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REVIEW

Adherence to Continuous Positive Airway Pressure Therapy in Pediatric Patients with Obstructive Sleep Apnea: A Meta-Analysis

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Introduction: Obstructive sleep apnea (OSA) is a public health problem that affects children. Although continuous positive airway pressure (CPAP) therapy is effective, the CPAP adherence rate in children is varied. This study aimed to evaluate the CPAP adherence rate and factors associated with CPAP adherence in children with OSA using a systematic review.

Methods: The inclusion criteria were observational studies conducted in children with OSA and assessed adherence of CPAP using objective evaluation. The literature search was performed in four databases. Meta-analysis using fixed-effect model was conducted to combine results among included studies.

Results: In all, 34 studies that evaluated adherence rate and predictors of CPAP adherence in children with OSA were included, representing 21,737 patients with an average adherence rate of 46.56%. There were 11 calculations of factors predictive of CPAP adherence: age, sex, ethnicity, body mass index, obesity, income, sleep efficiency, the apnea-hypopnea index (AHI), severity of OSA, residual AHI, and lowest oxygen saturation level. Three different factors were linked to children with adherence and non-adherence to CPAP: age, body mass index, and AHI.

Conclusion: The CPAP adherence rate in children with OSA was 46.56%. Young age, low body mass index, and high AHI were associated with acceptable CPAP adherence in children with OSA.

Keywords: age, body mass index, apnea-hypopnea index

Introduction

Obstructive sleep apnea (OSA) is a public health problem in children. A review reported a prevalence rate of pediatric OSA that varied among countries with a range of 0.1% (Singapore) to 13.0% (Italy).[1] A report from China found that the prevalence of OSA may be as high as 63.9% of 1578 children between 2 and 15 years of age with snoring.[2] OSA is reported to be more common in children with certain conditions such as obesity, allergic rhinitis, or Down syndrome.[3–6] The prevalence of OSA among children with obesity was 4.9 times higher than among non-obese children (44.6% vs 9.1%; p = 0.0002).[6] If left untreated, OSA in children increases their risks for neurocognitive dysfunction, abnormal behavior, and cardiovascular diseases such as hypertension or left ventricular hypertrophy.[7,8]

Continuous positive airway pressure (CPAP) is recommended for children with OSA if adenotonsillectomy is not performed or OSA is unresolved after this surgery.[9] A prospective study among children with OSA found that CPAP provided immediate and sustained improvement of OSA over a one-year period.[10] Scores on the Epworth Sleepiness Scale improved significantly at one year from baseline (14.44 to 7.86; p = 0.001).[10] However, information regarding the cardiovascular impact of OSA in children is lacking and evidence of CPAP benefits is quite limited.

A known problem with CPAP therapy is adherence. A previous systematic review of 46 included studies found that the average adherence rate from 20 studies (1079 participants) was 56.9% (range of 24–87%). Note that, for this

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systematic review, the average age of participants was 9.4 years with a range of 0.5–16 years; 34 studies had participants with developmental delays. Several factors were found to be associated with poorer CPAP adherence, including age (five studies), sex (two studies), race (one study), body mass index (BMI) (one study), and developmental delay (two studies).[11] However, this systematic review was reported as a scoping review without summarized calculation according to meta-analysis style.

Another meta-analysis on this topic published in 2020 with the final search in 2019 identified five factors calculated as predictors of CPAP adherence in children with OSA.[12] Studies conducted on non-invasive ventilator or a randomized controlled trial were included, resulting in an ability to report the CPAP adherence rate for children with OSA.[13,14] Additionally, the adherence rate was not reported. As the previous meta-analysis did not report the CPAP adherence rate with a gap of three years and limited predictors, this study aimed to evaluate the adherence rate and add more calculations regarding predictors of CPAP adherence in children with OSA by updating the search.

Methods

This was an update to a meta-analysis study to evaluate factors predictive of adequate CPAP adherence in children with OSA. The study was registered at PROSPERO (ID: CRD42022346132).

Eligibility Criteria

Population

This study included studies conducted among children with OSA. It evaluated CPAP adherence using objective evaluation regardless of types of CPAP device, CPAP company, adherence criteria, inclusion criteria, or other factors such as age, sex, or co-morbid diseases. The CPAP devices used to treat OSA in children were standard CPAP, automatic CPAP (APAP), or bilevel positive airway pressure (BPAP). The details regarding each device have been reported elsewhere.[15]

Intervention and Control Group

This study did not evaluate any type of intervention to assist CPAP use in children with OSA. We mainly evaluated personal and laboratory factors associated with CPAP adherence in children with OSA who experienced CPAP therapy. Those who adhered to CPAP therapy (studied group) were compared with those who did not (control group). The diagnosis of OSA is based on polysomnography with an apnea-hypopnea index (AHI) of 1/hour or higher.[2] During polysomnography, the lowest oxygen saturation level while asleep was reported as a percentage, and sleep efficiency percentage was reported defined as the total sleep time divided by the total time in bed during polysomnography. After treatment with CPAP, adherence data were downloaded either from the device or cloud technology.

Outcomes

The outcomes of the study were overall CPAP adherence rate and factors predictive of adequate CPAP adherence in children with OSA.

Study Types

The study types included in this study were any observational studies. Those studies with intervention, stimulation, no adherence data, non-CPAP or non-BPAP, non-objective data on adherence were excluded as were case reports/case series, commentaries, books, abstracts, and reviews.

Search Strategy

Four databases were used for systematic searching including PubMed, Central database, Scopus, and CINAHL Plus. Hand-searching for related studies was also conducted. Search terms included OSA, adherence, CPAP, and bilevel positive airway pressure (BPAP/BiPAP). The full list of search terms is shown in the Appendix. The final search was conducted on August 31, 2022.

Selection Process

After the removal of duplicates, initial screening was conducted for non-relevant articles. Only pediatric studies were eligible and were included if factors predictive of adequate CPAP adherence were evaluated. The initial screening process was performed independently by two authors (BS, KS). Studies selected by each reviewer were compared and entered in the full-text review process. Data extraction and full-text reviews were performed independently by two authors (BS, KS) using a priori form. Any disagreements between the authors were reviewed and decided by a third reviewer (CN). A Prima flowchart of article searching and included studies is illustrated in Figure 1.

