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Feasibility of High-Resolution Oximeter Plus Actigraphy Combined with a Cloud-Based Algorithm for the Detection of Obstructive Sleep Apnea in Children with Craniofacial Anomalies

Sergio Henrique Kiemle Trindade[1,2,3] Fábio Luiz Banhara[1] Leide Vilma Fidélis da Silva[1]
Sara Quaglia de Campos Giampá[4] Lais Mota Furtado Sena[3] Ivy Kiemle Trindade-Suedam[1,5]

[1] Sleep Studies Unit, Laboratory of Physiology, Hospital for Rehabilitation of Craniofacial Anomalies, University of São Paulo, Bauru, SP, Brazil
[2] Faculdade de Medicina de Bauru, Universidade de São Paulo (FMBRU-USP), Bauru, SP, Brazil
[3] Department of Otorhinolaryngology, Hospital de Reabilitação de Anomalias Craniofaciais (HRAC), Universidade de São Paulo (USP), Bauru, SP, Brazil
[4] Laboratory of Medical Research on Sleep (LIM/63), Division of Pulmonology, Department of Cardiopulmonology, Instituto do Coração (InCor), Hospital das Clínicas, Faculty of Medicine, Universidade de São Paulo (HCFMUSP), São Paulo, SP, Brazil
[5] Department of Biological Sciences, Bauru School of Dentistry, Universidade de São Paulo (USP), Bauru SP, Brazil

Address for correspondence Sergio Henrique Kiemle Trindade, PhD (e-mail: sktrindade@usp.br).

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Abstract

Objective To verify the feasibility of high-resolution oximeter plus actigraphy combined with a cloud-based algorithm for the detection of obstructive sleep apnea (OSA) in children with craniofacial anomalies.

Materials and Methods In the present prospective, cross-sectional study, we evaluated children previously submitted to primary surgical palate repair with a genetically confirmed diagnosis of Treacher Collins syndrome (TCS), non-syndromic Robin sequence (NSRS), or non-syndromic cleft palate (NSCP). The children underwent a clinical evaluation, had their anthropometric measures taken, and were submitted to OSA detection using high-resolution oximeter plus actigraphy combined with a cloud-based algorithm (Biologix Sleep Test, Biologix Sistemas S.A., São Paulo, SP, Brazil).

Results In total, 64 children (TCS: n = 16; NSRS: n = 29; NSCP: n = 19) were included in the final analysis (mean age: 10 ± 2 years; 64% of female patients). The Biologix Sleep Test showed that 59 patients (92%) presented OSA according to the oxygen desaturation index (ODI): 36 (56%) were diagnosed with mild OSA, 19 (30%), with moderate OSA, and 4 (6%), with severe OSA. The high-resolution oximeter recording showed excellent signal quality in 94.53 ± 5.29% of the exams, with a success rate of exams on

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- oximetry
- actigraphy
- sleep apnea
- obstructive
- Treacher Collins syndrome
- Pierre Robin syndrome

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the first night of 90%. No significant difference was found in terms of ODI among the subgroups ($p > 0.05$). A significant relationship was observed between increased ODI with greater hypoxic burden and lower estimated sleep efficiency. The multiple linear regression analysis demonstrated a significant association between changes in total ODI with lower estimated sleep efficiency and sleep ODI.

Conclusion High-resolution oximeter plus actigraphy combined with a cloud-based algorithm demonstrated adequate feasibility and applicability for OSA detection in children with craniofacial anomalies.

Introduction

Obstructive sleep apnea (OSA) is characterized by recurrent events of partial or complete upper airway obstruction, typically accompanied by oxyhemoglobin desaturation and arousal, which can significantly impact child development.[1,2] In the general pediatric population, the prevalence of OSA ranges from 2 to 5%, and it is more common in specific clinical conditions, such as craniofacial anomalies.[2]

