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Original Article

High-flow nasal cannula for children not compliant with continuous positive airway pressure

Alessandro Amaddeo [a, b, *], Sonia Khirani [a, b, c], Annick Frapin [a], Theo Teng [a], Lucie Griffon [a, b], Brigitte Fauroux [a, b]

[a] AP-HP, Hôpital Necker-Enfants Malades, Pediatric Noninvasive Ventilation and Sleep Unit, Paris, France
[b] Paris Descartes University, EA 7330 VIFASOM (Vigilance Fatigue Sommeil et Santé Publique), Paris, France
[c] ASV Santé, Gennevilliers, France

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ABSTRACT

Objectives: Continuous positive airway pressure (CPAP) is an effective treatment of severe obstructive sleep apnea (OSA) but poor compliance is a major limitation. High-flow nasal cannula (HFNC) has been used as an alternative but data about efficacy and objective long-term compliance are scarce; this study aims to address this lack of data.

Patients/methods: All consecutive patients, aged 0–18 years, treated with CPAP for a severe OSA defined as an apnea–hypopnea index (AHI) > 10 events/h, and not compliant with home CPAP therapy, defined by a CPAP use of <2 h/night, after at least four weeks from CPAP initiation were considered eligible for the study. HFNC was started during an outpatient visit. Study outcomes were the objective compliance (number of hours use/night) after one month and the improvement of OSA on a respiratory polygraphy (RP) with HFNC.

Results: Eight patients (two boys, mean age 8.9 ± 6.2 years, mean AHI 33 ± 22 events/h) were included in the study: Down syndrome ($N = 6$), Pierre Robin syndrome ($N = 1$), Pfeiffer syndrome ($N = 1$). After one month, five (62%) patients slept with HFNC more than 4 h/night (mean compliance 7 h 10 min ± 0 h 36 min/night). HFNC corrected OSA in the five compliant patients (mean AHI 2 ± 2 events/h with HFNC). HFNC was not accepted by the three oldest patients with Down syndrome.

Conclusion: A good compliance as well as a correction of OSA may be obtained with HFNC in selected children with OSA not compliant to CPAP. HFNC may be used as a rescue therapy for children not compliant with CPAP.

1. Introduction

The prevalence of obstructive sleep apnoea syndrome (OSA) in children varies widely from 0.1 to 13% [1]. OSA is thus a relatively common disease in children with important neurobehavioral, cardiovascular and metabolic consequences [2]. OSA in children is classically associated with adenoidal and tonsillar hypertrophy and adenotonsillectomy represents the first-line treatment [2]. However, success rate ranges from 50 to 80% according to different studies [3,4]. Residual OSA after adenotonsillectomy is more frequent in obese children [5] or in children with associated conditions such as congenital craniofacial malformations, neurological or neuromuscular diseases [3]. In these patients, OSA may be corrected by continuous positive airway pressure (CPAP) [2,3]. However, the efficacy of CPAP is counterbalanced by its poor compliance. Indeed, numerous studies report suboptimal compliance with CPAP use ranging from 3.3 to 5.3 h/night despite behavioral programs and close follow-up [6,7]. Low compliance has been associated with low maternal education [8], obesity [7] and Down syndrome [9].

Few alternatives to CPAP are available. Medical therapy with nasal steroids and anti-leukotriene drugs have proved their efficacy in case of moderate residual OSA after adenotonsillectomy [10]. Surgical or orthodontic treatments such as mandibular distraction [11] or rapid maxillary expansion [12] are reserved to selected patients with anatomical malformation.

* Corresponding author. Pediatric Noninvasive Ventilation and Sleep Unit, AP-HP, Hôpital Necker Enfants Malades, 149 rue de Sèvres, Paris, 75015, France. Fax: +33 1 7119 5770.
E-mail address: alessandro.amaddeo@aphp.fr (A. Amaddeo).

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High-flow nasal cannula (HFNC) is a noninvasive ventilatory device that is currently used for the treatment of acute and chronic respiratory failure in adults and children [13,14]. HFNC consists of the delivery of high-flowing heated and humidified air through the nose, with a fraction of oxygen (FiO_2) that may be set from 21% to nearly 100%. Moreover, the nasal cannula used with HFNC is less invasive and more comfortable than nasal masks or nasal prongs used for CPAP therapy. A few case series have reported the use of HFNC in children with OSA but none of the studies analyzed long term outcome and objective compliance [15–17].

