Can Assessment for Obstructive Sleep Apnea Help Predict Postadenotonsillectomy Respiratory Complications?

Kerryn Wilson, M.D., Indrani Lakheeram, M.D.,† Angie Morielli, R.P.S.G.T.,‡ Robert Brouillette, M.D.,§ Karen Brown, M.D.‖*

Background: The aim of this study was to determine the frequency and type of respiratory complications after adenotonsillectomy in children. A second aim was to assess the ability of preoperative sleep studies to identify children at risk for respiratory complications.

Methods: Children referred for sleep studies between 1992 and 1998, who underwent adenotonsillectomy within 6 months of the preoperative study, were reviewed. The study focused on two variables: the obstructive apnea and hypopnea index and the oxygen saturation nadir. Medical charts were reviewed for postoperative respiratory complications.

Results: Three hundred forty-nine children were referred for sleep studies, and 163 met the inclusion criteria. Thirty-four children (21%) had postoperative respiratory complications requiring a medical intervention. Children experiencing respiratory complications were younger (aged < 2 yr; adjusted odds ratio, 4.3; 95% confidence interval, 1.7–11) and had an associated medical condition (odds ratio, 3; 95% confidence interval, 1.4–6.5). A preoperative obstructive apnea and hypopnea index of 5 or more events per hour increased the chance of postoperative respiratory complications (odds ratio, 7.2; 95% confidence interval, 2.7–19.3), as did a preoperative oxygen saturation nadir of 80% or less (odds ratio, 6.4; 95% confidence interval, 2.8–14.5). A preoperative oxygen saturation nadir of 80% or less had a likelihood ratio of 3.1, increasing the probability of postoperative respiratory complications from 20 to 50%.

Conclusions: The data suggest, but do not prove, that preoperative nocturnal oximetry could be a useful preoperative test to identify children who are at increased risk for postoperative respiratory complications.

OBSTRUCTIVE sleep apnea syndrome (OSAS) has become an important indication for adenotonsillectomy in children.[1] The clinical presentation of OSAS in children includes behavioral and neurocognitive disorders, poor school performance, enuresis, headaches, and cardiovascular sequelae, including systemic and pulmonary hypertension.[2–5] History alone does not distinguish OSAS from

---

This article is featured in "This Month in Anesthesiology." Please see this issue of ANESTHESIOLOGY, page 5A.

---

* Clinical Fellow, † Resident, ‖ Associate Professor, Department of Anaesthesia, § Associate Professor, Department of Paediatrics, ‡ Chief Sleep Laboratory Technician, Sleep Laboratory.

Address correspondence to Dr. Brown: Montreal Children's Hospital, Department of Anaesthesia, 2300 Tupper Street, Room C-1117, Montreal, Quebec H3H 1P3, Canada. Address electronic mail to: maria.distefano@muhc.mcgill.ca. Reprints will not be available from the authors. Individual article reprints may be purchased through the Journal Web site, www.anesthesiology.org.

simple snoring and agrees with a polysomnographic diagnosis of OSAS in only 30–50% of children.[6–8] Thus, the diagnosis of OSAS is supported by polysomnography documenting recurrent complete or partial airway obstruction during sleep, episodic hypoxia and hypercapnia, arousals from sleep, and sleep fragmentation.[4,9] The prohibitive cost of polysomnography (quoted at $600–$2800 US)[6] has limited systematic study of the impact of pediatric OSAS on the anesthetic management of children undergoing adenotonsillectomy.

Although numerous studies have shown that adenotonsillectomy reverses the symptomatology associated with pediatric OSAS,[3,4,10] children with OSAS are at risk for respiratory complications in the immediate period after adenotonsillectomy.[11–14] Two recent reviews reported an increased respiratory morbidity in children with OSAS[11,13] who were monitored after adenotonsillectomy in an intensive care unit (ICU) setting. However, in many clinical practices, such children are usually observed postoperatively in a recovery room.

The Montreal Children's Hospital has an active ear, nose, and throat service that performed an average of 745 adenotonsillectomies annually for the years studied. As a referral center for children with sleep-disordered breathing, we sought to characterize the severity of the respiratory complications in a series of children who underwent sleep studies before adenotonsillectomy. We also determined which variables from a sleep study identified children with OSAS who will experience postoperative respiratory complications.

Materials and Methods

The study was approved by the McGill University Health Centre/Montreal Children's Hospital (Montreal, Quebec, Canada). The study was a retrospective chart review, and written informed consent was not required. Children were identified from the database of the Sleep Laboratory at the Montreal Children's Hospital, comprising 349 children referred for sleep studies between April 1992 and October 1998. The children had been referred by several different specialists, including otolaryngologists, pediatricians, pulmonologists, and neurologists for investigation of sleep-disordered breathing. The children were included and the medical charts reviewed if the children received adenotonsillectomy within a 6-month window after the sleep study. Patients were excluded if they had concomitant surgical procedures other than myringotomy and tubes.

313

The Sleep Study

Children were assessed with either laboratory or home polysomnography, and details of both recording systems have been published elsewhere.[15–18] A home study is a simplified or abbreviated laboratory study. Unlike a laboratory study, a home study does not include a recording of the electroencephalogram, submental electromyogram, or electrooculogram. Both record the cardiorespiratory signals of ribcage and abdomen, and toe or finger plethysmography and saturation, in addition to a video recording. Henceforth both the laboratory and home sleep studies will be referred to as a cardiorespiratory sleep study (CRSS).

We previously documented that our home CRSS provides equivalent assessments of apnea, hypopnea, sleep–wake state, and arousals to that of polysomnography.[18,19] Therefore, sleep–wake state for the laboratory CRSS was determined from the electroencephalogram and for the home CRSS from the cardiorespiratory recordings. Both the laboratory and home CRSS included an oximetry trend study (TREND O_2) that consisted of a printout of the record from a Nellcor N200 oximeter (Nellcor, Pleasanton, CA) used in the fast response Mode 2.

