6158$						

Desat/total, number of desaturation patients/total. [1]Low risk = ASA 1, 1E, 2, 2E; High risk = ASA 3, 3E, 4, 4E, 5, 5E. [2]Two-tailed Fisher exact *p*-values. [3]Combined incidence of desaturation in the hypoxic and nonhypoxic patients. *Analysis on OpenEpi version 3.01.

value similar to that of the hypoxic non-desaturation patients.

SpO2 time-courses of the adult patients. The adult patients' average-SpO2 time-courses are shown in Fig. 6. The hypoxic patients who experienced desaturation started at an average SpO2 (85%) that was similar to that of the patients who did not experience desaturation. The saturation of both of these groups of patients rapidly improved to normal in 4 min; although the non-desaturation patients stayed above 92%, the satu-

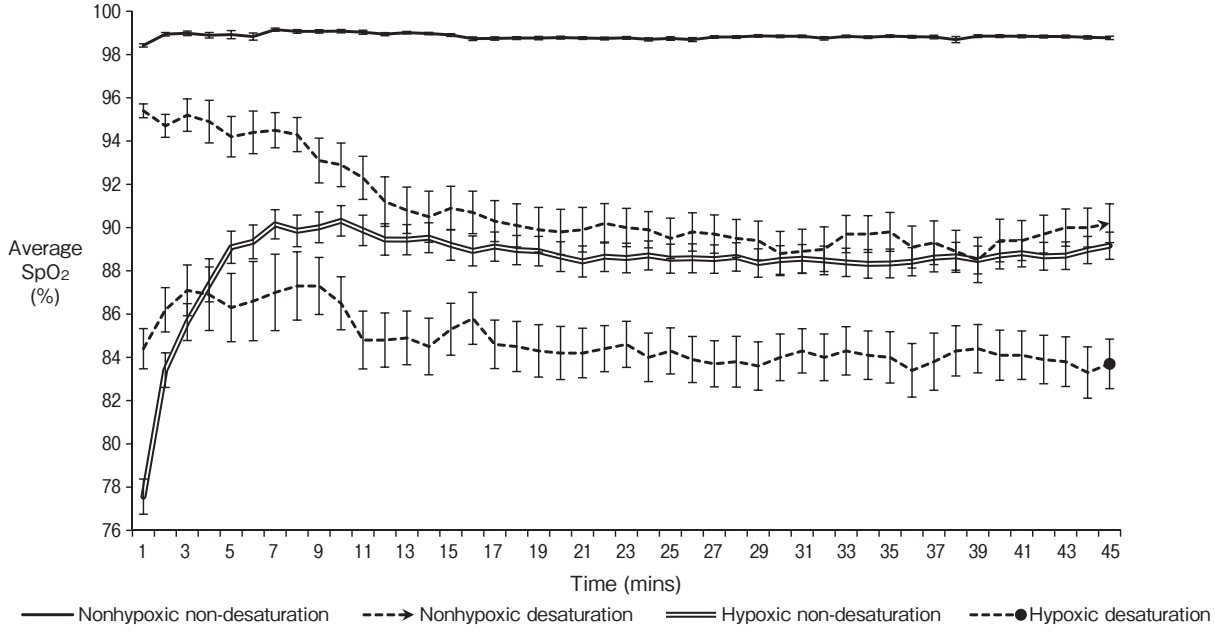

Fig. 5 The average SpO_2 time-course of the pediatric patients during the 45-min observation period. The time-courses for the hypoxic and nonhypoxic patients who experienced desaturation and those who did not (non-desaturation patients) are plotted separately. ——Nonhypoxic non-desaturation patients (n = 755), ----→ Nonhypoxic desaturation patients (n = 66), ═══ Hypoxic non-desaturation patients (n = 214), ----● Hypoxic desaturation patients (n = 55).

