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Original Article

Nasal cannula use during polysomnography in children aged under three with suspected sleep apnea

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ABSTRACT

Objective: Early diagnosis of obstructive sleep apnea (OSA) in children is important. The use of a nasal cannula as an airflow sensor during polysomnography has not been evaluated in younger children. The study aims to evaluate the use of nasal cannula in detecting respiratory events in children under three with suspected OSA during daytime nap studies.
Methods: A total of 185 patients were prospectively included. Respiratory events were scored using nasal cannula alone, thermistor alone, and both methods simultaneously as the airflow sensor. Agreement and diagnostic accuracy were assessed.
Results: One hundred and seventy-two children were finally analyzed and 110 (64.0%) presented OSA. Total sleep time with an uninterpretable signal was longer with the nasal cannula than with the thermistor (17.8% vs 1.9%; $p < 0.001$), and was associated with poor sensor tolerance and adenotonsillar hypertrophy. In the estimation of the apnea-hypopnea index, the nasal cannula showed lower agreement than the thermistor with the joint use of the two sensors (intraclass correlation coefficient: 0.79 vs 0.996 with thermistor). Compared with the thermistor, the nasal cannula presented lower sensitivity for detecting OSA (82.7% vs 95.5%) and a lower negative predictive value (76.5% vs 92.4%). Overall, fewer children were diagnosed with severe OSA with the nasal cannula (19.8% vs 30.8% with the thermistor, and 32.6% with both).
Conclusions: In children under the age of three, the ability of the nasal cannula to detect obstructive events was relatively low. Therefore, other non-invasive measurements for identifying respiratory events during sleep may be of additional value.

1. Introduction

Sleep disordered breathing is a continuum of severity with primary snoring at the mild end and obstructive sleep apnea (OSA) at the severe end [1]. Obstructive sleep apnea (OSA) is increasingly recognized in children and adolescents, with an estimated prevalence between 1% and 4% [2]. Untreated OSA in children is associated with cognitive and behavioral deficits, cardiovascular and metabolic dysfunction, enuresis and impaired growth [3–5]. For these reasons, an early and accurate diagnosis and management of

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Abbreviation list

AASM	American Academy of Sleep Medicine
BMI	Body mass index
CPAP	Continuous positive airway pressure
EEG	Electroencephalogram channels
EMG	Submental electromyogram
EOG	Electrooculogram
NA/SP	Nasopharyngeal airway/soft palate ratio
NC	Nasal cannula
NIMV	Non-invasive mechanical ventilation
OAHI	Obstructive apnea-hypopnea index
OSA	Obstructive sleep apnea
PSG	Polysomnography
RERA	Respiratory effort-related arousals
RERAI	Respiratory effort-related arousal index
SpO2	Peripheral oxygen saturation
TcCO2	Transcutaneous carbon dioxide
Th	Thermistor
TRT	Total recording time
TST	Total sleep time

OSA in children is of the utmost importance.

Nocturnal polysomnography (PSG) is the gold standard method for establishing the presence and severity of OSA in children of any age [3–5]. Polysomnographic manifestations differ in children and adults with OSA, and specific criteria for staging sleep and scoring respiratory events in children have been published [6,7]. Accurate monitoring of airflow and respiratory effort is essential in order to identify and quantify these respiratory events.

Pneumotachography via a snug-fitting mask is considered the most accurate representation of airflow assessment. Nevertheless, it is not used for routine PSG due to the associated patient discomfort and its negative effect on sleep architecture. The recommended alternative is the use of non-invasive methods, namely the oronasal thermal airflow sensor (Th) and the nasal pressure transducer using a nasal cannula (NC) [6]. Oronasal thermal sensors are considered adequate for the detection of apnea, but they underestimate hypopnea because of their slow response time and marked non-linearity [8]. Studies in adults have shown that the NC has excellent agreement with a pneumotachograph [9–11] and intraesophageal pressure [12], and is more sensitive for the detection of apneas, hypopneas and respiratory effort-related arousals (RERA) than Th, with reported differences ranging from 30% to 50% [13–18].

However, few studies have assessed the validity of NC in children or compared its performance with that of Th [19–23]. Consistent with research on adults, these few studies found NC to be more sensitive for detecting respiratory events than Th. A potential drawback to the use of NC in children is the possibility that the airflow signal will be unreliable for a substantial amount of time during sleep. This failure of the NC signal has been attributed to displacement due to movement and intolerance of the NC in the nares, occlusion of the probe with nasal secretions, and mouth-breathing potentially related to the frequent presence of adenotonsillar hypertrophy and recurrent upper airway viral infections [22,23]. All these problems are more likely in younger children, a population with an increased risk for OSA, which can be severe [24,25]. However, studies performed to date have included very few cases of children younger than three years of age. Only Trang et al. [23], in a study with a small sample of children, reported a notable presence of NC problems in this population. In this situation, the respiratory sleep disorder might be underestimated or pass unrecognized in this age group, leading to a delay in its appropriate treatment.