In this context, the presence of cleft palate (CP) in isolation already determines a three-fold higher risk of OSA compared to the general pediatric population. This risk is further elevated in the presence of syndromes and anomalies associated with CP, including Treacher Collins Syndrome (TCS) and Robin sequence (RS).[3,4] A rare congenital condition, TCS presents an approximate prevalence of 1 in every 50 thousand live births.[5] Its characteristics include mandibular hypoplasia and/or retrognathia, orbital dimorphism, zygomatic hypoplasia (with or without CP), auricular and pharyngeal hypoplasia, among other alterations.[5] Conversely, RS is a heterogeneous congenital craniofacial anomaly characterized by micro/retrognathia, glossoptosis, and, in most cases, a U-shaped CP.[6–9] It has a multifactorial etiology, with prevalence ranging from 1.2 to 40.4 per 100 thousand live births, leading to severe feeding difficulties and respiratory complications, which are associated in up to 60% of the cases with syndromic conditions and/or other congenital anomalies, which, in turn, increases the complexity of the clinical management[6,8–10]

The association between craniofacial anomalies and elevated OSA risk underscores the need for an accurate diagnosis. While polysomnography (PSG) combined with clinical evaluation remains the gold standard to assess OSA in the pediatric population,[1,11,12] its high cost and logistical challenges often limit its implementation. Therefore, portable monitoring (PM) has emerged as a promising objective OSA screening instrument, especially because it is low-cost, easy to use, it enables greater mobility, eliminating the bias related to maintaining a forced dorsal position, and it facilitates the performance of serial examinations.[13–15]

High-resolution oximeter plus actigraphy combined with a cloud-based algorithm (Biologix Sleep Test, Biologix Sistemas S.A., São Paulo, SP, Brazil) is a new PM device that has been validated for OSA diagnosis in adults when compared to PSG and traditional PM used at home.[14,16] However, there is lack of evidence regarding its applicability and feasibility in the pediatric population.[13] Therefore, the objective of the present study was to verify the feasibility of performing the Biologix Sleep Test in children with craniofacial anomalies and to identify the frequency of OSA in the study sample.

Materials and methods

Study Design

The present is a prospective, cross-sectional study that recruited school-aged children of both sexes from the Outpatient Clinic of (Hospital for Rehabilitation of Craniofacial Anomalies, Universidade de São Paulo). The study included children previously submitted to primary surgical palate repair with a genetically confirmed diagnosis of TCS, non-syndromic RS (NSRS), or non-syndromic CP (NSCP). Patients with other syndromes and associated anomalies/malformations, those previously submitted to orthognathic maxillary advancement surgery, subjects presenting tracheostomy at the time of evaluation, history of mandibular distraction osteogenesis and neuromuscular disorders, difficulty understanding the research instruments, and those in chronic use of medications, including respiratory system depressors, and/or in use of antibiotic therapy for upper-airway infection in the previous 3 months were excluded.

The present study was approved by the institutional Ethics Committee (report 5.880.145, CAAE:51879521.3.0000.5441 and report 5.144.944, CAAE; 52373721.0.0000.5441). All procedures were conducted in full compliance with the Declaration of Helsinki and its subsequent amendments or comparable ethical standards. The legal guardians and the participants signed an informed consent form and an assent form authorizing the collection of clinical data, images of examinations, and reports used for scientific purposes.

Clinical Assessment

Sociodemographic data (sex and age) and surgical history were assessed through the application of a structured questionnaire. Anthropometric data were verified, and the body mass index (BMI) was calculated and corrected for age and sex using the World Health Organization's WHO AnthroPlus software (free) as reference, scoring the participants according to their nutritional status using the Z-score.[17]

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Sleep Study

The patients underwent the Biologix Sleep Test, which consists of a high-resolution oximeter (Oxistar, Biologix Sistemas S.A.) with a built-in accelerometer, connected via Bluetooth to a smartphone application (app) that records snoring. The Oxistar firmware acquires 100 samples per second, generating beat-to-beat raw data of oxygen saturation (SpO_2) with a resolution of 0.1%. A moving average of four cardiac beats is applied. All collected data are transferred via the smartphone app to the cloud and automatically analyzed by a proprietary algorithm.[14,16]

Following the process, the oxygen desaturation index (ODI) is calculated with the number of dessaturations (defined as a reduction $>3\%$ in SpO_2) per hour of valid recording time. The ODI was used for the OSA diagnosis, and values from 1 to 5 were indicative of mild OSA, from 5 up to 10, of moderate OSA, and above 10, severe OSA.[1,18] Other variables provided by the Biologix Sleep Test, including sleep ODI, hypoxic burden, estimated sleep efficiency, $SpO_2 < 90\%$ and snoring time (%), were also evaluated as secondary outcomes. A minimum of 6 hours of recording was considered valid for analysis.