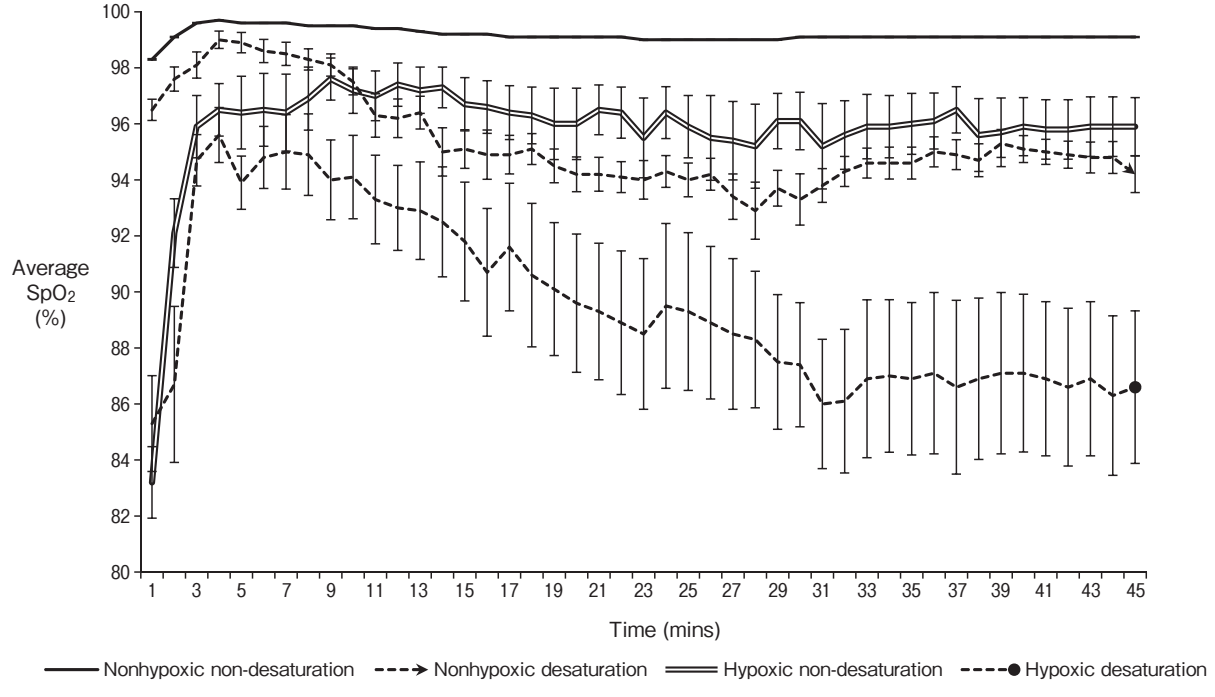

Fig. 6 The SpO_2 time-coursed of the adult patients during the 45-min observation period. The time-courses for the hypoxic and nonhypoxic patients who experienced desaturation and those who did not (non-desaturation patients) are plotted separately. ——Nonhypoxic non-desaturation patients (n = 5,030), ----→ Nonhypoxic desaturation patients (n = 34), ═══ Hypoxic non-desaturation patients (n = 64), ----● Hypoxic desaturation patients (n = 10).

ration values of the desaturation patients gradually dropped to 86% by the 31st minute. The nonhypoxic desaturation and non-desaturation patients maintained normal saturation during the entire observation period.

Discussion

Key results. Our analyses revealed that the overall incidence of desaturation was 11.1% in the adult patients and 0.9% in the pediatric patients during the first 45 min of anesthesia. During our 45-min observation period, SpO_2 time-course showed a rapid improvement in most of the hypoxic adult and hypoxic pediatric patients from their average starting level to a better or normal SpO_2. This improvement was maintained during the remainder of the observation period. Both the crude and adjusted (ASA-PS) risk ratios showed that the hypoxic adults had multiple times the risk of desaturation compared to the nonhypoxic adults (crude RR = 20.1, 16.0-25.7, $p < 0.001$; $RR_{MH} = 13.8$, 6.9-27.6, $p < 0.001$), whereas in the pediatric patients, the risk found in the hypoxic patients was only moderately elevated from that of the nonhypoxic patients: crude RR = 2.5, 1.8-3.5, $p < 0.001$; ASA-PS-adjusted $RR_S = 1.6$, 1.8-2.2, $p = 0.005$, age-adjusted $RR_S = 1.8$, 1.3-2.5, $p < 0.001$.

