Reference Values for Nocturnal Home Pulse Oximetry During Sleep in Primary School Children*

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Objective: **To provide reference values for pulse oximeter saturation (Spo_2) in primary school children, measured at home during sleep.**

Methods: **Recordings of Spo_2 and signal quality from 100 children were randomly selected from a larger population-based sample intended to study the prevalence of sleep-disordered breathing. Recordings were analyzed for the duration of artifact-free recording time (AFRT), minimum Spo_2 (SATmin) and median Spo_2 (SAT_{50}), the Spo_2 below which the child spent 5% of AFRT (SAT_5), and the Spo_2 below which the child spent 10% of AFRT (SAT_{10}). In addition, the time in seconds with $Spo_2 \leq 90\%$ per hour of AFRT (TI_{90}) was calculated, as were the number of falls in Spo_2 by $\geq 4\%$ per hour of AFRT (DI_4), the number of falls in Spo_2 to $\leq 90\%$ per hour of AFRT (DI_{90}), and the number of falls in Spo_2 to $\leq 92\%$ per hour of AFRT (DI_{92}).**

Results: **Ten recordings had to be excluded because of insufficient AFRT (< 5 h). Mean age of the remaining 90 children (54 girls) was 9.3 years (SD, 0.6). Median (range; fifth centile) values for SATmin, SAT_5, SAT_{10}, and SAT_{50} were 93% (76 to 97; 87.5), 97% (88 to 99; 95), 97% (89 to 99; 96), and 98% (94 to 100; 97). Median values (range; 95th centile) for TI_{90}, DI_4, DI_{90}, and DI_{92} were 0.0 s (0.0 to 5.8; 1.6), 0.8 (0.0 to 6.1; 3.9), 0.0 (0.0 to 1.2; 0.2), and 0.0 (0.0 to 2.0; 0.6).**

Conclusion: **Baseline Spo_2 values < 97% were uncommon in these children, as were intermittent desaturations to $\leq 90\%$. These data may serve as a basis for the interpretation of clinical recordings of Spo_2 in children referred for sleep-related breathing disorders.**

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Key words: hypoxemia; pulse oximetry; reference values; sleep-disordered breathing

Abbreviations: AFRT = artifact-free recording time; D_4 = fall in pulse oximeter saturation by $\geq 4\%$; D_{90} = fall in pulse oximeter saturation to $\leq 90\%$; D_{92} = fall in pulse oximeter saturation to $\leq 92\%$; DCL = desaturation cluster; DI_4 = fall in pulse oximeter saturation by $\geq 4\%$ per hour of artifact-free recording time; DI_{90} = fall in pulse oximeter saturation to $\leq 90\%$ per hour of artifact-free recording time; DI_{92} = fall in pulse oximeter saturation to $\leq 92\%$ per hour of artifact-free recording time; DICL = DCL per hour of artifact-free recording time; IQR = interquartile range; NHPO = nocturnal home pulse oximetry; OSAS = obstructive sleep apnea syndrome; REM = rapid eye movement; SAT_5 = pulse oximeter saturation below which the child spent 5% of artifact-free recording time; SAT_{10} = pulse oximeter saturation below which the child spent 10% of artifact-free recording time; SAT_{50} = median pulse oximeter saturation; SATmin = minimum pulse oximeter saturation; SDB = sleep-disordered breathing; Spo_2 = pulse oximeter saturation; T_{90} = time in seconds with pulse oximeter saturation $\leq 90\%$; TI_{90} = time in seconds with pulse oximeter saturation $\leq 90\%$ per hour of artifact-free recording time; TRT = total recording time; URTI = upper respiratory tract infection

Pulse oximeters are increasingly used for the evaluation of sleep-disordered breathing (SDB).[1] They are easy to use and provide accurate information on both baseline oxygenation and the frequency of intermittent falls in oxygenation (*eg*, during sleep apnea). To interpret patient data, it is essential to obtain reference values. With regard to children, such data are sparse,[2–5] with most studies being

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performed in the hospital (*ie*, in a nonnatural sleep setting[2,4]) and/or involving comparatively small numbers of subjects[2–3]; some studies excluded motion artifact (*ie*, periods with a high likelihood of spuriously low values),[2–4] and others did not.[5] Moreover, the recent introduction of more motion-resistant pulse oximeters necessitates the establishment of reference values obtained with this new generation of instruments.