The aim of the present study was to test the hypothesis that children with OSA who do not comply with CPAP may accept overnight HFNC. The secondary hypothesis was that HFNC was able to correct OSA on a respiratory polygraphy (RP).

2. Material and methods

2.1. Patients

This prospective study was conducted between January and December 2016 at the noninvasive ventilation (NIV) and sleep unit of Necker Children's Hospital in Paris. All consecutive patients, aged 0–18 years, treated with CPAP for a severe OSA defined as an AHI>10 events/h, and not compliant with home CPAP therapy, defined by a CPAP use <2 h/night, after at least four weeks of an 'optimal' CPAP trial, were considered eligible for the study. An 'optimal' CPAP trial included the trial of different interfaces and CPAP settings, therapeutic education of the patient and the caregivers and/or behavioral interventions. Patients in an unstable medical condition or with non-French-speaking parents were excluded.

Medical records, demographic data and results of the baseline RP were collected for each patient. RP were performed using CID 102* (Cidelec, Angers, France) and Alice 6 (Respironics, Carquefou, France). The recorded data included nasal airflow, oronasal thermal flow, body position, body movements, thoracic and abdominal movements assessed with inductance belts, pulse oximetry (SpO_2), continuous video recording and transcutaneous carbon dioxide (CO_2) recording. Respiratory events were scored according to the American Academy of Sleep Medicine (AASM) manual and following update [18]. Written informed consent was obtained before enrolment from patient's parents or from the patient's legal guardian. The protocol was approved by the local ethical committee (CPP Ile de France XI, no. 2016-A00305-46).

2.2. HFNC initiation program

The HFNC initiation program was performed in an outpatient setting with the MyAirvo device (Fisher & Paykel Healthcare, Auckland, New Zealand) and lasted approximately 2 h. As all the patients (if aged >2–3 years) and caregivers had already received a therapeutic education on CPAP, which includes the explanation of the results of the RP, the HFNC initiation program was focused on HFNC and the differences with CPAP. Accordingly, during the first 15 min, the principles of HFNC were explained to the patient and the caregivers by a pediatric pulmonologist and a nurse specialized in NIV and therapeutic education. The size of the nasal cannula was chosen in order to obtain a cannula-to-nares ratio of approximately 80% and in any case <90%, in order to prevent high pressures, as recommended by the manufacturer. The device was set at an arbitrary initial flow of 1 L/kg/min with a maximal flow of 20 L/min, a temperature of 34° and a FiO_2 of 21% (no additional oxygen was used). Then, the patient tried the nasal cannula with the device during the following 30 min. After this initial trial, the parents (and the patient if aged >4–5 years) were trained to put on and take off the nasal cannula and to switch on and off the device. Afterwards, the nurse reviewed the use and maintenance of the nasal cannula and device with the parents. The hour counter of the device was recorded in order to allow the monitoring of the objective compliance with the HFNC. The patient was then discharged home and was encouraged to use the HFNC every night for the entire night. A follow-up phone call was made after one week and the parents were asked to contact the NIV unit by phone or email earlier in case of any problem at home.

An in-hospital titration RP was planned once the patient slept with the HFNC for at least 4 h per night for at least one week. RP was performed as described above, with the exception that nasal pressure could not be directly measured due to the nasal cannula. A pressure signal was obtained by the outlet of a T-tube, originally created by the manufacturer to add nebulization to the device. A follow-up visit was planned one month after the titration RP. Objective compliance (number of hours' use per night) was evaluated from the device hours counter after one month. If the objective compliance was less than 2 h per night, the patient was considered to refuse the treatment and HFNC was stopped. If the patient slept with HFNC more than 4 h per night, follow-up visits at three months and then every six months were planned.

Data are presented as mean and standard deviation. Student paired *t*-test (parametric test) was used to compare pre- and post-treatment RP. A *P*-value less than 0.05 was considered statistically significant.

3. Results

Eight patients, mean age 8.9 ± 6.2 years, six females and two males, were included in the study (Table 1). Six patients had Down syndrome, one patient had Pfeiffer syndrome with the youngest patient (patient no. 1) being a two-month-old girl with Pierre Robin syndrome. All the patients had severe OSA with a mean AHI of 33 ± 22 events/h (range 10–64 events/h) (Table 2). Anthropometric data, the type of cannula, and the post titration HFNC flow rate are reported in Table 1.

Five (62%) patients achieved a good compliance (7 h 10 min ± 0 h 36 min/night) with HFNC and underwent a titration RP

Table 1
Anthropometric data, type of nasal cannula, and final high-flow nasal cannula (HFNC) flow rate.