Data Collection

Data collection for each included study was retrieved for the following: publication characteristics, study characteristics, outcome characteristics, and predictor characteristics. The publication characteristics comprised the first author, year of publication, and

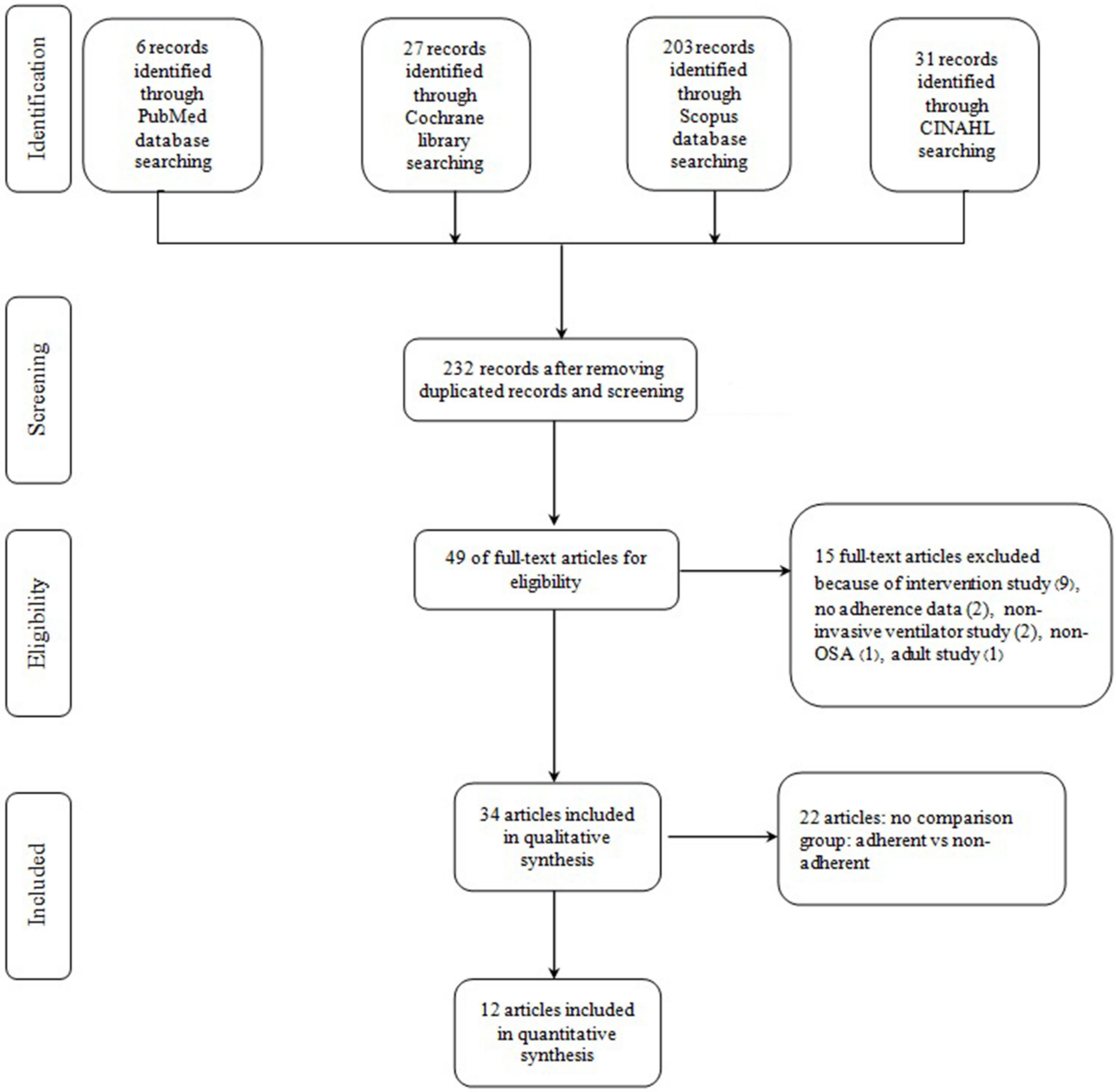

Figure 1 A Prima flowchart for adherence rate and predictors adherence of a positive airway pressure machine (CPAP) in pediatric patients with obstructive sleep apnea.

country of study origin, while study characteristics comprised the study aim and design; age, sex, comorbidities (if any), and AHI; and duration of CPAP use. The outcome characteristics included method of assessment of CPAP adherence, definition of adherence, numbers of total cases, numbers of cases in adherence group, and numbers of cases in non-adherence group. For predictor characteristics, numbers and percentages of each potential predictor in the adherence and non-adherence groups were tabulated.

Data Analysis

There were two groups in this study: an adherence and a non-adherence group. Differences between both groups were computed for CPAP adherence. Mean differences with 95% confidence interval (CI) of numerical factors between both groups were calculated, while odds ratio with 95% CI of categorical factors between both groups were executed. I^2 statistic was used to measure heterogeneity among the results of included studies. Substantial heterogeneity was identified when I^2 was greater than 75%. Fixed-effect model was used to perform meta-analysis when I^2 was less than 75%. Random-effects model was used to combine the results of included studies when substantial heterogeneity was found. A forest plot of each factor was created to show differences between both groups. All analyses were performed by Review Manager 5.4 (RevMan).

Risk of Bias

Study quality of observational studies including retrospective, prospective, and cross-sectional studies was evaluated using the Newcastle-Ottawa Scale (NOS), which was adapted for cross-sectional studies and applied to evaluate study quality.[16] Details of the scale have been described elsewhere.[16,17] Study quality is categorized as very good, good, satisfactory, and unsatisfactory. Risk of bias was performed by two authors independently (BS, CN). A disagreement between authors was reviewed and decided by a third reviewer (KS).

