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Computer assisted pulse oximetry for detecting children with obstructive sleep apnea syndrome

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Abstract

A prospective study was carried out on 110 children undergoing tonsillectomy or adenotonsillectomy to evaluate the usefulness of computer assisted pulse oximetry (POM) as a screening tool for nocturnal obstructive sleep apnea episodes. Twenty-one healthy age-matched children served as a control group. A self-designed software (CAPO version 1.0) was used to analyse collected oximetric data. Pre-operatively up to 25% of children showed a characteristic pattern of repeated oxygen desaturations related to partial or complete airway obstruction, which was not seen in the matched group. Thirty-one percent had an oxygen desaturation index (ODI) of more than 2 phases/h, being significantly higher than in the matched group. These children could not be identified from history or clinical examination with an acceptable sensitivity. A second monitoring has been performed in 32 patients 5 days after surgery. The nocturnal cyclic oscillations of oxygen saturation resolved in almost all cases. Computer assisted POM is useful in predicting and grading nocturnal obstruction and adds decision making data for the treatment in children suspected of suffering from obstructive sleep apnea.

Keywords: Pulse oximetry; Screening; Obstructive sleep apnea; Tonsils; Adenoids; Tonsillectomy

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1. Introduction

Obstructive sleep apnea syndrome (OSAS) in children due to tonsillar hyperplasia is a well-defined clinical entity with nocturnal cyclical hypoxemia and CO_2 retention, retarded growth, developmental delay and behavioral disturbances [15]. Right ventricular hypertrophy correlates with nocturnal apneas and has been found in about 20% of children with OSAS [14]. Pulmonary hypertension and cor pulmonale may develop in severe cases [19,33]. Furthermore, upper airway obstruction caused by adenoid-tonsillar hypertrophy has been found to be closely related to the sudden infant death syndrome [20]. On the other hand, not all children with adenotonsillar hypertrophy suffer from OSAS, and this syndrome may also occur in children with only moderately enlarged tonsils [16]. Neuromuscular hypotonia or anatomical abnormalities contribute to the aetiology of OSAS [22]. Most often the syndrome is reversed completely by tonsillectomy [15]. In about 7% of children with a pre-operative diagnosis of OSAS post-operative respiratory problems have been reported [29]. Pre-operative danger signals of potentially post-operative respiratory complications are a history of severe obstructive symptoms with apnea and a pathological sleep study [25].

Obstruction and apnea may go underdetected for years as signs are often not present when the child is awake in the doctor's office and parents usually do not mention snoring and nocturnal apneas. Moreover, there is no agreement on the question about what degree of obstruction is actually significant. Due to the lack of objective parameters tonsillectomy for enlarged tonsils has been criticized [11]. Polysomnography, as the most sophisticated method of assessing nocturnal respiration, is neither readily available nor cost-effective. In order to establish objective quantitative criteria which should detect children with significant nocturnal hypoxemia due to airway obstruction and to facilitate selection of children for T&A we have developed a computer assisted pulse oximetry (POM).

2. Materials and methods

One-hundred-and-ten selected children (mean age 5.7 years, range 15 months–13 years) undergoing routine adenoidectomy and/or tonsillectomy with indications of hyperplasia or recurrent infections were included (adenotomy only 13, tonsillectomy only 16, adenotonsillectomy 81). None of these children showed functional or structural anomalies known to be associated with OSAS other than adenotonsillar hypertrophy. Twenty-one age-matched children without symptoms of obstructed breathing and without enlarged tonsils served as a control group. Institutional review board approval and informed consent from the parents were obtained. A detailed history was attained through the parents using a standard questionnaire emphasizing the signs of OSAS. Pre-operatively all children had a pulsoximetric monitoring during nocturnal sleep. An Ohmeda Biox 3700 pulsoximeter was used to measure O_2-saturation (SaO_2) and pulse frequency at 2 and 12 s intervals during a sleep period of at least 4 h. Snoring and apneas were noted by a nurse, who observed the children periodically during the night. In the morning the collected

data were transferred into a personal computer via an RS 232 serial interface to perform a statistical analysis and graphical printout using a self-designed software (CAPO version 1.0) [35]. The software algorithm recognizes and excludes automatically erroneous SaO_2-readings, e.g. due to movements of the child or probe displacement. In accordance with other reports a significant desaturation was defined as a SaO_2-drop equal or greater than 4% [37]. The CAPO-software calculates different indices: an oxygen desaturation index (ODI), which expresses the mean number of significant desaturations/h; a maximal ODI (ODI_{max}), which represents the ODI of that 1 h interval with the most desaturations; a pulse variation index (PVI) and a PVI_{max}. Norms for oximetric data were established upon the results of the matched group. Comparative statistical analysis was performed with ANOVA and χ-square test.