Furthermore, we analyzed the Oxistar signal quality in measuring SpO_2 in children. This involved removing signal segments considered invalid due to movement artifacts, poor sensor positioning, or very low perfusion index. After the cleaning of the signal, only valid segments were retained to calculate the ODI and other variables. Considering that the present study is focused on a pediatric population, the processed data was compared to the adult population from the Biologix database.

The objective of this comparison was to verify if the proportion of valid recording time was equivalent between adults and children. This comparison enabled the assessment of the accuracy and reliability of SpO_2 measurements in a population for which the Biologix Sleep Test has not yet been validated.

Statistical Analysis

The sample size calculation was performed considering the prevalence of 26.5% of sleep-disordered breathing (SDB) symptoms assessed by a study[19] that applied the Brazilian version of the Sleep Disturbance Scale for Children (SDSC); and the prevalence of OSA (22%) was assessed in another study[20] by PSG in children and adolescents with RS aged 1 to 18 years. Since the total population of children and adolescents with RS in the study was of 250 individuals under active treatment during the study period, the sample size calculation resulted in 52 participants with NSRS and 52 children with NSCP, considering the expected prevalence of 22% of OSA, adopting an error margin of 10% and a test power of 80%. Regarding the subgroup with TCS, the formal sample calculation was performed considering an alpha error of 5%, a beta error of 20%, a minimum difference to be detected in SpO_2 levels of 2%, and a standard deviation (SD) of ± 2.527, obtaining a minimum of 14 individuals to compose the sample.

Data were analyzed by descriptive analysis and expressed as absolute frequencies (n) and mean and SD, median, minimum and maximum values, and quartiles (25% and 75%). The variables studied in the three groups (NSCP, NSRS, and TCS) were compared using the Kruskal-Wallis's test, which was also used to analyze the degrees of ODI, the hypoxic burden, the snoring time, ODI sleep, estimated sleep efficiency, and time of $SpO_2 < 90\%$, considering all study participants for the variables of interest. Multiple linear regression analysis was applied to the same variables of the patients in the three groups. Statistical analyses were performed on the Jamovi software (free and open source), version 2.2.

Results

A total of 176 children were approached according to the primary diagnosis of TCS, NSRS and NSCP, and the final sample consisted of 64 children (►**Fig. 1**). The main cause of exclusion was lack of return after the initial approach, followed by refusal to undergo the sleep study. There were 16 children with TCS (25%), 29 children with NSRS (45%), and 19 children with NSCP (30%). In general, a lower mean age was observed among children with NSRS (8.72 ± 2.12 years), with significant differences in the sample regarding mean age and BMI Z-score in relation to the TCS group. Regarding the BMI Z-score, a prevalence of eutrophic and thin profile was observed, ruling out obesity and overweight bias in the population as influencing the changes in ODI present in the study. The anthropometric characteristics of the population studied are presented in ►**Table 1**.

In the current study, we identified the presence of excellent signal quality, with a means of 95%, and reduced error events, with percentages below 5%. The detailed signal analysis is presented in ►**Table 2**. A total of 58 patients successfully underwent the exam on the 1st night, and 6 patients required an additional night to record more than 6 hours. Overall, a successful rate of examinations of 90% was observed in the first night.