Results

There were 232 studies related to adherence to CPAP in patients with OSA after duplicate studies were removed (Figure 1). Of these, 50 were eligible for a full-text review and 16 of them were excluded because they were intervention studies (nine), had no objective adherence assessment (two), were based on non-invasive ventilation (two), were non-OSA (one), had no objective adherence data (one), or were conducted with adults (one). Thus, 34 studies remained that evaluated adherence in children with OSA; these were published from 2011 to 2022 (Tables 1–4).[18–51] Of these 34, 12 studies had compared those who were adherent with those who were not and had applied a meta-analysis calculation (Tables 3 and 4).[40–51] Most of the 34 studies were conducted in North America (23 of 34 studies) and had a retrospective study design (20 of 34 studies). The longest duration for CPAP adherence evaluation was four years[22] with an average duration of 10.04 (SD 9.82) months.

The adherence rate was assessed using data downloaded from CPAP devices either online or from the device in most studies, while CPAP adherence was defined by case notes, clinical data, parent report, or durable medical equipment (DME) providers as shown in Tables 2 and 4.[24,42,43,46] The adherence criteria differed slightly among studies but was mostly defined as usage of four hours or more per night for 50–70% of nights. For the included studies without meta-analysis calculation (Tables 1 and 2), the adherence rate was 46.53% (9,883/21,240) from 13 studies based on usage of four hours or more per night (Table 2). The adherence rate for included studies for meta-analysis was 47.69% (237/497). In total, the adherence rate in children with OSA was 46.56% (10,120/21,737). The average CPAP usage in four studies (Table 2) ranged from 2.8 to 7.0 hours/night. Note that three studies compared clinical factors per specific group: developmental disabilities,[25] family members with CPAP therapy,[32] and age group.[18] Additionally, one study compared those with CPAP adherence to intermittent users, who were categorized as non-adherent.[47]

There were 11 calculations of factors predictive of CPAP adherence: age, sex, ethnicity, BMI, obesity, income, sleep efficiency, AHI, severity of OSA, residual AHI, and lowest oxygen saturation level (Figures 2-12). Three factors in regard to children who were adherent and those who were non-adherent with CPAP use were identified as age (Figure 2), BMI (Figure 5), and AHI (Figure 9). Children with OSA with effective adherence to CPAP use were younger and had lower BMIs than those with non-adherence. The mean differences (95% CI) of these two factors were −1.42 years (−2.07, −0.77) and −6.55 kg/m^2 (−11.80, −1.30), respectively, as shown in Figures 2 and 5. Children with OSA with satisfactory adherence to CPAP had significantly higher AHIs than those who were non-adherent, with a mean difference of 4.75 events/hour (95% CI of 1.07, 8.43 events/hour) as

Table 1 Characteristics of Pediatric Studies with Obstructive Sleep Apnea (OSA) on Compliance of a Continuous Positive Airway Pressure Machine (CPAP): Included Studies but Not in a Meta-Analysis

Study	Year	Country	Study Aim	Study Design	Age	Male Sex/ Total	Comorbidities	AHI (events/ hour)[a]	Factors of Interest
Bhattacharjee[18]	2020	USA	Find adherence patterns of CPAP therapy	Cross-sectional	4–18 years	NA	NA	NA	Age group, residual apnoea–hypopnoea index, use and onset of patient engagement programmes, PAP pressure, and nightly median PAP mask leak
Blinder[19]	2021	Canada	Factors associated with CPAP adherence	Retrospective cohort	8–17 years	80/104 (77%)	Developmental delay, obesity, asthma, mental health disorder, behavioral disorder	11 (5–23)	age, sex, SDB diagnosis, CPAP mode, comorbidities, PSG indices, sleep symptoms
Cielo[20]	2021	USA	Compare CPAP in infant vs school-age children	Retrospective	6 months-10 years	95/150 (63.3%)	Obesity, craniofacial abnormality, neurologic abnormality, Down syndrome	25.7 (17.8–35.9) infant vs 12.1 (7.6–21.5) school-aged	Infant vs school-aged
Castorena-Maldonado[21]	2008	Mexico	Preoperative compliance	Prospective	4–7 years	37/48 (77%)	Obesity	RDI 63 (50–80)	Body weight, type of CPAP
Com[22]	2015	USA	Characters and surgical outcomes	Retrospective cohort	NA	87/143 (61%)	Obesity	17.7 (8.3–37.2)	AHI, PSG parameters
DiFeo[23]	2012	USA	Factors associated with CPAP adherence	Prospective	2–16 years	38/56 (68%)	Genetic syndrome, central nervous system abnormality, craniofacial syndrome, pulmonary disease, growth hormone deficiency, neurodevelopmental disability	19 (16)	Age, sex, obesity, AHI, CPAP mode, maternal education, race, developmental delay, social support, child behavior, parental stress, nasal symptoms
Elder[24]	2022	New Zealand	Long term CPAP outcome	Retrospective	NA	52/70 (70%)	OSA (82%), obesity, Down syndrome, craniofacial abnormality, cerebral palsy, chromosomal abnormality, nasal obstruction, muscular dystrophy, Prader-Willi syndrome, CNS lesion, asthma, chronic lung disease, subglottic stenosis	NA	Periods of offered CPAP

(*Continued*)

Table 1 (Continued).