The simultaneous adjustment for ASA-PS and age in the pediatric patients showed an interaction between the stratum-specific risk ratios, rendering it unable to be pooled for a combined estimate. However, our examination of the stratum-specific risk ratios and overall risks (incidences) showed that the ASA-PS class confounded the risk of desaturation and also modified the risk of desaturation in the pediatric patients during the observation period.

Comparison with previous studies. The overall incidence of desaturation in our pediatric and adult patients is low among the wide reported range of desaturation incidence for adults [3,5,6] and pediatric patients [4,5,6,21]. These prior investigations were conducted in elective, healthy, and non-cardiac patients. Here we included all patients regardless of the type of surgery or ASA-PS class, as we wanted to increase the generalizability of our findings. A significant proportion of our pediatric patients were undergoing cardiac-related surgeries (46% of the hypoxic patients, 20% of the nonhypoxic patients). If we exclude these cardiac patients from our analysis, the incidence of desaturation among the pediatric patients would be zero, and thus there would be no SpO_2 time-course for the pediatric patients who experienced desaturation.

Regarding our comparison of the preoperatively hypoxic and nonhypoxic patients, we could not find any reference in the literature about a similar comparison, and thus we cannot compare our risk-ratio findings to previous studies and comment on their magnitude. However, the high risk ratio that we observed between the hypoxic and nonhypoxic adults and the low risk ratio between the hypoxic and nonhypoxic pediatric patients are noteworthy.

We plotted the average SpO_2 during the first 45 min of anesthesia, and the tracings showed that most of the hypoxic patients improved to a normal SpO_2 within the first 7 min of anesthesia induction. Although a similar SpO_2 trace had been reported in pediatric and adult groups [5], those findings were obtained during the period from admission to the post-anesthesia recovery unit and the study was carried out in healthy elective patients; thus, all SpO_2 values were trending within normal ranges, except for the infant subgroup which only had mild hypoxemia (91% SpO_2). Our present study's SpO_2 time-course demonstrated the average SpO_2 at each 1-min interval for hypoxic and nonhypoxic pediatric and adult patients and how the SpO_2 values progressed during the studied observation period. Since the majority of the desaturation or hypoxemic episodes during anesthesia occur during anesthesia induction [3,9], we propose that our SpO_2 time-course findings are relevant in managing desaturation.

Interpretation. The crude estimates in our analysis showed that the preoperative hypoxic patients had a higher risk of experiencing desaturation during our 45-min observation period compared to the nonhypoxic patients. In the pediatric group, the separate stratifications for ASA-PS and age revealed that both ASA-PS and age confounded the relationship between being preoperatively hypoxic and desaturation during the observation period to varying degrees: ASA-PS $RR_S = 1.6$, 1.8-2.2 versus age $RR_S = 1.8$, 1.3-2.5 versus crude RR = 2.5, 1.8-3.5. Although the simultaneous stratification showed non-homogenous risk ratios that could not be pooled, it enabled us to examine the combined effect of ASA-PS and age on desaturation in each stratum, as detailed in Table 4.