	Gender	Age (years)	Weight (kg)	Height (m)	Underlying disorder	Type of cannula	HFNC flow rate (L/min)
Patient 1	Female	0.1	4.9	0.60	Pierre Robin sequence	Infant	5
Patient 2	Female	1.8	9.4	0.70	Down syndrome	Pediatric	15
Patient 3	Female	6.4	19.5	1.10	Pfeiffer syndrome	Pediatric	15
Patient 4	Male	7.6	29	1.20	Down syndrome	Adult Small	20
Patient 5	Male	9.2	27	1.20	Down syndrome	Adult Medium	20
Patient 6	Female	12	76	1.50	Down syndrome	Adult Medium	20
Patient 7	Female	16.2	44	1.30	Down syndrome	Adult Medium	20
Patient 8	Female	17.3	85	1.50	Down syndrome	Adult Medium	20

Table 2
Respiratory polygraphy data during spontaneous breathing and with high-flow nasal cannula.

Patient	Spontaneous breathing							Compliance at 1 month (h/night)	With high-flow nasal cannula						
	AHI (events/h)	OAI (events/h)	OHI (events/h)	Mean SpO_2 (%)	Minimal SpO_2 (%)	ODI (events/h)	Mean $PtcCO_2$ (mmHg)	Maximal $PtcCO_2$ (mmHg)	AHI (events/h)	OAI (events/h)	OHI (events/h)	Mean SpO_2 (%)	Minimal SpO_2 (%)	ODI (events/h)	Mean $PtcCO_2$ (mmHg)	Maximal $PtcCO_2$ (mmHg)
1	27	5	18	95	77	27	43	51	6 h 40 min	6	2	3	99	93	5	44	48
2	11	1	8	97	87	15	43	47	7 h 30 min	1	0	1	96	91	6	44	46
3	13	9	4	98	85	4	39	50	6 h 50 min	0.5	0	0.5	97	93	5	46	48
4	64	19	45	98	83	31	59	66	6 h 45 min	2	0	2	96	88	9	42	49
5	64	12	52	96	82	25	48	50	8 h 5 min	0.5	0	0	96	89	3	48	50
Mean ± SD[a]	36 ± 26	9 ± 7	25 ± 2	97 ± 1	83 ± 4	20 ± 11	46 ± 8	53 ± 7	7 h 10 min ± 0 h 36 min	2 ± 2	0.5 ± 1	1 ± 1	97 ± 1	91 ± 2	6 ± 2	45 ± 2	48 ± 2
6	45	13	31	93	80	48	45	51	1 h 30 min	Not compliant with high-flow nasal cannula							
7	28	12	16	95	78	16	45	52	0 h 50 min	Not compliant with high-flow nasal cannula							
8	10	1	9	97	91	8	40	48	1 h 15 min	Not compliant with high-flow nasal cannula							
Mean ± SD[b]	33 ± 22	9 ± 6	23 ± 18	96 ± 2	83 ± 5	21 ± 14	45 ± 6	52 ± 6	–	–	–	–	–	–	–	–	–

AHI, apnea–hypopnea index; OAI, obstructive apnea index; ODI, oxygen desaturation index; OHI, obstructive hypopnea index; $PtcCO_2$, transcutaneous carbon dioxide; SD, standard deviation; SpO_2, pulse oximetry.
[a] Mean and standard deviation for the five compliant patients.
[b] Mean and standard deviation for the eight patients.

with HFNC at a flow rate of 5 L/min in the youngest patient (patient no. 1), 15 L/min for patients no. 2 and no. 3, and 20 L/min for patients no. 4 and no. 5 (Table 2). HFNC was associated with a normalization of the AHI in four patients and a significant reduction in the AHI in patient no. 1 (from 27 to 6 events/h) (Fig. 1). HFNC was also associated with a significant improvement in minimal SpO_2 ($p = 0.02$) and oxygen desaturation index (ODI) ($p = 0.03$).

Because of the persistence of a moderate residual OSA in patient no. 1, the HFNC flow rate was increased from 5 to 10 L/min. This patient underwent cleft palate repair at eight months of age. An RP confirmed the resolution of OSA with a normalization of the AHI on room air two months after the palate repair, allowing the weaning from HFNC. Patient no. 2 had an adenoidectomy after one year of HFNC. HFNC was continued for a further six months and was withdrawn after the correction of OSA on a follow-up RP. Patient no. 3 continued HFNC for two months and then underwent a craniofacial LeFort III advancement surgery. She developed a postoperative tracheal stenosis and required a tracheotomy. Patients no. 4 and no. 5 are still on HFNC with a good compliance after a follow-up of 20 and 28 months, respectively. No adverse events related to HFNC were reported for the five patients.