The CRSS record was analyzed for several variables, including the apnea and hypopnea (OAH) index, mean and minimum nocturnal saturation, desaturation index, percent time less than 90% saturation ($T_{<90\%}$), mean heart rate, mean respiratory rate, and the respiratory movement–arousal index. We report four of these parameters: the OAH index, oxygen saturation (Sao_2) nadir, the desaturation index, and $T_{<90\%}$. The OAH index was defined as the number of respiratory events (*i.e.*, apnea and hypopnea) per hour of sleep. Apnea was defined as an 80% or greater decrease in respiratory amplitude, for one or more breaths, on the respiratory inductive plethysmographic summation channel (ribcage plus abdomen). Hypopnea was defined as a 50–80% decrease in the amplitude of the summation channel associated with a decrease in the Sao_2 of 4% or greater. For categorical statistics, the severity of sleep-disordered breathing was classified as normal, mild, moderate, or severe if the OAH index was less than 1, 1–2.9, 3–4.9, or 5 or more events per hour, respectively. As will become evident, the CRSS saturation parameters were of particular interest, and several parameters of the saturation were assessed. The Sao_2 nadir was defined as the minimum oxygen saturation, regardless of duration, occurring during the sleep. The desaturation index was the number of desaturations, defined by a greater than 4% decrease in saturation per hour of sleep. The $T_{<90\%}$ was defined as the percent time with a saturation less than 90%.

Medical Chart Review

Pertinent history and operative and postoperative information were recorded by a pediatric anesthesiologist (K. Wilson and I. Lakheeram). Possible risk factors that might have contributed to postoperative respiratory complications included gender, age, preoperative medical status, anesthetic technique, opioid administration, surgical technique, and duration of surgery.

The postoperative period began on admission to the recovery room and ended with discharge from hospital. It is our routine to extubate children in the operating room. In fact, no intubated child may be admitted to our recovery room. Once admitted to the recovery room, it is our routine to administer prophylactic oxygen by a mask placed near the face in all children. All children are monitored with a Nellcor N200 pulse oximeter until they are awake and for 30 min after opioid administration. During the 6-yr study period, we had no set policy on discharge criteria from the recovery room for children with a diagnosis of OSAS. However, a discharge criteria from the recovery room was documentation of an "awake" room air saturation greater than 95%.

Postoperative events of interest were identified from the chart records and included both respiratory complications and medical interventions. The respiratory complications were classified as *desaturation*, defined as a recorded oxygen saturation less than 95%, and *airway obstruction*, categorized as (1) obstructive apneas, identified in the chart record by such words as "stopped breathing" or "apnea," and (2) obstructive apneas with desaturation less than 95%. Medical interventions were classified as oxygen administration for longer than usual, a requirement for the jaw thrust maneuver, use of an artificial airway or reintubation, and positive pressure ventilation. Because of the limitations of a retrospective review, we were not able to report with confidence the exact time in the postoperative period at which the complication–intervention occurred, but we did identify whether the complication–intervention occurred in the recovery room or on the ward. Likewise, we were not able to ascertain the rationale for overnight admission to the recovery room *versus* a ward because bed and nursing availability probably had a major impact on these decisions.

The children were divided into two groups based on the requirement for medical interventions: those who required postoperative medical interventions (INT group) and those who did not (non-INT group). Complications occurring intraoperatively, *i.e.*, before the child left the operating room, while recorded, did not influence the grouping criteria. The INT group was further subdivided into those requiring minor and major interventions (INT_{minor} and INT_{major}). Minor interventions included oxygen therapy beyond usual period (identified from the chart record by a notation that oxygen was still required) or airway instrumentation with an oropharyngeal–nasopharyngeal airway. Major interventions included ventilation with a bag and mask, administration of continuous positive airway pressure, intubation, or admission to the ICU. Given the nature of a retrospective

review, it was not possible to validate the appropriateness and efficacy of medical interventions, particularly the "elective" ICU admissions.

Statistical Analysis

Medical and CRSS variables were analyzed using SPSS (Version 10; SPSS Inc., Chicago, IL). Qualitative data are presented as proportions and continuous variables as mean ± SD. Continuous variables for the main outcome parameters, the OAH index and the Sao_2 nadir, are presented as proportions, mean ± SD, and 95% confidence intervals (CIs).

The main outcome was the requirement for postoperative medical intervention. Potential risk factors for postoperative interventions were age, gender, weight percentile, preoperative medical status, opioid administration, and CRSS parameters, including the OAH index and Sao_2 nadir. Associations were tested by chi-square statistics, and the corresponding Mantel Haenszel odds ratios were estimated.

One-way analysis of variance was used for the non-INT and INT groups to determine whether significant differences occurred among the preoperative CRSS variables of the OAH index, the desaturation index, the Sao_2 nadir, and the $T_{<90\%}$. The Tukey modification of the t test for multiple comparisons (three) was then used. $P < 0.05$ was considered significant.

A multivariate logistic regression analysis was then performed to select a model based on effect sizes, confounding effects, and the Akaike information criterion. This criterion adjusts standard significance tests for the number of terms in the model such that when choosing between models with similar statistical properties, the Akaike information criterion favors the model with fewer parameters. The Hosmer and Lemeshow test was used to evaluate the goodness of fit of the model.[20] $P < 0.05$ was considered significant.

The four risk variables (age, medical condition, Sao_2 nadir, and OAH index) identified as risk factors by univariate analysis (see Results) were used in a stepwise logistic multiple regression to assess risk models for the outcome of interest, namely, the need for postoperative intervention. Data were stratified and recoded such that age risk = age less than 2 yr, medical risk = the presence of an associated medical condition, saturation risk = Sao_2 nadir 80% or less, and apnea risk = OAH index of 5 or more events per hour. Two models were assessed and compared: (1) age, medical and saturation risk; and (2) age, medical, and apnea risk. In addition, the effect of sequentially adding an assessment of saturation risk and apnea risk on the risk model for outcome was assessed for three models: (1) age and medical risk; (2) age, medical, and saturation risk; and (3) age, medical, saturation, and apnea risk.