We are currently performing a population-based study on the prevalence of SDB in third-grade and fourth-grade primary school children. Enrolled children are screened for signs and symptoms of SDB and for frequent desaturations during sleep using a questionnaire and nocturnal home pulse oximetry (NHPO). Children with outlying results on either screening method subsequently undergo nocturnal home polysomnography. In this initial report from that study, we determined reference values for NHPO recordings in a subgroup of 100 children.

Materials and Methods

Subject Recruitment

Twenty-seven of the 59 regular primary schools located within the city limits of Hannover, Germany, were selected at random within strata of socioeconomic status (*ie*, the percentage of pupils from low-income families). Eleven of the selected schools were contacted between February 2001 and May 2001, and all children attending third grade were identified. With institutional review board approval, parental informed consent and child assent were obtained. Of the 739 children attending third grade, 468 children (63%) agreed to participate; 100 recordings from this sample were randomly chosen for this study.

Methods

Children underwent NHPO recordings using an instrument (VitaGuard VG 300; Getemed AG; Teltow, Germany) with a new-generation oximeter module (Masimo SET, software version 3.0.2.1; 2- to 4-s moving averaging mode; Masimo Corporation; Irvine, CA) capable of storing continuous data for pulse oximeter saturation (Spo_2), pulse rate, signal quality ("signal IQ"), and device status for up to 12 h at a sampling rate of 1 Hz. Signal IQ and device status are data entries developed by the pulse oximeter module and device manufacturer. Signal IQ is derived from the raw plethysmogram indicating the signal-to-noise ratio and, thereby, the confidence of the measured Spo_2 values. The range span is normalized from 0 to 1; > 0.3 spurious desaturation is extremely unlikely to occur.[6] Entries for device status are integer values ranging from 0 to 13 yielding a simple data abstraction layer, with 0 representing optimal measurement conditions, 1 to 8 indicating problems with signal reliability (*eg*, low perfusion), and 9 to 13 indicating alarm limit violations (*eg*, low Spo_2).

In addition to these trend data, desaturation events, defined as $Spo_2 \leq 92\%$, were recorded separately over a 120-s period prior to and during the event onto event data memory. These event recordings comprised the pulse waveform signal, sampled at 32 Hz, in addition to the above-mentioned trend data. Alarms were muted and visual displays dimmed to avoid unnecessary disturbance of the children's sleep.

A study nurse explained handling of the pulse oximeter to the children in their classroom. Sensor placement was taught in a hands-on session supervised by two additional staff members. The children were instructed to start the recording at bedtime and terminate it in the morning. They were also given an instruction manual for sensor placement and pulse oximeter handling, and a parental questionnaire asking for factors potentially influencing pulse oximetry results, which contained the following questions: (1) Does your child have any heart disease (*eg*, cardiac insufficiency); if yes, please specify; (2) Does your child have any chronic lung disease (*eg*, asthma); if yes, please specify; (3) Does your child have a diagnosed allergy or chronic rhinitis; if yes, please specify; (4) Does your child currently have an upper respiratory tract infection (URTI) [*eg*, acute rhinitis or coughing]; if yes, please specify; and (5) Does your child have an anemia that is under treatment? In addition, information on age, weight, and height was obtained. An overnight telephone hotline was implemented to help parents with equipment problems.

Data Analysis

Duration of Recording: Following the night of recording, children were asked to bring the equipment back to school, where trend and event data were downloaded to a computer. Total recording time (TRT) and artifact-free recording time (AFRT) were calculated using data analysis software (Matlab; MathSoft; Cambridge, MA). For AFRT, recording periods associated with a device status between 1 and 8 and/or a signal IQ ≤ 0.3 were identified and subtracted from TRT. If AFRT was < 5 h, the recording was excluded because it was likely not to comprise at least three full sleep cycles.[7]

Baseline Values: The median Spo_2 (SAT_{50}), the Spo_2 below which the child spent 5% of AFRT (SAT_5), and the Spo_2 below which the child spent 10% of AFTR (SAT_{10}) were calculated for each recording using the above-mentioned analysis software.