Based on these considerations, the aim of this study is to assess the adequacy of the NC for detecting respiratory events in younger children. Specifically, we evaluated the use of NC and Th, both separately and in combination for detecting respiratory events in children under 3 years of age with suspected OSA.

2. Methods

2.1. Study population

A prospective observational study was performed in 256 consecutive patients under the age of three referred to our Sleep Unit for suspected sleep disorder. Children presenting clinically suggestive symptoms of OSA – snoring, witnessed apneas and mouth breathing – were included in the study. Those who used oxygen, continuous positive airway pressure (CPAP) or non-invasive mechanical ventilation (NIMV), and children with symptoms suggestive of sleep disorder other than OSA were excluded. The study was approved by the Hospital's Ethical Committee, and written informed consent was obtained from the parents/legal caretaker of all participating children.

2.2. Study design

All participants were evaluated by an expert in sleep medicine. The evaluation protocol consisted of a clinical and sleep history obtained from the parents/legal caretaker, a complete physical and ear, nose and throat examination, a lateral neck X-ray and an attended PSG. The clinical data recorded were demographic variables, anthropometric measurements including weight, height, body mass index (BMI) for sex/age z-score, tonsils and adenoid grade, and co-morbidities including prematurity, obesity, gastroesophageal reflux, respiratory and neurologic co-morbidities. Obesity was defined if BMI z-score $\geq$2, using national reference values [26].

Adenoid hypertrophy was determined based on a lateral neck X-ray measuring the airway space immediately behind the upper part of the soft palate (nasopharyngeal airway/soft palate (NA/SP) ratio) according to the Cohen and Konak method [27]. Patients were graded as normal = NA/SP ratio $\geq$1; mild-to-moderate hypertrophy = NA/SP ratio 0.5–1; and severe hypertrophy = NA/SP ratio <0.5. Tonsils were graded according to the Brodsky grading scale [28] where 0 = no tonsils visible, +1= <25% of the oropharynx occupied by the tonsils, +2 = 25–50% of the oropharynx occupied by the tonsils, +3 = 50–75% of the oropharynx occupied by the tonsils, and +4= >75% of the oropharynx occupied by the tonsils. Tonsils and adenoid grade variables were reduced as a single combined variable. Patients were classified in three groups: normal (NA/SP ratio $\geq$1 and tonsils grade 0 or +1), mild-to-moderate hypertrophy (NA/SP ratio 0.5–1 and/or tonsils grade +2), and severe hypertrophy (NA/SP ratio <0.5 and/or tonsils grade +3 or +4).

2.3. Polysomnography (PSG)

An attended PSG was performed in the sleep laboratory using an E-Series system (Compumedics Inc, Melbourne Abbotsford, Australia). The company of a parent/legal caretaker beside the child was allowed, for greater patient comfort. Polysomnography was performed during a daytime nap from 09:00am to 02:30pm, after a night of partial sleep deprivation as described previously [29]. Children were allowed to sleep in their preferred position. No sedation was used.

Monitoring included electroencephalogram channels (EEG), electrooculogram (EOG), intercostal and submental electromyogram (EMG), airflow, chest and abdominal movements using respiratory inductive plethysmography, arterial oxygen saturation by pulse oximetry (SpO2), transcutaneous carbon dioxide (TcCO2) (TCM4, Radiometer, Copenhagen, Denmark), snoring by microphone, electrocardiography, body position and simultaneous video recording. The airflow signal was simultaneously monitored using an oronasal thermistor (Th) (Protech Services Inc, Murrysville, PA, USA) and a pediatric nasal cannula (NC) (Salter Labs, Arvin, California; USA) connected to an AC pressure transducer with filter settings recommended by the AASM [6], low-frequency filter 0.1Hz and high-frequency filter 15Hz for Th, and 0.03Hz and 100Hz respectively for NC.