3. Results

Pre-operatively up to 25% of children showed a characteristic pattern of repeated oxygen desaturations related to partial or complete airway obstruction. In severe cases pulse frequency variations were associated with the desaturation episodes. These events and patterns were not found on recordings of the 21 age-matched healthy children. As evidenced by the results of the matched group an ODI of more than 2 phases/h was considered as pathological (Table 1). According to this ODI the incidence of pathological POM in all children referred for T&A was 31% whereas only 1 child in the matched group was found to have an abnormal study (Table 1). Table 2 demonstrates symptoms and clinical findings of children with normal and abnormal POM. No significant differences existed between the two groups as far as reported snoring, diurnal hypersomnolence and adenoid hypertrophy at examination are concerned, whereas apneas, restless sleep and the clinical finding of large palatine tonsils were significantly related to a pathological POM.

Table 1
Pulsoximetric data of children before A and/or T and of an age-matched control group

	Children before T&A ($n = 110$)	Matched group ($n = 21$)	P-value (ANOVA)
ODI[a]	2.9	1.4	< 0.05
ODI_{max}[b]	7.3	2.9	< 0.05
PVI[c]	3.9	3.8	ns
PVI_{max}[d]	8.0	8.1	ns
SD SaO_2[e]	1.4	0.8	< 0.02
ODI > 2	31%	5%	< 0.05
Age	5.8 years	6.3 years	ns

[a]ODI, oxygen desaturation index;
[b]ODI_{max}, maximal oxygen destaturation index;
[c]PVI, pulse variation index;
[d]PVI_{max}, maximal pulse variation index;
[e]SD SaO_2, standard deviation of oxygen saturation.

Table 2
History obtained from parents and clinical findings of children with normal and abnormal pulse oximetry (POM) before surgery

	Normal POM ($n = 62$)			Abnormal POM ($n = 48$)		
	Yes (%)	No (%)	Don't know (%)	Yes (%)	No (%)	Don't know (%)
Snoring	82	6.5	11.5	81	6.5	12.5
Apneas	40.5	29	30.5	71	14.5	14.5
Restless sleep	14.5	45	40.5	44	23	33
Daytime somnolence	13	79	8	21	75	4
Hypertrophied adenoid	59.5	40.5		73	27	
Hypertrophied tonsils	51.5	48.5		71	29	
Age		6.3 years			4.8 years	

Sensitivity and specificity of history and physical findings with regard to nocturnal hypoxemia are summarized in Table 3. History and clinical examination did not identify children having a pathological POM with an acceptable sensitivity. Thirty-two children were available for a second monitoring 4 or 5 days after adenoidectomy and/or tonsillectomy. In all children presenting an ODI > 2 phases/h pre-operatively the abnormal episodes of nocturnal hypoxemia entirely disappeared or greatly improved after surgery (Fig. 1). Post-operatively none of our pediatric patients showed clinical evidence of cardiopulmonary or airway compromise.

4. Discussion

Adenotonsillar hypertrophy has been recognized as the most common cause of OSAS in children. The prevalence of OSAS in children with T&A diseases varies between 20 and 40% [8,18]. Though there has been a clear rise in OSAS as a significant indication for adenotonsillectomy, identification of children with even severe airway obstruction is often delayed [28]. As an example, Fig. 2 illustrates the oximetric tracing of a child who was not referred for tonsillectomy because of hypertrophied tonsils before stridorous breathing occurred as a consequence of an

Table 3
Sensitivity and specifity of history and clinical findings compared to patients with a pathological POM (χ-square test)