Study	Year	Country	Study Aim	Study Design	Age	Male Sex/ Total	Comorbidities	AHI (events/ hour)[a]	Factors of Interest
Kang[25]	2019	USA	Factors associated with CPAP adherence in children with developmental disabilities	Retrospective	0–18 years	141/ 240 (58.8%)	Developmental disabilities	18 (10.9–51.8)*, 12.9 (9.4–18.5)**	Developmental disabilities
Katz[26]	2017	Canada	Prevalence of cardiometabolic disease, CPAP and cardiometabolic markers	Prospective	8–16 years	22/27 (81.5%)	Obesity	15.5 (7.4–25.2)	BMI, CPAP mode
Machaalani[27]	2016	Australia	Factors associated with CPAP/BPAP adherence	Retrospective	0–18 years	63/99 (63.6%)	Chromosomal syndrome, neuromuscular, lung disorder, central nervous system	21.2 (21.5) BPAP; 24.9 (22.8) CPAP	Age, gender, BMI, AHI, duration of CPAP, CPAP pressure
Marcus[28]	1995	USA	Safety and efficacy of CPAP	Retrospective	NA	64%	Obesity, craniofacial anomalies, Down syndrome, neuromuscular disease, mental retardation/cerebral palsy, pharyngeal flap surgery, Arnold-Chiari malformation	NA	Age, CPAP device, frequent clinic visit, professional counseling, parental neglect
Mulholland[29]	2021	Australia	CPAP adherence in children between remote APAP vs fixed CPAP	Retrospective	> 3 years	67/87 (77.0%)	Down syndrome, cerebral palsy, craniofacial syndromes	14.3 (9.5–34.9) CPAP; 23.3 (13.3–52.0) APAP	APAP vs CPAP
O'Donnell[30]	2006	Canada	Compliance rate	Retrospective cohort	6 months-18 years	67/79 (84.8%)	Down syndrome, developmental delay, obesity, cerebral palsy, Pierre-Robin syndrome, tumor, seizure, neuromuscular disease, Tetralogy of Fallot, Klippel-Feil syndrome, Marfan syndrome, bipolar disorder, severe asthma	11.2	Behavioral modification and parental commitment
Perriol[31]	2019	France	Ambulatory CPAP and its adherence	Prospective	NA	59/78 (75.6%)	Neurocognitive dysfunction	12.2 (10.6)	Age, AHI, education level, neurocognitive disorders

(*Continued*)

Table 1 (Continued).

Study	Year	Country	Study Aim	Study Design	Age	Male Sex/ Total	Comorbidities	AHI (events/ hour)[a]	Factors of Interest
Puri[32]	2016	USA	Factors associated with CPAP adherence	Retrospective	< 18 years	34/56 (60%)	Obesity, genetic syndrome, central nervous system abnormality, craniofacial syndrome, neurodevelopmental disability, attention deficit hyperactivity disorder, asthma, allergic rhinitis, post-adenotonsillectomy	25.2 (28.7)	Family member on CPAP therapy
Ramirez[33]	2013	France	Predictors of CPAP or NIV adherence	NA	2–18 years	NA	OSA (82%), lung disease, neuromuscular disease	NA	Type of interface
Trucco[34]	2018	UK	Types of sleep disordered breathing and adherence to respiratory support	Retrospective	< 18 years	34/60 (56.7%)	Down syndrome	11.1 (4.4–24.9) n = 42	Oxygen therapy, CPAP, NIV
Uong[35]	2007	USA	CPAP effectiveness and adherence in students	Retrospective	> 7 years	26/46 (56.5%)	Obesity, Down syndrome, myelomeningocele, Asperger syndrome, autism, Chiari malformation, Prader-Willi syndrome, allergic rhinitis, cerebral palsy, developmental delay, fragile X, muscular dystrophy, otopalatodigital syndrome, Toureete's syndrome	28.4 (31.8)	AHI, CPAP mode, PSG parameters, OSA symptoms
van den Broek[36]	2021	Netherlands	Adherence to CPAP in children with intellectual disabilities	Prospective cohort, subgroup	1–18 years	4/9 (44.4%)	Intellectual disabilities, autism spectrum disorder, attention deficit hyperactivity disorder, challenging behavior, epilepsy	21.9 (18.6)	Age group
Weiss[37]	2021	USA	Factors associated with CPAP adherence	Retrospective	1 month-18 years	152/ 250 (61%)	Down syndrome, developmental delay, obesity	22.8 (28) IQR	BMI, AHI, CPAP setting, adenotonsillectomy

(*Continued*)

Table 1 (Continued).

Study	Year	Country	Study Aim	Study Design	Age	Male Sex/ Total	Comorbidities	AHI (events/ hour)[a]	Factors of Interest
Willis[38]	2022	USA	PSG titration and CPAP prescription; adherence of CPAP before and after PSG titration	Retrospective	NA	77/121 (64%)	Obesity, allergic rhinitis, asthma, Down syndrome, attention deficit disorder, depression, gastroesophageal reflux, seizure, hypertension, developmental delay, Asperger syndrome, cardiac diagnoses, neuromuscular disease, cerebral palsy, Prader-Willi, diabetes, hypothyroidism, unspecified behavioral issue, anxiety, upper-airway anomalies, obsessive-compulsive disorder, spina bifida, adjustment disorder, eating disorder	20.1 (11–34)	PSG titration
Xanthopoulos[39]	2017	USA	Perceptions of OSA, self-efficacy on CPAP use	Retrospective	NA	95/141 (67.4%)	Obesity, genetic disorder, craniofacial anomaly, CNS abnormality	13.8 (7.1, 29.7)	Caregiver-reported and patient-reported perception, self-efficacy on CPAP use

Notes: [a]Mean (SD) or median (1st-3rd interquartile range: IQR); *Indicating children with developmental disabilities; **Indicating typically developing children.
Abbreviations: NA, not available; NAFLD, nonalcoholic fatty liver disease; MPS, mucopolysaccharidosis; NIV, non-invasive ventilator; BPAP, bilevel positive airway pressure; APAP, automatic CPAP; AHI, mean or median (IQR); SDB, sleep-disordered breathing; BMI, body mass index; RDI, respiratory disturbance index; PSG, polysomnography; CNS, central nervous system.

Table 2 Characteristics and Outcomes of Pediatric Studies with Obstructive Sleep Apnea (OSA) on Compliance of a Continuous Positive Airway Pressure Machine (CPAP): Included Studies but Not in a Meta-Analysis

Study	Devices	Data	Criteria for Adherence	Duration of CPAP Use	Total Cases, n	Adherence, n (%)
Bhattacharjee[18]	AirSense 10 or AirCurve 10; ResMed	Airview: cloud technology	Usage >4 h/night for >70% of nights	90 days	20,553*	9504 (46.3%)
Blinder[19]	NA	Device download and clinic note	Use of >4 h/night for >70% of the nights	6 months	104*	46 (51%)
Castorena-Maldonado[20]	Resmed S7 Spirit or Americas	Device download	NA	8–71 days	48*	26/48 (54%) 4 h usage
Cielo[21]	Philips Respironics	Device download	Percentage of night usage >4 h	63–110 days	150	76.5% of nights (infants), 61.2% of nights (school-aged children)

(*Continued*)

Table 2 (Continued).