2.4. Scoring criteria and data analysis

Sleep stages, arousals and respiratory events were scored according to standard criteria [6,7]. Respiratory events were manually scored in 2-min epochs using three different respiratory montages for each patient based on which airflow signal was displayed on the computer screen: NC + Th, Th alone and NC alone. This procedure was performed by the same expert in sleep medicine (MJJ) blinded to the results of each particular participant. The three analyses for each patient were scored in random order and were performed on three different days, at least seven days apart. Obstructive apnea was defined as the cessation of airflow (<10% of baseline level) for at least the duration of two breaths associated with respiratory effort. Central apnea was defined as the cessation of airflow (<10% of baseline level) with absent inspiratory effort for at least the duration of two breaths and followed by an arousal or an oxygen desaturation ≥3% or for at least 20 s in the absence of any associated arousal or oxygen desaturation events. Mixed apnea was recorded if apnea criteria were met for at least the duration of two breaths with absent respiratory effort during one portion of the event and the presence of inspiratory effort in another portion. Hypopnea was defined as a decrease in airflow ≥30%, for the duration of at least two breaths and associated with an arousal or ≥3% oxygen desaturation. Hypopnea was scored as obstructive if snoring, increased inspiratory flattening of the NC signal or an associated thoracoabdominal paradox were present during the event, and as a central character when none of them were present. Although the NC is the sensor of choice for detecting hypopneas and the Th for apneas, in case of failure of the sensor of choice we use the other flow sensor as an alternative as has been recommended. Respiratory effort-related arousals (RERA) were defined as a sequence of breaths lasting ≥2 breaths characterized by increasing respiratory effort, flattening of the inspiratory portion of the NC waveform or snoring, that did not meet criteria for an apnea or hypopnea and lead to an arousal from sleep.

The obstructive apnea–hypopnea index (OAHI) was calculated based on the number of obstructive and mixed apneas and hypopneas per hour of total sleep time (TST). OSA was diagnosed with OAHI ≥1, and was classified as mild when OAHI ≥1–4.9, moderate when OAHI ≥5–9.9 and severe when OAHI ≥10, according to international guidelines [3–5].

Airflow sensors were repositioned if displacement from their position resulted in absent or poor quality signal. The NC was replaced if the probe was blocked by excessive nasal secretions. These interventions during sleep were performed mainly during periods of slow wave sleep in order to minimize patient disturbances or during spontaneous awakenings.

2.5. Quality of flow tracings

Quality of the NC and Th signals was visually assessed and was defined as uninterpretable when no airflow signal was recorded for 30 s while respiratory motion signals and SpO_2 signal and values remained unchanged. Time spent with an uninterpretable airflow signal with Th and NC was expressed as a percentage of TST.

2.6. Statistical analysis

Data analysis was carried out using the software IBM SPSS Statistics 26.0 (SPSS Inc., Chicago, IL, USA). Continuous variables were expressed as median (IQR) unless otherwise indicated, while categorical variables were reported as absolute numbers and percentages. As most quantitative variables were not normally distributed, non-parametric tests were applied in all comparisons. Differences between NC and Th in airflow sensor repositioning were evaluated using the McNemar test. Comparison of sleep time with uninterpretable signal between NC and Th was performed using the Wilcoxon test. Factors associated with an uninterpretable signal ≥25% of TST were evaluated using Pearson's chi-square or Fisher's exact test for categorical variables and the linear-trend chi-square test for ordinal variables. A logistic regression analysis was performed to obtain variables independently associated with a longer uninterpretable signal time. The number of respiratory events detected using the different methods was compared using Friedman's test followed by a pairwise post-hoc analysis with Bonferroni correction. Differences in OSA severity were assessed using the McNemar-Bowker test.

The agreement between respiratory events obtained with Th, NC and both sensors was evaluated using the intraclass correlation coefficient (ICC). The diagnostic accuracy of Th and NC was evaluated by obtaining receiver operating characteristic (ROC) curves and by calculating the sensitivity, specificity, positive and negative predictive values, and likelihood ratios for different cut-off points of the OAHI. A p-value <0.05 was considered statistically significant.

3. Results

A flow-chart of the study is shown in Fig. 1. Of the 185 children included in the study, ten (5.5%) did not tolerate the placement of the NC from the beginning of the PSG recording, and one of them (0.5%) did not tolerate the Th ($p = 0.04$). In three patients the PSG could not be assessed due to technical problems. Thus, 172 PSG records included both flow sensors and were available for analysis. The characteristics of the sample finally included are shown in Table 1, and the main results of the PSG in Table 2. The prevalence of OSA was 64.0%, and the proportions of children with mild, moderate, and severe OSA were 23.3%, 8.1%, and 32.6% respectively.

3.1. Flow signal quality and interpretability

During the sleep study, the intervention of the technician was frequently required for the repositioning of both the NC and the Th (45.3% of patients and 40.1% respectively, $p = 0.306$). The number of times the sensor was repositioned was 0 (0–2) for the NC and 0 (0–1) for the Th ($p = 0.018$). Repositioning more than twice was required in 9.9% of patients in the case of NC and in 4.7% of patients in the case of Th ($p = 0.022$). In most cases, the repositioning of both the NC and the Th was due to a poor tolerance of the sensor with voluntary displacement of the airflow sensor during a period of awakening (36.5% vs 29.1% respectively, $p = 0.047$), and to a lesser extent to the displacement of the sensor due to movements during sleep (4.7% vs 11.0%, $p = 0.027$). Furthermore, NC required repositioning or changing due to secretion obstruction in three patients (4.1%).