Desaturation Events: These were defined as a fall in Spo_2 to $\leq 90\%$ (D_{90}), a fall in Spo_2 to $\leq 92\%$ (D_{92}), and/or a fall in Spo_2 by $\geq 4\%$ (D_4), with the latter defined as a continuous decrease in Spo_2 by $\geq 4\%$ occurring within 10 s from a prior peak value.[8] All desaturation events were visually confirmed to exclude spuriously low values not identified by the software tool. Events with a distorted pulse waveform signal, a signal IQ ≤ 0.3 (indicating motion artifacts), or a low perfusion tag occurring during or within 7 s prior to the desaturation event were considered artifactual and therefore excluded. This was done using analysis software provided by the device manufacturer (VitaWin, version 2.3.1 5b and 2.3.2; Getemed AG). Recordings were also analyzed for desaturation clusters (DCLs), defined as five or more D_4 events occurring within a 30-min period.[8] Desaturation indexes were calculated for D_4 per hour of AFRT (DI_4), D_{90} per hour of AFRT (DI_{90}), D_{92} per hour of AFTR (DI_{92}), and DCL per hour of AFRT (DICL). From the event data, the total time in seconds with $Spo_2 \leq 90\%$ (T_{90}) and T_{90} per hour of AFRT (TI_{90}) were also calculated.

Statistics

To allow comparisons with published data, values are expressed both as mean and SD, and as median, range, and interquartile range (IQR). Reference ranges were calculated using the fifth and 2.5th percentiles for baseline values and the 95th and 97.5th percentiles for desaturations. The Mann-Whitney *U* test was used to compare data between subgroups; because of multiple significance testing, a Bonferroni correction was performed. These analyses were done using statistical software (SPSS version 10.0.7; SPSS; Chicago, IL).

Table 1—*Descriptive Statistics for Spo_2 Baseline Values of the Entire Study Group (n = 90)

Variables	Mean ± SD	Median	IQR	Range	Fifth Centile	2.5th Centile
SATmin	92.5 ± 3.0	93	92–94	76–97	87.5	85.2
SAT_5	96.9 ± 1.4	97	96–98	88–99	95	94
SAT_{10}	97.1 ± 1.3	97	97–98	89–99	96	94.2
SAT_{50}	97.9 ± 0.8	98	98–98	94–100	97	97

*Data are presented as %.

Results

All recordings contained analyzable data, but 10 recordings (10%; seven of these were from boys) had to be excluded because of insufficient (< 5 h) recording time. The remaining recordings were from 54 girls and 36 boys studied at a mean age of 9.3 years (SD, 0.6). Mean height was 137.5 cm (SD, 6.6), mean weight was 31.8 kg (SD, 5.9), and mean body mass index was 16.7 (SD, 2.3). Mean TRT was 591.2 min (SD, 61.3), with an AFRT of 578.3 min (SD, 63.8), *ie*, 97.4% (SD, 6.1) of recording time was artifact-free.

The parental questionnaire revealed the following medical conditions at the time of study: mild pulmonary artery stenosis (1 child), asthma (6 children), allergy (16 children, with 10 of these having allergic rhinitis and 1 child having multiple, nonrespiratory allergies), URTI (21 children; 11 children with rhinitis, 5 children with a cough, 4 children with both rhinitis and cough, and 1 child with sinusitis). No child had a temperature ≥ 38.5°C on the night of recording or was receiving treatment for anemia; all were able to attend school on the following day. One child was subsequently found to have obstructive sleep apnea syndrome (OSAS).

A number of tests were performed to compare data between subgroups (*eg*, girls vs boys, or children with asthma vs children without asthma), but none of the differences remained significant when results were corrected for multiple testing (Bonferroni correction, accepted probability value < 0.006). Nevertheless, in addition to the results for the entire study group, data are also presented on the subset of 58 subjects (36 girls) without major (*eg*, OSAS, asthma) or minor (*eg*, allergic rhinitis and URTI) respiratory complaints.