Results

Between October 1992 and April 1998, 349 children were referred for CRSS, 163 of whom met the inclusion criteria. The remaining 186 children were excluded because they had not undergone adenotonsillectomy within a 6-month period after CRSS (n = 184) or had concomitant surgery (n = 2). The referral pattern to our sleep laboratory includes children with complex medical problems, including myelodysplasia, developmental delay, and achondroplasia, for whom adenotonsillectomy may not be indicated. Both children excluded for concomitant surgery had Crouzon syndrome, and the surgeries were cranioplasty and orbital bar advancement. One hundred forty-three children underwent adenotonsillectomy, 14 underwent adenoidectomy alone, and 6 underwent tonsillectomy alone (table 1). The various surgical procedures are henceforth referred to as adenotonsillectomy.

Anthropometric data are presented in table 1. Twenty-one percent (n = 34) experienced postoperative respiratory complications requiring medical intervention (group INT); 24 of these children required a minor intervention, and 10 required a major intervention. (Three children experienced postextubation laryngospasm in the operating room. One child had no complications in the postoperative period and was assigned to the non-INT group. Two children required supplemental oxygen beyond the usual period in the recovery room and were assigned to the INT_{minor} group.)

Postoperative respiratory complications included desaturation (n = 33) and airway obstruction (n = 10). Both of these complications required medical intervention: oxygen therapy (n = 34), positive pressure ventilation (n = 6), continuous positive airway pressure (n = 2), a nasopharyngeal airway (n = 1), or reintubation (n = 1). One hundred fifty-eight children were admitted to the recovery room, and a breakdown of their respiratory complications and medical interventions are shown in table 2. Ninety-five children were admitted to the ward before discharge home, and 14 respiratory complications occurred (table 3). All children who required medical intervention on the ward had also required medical intervention in the recovery room. Six children were admitted to the ICU after adenotonsillectomy (table 4). Patients no. 5 and 7 (table 4) were admitted to the ICU preoperatively after a very abnormal overnight laboratory CRSS.

Minor Intervention Group

Fourteen children (58%) in the INT_{minor} group had a preoperative Sao_2 nadir of 80% or less. All patients in the INT_{minor} group experienced postoperative oxygen desaturation, and the postoperative saturation nadir was 88.9 ± 4.0%. All children were given supplemental oxygen. Further data are presented in tables 1, 2, and 5.

Table 1. Demographic Data

	nonINT	INT	INT$_{minor}$	INT$_{major}$
Number of Children	129	34	24	10
Gender (F, M)	(52, 77)	(13, 21)	(8, 16)	(5, 5)
Age (yr)	4.8 ± 2.9	4.4 ± 3.3	4.3 ± 3.3	4.5 ± 3.8
Coexistant Medical Condition				
# (%)	27 (20.9)	15 (44.1)	11 (45.8)	4 (40.0)
Surgery				
Procedure				
Tonsillectomy	5	1	1	0
Adenoidectomy	10	4	3	1
T and A	114	29	20	9
Duration (min)	46.3 ± 12.4	49.4 ± 12.4	47.8 ± 12.3	52.2 ± 12.0
Opioid Administration				
Intraoperative				
# (%)	109 (84.5)	30 (88.2)	22 (91.7)	8 (80.0)
First 2 hr post-op				
# (%)	110 (85.3)	24 (70.6)	18 (75.0)	7 (70.0)
Children receiving no opioids during surgery and in first 2 hr post-op				
# (%)	5 (3.9%)	2 (5.9%)	1 (4.2%)	1 (10.0%)

Demographic data for children in Groups nonINT and INT. Children requiring medical intervention (Group INT) have been grouped into 2 subgroups: those requiring minor interventions (INT$_{minor}$) and those requiring major interventions (INT$_{major}$). See text for a definition of minor and major interventions. Continuous variables presented mean ± SD; Qualitative data presented as # (%).

INT = intervention.

Major Intervention Group

Five children (50%) in the INT$_{major}$ group had a preoperative Sa$_{O_2}$ nadir of 80% or less. Six children were admitted to the ICU postoperatively, one nonelectively and five electively (table 4). The case scenarios of these six children are as follows. The nonelective ICU admission was a 1-yr-old girl with developmental delay who had severe OSAS on preoperative CRSS. Postoperatively she desaturated (< 80%) and required an unplanned admission to ICU for oxygen therapy and monitoring. Of the five planned admissions to ICU, four required additional interventions. Patient no. 2 required preoperative intubation because of severe OSAS and remained intubated for 7 h postoperatively. After extubation, he required nasal continuous positive airway pressure for an additional 4 days. Patient no. 3 was admitted to the ICU extubated but had continued upper airway obstruction and desaturated (< 70%) repeatedly. She required a nasopharyngeal airway and continuous positive airway pressure for 2 days before discharge on postoperative day 11. Patient no. 4 was admitted to the ICU extubated but needed reintubation 3 h postoperatively for 7 h, for relief of persistent upper airway obstruction. He was discharged home on postoperative day 3. Patient no. 5

Table 2. Postoperative Respiratory Complications Occurring in the Recovery Room

	nonINT (n = 129)	INT (n = 29)	INT$_{minor}$ (n = 24)	INT$_{major}$ (n = 5)
Complications				
Desaturation < 95% (#)	4	24	19	5
Desaturation < 90% (#)	0	18	12	5
Desaturation minimum	90%	69%	85%	69%
Airway obstruction (#) obstructive apnea	—	1	1	—
Obstructive apnea + desaturation	—	7	2	5
Interventions (#)				
Oxygen longer than usual	0	24	19	5
Jaw thrust maneuver	0	7	2	5
Artificial airway	0	0	0	0
Reintubation	0	0	0	0
Ventilation	0	5	0	5
Transfer to ICU		1		1*

Postoperative respiratory complications and medical interventions occurring in the 158 children admitted to the recovery room in the nonINT and INT groups. Children requiring medical intervention (Group INT) have been grouped into 2 subgroups: those requiring minor interventions (INT$_{minor}$) and those requiring major interventions (INT$_{major}$). See text for a definition of minor and major interventions. The patient * is patient 1 in Table 4.