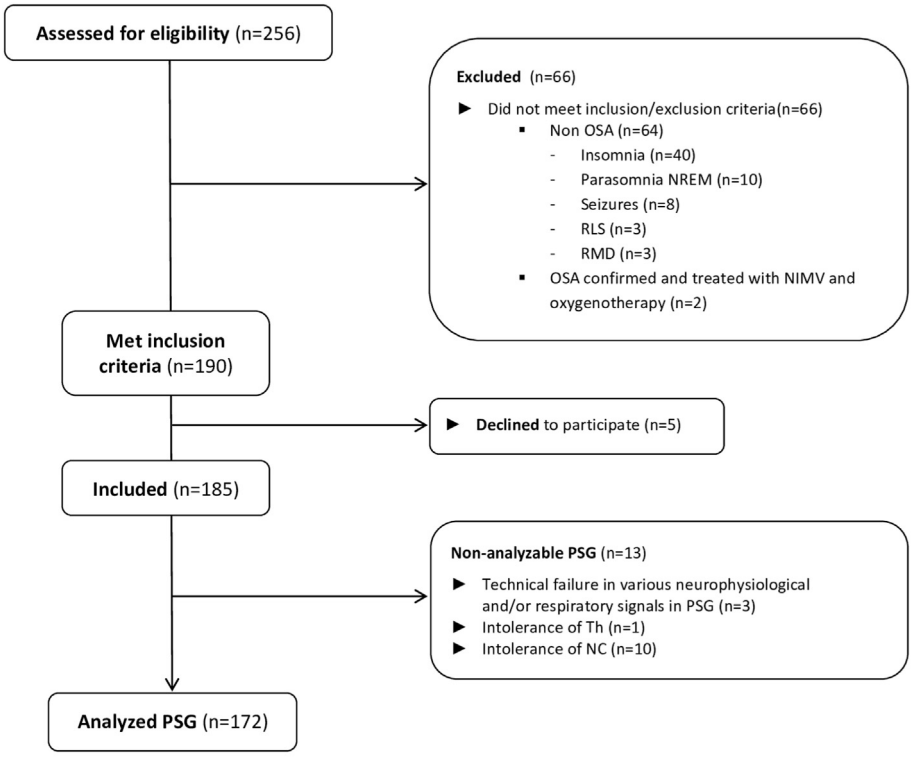

Fig. 1. Flow chart of the study.
OSA: obstructive sleep apnea; NREM: non-rapid eye movement; RLS: restless legs syndrome; RMD: rhythmic movement disorder; NIMV: non-invasive mechanical ventilation; PSG: polysomnography; Th: thermistor; NC: nasal cannula.

Table 1
Demographic and clinical characteristics of the study population (n = 172).

Variable	
Age [years]; mean (SD)	2.3 (1.2)
Sex [M/F]; n (%)	103 (60)/69 (40)
Ethnicity; n (%)	
White	140 (81.4)
Hispanic	27 (15.7)
Black	4 (2.3)
Asian	1 (0.6)
Prematurity; n (%)	29 (16.9)
BMI [Kg/m2]; mean (SD)	16.5 (2.5)
BMI z-score; mean (SD)	0.1 (1.7)
Obesity; n (%)	21 (12.2)
Gastroesophageal reflux; n (%)	21 (12.2)
Tonsils and adenoid grade; n (%)	
No hypertrophy	42 (24.4)
Mild-moderate	44 (25.6)
Severe	86 (50.0)
Respiratory co-morbidities; n (%)	99 (57.6)
Recurrent upper respiratory infection	93 (54.1)
Laryngomalacia	3 (1.7)
Bronchopulmonary dysplasia	2 (1.2)
Asthma	1 (0.6)
Neurologic co-morbidities; n (%)	46 (26.7)
Developmental delay	28 (16.3)
Epilepsy	4 (2.3)
Genetic conditions	36 (20.9)
Neuromuscular disorders	7 (4.1)
Metabolic disorders	2 (1.2)
Neurodevelopmental disorder	10 (5.8)
Congenital hindbrain abnormalities	9 (5.2)

M/F: Male/Female; BMI: body mass index; BMI z-score: BMI standard deviation; SD: standard deviation.

Table 2
Polysomnographic measures (n = 172).

Variable; median (IQR) or n (%)	
TRT [min]	262.5 (228.2–317.6)
TST [min]	184.3 (146.0–239.1)
Sleep efficiency [%]	79.3 (64.0–89.0)
Stage NREM [%TST]	82.9 (78.8–88.7)
Stage NREM 1 [%TST]	9.4 (5.8–13.9)
Stage NREM 2 [%TST]	40.0 (31.4–47.5)
Stage NREM 3 [%TST]	32.9 (26.8–40.2)
Stage REM [%TST]	17.0 (11.3–21.3)
Patients without stage REM	11 (6.4)
Sleep cycles [No.]	3.0 (2.0–4.0)
Arousal index [No./h]	15.4 (10.9–25.1)
Respiratory arousal index, [No./h]	3.3 (0.7–12.7)
AHI [events/h]	4.9 (1.8–21.1)
OAHI [events/h]	4.0 (0.3–17.0)
AI [events/h]	1.4 (0.3–3.4)
HI [events/h]	2.2 (0.3–13.9)
RERAI [events/h]	0.0 (0.0–0.4)
SpO2 mean [%]	97.0 (96.0–98.0)
SpO2 nadir [%]	89.0 (85.2–93.0)
CT90 [%]	0.0 (0.0–0.3)
ODI3 [No./h]	2.6 (0.9–8.8)
TcCO2 [mmHg]	38.0 (36.0–40.0)
TcCO2>50 [%TST]	0.0 (0.0–0.2)