In the low-risk (*i.e.*, ASA 1,1E,2,2E) pediatric patients, despite their varying absolute RR values, the

stratum-specific RRs are homogenous, and the descending trend seen in the hypoxic patients' incidences, and overall incidences, in the age groups of these low-risk pediatric patients shows the expected correlation between age and desaturation risks in pediatric patients that is consistent with the literature [4, 8]. In contrast, the stratum-specific RRs are not homogenous in the high-risk (*i.e.*, ASA 3, 3E, 4, 4E, 5, 5E) pediatric patients, and the descending trend observed in the overall incidences of the low-risk patients is also not present. The descending trend is also not present in the age-only stratification in Table 3. These findings led us to suspect that the ASA-PS class has a modifying effect on the risks of desaturation [22]. This point is further supported when we compare the overall risks in the age groups of the low-risk and high-risk patients: the stratum-specific overall incidences of the low-risk patients were multiple-fold increased in the high-risk patients.

Among the adult patients, hypoxic adult patients had a 13.8-fold higher risk of desaturation compared to the nonhypoxic adult patients, and the 5-fold higher overall incidence in the high-risk patients supports the suspicion that the ASA-PS class increases the risk for desaturation by several-fold. The significance of these risks may differ between high- and low-income operating theater settings; it could have a significant impact in low-resource operating theaters where there are frequent encounters with preoperatively hypoxic patients presenting for surgery to be carried out by non-physician anesthetic practitioners, as is sometimes the case in district hospitals or in low-and middle-income countries' settings [23, 24].

Several points regarding the SpO_2 time-course should be considered. In our studied population, the SpO_2 of the adult hypoxic non-desaturation patients who made up the majority of this subgroup (n = 64, 86%) rapidly improved from an average baseline 83% SpO_2 and stayed at an average of ≥ 95% throughout the remainder of the observation period. This suggests that the majority of adult patients with an SpO_2 < 92% before anesthesia induction are likely to rapidly improve to normal SpO_2 levels and maintain those levels.

Our study may lack generalizability with regard to different geographical regions, and pulse-oximetry studies are also lacking in many regions [25]. Such regions are likely to be where pulse-oximetry findings may be the most applicable. It may thus be appropriate to use our SpO_2 time-course data to forewarn the likely occurrence of desaturation in anesthetized patients. A lack of oxygen is a problem in the surgical settings in many low-income countries [1]. Being aware of both the risk of desaturation in preoperative nonhypoxic and hypoxic patients and the likely SpO_2 time-course that patients may experience will help anesthesia providers estimate the perioperative oxygen utilization.

Limitations. This study has several limitations to consider when interpreting our findings. First, as is true for retrospective studies, we can only discuss associations between preoperative hypoxia and desaturation, and we cannot state with confidence the cause of the desaturation. It was also not possible to collect all potential confounding factors for desaturation, and thus we could not control for these factors in our statistical analyses.

Second, as is common with storage databases [26], the data we collected from our hospital's database were limited to what had been inputted, and we could not confirm the accurate classification of true hypoxic and true nonhypoxic patients to the appropriate subgroup based on the method we used to classify the patients. This was due to our inability to collect the data of the underlying diseases and complications of each patient to assess what contributed to their being in a pre-operative hypoxic condition. If we had been able to assess the lung function test results of each patient and correlate them with their starting SpO_2 values, we could have more accurately classified our patients.

Third, we could not confirm the exact starting time of anesthesia induction. Fourth, despite the reported low occurrence of artefact SpO_2 [3], we were unable to differentiate the presence of low artefact SpO_2 from truly low SpO_2. Fifth, there was only a small number of hypoxic adult patients within the 1-year data collection period compared to nonhypoxic adult patients, and this imbalance in patient numbers contributed to the wide margin of error for the adult patient estimates. Taking all our limitations into consideration, we suggest that a prospective study of the same nature should be conducted.

In conclusion, our analyses revealed an association between preoperative hypoxic SpO_2 and desaturation during the 45-min observation period that was of large magnitude in adult patients and small magnitude in pediatric patients. The association seemed to be modified by the ASA-PS status of the patients. Paying attention to high ASA-PS status patients and attaching the

pulse oximeter probe to check the patients' oxygen saturation is recommended, and re-emphasized as doing so could help estimate the patients' desaturation risk and safely prepare for it preoperatively before anesthesia is initiated.

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