Out of 64 patients evaluated, 59 patients (92%) presented OSA: 36 (56%) mild cases, 19 (30%) moderate cases, and 4 (6%) severe cases. Descriptive data regarding the sleep study results are shown in ►**Table 2**. The frequency of OSA was similar among patients with NSCP, NSRS and TCS. The mean SpO_2 was significantly lower in the TCS group ($p = 0.028$)

In the study sample, a positive relationship was observed involving changes in ODI indicative of OSA (above 1) and greater hypoxic burden, presence of more episodes of $SpO_2 < 90\%$, and lower sleep efficiency, as shown in ►**Table 3**. When performing the multiple regression analysis, regarding the anthropometric variables, a significant association was observed between older age and longer snoring time (in minutes) in the STC group ($p = 0.049$), as shown in ►**Table 4**. No significance was observed in the other relationships evaluated ($p > 0.05$). If we consider the total group of children, in the multiple regression analysis, a significant association was observed between changes in

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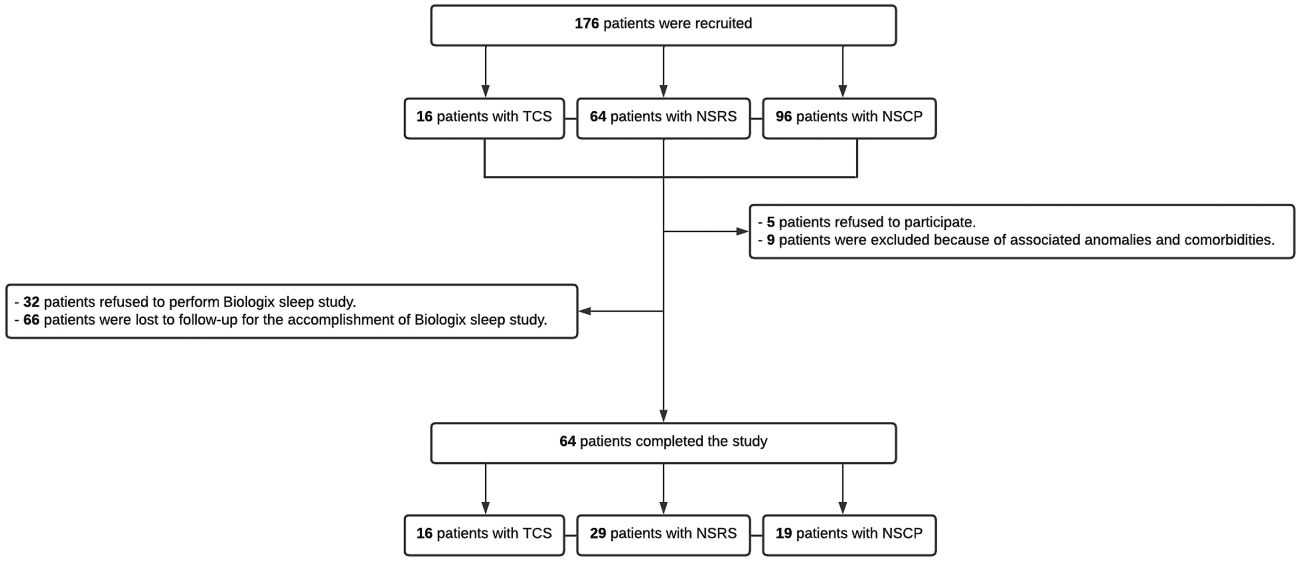

Fig. 1 Flowchart of patient recruitment and inclusion. **Abbreviations:** TCS, Treacher Collins syndrome; NSCP, non-syndromic cleft palate; NSRS, non-syndromic Robin sequence.

Table 1 Baseline characteristics of the study sample.