INT = intervention; ICU = intensive care unit.

Table 3. Postoperative Respiratory Complications and Medical Interventions Occurring on the Ward

	nonINT (n = 72)	INT (n = 23)	INT$_{minor}$ (n = 17)	INT$_{major}$ (n = 6)
Complications				
Desaturation < 95% (#)	4	7	5	2
Desaturation < 90% (#)	1	5	4	1
Desaturation minimum	85%	77%	81%	77%
Airway obstruction (#)				
obstructive apnea	—	1		1
Obstructive apnea + desaturation	—	1	—	1
Interventions (#)				
Oxygen	—	6	5	1
Artificial airway	—	1	—	1
Ventilation	—	0	0	1

Postoperative respiratory complications and medical interventions occurring in the 95 children admitted to the ward in the non-INT and INT groups. Children requiring medical intervention (Group INT) have been grouped into 2 subgroups: those requiring minor interventions (INT$_{minor}$) and those requiring major interventions (INT$_{major}$). See text for a definition of minor and major interventions.

INT = intervention.

was a 2-yr-old girl who had been in the ICU preoperatively for monitoring because of severe OSAS. She was a planned admission to the ICU postoperatively and required supplemental oxygen for a mild desaturation (90%). Patient no. 7 had been monitored preoperatively in the ICU for severe OSAS but postoperatively was admitted to the recovery room, where he had an episode of desaturation less than 80% and needed ventilation with bag and mask and 100% oxygen. He remained in the recovery room overnight before discharge to the ward, where there were no further problems. Patients no. 8–10 recovered in the recovery room. All had episodes of oxygen desaturation (69–85%) and airway ob-

struction requiring oxygen therapy and ventilation with bag and mask.

Predictors of Postoperative Complications– Interventions

Gender, surgical technique, surgery type, duration of anesthesia, anesthetic technique, and opioid administration did not statistically differ between the non-INT and INT groups. Anesthetic technique was variable during the 6-yr study period, with both groups receiving a mixture of inhalational agents, induction agents, and analgesics, including ketorolac, acetaminophen, and opioids. Intraoperative opioids were administered to 139 of the 163 patients (tables 1 and 6). Five children (3.9%) in the non-INT group and two children (5.9%) in the INT group did not receive an opioid within 2 h of surgery. Opioids were administered to 34 children (88%) in whom respiratory compromise occurred and in 109 of the 129 children (84%) in whom it did not. Intraoperative opioids were administered to 112 of 134 children with CRSS-documented OSAS (table 7). In addition, opioids were administered within the initial 2 h postoperatively in 106 of the 134 children with CRSS-documented OSAS. No correlation between the preoperative CRSS parameters and opioid administration and postoperative outcome was found.

Univariate analysis identified two clinical predictors of postoperative complications: age and the presence of an associated medical condition. Age younger than 2 yr had an adjusted odds ratio (OR) of 4.3 (95% CI, 1.7–11). Nineteen of the 163 children were younger than 2 yr. The presence of a preoperative medical condition gave an OR of 3 (95% CI, 1.4–6.5). Twenty-seven children in the non-INT group had an associated medical condition,

Table 4. Clinical and Preoperative CRSS Data of Children in Group INT$_{major}$

Patient	Sex	Age (yr)	Preoperative Medical Condition	Preop CRSS OAH Index (# · hr^{-1})	Preop CRSS Sa$_{O_2}$ Nadir (%)	Postoperative Complications and Interventions Sa$_{O_2}$ Nadir (%)	Medical Interventions
1	F	1	Yes	23	68	80	O$_2$ Rx, ICU unplanned
2	M	5	Yes Intubated from ICU	7	79	—	ICU planned, IPPV, CPAP
3	F	3	No	142	50	70	ICU planned, nasopharyngeal airway, O$_2$ Rx, CPAP
4	M	12	No	84	51	89	ICU planned, intubation, O$_2$ Rx
5	F	2	Yes Preoperative ICU	42	59	90	ICU planned, O$_2$ Rx
6	F	2	No	32	81	97	ICU planned
7	M	9	Yes Preoperative ICU	19	67	80	IPPV, O$_2$ Rx, Postoperative RR
8	M	4	No	38	59	85	O$_2$ Rx, IPPV
9	M	4	No	19	87	80	O$_2$ Rx, IPPV
10	F	4	No	3	91	69	O$_2$ Rx, IPPV

CRSS = cardiorespiratory sleep study; M = male; F = female; OAH index = #apnea&hypopnea · hr^{-1}; Sa$_{O_2}$ nadir = lowest O$_2$ saturation achieved. O$_2$ Rx = oxygen administration; IPPV = intermittent positive pressure ventilation; CPAP = continuous positive airway pressure; ICU planned = elective post-op admission to ICU. ICU = intensive care unit. See text for details of perioperative course.

Table 5. Preoperative Cardiorespiratory Sleep Study Parameters and Postoperative Outcome

	nonINT	INT	INT$_{minor}$	INT$_{major}$
Awake saturation (%)	97.2 ± 1.2	96.0 ± 2.1	96.0 ± 2.2	96.5 ± 1.9
T$_{< 90\%}$ (%)	0.8 ± 2.4	7.1 ± 14.0*	6.5 ± 15.7	7.8 ± 9.0
Desaturation index # · hr^{-1}	7.0 ± 9.2	27.5 ± 33.1*	21.9 ± 26.7	37.5 ± 15.5
Sao$_2$ nadir (%)	84.9 ± 9.2	71.4 ± 16.7*	72.4 ± 17.7	71.3 ± 12.4
OAH index (# events · hr^{-1})	9.1 ± 10.4	28.3 ± 32.2*	23.1 ± 26.3	37.9 ± 41.4

Results from the preoperative Cardiorespiratory Sleep Study for children in the nonINT and INT groups. (* $P < 0.05$, one way analysis of variance, different from nonINT group.) Children requiring medical intervention (Group INT) have been grouped into 2 subgroups: those requiring minor interventions (INT$_{minor}$) and those requiring major interventions (INT$_{major}$). See text for a definition of minor and major interventions.