TRT: total recording time; TST: total sleep time; NREM: non-rapid eye movement; REM: rapid eye movement; AHI: apnea-hypopnea index; OAHI: obstructive apnea-hypopnea index; AI: apnea index; HI: hypopnea index; RERAI: respiratory effort-related arousal index; SpO2: peripheral oxygen saturation; CT90: percentage of total sleep time with saturation under 90%; ODI3: 3% oxygen desaturation index; TcCO2: basal transcutaneous carbon dioxide; TcCO2>50: percentage of total sleep time with transcutaneous carbon dioxide value exceeding 50mmHg; IQR: inter-quartile range.

Overall, the time with interpretable flow signal was shorter with the NC. Percentage of total recording time (TRT) with uninterpretable signal was 21.8% (8.7–55.2) with NC and 5.8% (1.9–17) with Th ($p < 0.001$). Differences were also observed when considering the percentage of TST, 17.8% (5.3–49.7) with NC vs 1.9% (0–8.5) with Th ($p < 0.001$); NREM sleep time, 15.9% (3.5–44.5) vs 1.4% (0–8.5) ($p < 0.001$); and REM sleep time, 6.2% (0–34.2) vs 0% (0–0.5) ($p < 0.001$). The signal was uninterpretable ≥25% of TST in 40.7% of the PSG studies with the NC, compared to 8.7% with Th ($p < 0.005$). Age ≥1 year and the presence of severe adenotonsillar hypertrophy were the only clinical variables associated with a longer time with an uninterpretable NC signal (Table 3), and in a logistic regression model only severe adenotonsillar hypertrophy was associated with non-interpretability ≥ 25% of the TST, with an odds ratio of 2.01 (95% CI: 1.29–3.14) ($p < 0.002$).

3.2. Detection of respiratory events

Table 4 summarizes the overall values of respiratory events obtained using the three methods, NC, Th and the combination NC + Th. NC detected fewer respiratory events due to periods without an interpretable signal (Fig. 2). In contrast, Th identified a similar number of events to the NC + Th combination. We did not detect central hypopneas in our patients. Of the 110 children with OSA, the use of Th alone allowed diagnosis of 105 (95.5%), while the NC alone diagnosed 91 (82.7%) ($p < 0.001$).

Table 5 shows the intraclass correlation coefficients between NC, Th and the combination of the two. Th presented greater reliability than NC in estimating OAHI.

Table 6 shows the sensitivity, specificity, predictive values, likelihood ratio values and the area under the ROC curve (AUC) obtained with each sensor separately for different OAHI cut-off points. The diagnostic capacity of Th was higher than that of NC, with higher values of sensitivity and AUC. The lower sensitivity of the NC at the different cut-off points of the OAHI affected the classification of OSA severity, with a lower proportion of severe cases (19.8% using the NC alone vs 30.8% using the Th alone, $p < 0.001$)), and a higher proportion of non-OSA cases (47.1% vs 38.4%, respectively ($p < 0.001$)).

4. Discussion

In this study in children under the age of three with suspected OSA, the capacity of NC to detect respiratory events was lower than that of Th, due to the presence of a longer sleep time with an uninterpretable signal. The factors underlying this limitation were the poorer tolerance of the sensor and the poor quality signal associated with the presence of adenotonsillar hypertrophy. There is a rationale for the current practice of using both sensors because one may not work for periods during the study; however, our results show some limitations associated with the use of NC in this age group.

In our patients, the use of NC as the sole flow sensor led to an underdiagnosis of OSA and an underestimation of its severity. These findings contrast with those of multiple studies in adults, which have reported a greater sensitivity with NC for identifying respiratory events than with Th [13–18,30]. Studies in children have also found a good correlation of respiratory events identified by NC with the increase in respiratory effort identified by esophageal manometry [19,23], as well as a greater sensitivity than Th for the identification of respiratory events [19,23]. However, these studies evaluated small samples and included very few children under three years of age [19,21–23] or none at all [20]. Additionally, in their comparisons of NC and Th some studies have included only polysomnographic tracings with a good quality signal for both sensors [20]. In our study, in contrast, we assessed a wide series of patients with frequent neurologic and respiratory co-morbidities and a wide range of OAHI values, which reflect the challenging situations encountered at a sleep unit in this age range. We found that NC performed worse than Th in detecting upper airway obstructive events because its potential greater sensitivity in detecting these events was outweighed by a greater available time of flow signal with Th.