Study	Devices	Data	Criteria for Adherence	Duration of CPAP Use	Total Cases, n	Adherence, n (%)
Com[22]	NA	Device download	Usage >4 h/night for >70% of nights	4 years	36*	4 (11%)
DiFeo[23]	Philips Respironics	Device download	Night used, and duration of used	3 months	56	Night used 19 (9) night/month; duration 2.8 (2.7) h/night
Elder[24]	NA	Clinical data	Usage >4 h/night for >70% of nights	NA	74*	25 (34%)
Kang[25]	APAP, CPAP, BPAP of Philips Respironics	EncoreAnywhere web-based	Percentage of nights used, h of usage on nights used	6 months	177	73/81 (90%) for DD, 68/96 (70.7%) for TD
Katz[26]	NA	Device download	Use of >4 h/night for >50% of the nights	12 months	16*	11 (68.8%)
Machaalani[27]	Philips Respironics; ResMed	Device download	Usage >4 h/night, 70% of nights	12 months	99; 55 CPAP, 44 BPAP*	41/55 (75%) CPAP; 40/44 (91%) BPAP
Marcus[28]	Varied	Device download	50% of the hour prescribed	1 year	94	82 (87%)
Mulholland[29]	RemStar Auto, Respironics; Fisher & Pakel or ResMed for fixed CPAP	Device download	Usage >4 h/night for >70% of nights	90 days	87*	21/61 (34%) APAP; 7/26 (27%) fixed CPAP
O'Donnell[30]	Aria LX, REMstar Pro	Device download	Day used and hour used	46 months	65	50 available: 76% used half night and 52% used 75% (26/50)
Perriol[31]	NA	CPAP machine	Mean CPAP use, h	24 month	34	7.0 (2.7) h/night**
Puri[32]	Philips Respironics	EncoreAnywhere	Hours of night used	3 months	56	4.8 (0.6) h: family; 3.8 (0.4) no family
Ramirez[33]	VPAP IV & S9, ResMed; Trilogy 100, Respironics; ICON, Fisher & Paykel	Device download	Usage >8 h/night	NA	62*	45 (72%)
Trucco[34]	NA	Device download	Usage >4 h/night for >50% of nights	1.9 years	18*	7 (39%)
Uong[35]	NA	Device download and parent report	Use of >4 hours per night of use and >5 nights per week	18.1 months (average)	27*	19 (70.4)
van den Broek[36]	NA	Device download	Use of >4 h/night for >70% of the nights	8 months	9*	6 (66.7%)
Weiss[37]	NA	Device download	Average hours and percentage of CPAP use	NA	250	4.4 (5.8) h/night; 65.8% day used

(*Continued*)

Table 2 (Continued).

Study	Devices	Data	Criteria for Adherence	Duration of CPAP Use	Total Cases, n	Adherence, n (%)
Willis[38]	NA	Device download	Usage >4 h/night	NA	107*	81 (76%)
Xanthopoulos[39]	Philips Respironics	Device download	Average use >20 minutes/night	1 month	70	50 (79%), total used on days used (269.7 minutes)

Notes: *For adherence rate; **At 24 months.
Abbreviations: NA, not available; APAP, automatic CPAP; BPAP, bi-level positive airway pressure machine; h, hours; DD, children with developmental disabilities; TD, typically developing children.

Table 3 Characteristics of Pediatric Studies with Obstructive Sleep Apnea (OSA) on Compliance of a Continuous Positive Airway Pressure Machine (CPAP): Included Studies for a Meta-Analysis

Study	Year	Country	Study Aim	Study Design	Age	Male Sex/ Total	Comorbidities	AHI (Events/ Hour)[a]	Factors of Interest
Alebraheem[40]	2018	Canada	Find predictors and barriers for CPAP	Qualitative	11–17 years	13/21 (61.9%)	Obesity, Chiari malformation, renal transplant, sickle cell diseases, narcolepsy, NAFLD, MPS, mitochondrial disease	14.1 (13.9)	Restriction of the tubing, the discomfort of the mask, and concerns with its size and weight
Avis[41]	2019	USA	CPAP therapy and pedestrian injury	Prospective	8–16 years	17/29 (58.6%)	Obesity	10.7 (15.0)	CPAP improved daytime functioning
Beebe[42]	2011	USA	CPAP and academic function	Prospective	10–16 years	9/13 (69.2%)	Obesity	10.0 (6.8)* 9.3 (5.7)**	Academic grade, vigilance, academic quality of life
Hawkins[43]	2016	USA	Factors associated with CPAP adherence	Retrospective	NA	76/140 (52.3%)	NA	20.3 (26.8)*, 16.5 (21.2)**	Female sex and developmental delay
Katz[44]	2020	Canada	Factors associated with CPAP adherence in children with obesity	Prospective, substudy	8–16 years	13/14 (92.9%)	Obese, moderate to severe OSA	12.2 (7.1–36.4)	Age, AHI, lowest oxygen saturation, highest carbon dioxide
Lynch[45]	2019	USA	Evaluated CPAP adherence on quality of life	Prospective, substudy	8–16 years with caregiver	16/25 (64.0%)	NA	13.15 (19.58) *, 10.45 (7.62) **	CPAP adherence improved quality of life

(*Continued*)

Table 3 (Continued).