T$_{< 90\%}$ = time spent with a saturation < 90%; SaO$_2$ = oxygen saturation; OAH = obstructive apnea and hypopnea; INT = intervention.

of which asthma (n = 15), cardiac anomalies (n = 4), and trisomy 21 (n = 3) were the most common. Fifteen children in the INT group had associated medical conditions, of which asthma (n = 5), hypotonia–developmental delay (n = 4), and craniofacial abnormalities (n = 2) were the most common.

Multiple logistic regression analysis was performed using the two clinical factors identified from the univariate analysis. The adjusted ORs for age younger than 2 yr and the presence of an associated medical condition were 3.0 (95% CI, 0.9–9.4; $P = 0.06$) and 2.4 (95% CI, 1.0–6.3; $P = 0.06$), respectively.

Polysomnographic Predictors of Postoperative Complications–Medical Interventions

Of the 163 CRSS studies, 136 were home studies and 27 were laboratory studies. The nocturnal oximetry study (TREND O$_2$) was abnormal (defined as three clusters of desaturation events and three desaturations < 90%) in 45 studies, normal in 52, and indeterminate in 66 studies. (Indeterminate studies could not distinguish movement artifact from desaturations. See Brouillette *et al.*[16] for a discussion of this method.) Four nocturnal saturation variables are reported: the awake saturation, T$_{<90\%}$, desaturation index, and Sao$_2$ nadir (table 5). With regard to the T$_{<90\%}$, 47 children with OSAS spent 0% of sleep with a saturation less than 90%, and 37 had a T$_{<90\%}$ greater than 1%, of whom 35 had severe OSAS and 2 had moderate OSAS.

Twenty-nine children did not meet the diagnostic criteria OSAS (OAH index < 1), and none of these children developed respiratory complications or required medical interventions after adenotonsillectomy (table 8). Of

Table 6. Intraoperative Opioid Administration by Type and Dose in 163 Children Undergoing Adenotonsillectomy

Opioid (units)	Number of Children	% Total	Dose/kg Mean ± SD (units · kg^{-1})
Nil	24	14.7	—
Morphine (mg)	16	9.8	1.12 ± 0.05
Fentanyl (μg)	64	39.3	1.37 ± 0.50
Sufentanil (μg)	56	34.4	0.33 ± 0.34
Codeine (mg)	3	1.8	1.07 ± 0.20

the 134 patients who met our diagnostic criteria for OSAS, namely, an OAH index of more than 1 event per hour, 100 (74.6%) did not require an intervention.

Eighty-eight percent of the INT group compared with 51% of the non-INT group had severe OSAS. Three percent of the INT group compared with 13% of the non-INT group had mild OSAS. The mean preoperative OAH index was 14.0 events per hour (95% CI, 5.0–22.9) higher in the INT group compared with the non-INT group. The F statistic was 17.0 with 162 degrees of freedom and an associated P value < 0.001 (table 5). The adjusted OR for an OAI index of 5 or more events per hour was 7.2 (95% CI, 2.7–19.3; $P = 0.001$). The adjusted OR for a Sao$_2$ nadir 80% or less gave an OR of 6.4 (95% CI, 2.8–14.5; $P < 0.001$).

The CRSS nocturnal saturation nadirs for the OSAS severity scores of normal, mild, moderate, and severe were 91.3, 88.6, 87.4, and 77.1%, respectively (table 8). Compared with the non-INT group, the INT group had lower preoperative Sao$_2$ nadirs (71.4 *vs.* 84.9%; $P < 0.001$; table 5). One-way analysis of variance of the INT groups and the preoperative Sao$_2$ nadir showed a mean difference of 13.6% between non-INT and INT$_{major}$, with a 95% CI of 5.3–21.9%, an F statistic of 17.8, 162 degrees of freedom, and an associated P value < 0.01. Sixty percent (n = 21) of the children in the INT group had an oxygen saturation nadir of 80% or less compared with 20% (n = 26) of children in the non-INT group (fig. 1).

Severe OSAS, defined polysomnographically as an OAH index of 5 or more events per hour (adjusted OR, 3.7; 95% CI, 1.1–12.6; $P = 0.04$) and a preoperative nocturnal Sao$_2$ nadir of 80% or less (adjusted OR, 3.7; 95% CI, 1.4–9.3; $P < 0.01$) significantly increased the incidence of respiratory complications.

Likelihood Ratios

The probability of postoperative medical interventions was 20% (34 of 163 children), increasing to 25% (34 of 134 children) in the OSAS population. The likelihood ratio for postoperative medical interventions calculated for an OAH index of 5 or more events per hour was 1.7, whereas the ratio for OAH index of less than 5 events per hour was 0.4. The likelihood ratio for postoperative

Table 7. Perioperative Opioid Administered to 134 Children with Cardiorespiratory Sleep Study–documented OSAS

OSAS Severity Based on OAH Index	Intraoperative Opioid Administration (n = 112)				Postoperative Opioid Administration (n = 108)		
	Morphine	Codeine	Fentanyl	Sufentanil	Morphine	Codeine	Meperidine
Mild	2	1	8	3	15	2	
Moderate	6		5	7	18		
Severe	7	2	39	32	69	3	1
Total	15	3	52	42	102	5	1

OSAS = obstructive sleep apnea syndrome; OAH = obstructive apnea and hypopnea.

medical interventions calculated for a preoperative Sao_2 nadir of 80% or less was 3.1, increasing the posttest probability of respiratory morbidity from 20 to 50%. The likelihood ratio for postoperative medical interventions calculated for a preoperative saturation nadir greater than 80% was 0.5, decreasing the posttest probability of respiratory morbidity from 20 to 10%.