Baseline Values

Descriptive statistics for minimum Spo_2 (SATmin), SAT_5, SAT_{10}, and SAT_{50} are shown in Tables 1, 2. There were eight children with baseline values below the fifth centile for SATmin, SAT_5, and/or SAT_{10}. One girl had values below this threshold for all three parameters (SATmin, 85%; SAT_5, 88%; SAT_{10}, 89%). The questionnaire revealed multiple nonrespiratory allergies, but no medical condition to explain her low Spo_2 values was reported. Three children had SAT_5 and SAT_{10} values below the fifth centile; two of these children had a URTI (SAT_5, 92% and 94%; SAT_{10}, 92% and 95%, respectively). Four children had only a SATmin below the fifth centile: two children had a URTI (SATmin, 76% and 86%, respectively), one child had allergic rhinitis (SATmin, 87%), and one child was subsequently found to have OSAS (SATmin, 85%). Thus, seven of the eight children had medical conditions potentially explaining their abnormally low baseline values.

Desaturation Events

Thirty-seven D_{90} events and 106 D_{92} events were found in 12 recordings and 29 recordings, respectively. Of the 12 children with desaturations to ≤ 90%, 6 children had 1 D_{90} event, 2 children had 2 D_{90} events, and the remaining 4 children had 3, 4, 9, and 11 D_{90} events, respectively. All children with

Table 2—*Descriptive Statistics for Spo_2 Baseline Values of Subjects Without Respiratory Complaints (n = 58)

Variables	Mean ± SD	Median	IQR	Range	Fifth Centile	2.5th Centile
SATmin	93.1 ± 2.2	93	92–94	85–97	88	88
SAT_5	97 ± 1.6	97	96.3–98	88–99	95.9	94.4
SAT_{10}	97.3 ± 1.4	97	97–98	89–99	96	94.9
SAT_{50}	98.1 ± 0.8	98	98–98.8	95–100	97	97

*Data are presented as %.

Table 3—*Descriptive Statistics for Spo_2 Desaturation Events and Indices of the Entire Study Group (n = 90)

Variables	Mean ± SD	Median	IQR	Range	95th Centile	97.5th Centile
D_{90}	0.4 ± 1.6	0	0–0	0–11	2	3.8
DI_{90}	0.0 ± 0.2	0	0–0	0–1.2	0.2	0.4
D_{92}	1.2 ± 2.9	0	0–1	0–19	5.6	9.3
DI_{92}	0.1 ± 0.3	0	0–0.1	0–2	0.6	0.9
D_4	11.6 ± 12.1	8	3–14	0–61	31.6	48.9
DI_4	1.2 ± 1.3	0.8	0.3–0.5	0–6.1	3.9	4.8
DCL	0.6 ± 1.4	0	0–0	0–7	3	5.8
DICL	0.1 ± 0.2	0	0–0	0–0.7	0.4	0.5
T_{90}	2.3 ± 8.6	0	0–0	0–54	16	30.3
TI_{90}	0.3 ± 1	0	0–0	0–5.8	1.6	4.3

*Data are presented as No.

more than one D_{90} event had some respiratory condition: three children had a URTI, two children had allergic rhinitis, and one child was subsequently found to have OSAS (Tables 3, 4).

D_4 events were common: 1,041 such events were found in 85 recordings (94%), with an average of 1.2 events per hour of AFRT; 38 recordings contained ≥ 10 events with a maximum number of 61 events. The 95th centile for DI_4 was 3.9. Again, three of the children with a DI_4 above the 95th centile had a URTI, one child had allergic rhinitis, and the remaining child was a child with multiple allergies who also had abnormally low baseline values.

In contrast, DCLs were less common: only 57 DCLs were found in 22 recordings, with a maximum of 7 DCLs per recording. The children with outlying values for this parameter were identical to those with a DI_4 above the 95th centile. Four of the five children with a TI_{90} above the 95th centile (> 1.6 s per hour of AFRT) also had an abnormally high DI_{90}. The remaining subject was the child with multiples allergies who had outlying values for several parameters.