	Sensitivity	Specifity	P-value
Snoring	0.43	0.57	ns
Apneas	0.58	0.72	< 0.01
Restless sleep	0.70	0.72	< 0.001
Daytime somnolence	0.56	0.58	ns
Hypertrophied adenoid	0.49	0.66	ns
Hypertrophied tonsils	0.52	0.68	< 0.05

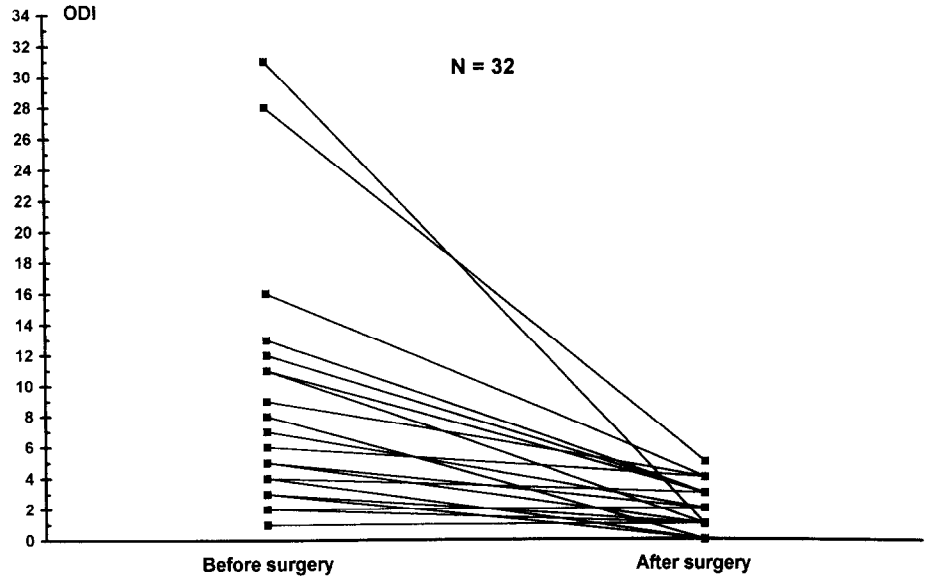

Fig. 1. Oxygen desaturation index (ODI) before, and 4 or 5 days after adenoidectomy and/or tonsillectomy of 32 randomly selected children.

upper respiratory infection. After the child fell asleep (arrow) obstructive apneas up to 40 seconds with paradoxal breathing movements and periodic oxyhemoglobin desaturations were observed. After performing an adenotonsillectomy before midnight, obstructive apneas and oxyhemoglobin desaturations completely resolved. However, most children with obstruction present less obvious signs and symptoms. Brouillette et al. found a high sensitivity and specificity applying a standardized questionnaire in order to detect children with OSAS [1]. In accordance with the results of Croft et al. a history of snoring was not helpful in our patients either, whereas one of the breathing irregularities was found to be highly specific (Table 3) [6]. Unfortunately parents are often unable to report whether apneas and restless sleep occur or not (Table 2). Clinical findings like oropharyngeal dimensions and tonsillar size were also correlated to nocturnal obstructed breathing [3]. The impression of markedly enlarged tonsils can predict nocturnal airway obstruction to some degree (Table 3). However, severe symptoms of obstruction can be observed in children with nearly normal tonsillar size as well as in those with large tonsils [1]. Polysomnography remains the definitive diagnostic technique, but is too expensive and time-consuming and therefore is reserved for very selected cases. A simple screening method is desirable. Several screening tests have been proposed including electrocardiography [12], thoracic impedance, respiratory inductive plethysmography [4], acoustic monitoring of breath sounds [24], flow detection [2], nasal capnography [30] and oximetry [23]. The handicap of most of these devices is that they are often not easily available, are not applicable on an outpatient basis or lack standard criteria for evaluation. In children hypoxemia, as a consequence of upper

airway obstruction during sleep, may not lead to significant changes in heart rate [7]. As such, heart rate and pulse frequency are not reliable screening parameters. In our pediatric patients pulse frequency variations, often being associated with desaturation phases in adults with OSAS, were not seen either except for some more severe cases (Table 1). Microphone breath sound detector, coupled to the chest wall, has been found to be as capable of detecting obstructive apneas as airflow measurement [2]. Portable multichannel recordings are a new screening approach to evaluate apnea in infants and children, but are not as easily practicable as POM [38].