Stepwise Logistic Linear Regression

As stated in Materials and Methods, the study population was reclassified by the four risk factors identified by univariate analysis into age risk (defined as an age < 2 yr), medical risk (defined by the presence of an associated medical condition), saturation risk (defined as a Sao_2 nadir $\leq$ 80%), and apnea risk (defined as an OAH index $\geq$ 5 events per hour). Stepwise logistic linear regression of the two models—(1) age, medical and saturation risk and (2) age, medical and apnea risk—to predict outcome (non-INT *vs.* INT) showed that the statistical properties of the two models were similar (Akaike information criterion = 28.3 and 24.6, respectively). Stepwise logistic linear regression gave a Nagelkerke pseudo R-squared value (a generalization of the ordinary R-squared to logistic regression) of 0.12, 0.26, and 0.30 for the following three models: (1) age and medical risk; (2) age, medical and saturation risk; and (3) age, medical, saturation, and apnea risk, respectively.

Discussion

The incidence of respiratory complications after adenotonsillectomy was 21% in this series of 163 children, 82% of whom had OSAS. This incidence of postoperative respiratory compromise is higher than the 1.3% incidence reported in a general pediatric population[21] but is comparable to that reported in other series of pediatric OSAS.[13,14] Ninety-six percent (128 of 134) of our children were managed in a recovery room–ward setting. Desaturation requiring oxygen administration was the most common respiratory complication. Major respiratory compromise requiring airway instrumentation, ventilation, or intensive postoperative monitoring occurred in 7.5% of children with OSAS and none of those without OSAS. This 7.5% incidence of major respiratory compromise is one third the incidence (23%) reported by McColley *et al.*[11] However, their study population (n = 69) had a higher incidence of associated cardiac and craniofacial conditions compared with our study population, in which asthma was the most prevalent medical condition. Therefore, differences in referral pattern, study populations, OSAS diagnostic criteria, definition of postoperative morbidity, and surgical and anesthetic management may have contributed to our lower incidence of major respiratory compromise.

Adenotonsillectomy should relieve the symptomatology of OSAS and normalize breathing during sleep.[4,10,22–24] What explanation can be offered for the paradox that children with OSAS continue to experience upper airway obstruction and desaturation in the immediate postoperative period? Blood, edema, and residual lymphoid tissue may continue to obstruct the postsurgical airway in the child with OSAS. In addition, pediatric OSAS is a disorder of upper airway function consequent to both anatomic and dynamic factors that promote upper airway collapse during inspiration. In children

Table 8. The Preoperative OSAS Severity Score and Postoperative Outcome

CRSS OAH index (# events/hr)	OSAS Severity Score	CRSS SaO_2 nadir (%)	CRSS Desaturation Index (# events/hr)	nonINT (n)	INT (n)
< 1	Normal	91.3 ± 3.9	0.8 ± 1.2	29	0
≥ 1 < 3	Mild	88.6 ± 2.6	2.8 ± 2.8	16	1
≥ 3 < 5	Moderate	87.4 ± 4.2	3.6 ± 2.7	18	3
≥ 5	Severe	77.1 ± 13.8	17.2 ± 22.5	66	30

This table relates the preoperative OSAS severity score, categorized by the OAH index, and the corresponding preoperative SaO_2 nadir and desaturation index (mean ± SD) with postoperative outcome for Groups nonINT and INT.

CRSS = cardiorespiratory sleep study; OSAS = obstructive sleep apnea syndrome; OAH = obstructive apnea and hypopnea; SaO_2 = arterial saturation; INT = intervention.
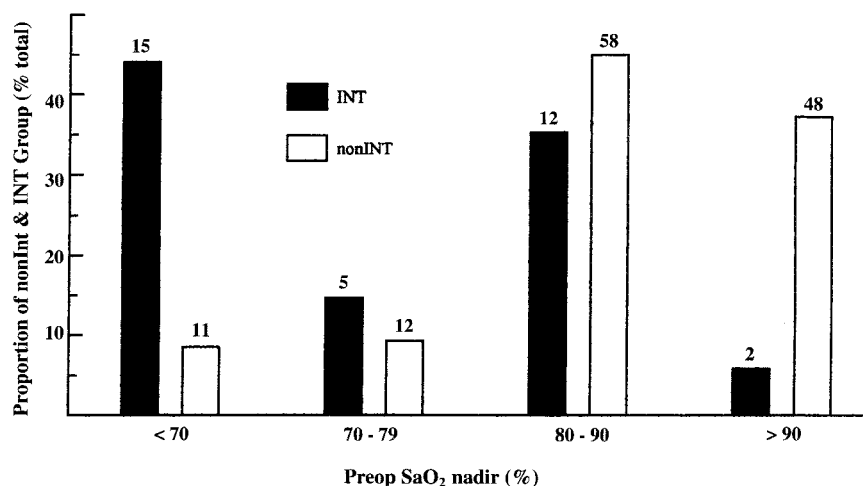
Fig. 1. Relationship between the preoperative polysomnographic oxygen saturation nadir and outcome. The numbers above the columns indicate the number of children in each group.

with sleep-disordered breathing, the pressure gradient for airway collapse between sleep and neuromuscular paralysis is reported to be half that measured in normal children,[4,10,24] suggesting that children with sleep-disordered breathing show altered neuromuscular control of upper airway patency. Therefore, impaired neuromuscular function in the recovery room caused by a residual effect of sedative, anesthetic, or analgesic agents[25-27] could contribute to airway obstruction in the postoperative period. It was surprising that we found no statistical correlation between opioid administration and the need for medical intervention. Indeed, the majority of children with OSAS received both intraoperative and postoperative opioids (table 7). However, other investigators[11,13,14,28] have failed to find a correlation between opioid administration and respiratory outcome in children with OSAS.

The airway in a child younger than 2 yr is at increased risk[11,13,14,29,30] for compromise after adenotonsillectomy because of its relatively small diameter. In addition, there may also be an age-dependent maturation of neuromuscular control of the upper airway, predisposing the young child to obstructive events in the postoperative period. Certainly there are maturational differences in the respiratory system of a toddler (including a compliant chest wall[31] and asymptomatic pulmonary hypertension[4,32]) that promote desaturation should an obstructive apnea occur.