The three oldest patients with Down syndrome did not comply with HFNC. Each of these three patients presented severe neurocognitive impairment with behavioral problems. An orthodontic treatment was started in patient no. 6 with an RP planned at the end of the treatment. CPAP was restarted in patient no. 7 without success. Patient no. 8 had a follow-up RP 18 months later which showed a spontaneous slight improvement inOSA with an AHI of eight events/h.

4. Discussion

Our study shows that a good compliance as well as a correction of OSA may be obtained with HFNC in selected children with OSA not compliant with CPAP. HFNC may be used as a rescue therapy for children not compliant with CPAP.

McGinley et al., were the first to report the use of HFNC for OSA in 11 adults with mild to severe OSA [16]. The authors used a modified air compressor coupled to a humidifier that was able to generate a maximum flow rate of 20 L/min with a temperature of 31–33 °C. They showed that an airflow of 20 L/min improved the AHI and sleep characteristics. Using the same protocol in 12 obese children, they then showed that HFNC was able to reduce the AHI with results comparable to those obtained with CPAP [19]. However, none of these patients were subsequently treated with the HFNC and therefore no data about adherence to treatment is available. Another study reported the use of HFNC in five children with OSA due to different underlying diseases who did not comply with CPAP ($N = 4$) or who could not be treated with CPAP because of facial deformities ($N = 1$) [15]. HFNC was able to correct AHI and nocturnal gas exchange. However, no information is available on the type of device used and, importantly, even if all the patients continued the treatment at home, no data on compliance is available. Finally, a recent study reported the results of the use of the MyAirvo device in 10 children with moderate to severe OSA, nonadherent or not eligible for CPAP treatment [17]. All patients had underlying disorders such as Down syndrome, craniofacial abnormalities, and obesity. A titration polysomnography (PSG) was performed on the day of HFNC initiation and showed a significant improvement of the AHI which decreased from a median of 11.1 (8.7–18.8) to 2.1 (1.7–2.2) events/h ($p = 0.02$). However, neither the flow rates nor the information on compliance and long-term follow up are provided. The present study is thus the first to report objective compliance and long-term outcome.

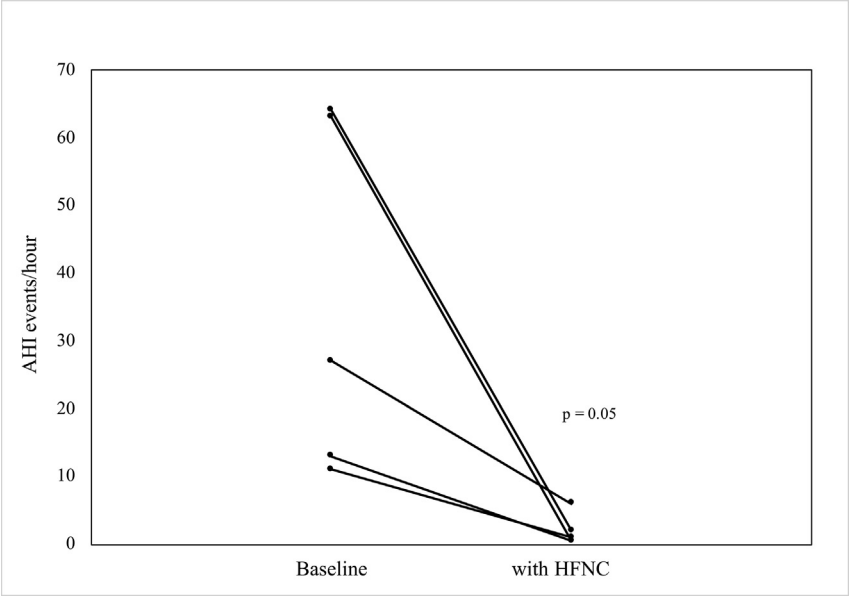

Fig. 1. Apnea–hypopnea index (AHI) at baseline and with high flow nasal canula (HFNC).