Variables	All patients (N = 64)	NSCP group (N = 19)	NSRS group (N = 29)	TCS group (N = 16)	*p*-value
Age (years)					0.005*
Mean ± SD	9 ± 2.74	9 ± 2.22	8 ± 2.12	12 ± 3.14	
Min–Max	6–12	6–12	6–12	7–12	
Sex					0,735^{x2}
Female: n (%)	37 (57.81)	11 (57.89)	18 (62.07)	8 (50.00)	
BMI Z-score					0.006*
Mean ± SD	-0.24 ± 1.18	0.11 ± 0.61	0.07 ± 0.73	-1.23 ± 1.75	
Min–Max	-3.2-2.8	-0.7-1.8	-0.7-2.5	-3.2-2.8	
ODI (events/hour)					0.408
Mean ± SD	4.39 ± 3.12	4.14 ± 3.90	4.22 ± 2.59	4.98 ± 3.10	
Min–Max	0.4–17.4	0.6–17.4	0.4–10.4	0.8–12.4	
Sleep ODI (events/hour)					0.492
Mean ± SD	3.01 ± 2.56	2.86 ± 3.06	2.92 ± 2.48	3.36 ± 2.18	
Min–Max	0–13.6	0–13.6	0.1–10.6	0.8–7.6	
Hypoxic burden (%, minutes/hour)					0.106
Mean ± SD	21.28 ± 14.40	18.92 ± 16.82	19.44 ± 12.41	27.44 ± 13.79	
Min–Max	0.8–74.6	3.3–74.6	0.8–56.6	9.6–52.3	
SpO_2: minimum (%)					0.723
Mean ± SD	89.09 ± 3.20	88.79 ± 3.69	89.45 ± 2.90	88.81 ± 3.23	
Min–Max	79–95	79–95	82–93	81–93	
SpO_2: mean (%)					0.028*
Mean ± SD	96.88 ± 1.28	97.21 ± 1.23	97.14 ± 0.99	96.00 ± 1.46	
Min–Max	93–99	95–99	95–98	93–98	

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Table 1 (*Continued*)

Variables	All patients (N = 64)	NSCP group (N = 19)	NSRS group (N = 29)	TCS group (N = 16)	*p*-value
SpO_2: maximum (%)					0.879
Mean ± SD	99.64 ± 0.84	99.74 ± 0.65	99.69 ± 0.71	99.44 ± 1.21	
Min–Max	96–100	98–100	97–100	96–100	
HR: minimum (bpm)					0.426
Mean ± SD	54.95 ± 11.75	52.68 ± 7.02	55.31 ± 6.66	57.00 ± 20.65	
Min–Max	39–131	44–74	44–77	39–131	
HR: mean (bpm)					0.515
Mean ± SD	77.05 ± 13.35	75.00 ± 9.23	77.72 ± 9.64	78.25 ± 21.56	
Min–Max	61–151	64–100	62–99	61–151	
HR: maximum (bpm)					0.630
Mean ± SD	124.44 ± 12.45	123.53 ± 7.40	126.34 ± 14.09	122.06 ± 14.16	
Min–Max	103–164	110–136	107–163	103–164	
Total sleep time (minutes)					0.155
Mean ± SD	377.91 ± 107.79	401.20 ± 95.93	382.16 ± 113.31	342.56 ± 112.10	
Min–Max	39–526	175–526	53–526	39–526	
Time awake after sleep (minutes)					0.482
Mean ± SD	64.97 ± 40.97	66.53 ± 38.52	68.22 ± 44.82	57.22 ± 35.97	
Min–Max	1.5–211	3.5–142	1.5–211	2–132	
Sleep efficiency (%)					0.287
Mean ± SD	78.94 ± 9.13	80.79 ± 9.90	79.10 ± 7.74	76.44 ± 10.45	
Min–Max	55–93	55–89	62–89	59–93	
Snoring time (%)					0.330
Mean ± SD	14.09 ± 20.76	11.74 ± 17.31	16.59 ± 24.80	12.38 ± 16.75	
Min–Max	0–115	0–58	0–115	0–62	
Snoring time (minutes)					0.334
Mean ± SD	59.22 ± 81.24	61.84 ± 92.14	68.34 ± 89.22	39.56 ± 45.77	
Min–Max	0–387	0–327	0–387	0–142	

Abbreviations: BMI, body mass index; bpm, beats per minute; HR, heart rate; Max, maximum; Min, minimum; NSCP, non-syndromic cleft palate; NSRS, non-syndromic Robin sequence; ODI, oxyhemoglobin desaturation index; SD, standard deviation; SpO_2, partial oxyhemoglobin saturation; TCS, Treacher Collins syndrome.

Notes: BMI Z-score: BMI corrected for age and sex, Z-score. All variables were evaluated with Kruskal-Wallis's test. Except for the gender variable where the chi square test was used. All records of the Nocturnal Hypoxia Index were equal to zero. ^{x2}Chi-squared test. *Statistically significant difference: $p < 0{,}05$.

total ODI with lower estimated sleep efficiency and sleep ODI, as shown in ►**Table 5**.