In this study, we investigated whether CRSS could predict postoperative respiratory complications in children undergoing adenotonsillectomy. We found that, although the sensitivity of a preoperative diagnosis of OSAS was 100%, the positive predictive value was only 25.4%. However, the severity of OSAS did correlate with the requirement for postoperative medical intervention in that mild, moderate, and severe OSAS were associated with a 6, 14, and 31% incidence of respiratory compromise, respectively (table 8). It is likely that OSAS represents a spectrum of disease, and disease severity may prove to be a useful predictor of postoperative risk.

Although polysomnography is widely accepted as the most accurate method of quantitating the presence and severity of pediatric OSAS, there remain substantial challenges, including standardization of definitions, procedures, and methodologies, and establishing the relation of CRSS parameters to clinically meaningful outcomes.[3,4,10,33] Furthermore, polysomnography is extraordinarily expensive as standard methods require the presence of a technician overnight in the sleep laboratory as well as the set-up and analysis time. We are not recommending polysomnography as a requirement before all adenotonsillectomies.

Several investigators have sought more cost-effective and less time-intensive alternatives for diagnosing OSAS, including sonography, home video recordings, cardiorespiratory sleep studies, and pulse oximetry.[15-18] We recently reported that a positive nocturnal TREND O_2 had a 97% predictive value for a diagnosis of OSAS by polysomnography.[16] Unlike other saturation indices, the nocturnal Sa_{O_2} nadir does not require an assessment of the duration of the saturation nadir and is not indexed to sleep time; therefore, it does not require an assessment of sleep state. The nocturnal saturation TREND O_2 analysis does not require formal polysomnography.

The current study extends our previous work to suggest that preoperative nocturnal oximetry could also predict which children are most likely to suffer respiratory compromise after adenotonsillectomy. The likelihood ratio for postoperative medical interventions calculated for a preoperative Sa_{O_2} nadir of 80% or less was 3.1 and increased the posttest probability of respiratory morbidity from 20 to 50%. Indeed, Isono *et al.*[34] reported that the preoperative hypoxemia was the best predictor of postoperative hypoxemia in a population of adults with sleep-disordered breathing.

We recognize that polysomnography provides an assessment of OSAS risk. The model of age, medical and apnea risk did provide a slightly better overall model fit. The addition of apnea risk to the model prediction of age, medical and saturation risk did account for an addi-

tional 4% of the variance in the outcome. However, in the choice of preoperative oximetry trend analysis *versus* polysomnography, the fact that saturation studies are feasible and potentially cost-effective to conduct on a population basis may make oximetry analysis more favorable in practice.

However, it is important to realize that the oximetry data presented here are based on the CRSS computerized recording of the pulse waveform, not the TREND O_2. The CRSS saturation analysis involves visual inspection of the data record and elimination of all segments containing movement artifact. Therefore, the reported Sa_{O_2} nadir in this study has been verified and quantitated in a manner that is impossible with oximetry trend reports. Of note in the current study, 40% (n = 66) of the oximetry TREND O_2 studies were indeterminate. Therefore, before pulse oximetry could be accepted as a useful preoperative test, several challenges remain to be sorted. First, different brands, models, and modes of pulse oximeters have different response characteristics that can markedly affect such parameters as the frequency and extent of saturation dips caused by apnea. A motion-resistant oximeter, Quartz Medical "Masimo" oximeter (Q400; Quartz Medical, Irvine, CA), with masimo technology, had fewer motion artifact desaturations but somewhat underestimated the frequency and extent of the saturation dips compared with the Nellcor N-200.[35] Second, methods of oximetric quantitation and analysis must become more standardized and objective.[16] Finally, a prospective trial involving a wide spectrum of children undergoing adenotonsillectomy is needed to demonstrate that oximetry results would significantly predict postoperative compromise and that it would modify clinical practice.

In conclusion, we report a 21% incidence of respiratory compromise requiring medical interventions after adenotonsillectomy among 163 children evaluated for OSAS. Because airway obstruction and desaturation were the two types of respiratory complications, we recommend monitoring all children with OSAS with an oximeter in the initial postoperative period. Ninety-six percent of the children with OSAS were managed in a recovery room or ward setting. Six children required postoperative admission to the ICU. Keeping in mind the aforementioned cautionary notes, we suggest that preoperative nocturnal saturation may prove to be a cost-effective test to both diagnose severe OSAS and predict postoperative risk in children undergoing adenotonsillectomy. Preoperative nocturnal saturation may prove to be a useful methodologic tool to enable prospective randomized clinical trials to rationalize the perioperative management of children with OSAS undergoing adenotonsillectomy.

References

1. Rosenfeld RM, Green RP: Tonsillectomy and adenoidectomy: Changing trends. Ann Otol Rhinol Laryngol 1990; 99:187–91

2. Brouillette RT, Fernbach SK, Hunt CE: Obstructive sleep apnea in infants and children. J Pediatr 1982; 100:31–40

3. Davidson SL, Marcus CL: Obstructive sleep apnea in infants and young children. J Clin Neurophysiol 1996; 13:198–207

4. Marcus CL, England SE, Annett RD, Brooks LJ, Brouillette RT, Carroll JL, Givan DC, Gozal D, Kiley J, Redline S, Rosen CL, Rosen GM, Tunkel DE: Cardiorespiratory sleep studies in children. Am J Respir Crit Care Med 1999; 160:1381–7

5. Guilleminault C, Eldridge FL, Simmons FB, Dement WC: Sleep apnea in eight children. Pediatr 1976; 58:23–31

6. Messner AH: Evaluation of obstructive sleep apnea by polysomnography prior to pediatric adenotonsillectomy. Arch Otolaryngol Head Neck Surg 1999; 125:353–6

7. Brouillette RT, Hanson D, David R, Klemka L, Szatkowski A, Fernbach S, Hunt CE: A diagnostic approach to suspected obstructive sleep apnea in children. J Pediatr 1984; 105:10–4