Discussion

Using new-generation, motion-resistant pulse oximetry and sophisticated methods to exclude spuriously low Spo_2 values without having to analyze the pulse waveform signal throughout, we determined baseline Spo_2 and the frequency of intermittent falls in Spo_2 (desaturations) in a group of primary school children. Our subject recruitment and selection procedures enabled us to establish population-based reference values for NHPO recordings in this age group. We found that average Spo_2 was approximately 98% (median SAT_{50}; range, 94 to 100%) during sleep in these children. While intermittent falls in Spo_2 by ≥ 4% were frequent, Spo_2 rarely fell to ≤ 90%, and all children with more than one such desaturation had some respiratory condition at the time of study.

Recordings were obtained at home (*ie*, in a setting familiar to the child) using ambulatory pulse oximetry. We avoided any attachment of equipment to the head or face and any sleep disruption by alarms, illuminated displays, or the presence of people un-

Table 4—*Descriptive Statistics for Spo_2 Desaturation Events and Indices of Subjects Without Respiratory Complaints (n = 58)

Variables	Mean ± SD	Median	IQR	Range	95th Centile	97.5th Centile
D_{90}	0.1 ± 0.3	0	0–0	0–1	1	1
DI_{90}	0.0 ± 0.0	0	0–0	0–0.2	0.1	0.1
D_{92}	0.5 ± 1	0	0–1	0–5	2.2	3.0
DI_{92}	0.0 ± 0.1	0	0–0.1	0–0.5	0.3	0.3
D_4	8.4 ± 6.5	6.5	3–12	0–26	23	23
DI_4	0.9 ± 0.8	0.7	0.3–1.3	0–4.4	2.2	2.4
DCL	0.3 ± 0.6	0	0–0	0–3	2	2
DICL	0.0 ± 0.1	0	0–0	0–0.5	0.2	0.2
T_{90}	0.7 ± 4.4	0	0–0	0–33	1	2.7
TI_{90}	0.1 ± 0.7	0	0–0	0–5.5	0.1	0.3

*Data are presented as No.

known to the child, factors frequently present in hospital-based studies. This was done to ensure that the data recorded reflected, as far as technically possible, those that can normally be expected during routine sleep in children. In contrast to other studies,[2,4,5] we opted against excluding children with adenotonsillectomy or minor symptoms such as allergic rhinitis or URTI, but provide data also separately for those children who did not have any respiratory complaint. As our results show, the inclusion of children with minor respiratory complaints likely biased our data toward lower baseline values and higher desaturation indexes, but was considered necessary to reflect the situation typically found in the population under study, where intermittent URTI or allergic rhinitis frequently occur but should not, on their own, provide sufficient treatment justification for intermittent mild hypoxemia.

There were few practical difficulties encountered with this ambulatory monitoring. Sensor placement and oximeter handling were taught to children in a hands-on session and, in addition, parents were given a written instruction manual containing detailed information on sensor placement and oximeter handling. As a result, 90% of recordings contained sufficient amounts of analyzable data. Reasons given for terminating a recording prematurely were inconvenience of the self-adhesive oximeter sensor, inability to fall asleep with the device running, and frequent night awakenings while suffering from a URTI.

Although pulse oximetry is a reliable technique, device limitations may lead to false-negative results for hypoxemia and/or false-positive results for normoxemia or hyperoxemia, particularly during motion.[9,10] We therefore used a newly developed oximeter that reliably measures Spo_2 even during motion and low perfusion, thereby reducing the amount of potentially artifactual readings.[10,11] Using this technique is likely to have raised the accuracy of our baseline data compared to studies using conventional oximetry. Accuracy was further improved by applying several artifact rejection methods, including an analysis of the pulse waveform during desaturation events[12] and a validated signal quality indicator developed by the pulse oximeter manufacturer.[6]

In contrast to previous studies on Spo_2 in healthy subjects,[2–5] we report descriptive statistics of cumulative percentage time (SATmin, SAT_5, SAT_{10}, SAT_{50}) and desaturation events to various threshold values per hour of AFRT. This is to provide a more comprehensive picture of the child's oxygenation.