Since 1980 pulse oximetry has made a dramatic impact on anesthesia monitoring [34]. It has become the preferred method of monitoring oxygen saturation because

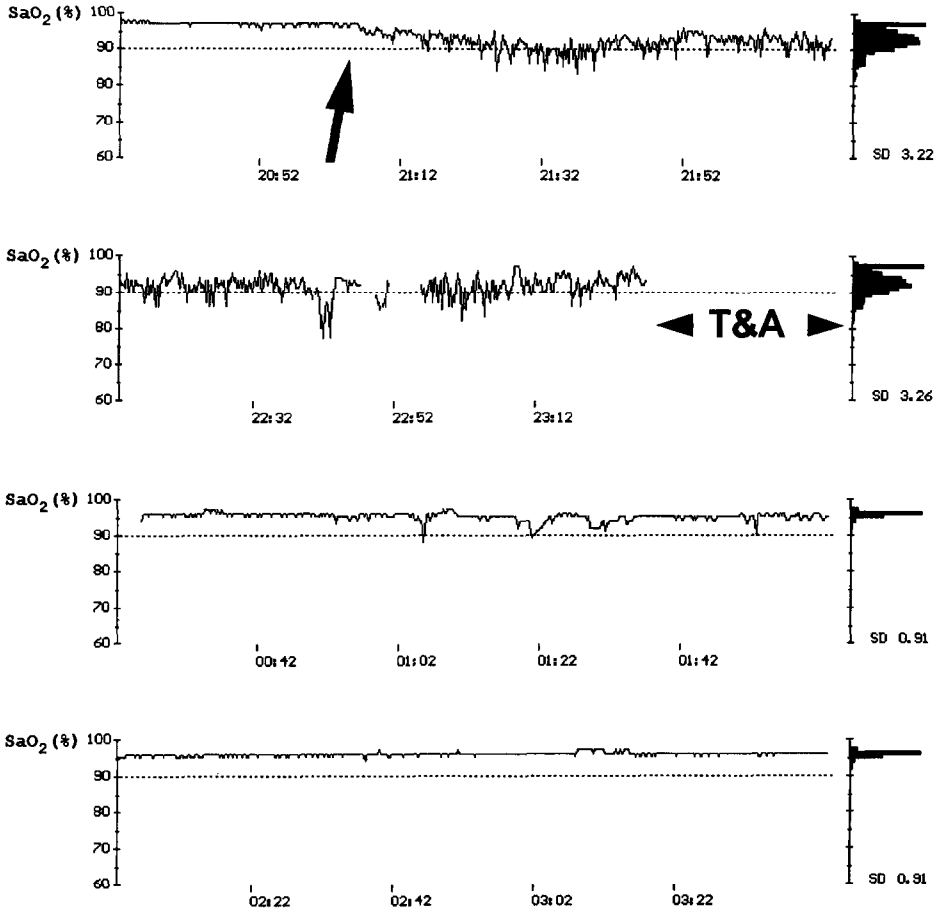

Fig. 2. Pulse oximetric tracing of a child with enlarged tonsils and OSAS, which exacerbated during an upper respiratory tract infection. After the child fell asleep (arrow), obstructive apneas up to 40 s occurred and were documented with an infrared camera, a breath sound recorder and POM. A T&A was performed the same night (arrows). During the second night period airway obstruction completely resolved and oxygen saturation reversed to normal values.

of non-invasivity, lack of side effects and high accuracy. Through its widespread use low-cost, high quality devices are now available. POM has been evaluated as a screening test for adult OSAS. Oximetry alone allowed recognition of a moderate or severe OSAS with a sensitivity between 75 and 100%, dependent on the apnea-hypopnea-index (AHI) used as the diagnostic criterion [5]. Pepin et al. found a sensitivity of 95% carrying out a mathematical analysis of the SaO_2 signal [23]. George et al. performed a computer assisted analysis of the SaO_2 signal with a resulting sensitivity of 98% for OSAS; only a few patients were falsely categorized as positive [10]. POM has been applied successfully to screen children for obstructed breathing during sleep [36]. If recorded for at least 4 h nocturnal oximetric monitoring provides accurate information for clinical purposes [31].