The frequent loss of flow signal during unsupervised home PSG in children has already been reported in a population-based study, in which only 42% of records showing an interpretable flow signal of both NC and Th for more than 47% of TST [20]. Similarly, Marcus et al. [31], also using unattended home PSG in children aged 5–12 years without suspected OSA, identified the NC as the most problematic sensor with only 67% of patients with more than 75% of the study with a satisfactoy NC signal; however, the combination of NC and Th provided the presence of some flow signal for more than 75% of the night in 96% of the subjects. With an attended PSG, 40% of our patients presented an uninterpretable NC signal for more than 25% of TST, while with Th this occurred in only 8% of cases. These findings are consistent with a previous study in 30 children with suspected OSA in whom problems with the flow signal were mainly observed with the NC and were more frequent in the subgroup under three years of age [23].

We identified poor sensor tolerance and adenotonsillar hypertrophy as factors related to the presence of an uninterpretable NC signal. During PSG, both NC and, to a lesser extent Th, required

Table 3
Clinical variables and sleep time with uninterpretable signal for nasal cannula (NC).

	TST with uninterpretable NC signal		
	<25% (n = 102)	≥25% (n = 70)	*P* Value
Age [years]; n (%)			0.003
<1 year	25 (24.5)	5 (7.1)	
≥1 year	77 (75.5)	65 (92.9)	
Obesity; n (%)	13 (12.9)	8 (11.4)	0.818
Recurrent upper respiratory infection; n (%)	49 (48.0)	44 (62.9)	0.055
Gastroesophageal reflux; n (%)	15 (14.7)	6 (8.6)	0.227
Prematurity; n (%)	18 (17.6)	11 (15.7)	0.739
Adenotonsillar grade; n (%)			<0.001
Normal	34 (33.3)	8 (11.4)	
Mild-to-moderate hypertrophy	31 (30.4)	13 (18.6)	
Severe hypertrophy	37 (36.3)	49 (70.0)	
Developmental delay; n (%)	19 (18.6)	13 (18.6)	0.993
Genetic conditions; n (%)	13 (12.7)	12 (17.1)	0.421

TST: total sleep time; OSA: obstructive sleep apnea; NC: nasal cannula.

Table 4
Respiratory events identified using the three methods.

	NC + Th	NC	Th	*P* Value
OAHI [events/h]; median (IQR)	2.5 (0.3–16.8)	1.4 (0.0–7.8)	1.9 (0.1–15.1)	<0.001
AI [events/h]; median (IQR)	1.4 (0.3–3.4)	1.0 (0.0–2.9)	1.5 (0.3–3.4)	<0.001
HI [events/h]; median (IQR)	2.2 (0.3–13.9)	1.0 (0.0–5.8)	1.7 (0.1–11.6)	<0.001

OAHI: obstructive apnea-hypopnea index; AI: apnea index; HI: hypopnea index; Th: thermistor; NC: nasal cannula; IQR: interquartile range.