Our values for SAT_{50} are somewhat lower than those one of us reported for baseline Spo_2 in a group of 7- to 11-year-old children.[3] This difference could be related to the fact that Spo_2 in the above-mentioned study[3] was measured only during regular breathing, which closely corresponds to non-rapid eye movement (REM) sleep, while excluding periods of apnea. Spo_2 tends to be higher during non-REM sleep,[13] at least in infants. The method applied in this study to determine average or "baseline" Spo_2 has the advantage of not requiring a recording of breathing movements or EEG (to determine periods of regular breathing and/or non-REM sleep) and that it can be computed (*ie*, does not require time-consuming manual analysis). In contrast to our previous method for determining baseline Spo_2, however, SAT_{50} will be lower in subjects with a high frequency of intermittent desaturations: it not only reflects a subject's ability to oxygenize his or her arterial blood but is also influenced by intermittent disturbances to respiration.

Marcus et al[2] were the first to obtain reference values for desaturation events, defined as a fall in Spo_2 by $> 4\%$, in 50 1- to 17-year-old children. Artifact was excluded via analysis of the pulse waveform signal. They found a mean SATmin of 96% (range, 89 to 98%) and a mean DI_4 of 0.3 (range, 0 to 4.4), indicating that their children exhibited markedly less desaturation than our study population. This could be related to the different desaturation definition ($> 4\%$ vs $\geq 4\%$), study setting (sleep laboratory vs home), and age range (1 to 17 years vs 7.6 to 11.1 years). In addition, no information was given on the proportion of time the Spo_2 signal had to be excluded because of artifact or what signal-averaging time was used; results are therefore not directly comparable to the present data. However, the limited age range in our study likely provides a more accurate description of saturation values within the specific age range chosen here.

Gries and Brooks[4] measured Spo_2 in 180 children between 1 year and 10 years of age. Their mean SATmin, SAT_{10}, and SAT_{50} was 90.1%, 95.1%, and 96.8%, respectively, and thus markedly lower than that found in the present study. This finding is most likely related to differences in age range and artifact rejection procedures (*ie*, the inclusion of spuriously low values), as the quality of the Spo_2 signal was not analyzed in their study.

Owen and Canter[5] analyzed home recordings of Spo_2 in 222 children 0 to 11 years of age using a Biox 3700e (Ohmeda; Boulder, CO) instrument. They reported a median SAT_5 of 96%, which is 1% below the corresponding value in the present study. The Ohmeda Biox 3700e displays an estimate of fractional Spo_2, which tends to be lower than the functional Spo_2 measured by most other instruments.[9]

Our study has a number of limitations. Data are only reported on 90 children, not on the total sample. This was because these reference data were

needed as a basis for the interpretation of data from our larger project on the prevalence of SDB. We did not record EEG and cardiorespiratory signals, and do not, therefore, have any information on total sleep time or whether desaturations were associated with apneas. Desaturation indexes were therefore based on total AFRT and not on total sleep time. The oximeter used in this study could not be switched into a beat-to-beat mode, but had a 2- to 4-s averaging time instead. This makes it difficult to compare our data on desaturation rates with some previous studies in infants and children also excluding motion artifact.[3] Pilot data from our laboratory, however, suggest that an intermittent desaturation to 90% with a pulse oximeter in the beat-to-beat mode roughly corresponds to a fall in Spo_2 to 92% using a 2- to 4-s averaging mode (own unpublished observation). Finally, it has been questioned whether pulse oximetry can be used to diagnose OSAS,[8] and we have been careful not to imply that a high DI_4 or DI_{90} values are in any way diagnostic of this disorder.

In conclusion, we defined a reference range for Spo_2 in primary school children at sea level with a new-generation pulse oximeter. Our data show that almost all children spent most of the night at Spo_2 values $\geq$ 98% and suggest that intermittent falls in Spo_2 of $\geq$ 4% are frequent in this age group, while those $\leq$ 90% Spo_2 are rare. Almost all children with outlying values had a respiratory condition potentially related to their recording results. These data may serve as a basis for the interpretation of clinical recordings in subjects referred for suspected SDB or a reduced baseline oxygenation.

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