Study	Year	Country	Study Aim	Study Design	Age	Male Sex/ Total	Comorbidities	AHI (Events/ Hour)[a]	Factors of Interest
Nathan[46]	2013	Singapore	Factors associated with CPAP adherence	Retrospective	8–13 years	36/51 (70.6%)	Obesity, asthma, allergic rhinitis, large tonsils/ adenoids, neurodevelopmental delay, chronic lung disease, cardiovascular disease, neuromuscular disease	24.75 (6.7–53.8)*, 12.5 (5.7, 29.2)**	Female gender and asthma
Nixon[47]	2011	Australia	Factors associated with CPAP adherence	Retrospective	NA	21/30 (70.0%)	Down syndrome, craniofacial syndrome, intellectual disability	NA	Usage in the first week
Prashad[48]	2013	USA	Factors associated with CPAP adherence	Qualitative	12–18 years	15/21 (71.4%)	Obesity, developmental disabilities	25.4 (24.6)	Adolescent and family experience
Roberts[49]	2016	USA	CPAP use and facial change	Retrospective cohort	0–18 years	57/100 (57%)	NA	17.61 (19.80) *, 12.03 (19.12)**	CPAP may change facial growth
Simon[50]	2012	USA	Factors associated with CPAP adherence	Cross-sectional	8–17 years	NA	Obesity	22.59 (25.48) *, 14.63 (19.28)**	Age, OSA symptoms
Tovichien[51]	2022	Thailand	CPAP versus APAP adherence	Prospective	NA	17 (63%)	Obesity, Duchenne muscular diseases, allergic rhinitis, Down syndrome, asthma	24 (19)	Age, sex, AHI, oronasal mask, lower maternal education, discomfort from CPAP, lack of clinical benefits

Notes: [a]Mean (SD) or median (1st-3rd quartile range); *Indicating adherent group; **Indicating non-adherent group.
Abbreviations: NA, not available; NAFLD, nonalcoholic fatty liver disease; MPS, mucopolysaccharidosis; APAP, automatic CPAP.

Table 4 Characteristics and Outcomes of Pediatric Studies with Obstructive Sleep Apnea (OSA) on Compliance of a Continuous Positive Airway Pressure Machine (CPAP): Included Studies for a Meta-Analysis

Study	Devices	Data	Criteria for Adherence	Duration of CPAP Use	Total Cases, n	Adherence, n (%)	Non-Adherence, n (%)
Alebraheem[40]	NA	Device download	Usage >4 h/night for >50% of nights	3–12 months	14	6 (42.9%)	8 (57.1%)
Avis[41]	NA	Device download	Usage >4 h/night	3 months	20	11 (55%)	9 (45%)
Beebe[42]	NA	Parent report	Percent of sleep time with CPAP >21%	4 months	13	7 (53.8%)	6 (46.2%)

(*Continued*)

Table 4 (Continued).

Study	Devices	Data	Criteria for Adherence	Duration of CPAP Use	Total Cases, n	Adherence, n (%)	Non-Adherence, n (%)
Hawkins[43]	NA	DME providers	Usage >4 h/night for >70% of nights	>1 year	140	69 (49%)	71 (51%)
Katz[44]	CPAP (42.9%), BPAP (57.1%)	Machine download	Usage >4 h/night for >50% of nights	1 year	14	11 (78.6%)	3 (21.4%)
Lynch[45]	ResMed	Smartcards	Usage >4 h/night for >50% of nights	3 months	25	15 (60%)	10 (40%)
Nathan[46]	CPAP (92.2%), BPAP (7.8%)	Case note	>4 days/week	6 months	51	21 (41.2%)	68 (37%)
Nixon[47]	Fisher and Paykel Healthcare, ResMed	Device download	Use >1 h/night for >6 nights/week	3 months	30	10 (33.3%)	20 (66.7%)*
Prashad[48]	Phillips Respironics	Encore Pro2	Tertiles of number of minutes used/ night	1 month	14	7 (50%)	7 (50%)
Roberts[49]	Philips Respironics	EncoreAnywhere	Usage >4 h/night, 70% of nights	6 months	100	50 (50%)	50 (50%)
Simon[50]	APAP, CPAP, BPAP	Device download	Usage >4 h/night	6 months	49	19 (38.8%)	30 (61.2%)
Tovichien[51]	APAP, CPAP	Device download	Usage >4 h/night, 70% of nights	1 year	27	11 (40.7%)	16 (59.3%)

Note: *Indicating intermittent users.
Abbreviations: NA, not available; DME, durable medical equipment; APAP, automatic CPAP; BPAP, bi-level positive airway pressure machine; h, hours.

shown in Figure 9. Regarding the quality of the included studies (Table 5), most had a score of satisfactory (8/10; 80%). Two studies were not evaluated due to non-cross-sectional study design.

Discussion

This meta-analysis showed that the adherence rate in children with OSA was 46.56% with CPAP usage of four hours or more based on 21,737 children with OSA. Age, BMI, and AHI were related to adequate CPAP adherence.

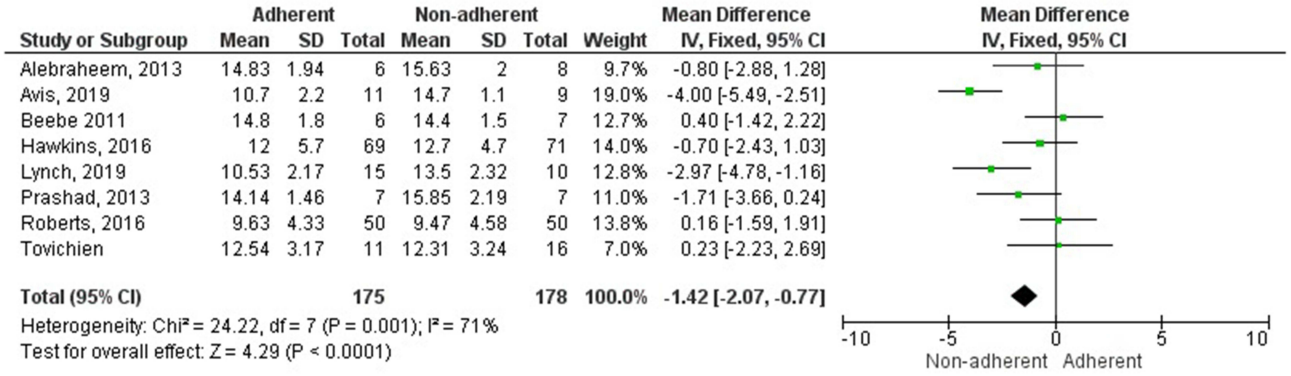

Figure 2 Calculation of age (years) of pediatric patients with obstructive sleep apnea on adherence of a continuous positive airway pressure machine.[40–43,45,48,49,51]