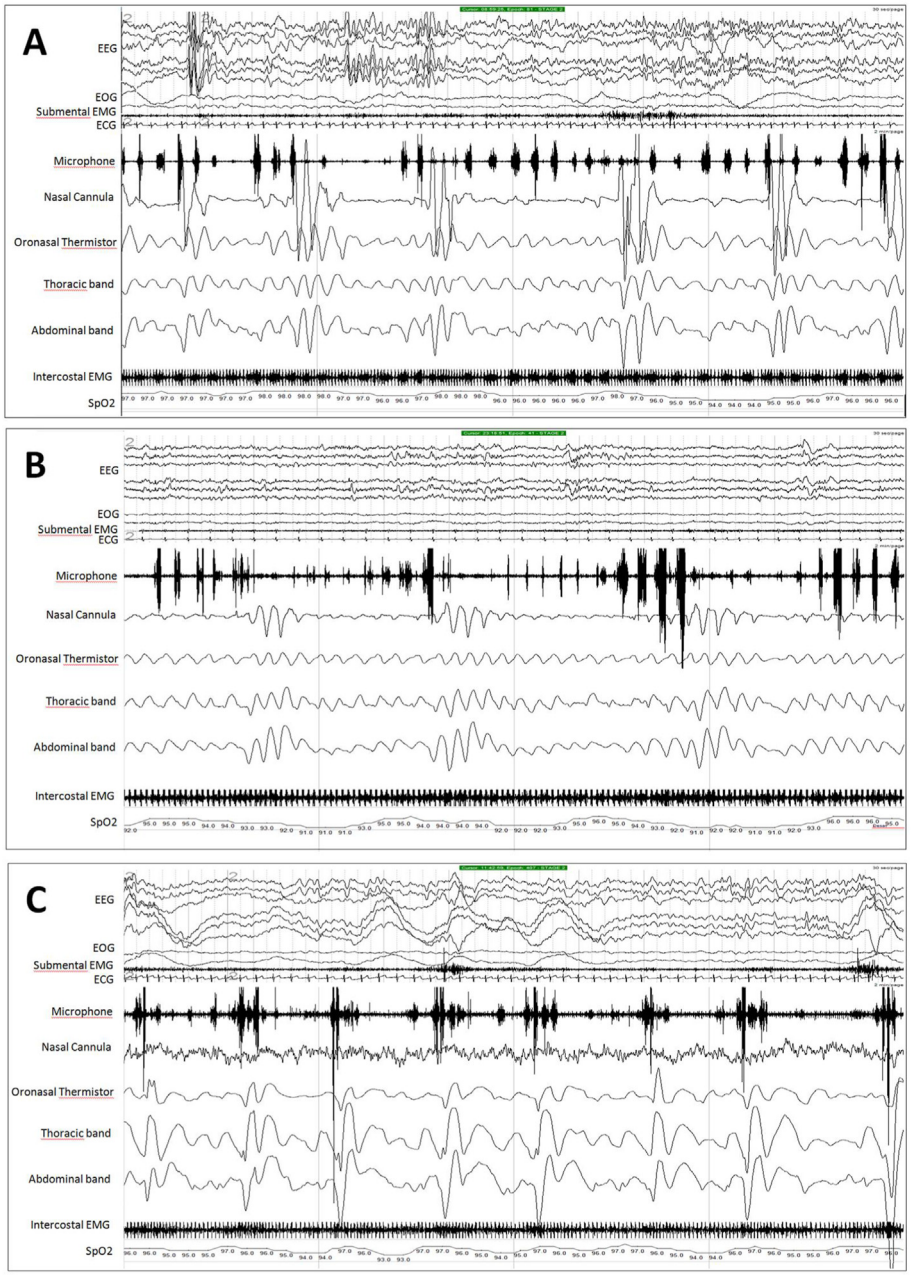

Fig. 2. Polysomnographic views of the behaviour of nasal cannula and thermistor during hypopneas in children under the age of three with obstructive sleep apnea.
A) Obstructive events detected by nasal cannula and thermistor; B) Obstructive hypopnea detected by nasal cannula. It could be missed if relying only in thermistor; C) Period without nasal cannula signal due to displacement of the sensor by the patient. Only hypopneas detected by the less sensitive thermistor are considered.

frequent intervention by the sleep technician for their repositioning due to voluntary or involuntary displacement by the patient. Previously, studying the two sensors in a series of ten children with a mean age of five years Verginis and cols [22] reported that the NC was more bothersome and difficult to reposition during sleep without waking the child. It may also be the case that the NC signal, dependent on the changes in nasal pressure, is more likely to be lost due to displacement or blockage by secretions than the Th signal, which is sensitive to the temperature of the nasal and mouth flow. As in other series of patients of a similar age with suspected OSA, a

Table 5
Intermeasurement agreement using nasal cannula (NC), thermistor (Th) and both (NC + Th) in estimation of OAHI.

	ICC	95% CI
Between NC + Th and Th	0.995	0.993–0.997
Between NC + Th and NC	0.618	0.482–0.718
Between NC and Th	0.609	0.485–0.705

ICC: intraclass correlation coefficient; CI: confidence interval; Th: thermistor; NC: nasal cannula.

high percentage of our participants had neurological and respiratory co-morbidities that may have affected in some degree the problems related to flow sensors tolerance.

We also identified the presence of severe adenotonsillar hypertrophy as a factor associated with poor NC signal. Adenotonsillar hypertrophy is known to be a risk factor for the development of OSA in children [32], particularly in predominantly non-obese populations such as ours and in children of similar age; its influence is lower in older children, who have a proportionally larger upper airway and in whom the role of obesity in the development of OSA is more relevant [24,33–35]. In adults, mouth breathing due to nasal obstruction has been associated with a poor NC signal but with an unchanged Th signal [15,16]. However, the influence of adenotonsillar hypertrophy on the flow signal during PSG has not been previously studied. Supporting our findings, it is known that adenotonsillar hypertrophy, frequently associated with recurrent upper airway infections, and the presence of neurological syndromes or anatomical alterations related to OSA have been associated with mouth breathing in children under 3 years of age [24].