Discussion

In the present study, we could observe good applicability in the use of a high-resolution oximeter plus actigraphy in home sleep assessments in children with craniofacial anomalies based on the high success rate of the exam on the first night and the signal quality demonstrated. The high occurrence of altered ODI (92%) was also evident in the group evaluated with a predominance of ODI indicative of mild and moderate OSA (86%). These results point to the importance of evaluating OSA in school-aged children with craniofacial anomalies.

Excellent signal quality and a low percentage of signal errors that could compromise the quality of the physiological data obtained for analysis were observed. These data demonstrate that the use of PM without supervision by a technician is feasible from an operational standpoint, with a small need for repeat examinations (10%), considering the 6-hour recording time as adequate. Examinations with inadequate signal were not observed. Although the viability of its use in adult populations as an alternative method to level-I PSG (PSG I) is well defined,[14,16] its viability in children must be better elucidated.[13] It is also worth noting that the adoption of measures such as prior guidance for primary caregivers, provision of written guidance and information, as well as adequate remote support for children's caregivers contributed to the successful completion of exams.

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Table 2 Evaluation of high-resolution oximeter plus actigraphy combined signal quality in children with craniofacial anomalies.

Signal quality across patients (%)		
Variable	**Mean**	**± SD**
Mean signal quality (total)	94.53	± 5.29
Mean signal quality (Biologix databank)	97.24	± 5.08
Duration of errors across patients (%)		
Variables (errors)	Mean	
Status variation[a]	3.93	
Poor signal quality[b]	1.45	
Off finger[c]	0.12	

Abbreviation: SD, standard deviation.
Notes: [a]"Status variation" indicates significant fluctuation between good and poor signal quality, often due to patient movement or sensor instability. [b]"Poor signal quality" indicates insufficient signal quality due to external interference such as body movements or inadequate sensor positioning. [c]"Off fingers indicate absence of finger signal, typically caused by sensor disconnection or turning off by the user, leading to absence of physiological data.

Table 3 Correlation of ODI with the sleep variables.

Variables		**ODI**				
		Normal	**Mild**	**Moderate**	**Severe**	***p*-value**
		N = 5	**N = 36**	**N = 19**	**N = 4**	
Sleep ODI	Normal	5	6	–	–	< 0.001*
	Mild	–	30	15	–	
	Moderate	–	–	4	3	
	Severe	–	–	–	1	
Hypoxic burden (%, minute,/hour)	Mean	6.7	15.23	32.7	40	< 0.001*
Minimum SpO_2 (%)	< 80	–	–	1	–	
	< 90	–	17	11	2	0.004*
	≥ 90	5	19	7	2	
Mean SpO_2 (%)	< 80	–	–	–	–	0.512
	< 90	–	–	–	–	
	≥ 90	5	36	19	4	
Minimum HR (bpm)	< 50	–	8	5	2	0.746
	50 to 100	5	27	14	2	
	> 100	–	1	–	–	
Mean HR (bpm)	< 50	–	–	–	–	0.356
	50 to 100	5	35	19	4	
	> 100	–	1	–	–	
Maximum HR (bpm)	< 50	–	–	–	–	0.161
	50 to 100	–	–	–	–	
	> 100	5	36	19	4	
Time awake after sleep (minutes)	Mean	46.5	59.5	80.8	62.4	0.291
Sleep efficiency (%)	< 85	1	22	16	3	0.001*
	≥ 85	4	14	3	1	
Snoring time (%)	Mean	21.6	12.6	12.6	25.8	0.364
Snoring time (minutes)	Mean	46.6	49.1	64.5	140.8	0.367

Abbreviations: bpm, beats per minute; HR, heart rate; ODI, oxyhemoglobin desaturation index; SpO_2, partial oxyhemoglobin saturation.
Notes: All variables were avalied with Kruskal-Wallis's test. *Statistically significant difference: $p < 0.05$.

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Table 4 Multiple regression analysis considering the anthropometric variables of the study sample.