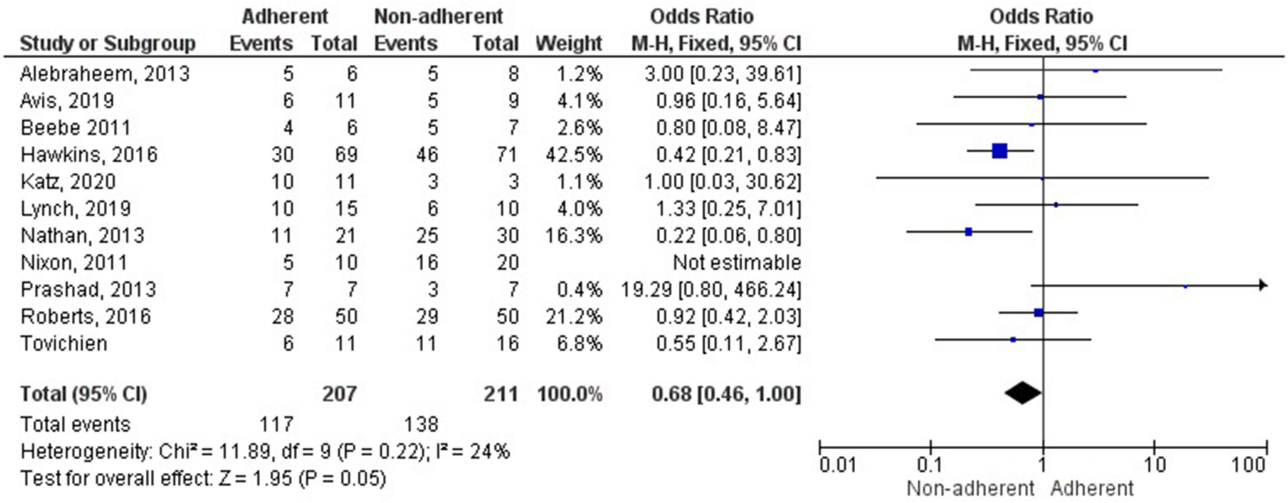

Figure 3 Calculation of sex of pediatric patients with obstructive sleep apnea on adherence of a continuous positive airway pressure machine.[40–49,51]

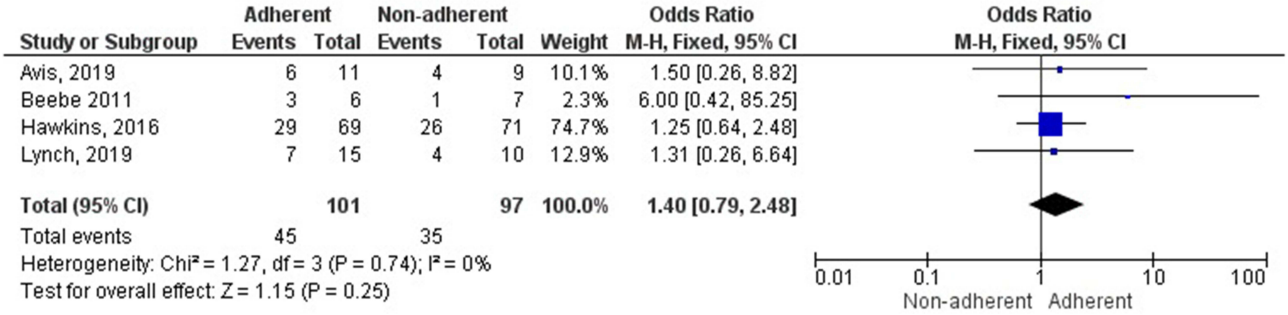

Figure 4 Calculation of ethnicity (Caucasian) of pediatric patients with obstructive sleep apnea on adherence of a continuous positive airway pressure machine.[41–43,45]

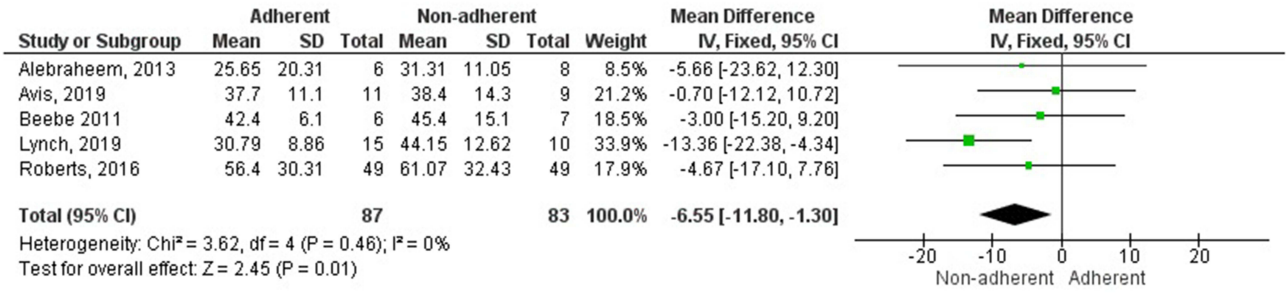

Figure 5 Calculation of body mass index (kg/m^2) of pediatric patients with obstructive sleep apnea on adherence of a continuous positive airway pressure machine.[40–42,45,49]

Compared with the previous meta-analysis, we summarized the adherence rate based on a large study population. Meta-analysis calculations were added for 11 factors, and we added 11 articles published after 2019 that were not included in the previous systematic review.[12] After including more studies in the present meta-analysis, we found significant results in regard to age, BMI, and AHI on CPAP adherence in children with OSA (Figures 2, 5 and 9) and nearly significant results regarding sex with a 95% CI of 0.46, 1.00 (Figure 3). The previous meta-analysis was unable to declare significance in regard to age (not performed), BMI (difference −0.14; 95% CI: −0.47, 0.19), or AHI (difference 4.32; 95% CI: −0.61, 9.26).[12] As previously noted, these three factors were significant predictors of CPAP adherence in this study. These differences between the two meta-analysis studies may be due to more studies included in the present