A good compliance was achieved in five of the eight (62%) patients. One could argue that this is a low rate. First of all, the reported failure rate of CPAP treatment in children is high. In a standard care program in the USA, which represents a classical initiation program for most centers in the world, only 68% of the patients initiated on CPAP attended the follow-up clinic visit and only 38% of them had a titration PSG [20]. More recently, among 90 children who were started on CPAP, 24 (27%) did not present to follow-up visits or to PSG, meaning that only 73% of patients adhered to treatment [21]. Although these data may not be directly compared to ours because of a different organization of the healthcare system, we believe that a success rate of 62% may be considered as acceptable as all our patients were not compliant to CPAP treatment. This good compliance may be explained by the nasal cannula used with HFNC. Indeed, the cannula used with HFNC are softer and lighter, and are thus better accepted and tolerated than any other commercial CPAP nasal mask or nasal pillows. The good comfort of the HFNC was recently reported in nine children with OSA who did not tolerate any CPAP interface [22].

A correction of OSA was observed in the five compliant patients in the present study. Previous studies in children suggested that HFNC may be more efficient in patients with predominant hypopneas rather than apneas [15,17]. However, this hypothesis needs further evidence. Moreover, HFNC at a flow of 20 L/min has been shown to reduce apneas as well as hypopneas [16] as we observed in three of our patients who had an increased obstructive apnea index (OAI) which normalized with HFNC.

Several mechanisms may contribute to the improvement of obstructive respiratory events during HFNC. The direct measurement of pharyngeal pressure during HFNC therapy for OSA has never been performed due to technical difficulties. However, it has been demonstrated that when the cannula occlude less than 90% of the nares, as in the present study, the airway pressure is below 4 cmH_2O [23]. The flow currently used for treating OSA at different ages in our and other studies do not produce a pressure higher than 4–5 cmH_2O, which is a level below the minimal starting pressure proposed for titration studies [24]. Because positive airway pressure seems insufficient to treat OSA, some authors proposed additional mechanisms of action. The slight increase in pharyngeal pressure achieved with the HFNC increases lung volumes, leading to a stabilization of upper airways patency through genioglossus muscle activation during stable non-rapid eye movement sleep [25]. Moreover, the delivery of a humidified and warm airflow on nasopharynx mucosa may stimulate nasopharyngeal mechano- or thermoreceptors and elicit an increase in upper-airway patency [26]. Finally, HFNC may increase anatomical dead space washout which improves gas exchange [27]. For all these reasons, HFNC may be efficient in correcting hypopneas as well as apneas, at least in pediatric patients.

Our study has some limitations. We decided to perform titration study via RP. We acknowledge that this exam is less sensitive than PSG as it may overestimate total sleep time and it does not consider arousal-related respiratory events. However, in our unit all RPs are attended by trained staff and include video recording. Therefore, total sleep time was determined by the absence of body movements and by the changes in breathing patterns. The number of patients is small with predominantly children with Down syndrome. However, these patients are known to have a poor CPAP compliance and often severe OSA. A good objective compliance (mean night use of 8 h 46 min) was observed in 11 patients meaning that eight non-compliant patients have few remaining therapeutic options available. For these patients, HFNC may thus represent an interesting rescue treatment. We chose the MyAirvo device (Fisher & Paykel Healthcare, Auckland, New Zealand) because it was the only HFNC device approved for home care use in France at the time of the study. However, this device has been developed for home oxygen therapy with a technology that is not optimal for OSA monitoring. Adherence data were directly taken from the screen of the device, which shows the total time divided by the number of days of use. Unfortunately, the system does not consider the number of nights per months of use, which is an important parameter when considering adherence to treatment. There are no alarms in case of displacement of the cannula during the night. Moreover, the device does not provide a real-time monitoring of generated pressure, exposing the patient to potential pressure overshooting. In order to avoid this risk of overpressure, we deliberately chose a cannula-to-nares ratio of less than 0.9 which has been shown to prevent overshooting in bench studies models [28]. Finally, MyAirvo system does not have an integrated battery. This means that in case of break down, the patient is at risk of sleeping with the nares partially occluded by a cannula without any flow. This may be dangerous in infants who have an exclusive nasal breathing.

In conclusion, a good compliance as well as a correction of OSA may be obtained with HFNC in selected children with OSA not compliant to CPAP. Larger studies are needed in order to compare adherence between CPAP and HFNC on different patient profiles. However, HFNC may be used as a rescue therapy for children not compliant with CPAP. An improvement in the devices currently available is also needed in order to adapt their characteristics to the needs of children with OSA.

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Conflict of interest

All the authors declare that they have no conflict of interest with this manuscript. No funding was secured for this study.

The ICMJE Uniform Disclosure Form for Potential Conflicts of Interest associated with this article can be viewed by clicking on the following link: https://doi.org/10.1016/j.sleep.2019.05.012.

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