Variable		NSCP group	NSRS group	TCS group
Age		$r^2 = 0.304$	$r^2 = 0.226$	$r^2 = 0.536$
	ODI	$p = 0.315$	$p = 0.528$	$p = 0.814$
	ODI during sleep	$p = 0.332$	$p = 0.245$	$p = 0.832$
	Hypoxic burden	$p = 0.720$	$p = 0.576$	$p = 0.499$
	Snoring time (%)	$p = 0.828$	$p = 0.239$	$p = 0.140$
	Snoring time (minutes)	$p = 0.705$	$p = 0.771$	$p = 0.049^*$
	Sleep efficiency	$p = 0.549$	$p = 0.614$	$p = 0.383$
	Snoring intensity	$p = 0.695$	$p = 0.805$	$p = 0.324$
BMI		$r^2 = 0.292$	$r^2 = 0.171$	$r^2 = 0.504$
	ODI	$p = 0.474$	$p = 0.304$	$p = 0.504$
	ODI during sleep	$p = 0.488$	$p = 0.140$	$p = 0.171$
	Hypoxic burden	$p = 0.846$	$p = 0.238$	$p = 0.282$
	Snoring time (%)	$p = 0.609$	$p = 0.760$	$p = 0.193$
	Snoring time (minutes)	$p = 0.756$	$p = 0.996$	$p = 0.400$
	Sleep efficiency	$p = 0.556$	$p = 0.173$	$p = 0.202$
	Snoring intensity	$p = 0.308$	$p = 0.556$	$p = 0.591$
BMI Z-score		$r^2 = 0.542$	$r^2 = 0.247$	$r^2 = 0.137$
	ODI	$p = 0.206$	$p = 0.243$	$p = 0.894$
	ODI during sleep	$p = 0.129$	$p = 0.086$	$p = 0.884$
	Hypoxic burden	$p = 0.968$	$p = 0.167$	$p = 0.846$
	Snoring time (%)	$p = 0.203$	$p = 0.840$	$p = 0.541$
	Snoring time (minutes)	$p = 0.270$	$p = 0.519$	$p = 0.793$
	Sleep efficiency	$p = 0.063$	$p = 0.053$	$p = 0.481$
	Snoring intensity	$p = 0.124$	$p = 0.508$	$p = 0.845$

Abbreviations: BMI, body mass index; ODI, oxyhemoglobin desaturation index; NSCP, non-syndromic cleft palate; NSRS, non-syndromic Robin sequence; TCS, Treacher Collins syndrome.
Notes: BMI Z-score: BMI corrected for age and sex, Z-score. *Statistically significant difference: $p < 0.05$

In the context of the use of PM for the diagnosis of OSA in children with craniofacial anomalies, there are many reports of use in children of different age groups, especially when PSG is not available,[21–23] with the benefit of speed and relative safety in the diagnosis of suspected moderate and severe SDB, especially if performing PSG would result in delayed diagnosis due to inaccessibility, high cost or complex logistics, while the use of type-IV polygraph is associated with early decision-making and no delay in establishing the appropriate treatment.[21,24]

In the present study, we observed a high frequency of ODI alteration, compatible with SDB, of 92% of the total sample, with 56% classified as mild, 30%, as moderate, and 6%, as severe. Similar data with higher prevalence of mild and moderate cases were also observed by authors who evaluated children with craniofacial anomalies.[20,25,26] There was a significant difference among the groups only regarding the mean SpO_2, with lower mean saturation observed in the TCS group ($p = 0.028$). The frequencies observed corroborate the literature reports[2,20,25,26] of high prevalence of SDB in children with craniofacial anomalies, which is significantly higher than the frequency observed in the general pediatric population, including the presence of snoring above the estimated rate in the general pediatric population (between 3% and 15%), with frequencies ranging from 11 to 17%.[1,27] These data are consistent with those of the literature, which demonstrates higher prevalence and severity associated with the presence of craniofacial anomalies when compared to the general pediatric population.[3,28]

Regarding the anthropometric variables, the TCS group presented lower Z-scores and higher mean age, with a statistically significant difference ($p < 0.05$). A correlation was also observed between higher mean age in the TCS group and longer snoring time in minutes, and these findings may be related to greater impairment of the upper airway in this population and complications that would decrease adequate weight gain.[5,25,26] Moreover, there is reduction in the reporting of symptoms by the population with NSRS due to the "catch-up" of mandibular growth between 6 and 8 years of age.[29,30]

In the present study, a significant relationship was found regarding ODI (above 1) and changes in ODI during sleep,

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Table 5 Multiple linear regression analysis of the ODI scores considering the variables of the sleep examination in the study sample.