One limitation of POM is that arterial oxygen desaturation does not occur until PaO_2 has decreased below 90 mm Hg. Therefore, mild apneas may not be followed by a significant desaturation and may go underdetected. An unconspicuous POM does not prove that no obstruction exists. Partial upper airway obstruction, even without apneas, may influence pulmonary arterial pressure and children with upper airway resistance syndrome (UARS) may suffer from the same consequences of sleep disordered breathing as obstructive sleep apnea patients [9]. If the result of POM is indeterminate, history and clinical assessment offer additional criteria to the detection of OSAS. Apneas with apparent continued efforts to breathe are pathognomonic, if reported accurately. Restless sleep as well as the finding of considerably enlarged tonsils are suggestive of OSAS. As such, if clinical suspicion is high, POM should be repeated or tonsillectomy should be performed.

On the other hand, when desaturations occur, then a significant disturbance of arterial blood pO_2 is present. The evidence of several phasic drops in O_2-saturation is strongly indicative of OSAS [37]. The predictive value positive of POM as a screening test is expected to be high. But a pathological nocturnal oximetry alone does not necessarily mean that a tonsillectomy ought to be performed. Other causes known to produce obstruction must be excluded. In infants sleep associated dysfunctional pharyngeal obstruction without the presence of structural abnormalities, including tonsillar or adenoidal enlargement, can lead to airway obstruction. A fiberoptic endoscopy of the upper airways can be of essential help excluding such structural or functional abnormalities [32].

Another difficulty in screening children for OSAS is that adult criteria for obstructive apnea do not necessarily identify children with serious obstruction [26]. Polysomnographic results in the pediatric group differ from those in adults [17]. There is general agreement, that a respiratory distress index (RDI) greater than 10 is pathological in adults. Healthy children over 2 years only show very few apneas so that an RDI of 5 is already regarded as high [13]. Normal oximetric values for the pediatric age group have not been established yet and may be age-dependent. Upon the results of our matched group we have chosen an ODI of 2, respectively an ODI_{max} of 4 as a critical limit. Both a standard deviation of SaO_2 exceeding 1.0 and a saturation drop below 90% should also be considered as pathological (Table 1).

None of our children developed post-operative respiratory or cardiopulmonary complications. This is most probably due to the fact that the vast majority of our patients only presented a lesser degree of obstruction. Post-operative airway compromise in children undergoing A and/or T with associated medical problems that contribute to or result from their OSAS has been described ranging from O_2 desaturation $< 80\%$ to respiratory failure [27]. As a consequence, nocturnal oximetry monitoring should be part of the pre-operative evaluation of these mostly younger children. When the result indicates a manifest OSAS, surgery should be only performed in an inpatient setting. The anesthesiologist should be prepared for a perioperative airway obstruction [21]. More severe cases deserve a post-operative overnight observation with an apnea monitor and oximeter as well as the possibility to use CPAP or to perform re-intubation.

5. Conclusion

Measurement of nocturnal oxygen saturation may be an important adjunct to the evaluation of children suspected of suffering from obstructive sleep apnea due to adenotonsillar hyperplasia. A pulse oximetric examination of the sleeping child should facilitate selection of children for T&A and should result in earlier treatment and less morbidity.

Oximetric tracings of children with obstructive sleep apneas show a specific pattern, not being found in healthy children. More than 2 significant desaturations/h (ODI $>$ 2 phases/h) indicate a relevant sleep ventilatory disorder, whereas a normal POM does not necessarily exclude a mild degree of obstruction and therefore must be assessed in relation to history and clinical findings. Pathological desaturations due to tonsillar obstruction disappear in nearly all cases after adenoidectomy and/or tonsillectomy. Using the criteria of reported nocturnal apneas, restless sleep, markedly enlarged tonsils and pathological POM, children with significant obstruction can be identified accurately. Overnight POM is a simple, non-invasive screening tool, is acceptable to families and thus makes ambulatory home monitoring possible.

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