8. Carroll JL, McColley SA, Marcus CL, Curtis S, Loughlin GM: Inability of clinical history to distinguish primary snoring from obstructive sleep apnea syndrome in children. Chest 1995; 108:610–8

9. Marcus CL: Clinical and pathophysiological aspects of obstructive sleep apnea in children. Pediatr Pulmonol 1997; 16:123–4

10. Marcus CL, McColley SA, Carroll JL, Loughlin GM, Smith PL, Schwartz AR: Upper airway collapsibility in children with obstructive sleep apnea syndrome. J Appl Physiol 1994; 77:918–24

11. McColley SA, April MM, Carroll JL, Naclerio RM, Loughlin GM: Respiratory compromise after adenotonsillectomy in children with obstructive sleep apnea. Arch Otolaryngol Head Neck Surg 1992; 118:940–3

12. Weinberg S, Kravath R, Phillips L, Mendez H, Wolf G: Episodic complete airway obstruction in children with undiagnosed obstructive sleep apnea. ANESTHESIOLOGY 1984; 60:356–8

13. Rosen GM, Muckle RP, Mahowald MW, Goding GS, Ullevig C: Postoperative respiratory compromise in children with obstructive sleep apnea syndrome: Can it be anticipated? Pediatrics 1994; 93:784–8

14. Biavati MJ, Manning SC, Phillips DL: Predictive factors for respiratory complications after tonsillectomy and adenoidectomy in children. Arch Otolaryngol Head Neck Surg 1997; 123:517–21

15. Jacob SV, Morielli A, Mograss MA, Ducharme FM, Schloss MD, Brouillette RT: Home testing for pediatric obstructive sleep apnea syndrome secondary to adenotonsillar hypertrophy. Pediatr Pulmonol 1995; 20:241–52

16. Brouillette RT, Morielli A, Leimanis A, Waters KA, Luciano R, Ducharme FM: Nocturnal pulse oximetry as an abbreviated testing modality for pediatric obstructive sleep apnea. Pediatrics 2000; 105:405–12

17. Waters KA, Forbes P, Morielli A, Hum C, O'Gorman A, Vernet O, Davis G, Tewfik TL, Ducharme FM, Brouillette RT: Sleep disordered breathing in children with myelomeninocele. J Pediatr 1998; 132:672–81

18. Morielli A, Ladan S, Ducharme FM, Brouillette RT: Can sleep and wakefulness be distinguished in children by cardiorespiratory and videotape recordings? Chest 1996; 109:680–7

19. Mograss MA, Ducharme FM, Brouillette RT: Description, classification, and relationship to sleep apnea in children. Am J Respir Crit Care Med 1994; 150:1690–6

20. McCullagh P, Nelder JA: Generalized Linear Models, 2nd edition. London, Chapman and Hall, 1989, pp 21–135

21. Richmond KH, Wetmore RF, Baranak CC: Postoperative complications following tonsillectomy and adenoidectomy: Who is at risk? Int J Pediatr Otorhinolaryngol 1987; 13:117–24

22. Isono S, Remmers JE, Tanaka A, Sho Y, Nishino T: Static properties of the passive pharynx in sleep apnea. Sleep 1996; 19:S175–7

23. Isono S, Remmers JE, Tanaka A, Sho Y, Sato J, Nishino T: Anatomy of pharynx in patients with obstructive sleep apnea and in normal subjects. J Appl Physiol 1997; 82:1319–26

24. Isono S, Shimada A, Utsugi M, Konno A, Nishino T: Comparison of static mechanical properties of the passive pharynx between normal children and children with sleep-disordered breathing. Am J Respir Crit Care Med 1998; 157:1204–12

25. Nozaki-Taguchi N, Isono S, Nishino T, Numai T, Tagushi N: Upper airway obstruction during midazolam sedation: Modification by nasal CPAP. Can J Anaesth 1995; 42:685–90

26. Ochiai R, Guthrie RD, Motoyama EK: Effects of varying concentrations of halothane on the activity of the genioglossus, intercostals, and diaphragm in cats: An electromyographic study. ANESTHESIOLOGY 1989; 70:812–6

27. Warwick JP, Mason DG: Obstructive sleep apnoea syndrome in children. Anaesthesia 1998; 53:571–9

28. Helfaer MA, McColley SA, Pyzik PL, Tunkel DE, Nichols DG, Baroody FM, April MM, Maxwell LG, Loughlin GM: Polysomnography after adenotonsillectomy in mild pediatric obstructive sleep apnea. Crit Care Med 1996; 24:1323–7

29. Berkowitz RG, Zalzal GH: Tonsillectomy in children under 3 years of age. Arch Otolaryngol Head Neck Surg 1990; 116:685–6

30. Tom LWC, DeDio RM, Cohen DE, Wetmore RF, Handler SD, Potsic WP: Is outpatient tonsillectomy appropriate for young children? Laryngoscope 1992; 102:277–80

31. Papastamelos C, Panitch HB, England SE, Allen JL: Developmental changes in chest wall compliance in infancy and early childhood. J Appl Physiol 1995; 78:179–84

32. Jacobs IN, Teague WG, Bland JW: Pulmonary vascular complications of chronic airway obstruction in children. Arch Otolaryngol Head Neck Surg 1997; 123:700–4

33. Brown K, Aun C, Jackson E, Mackersie A, Hatch D, Stocks J: Validation of respiratory inductive plethysmography using the qualitative diagnostic calibration method in anaesthetized infants. Eur Respir J 1998; 12:935–43

34. Isono S, Suzukawa M, Sho Y, Ohmura A, Kudo Y, Misawa K, Inaba S, Nishino T: Preoperative nocturnal desaturations as a risk factor for late postoperative nocturnal desaturations. Br J Anaesth 1998; 80:602–5

35. Brouillette RT, Lavergne J, Leimanis A: Comparison of a Masimo Oximeter with a Nellcor N-200 Oximeter in a pediatric sleep lab setting (abstract). Pediatr Pulmonol 2000; 30:496