ODI	$r^2 = 0.773$	*p*-value
Sleep ODI		$< .001^*$
Hypoxic burden		0.982
Minimum SpO_2		0.473
Mean SpO_2		0.195
Maximum SpO_2		0.087
Minimum HR		0.218
Mean HR		0.283
Maximum HR		0.464
Time awake after sleep		0.925
Sleep efficiency		0.004^*
Snoring time in percentages		0.663
Snoring time in minutes		0.290

Abbreviations: HR, heart rate; ODI, oxyhemoglobin desaturation index; SpO_2, partial oxyhemoglobin saturation.
Note: *Statistically significant difference: $p < 0.05$

more episodes of $SpO_2 < 90\%$, higher percentages of hypoxic burden, and lower estimated sleep efficiency regardless of the group evaluated, thus demonstrating consistency in the data, indicating a lower probability of false negative results. It is important to note that data regarding the different desaturation levels and times, as well as calculations of hypoxic burden, are calculated by the algorithm with data obtained from oximetry, not specifically linked to the calculation of ODI, demonstrating the importance of using algorithms to improve the accuracy of the method.[31,32] Additionally, hypoxic burden is associated with changes in the apnea-hypopnea index (AHI), SpO_2 nadir, and sleep time with $SpO_2 > 90\%$; it is also associated with a higher risk of cardiovascular disease.[33]

Studies[31] have shown a high correlation between the AHI derived from PSG and the ODI, both when analyzed as an independent channel of PSG and by high-resolution oximeters, with sensitivity variations from 32 to 98.5% and specificity between 47.7% and 98%. The sleep ODI data is a refinement through the algorithm that identifies the desaturation occurring only in the period of effective sleep, with better refinement for use in the clinical practice.[16,31,34–36] There is evidence that the cumulative time spent with $SpO_2 < 90\%$ and the measurement of the variability of oxyhemoglobin saturation are important data to be compared with the AHI to improve the diagnostic accuracy of OSA.[31,37]

The analysis of estimated sleep efficiency is like PSG, although the PM relies on SpO_2, heart rate (HR), accelerometer and snoring signals to estimate the total sleep time, since it does not have electroencephalogram data. It is important to note that there was consistency between changes in ODI and lower sleep efficiency, demonstrating a correlation between these two aspects, which is clinically explained, since OSA negatively impacts sleep quality in general.[38] Recent studies[38] have observed an association regarding shorter sleep time, lower estimated sleep efficiency, severe cases of OSA, the male sex, and advanced age, without significant variation between data observed in PSG and in home sleep tests. In the present study, a relationship was observed between altered ODI and worse outcomes in terms of estimated sleep efficiency.

The strengths of the present study are a significant sample of children with craniofacial anomalies and proof of the applicability of PM, which consists of a high-resolution oximeter with a built-in actigraphy, with the clear advantage of reducing the first night effect and costs associated with sleep examination using a PSG.[13,15] Additionally, it makes logistics simpler and facilitates the screening of children with craniofacial anomalies for OSA, optimizing diagnosis and favoring the performance of serial exams that are well accepted by children.[39–41] Among the limitations we can list the lack of comparison of data with results from the PSG defined as the gold standard to evaluate OSA. Therefore, new studies are needed on the sensitivity and specificity of PM, in comparison with PSG, in school-aged children with craniofacial anomalies.

Conclusion

The present study demonstrates that PM in children is technically feasible and presents good applicability in children with craniofacial anomalies, with high frequency of ODI compatible with OSA. These data indicate the need to establish a routine to evaluate children with craniofacial anomalies for OSA. Further studies to validate PM in relation to the gold standard of PSG in children are needed to better elucidate this question.

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Conflict of Interests
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