Although the combined use of the NC and the Th during PSG is the accepted gold standard, our findings suggest a possible underdiagnosis and underestimation of OSA in children under three years of age because some obstructive events would remain undetected due to the lack of NC signal and the lower sensitivity of Th to detect obstructive hypopnea. It can be speculated that this might be associated with an increase in the neurocognitive, cardiovascular and metabolic effects that have been associated with childhood OSA in recent years [1–4]. Although respiratory polygraphy is not recommended in children <2 years [5] and may be considered an alternative if PSG is not available in children >2 years [4], our results may be especially noteworthy if we use simplified diagnostic methods that are available for home studies and that use NC as the sole flow sensor [36]. The clinical value of analyzing sleep studies in these patients considering exclusively the time with a correct signal from both sensors should also be evaluated. In addition, the accuracy of home respiratory polygraphy using NC together with Th [37] or respiratory inductance plethysmography [38] for the diagnosis of OSA should be specifically assessed in the age range evaluated in our work. Other possible consequences of the underestimation of OSA would be an increase in respiratory complications as well as a higher residual OAHI associated with adenotonsillectomy as a treatment for OSA, which have been reported to be more frequent in children under three years of age [39,40].

Our study has some limitations. First, we used a daytime nap, an option previously applied successfully in children [29,39–41]. The aim of studying children under three years of age in this way in our sleep unit is motivated by our intention to reduce the long waiting list. This procedure have limited the sleep time in our patients, as previously described with the same methodology by Trang et al. studying flow signals in children <12 months [23]. In addition, to maximize sleep time in our patients, 10 children who did not tolerate the NC at the beginning of the study were excluded from the analysis without trying to reposition the NC when the child is already asleep as we usually do in overnight sleep studies, reducing the studied sample. We believe that these facts did not affect the main results of our study; however, we cannot rule out that overnight studies, with longer TST and more REM sleep [42–44], could lead to different results. Second, we did not use intraesophageal pressure sensors to detect respiratory effort, or a pneumotachograph to detect airflow; their use would have provided us with an accurate OAHI value of our patients, but they are intrusive procedures that may cause sleep fragmentation and are thus unsuitable in routine PSG studies, especially in children. Third, to avoid a potential interaction between both sensors when measuring changes in airflow, an alternative design of our study would have been to compare both sensors in 2 studies performed with each sensor separately. However, our methodology using both sensors simultaneously is the usual one in clinical practice and we believe our results reflect a problem associated with this practice. And fourth, all children studied were referred due to suspicion of OSA and frequently presented neurological and respiratory co-morbidities, making sleep studies more difficult. This implies that our results can not be extrapolated to asymptomatic children.

In conclusion, in children under the age of three, the ability of NC to detect obstructive episodes during sleep was lower than previously reported in older children and adults. This is related to a poor tolerance of the sensor and the frequent presence of adenotonsillar hypertrophy in these patients, and may lead to an underestimation of OSA due to undetected events due to the absence of NC signal and less sensitivity of Th in detecting obstructive hypopneas. Therefore, other non-invasive measurements to identify respiratory events during sleep may be of additional value.

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Table 6
Diagnostic accuracy of nasal cannula (NC) and thermistor (Th) for detecting the different grades of OAHI.

	NC			Th		
	OAHI ≥1	OAHI ≥5	OAHI ≥10	OAHI ≥1	OAHI ≥5	OAHI ≥10
n (%)	91 (52.9)	52 (30.2)	34 (19.8)	106 (61.6)	68 (39.5)	53 (30.8)
Sensitivity (%)	82.7	74.3	60.7	95.5	97.1	94.6
Specificity (%)	100	100	100	98.4	100	100
PPV (%)	100	100	100	99.1	100	100
NPV (%)	76.5	85.0	84.1	92.4	98.1	97.5
LR+	∞	∞	∞	59	∞	∞
LR-	0.17	0.26	0.39	0.05	0.03	0.05
AUC (95%CI)	0.909 (0.864–0.955)	0.875 (0.808–0.942)	0.863 (0.787–0.939)	0.985 (0.967–1)	0.999 (0.997–1)	0.998 (0.995–1)

OAHI: obstructive apnea-hypopnea index; PPV: positive predictive value; NPV: negative predictive value; LR+: positive likelihood ratio; LR-: negative likelihood ratio; AUC: area under the ROC curve; Th: thermistor; NC: nasal cannula.

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CRediT authorship contribution statement

María José Jurado: Conceptualization, Formal analysis, Data curation, Methodology, Visualization, Writing - original draft, Writing - review & editing. **Gabriel Sampol:** Conceptualization, Formal analysis, Data curation, Methodology, Supervision, Visualization, Writing - original draft, Writing - review & editing. **Manuel Quintana:** Formal analysis, Writing - review & editing. **Odile Romero:** Formal analysis, Visualization, Writing-review, and editing. **Roser Cambrodí:** Formal analysis, Visualization, Writing-review, and editing. **Alex Ferré:** Formal analysis, Visualization, Writing-review, and editing. **Júlia Sampol:** Formal analysis, Visualization, Writing - review & editing.

Declaration of competing interest

The authors have no disclosures or financial conflicts of interest.

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