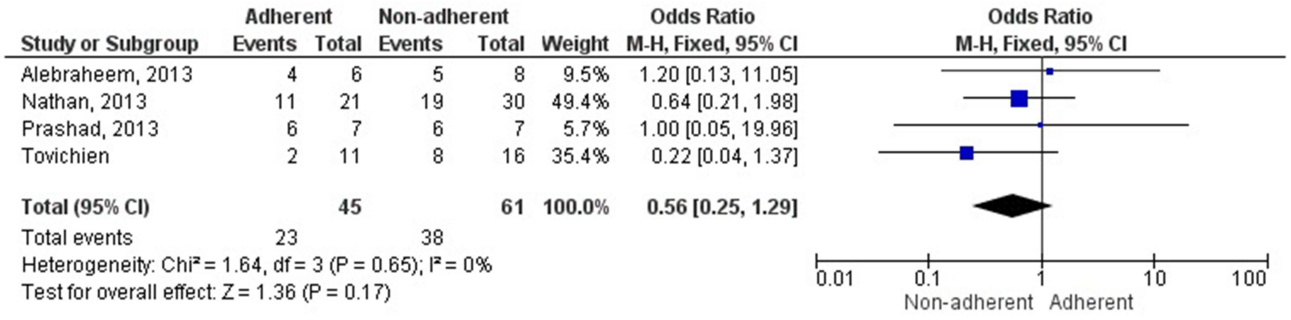

Figure 6 Calculation of obesity of pediatric patients with obstructive sleep apnea on adherence of a continuous positive airway pressure machine.[40,46,48,51]

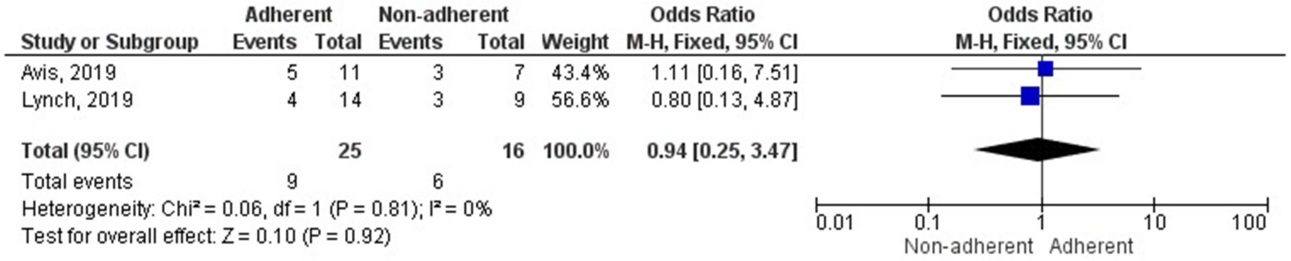

Figure 7 Calculation of income of family less than 20,000 USD of pediatric patients with obstructive sleep apnea on adherence of a continuous positive airway pressure machine.[41,45]

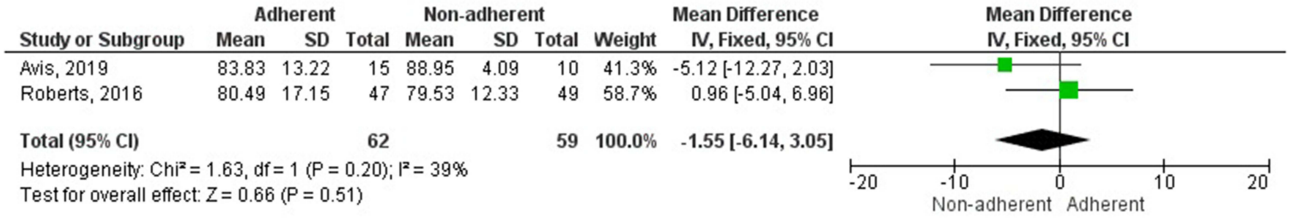

Figure 8 Calculation of sleep efficiency (%) during polysomnography of pediatric patients with obstructive sleep apnea on adherence of a continuous positive airway pressure machine.[41,49]

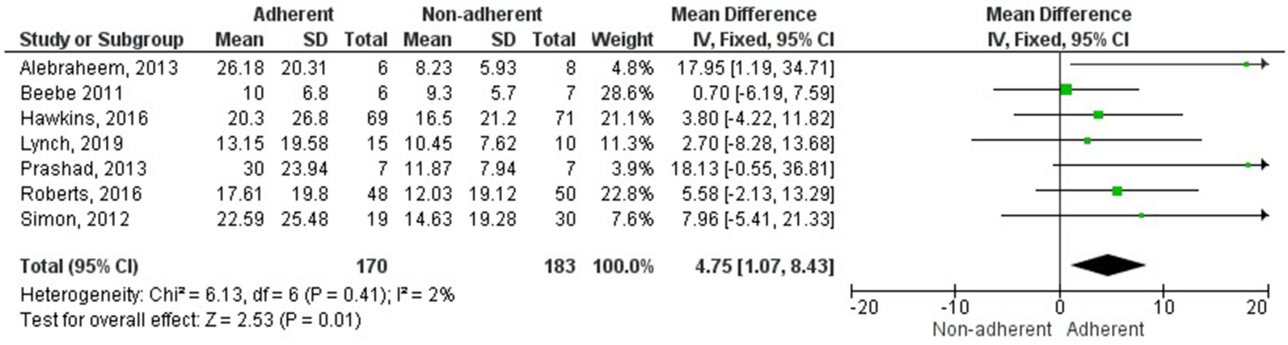

Figure 9 Calculation of apnea-hypopnea index (events/hour) of pediatric patients with obstructive sleep apnea on adherence of a continuous positive airway pressure machine.[40,42,43,45,48–50]

analysis. However, we did not perform an analysis on CPAP vs BPAP, as in the previous meta-analysis, as we were unable to find appropriate data for calculation in the two studies.[26,35] In our study, one study reported significant adherence between CPAP vs BPAP with an unadjusted odds ratio of 3.60 (2.39–5.10).[46] However, this was not significant

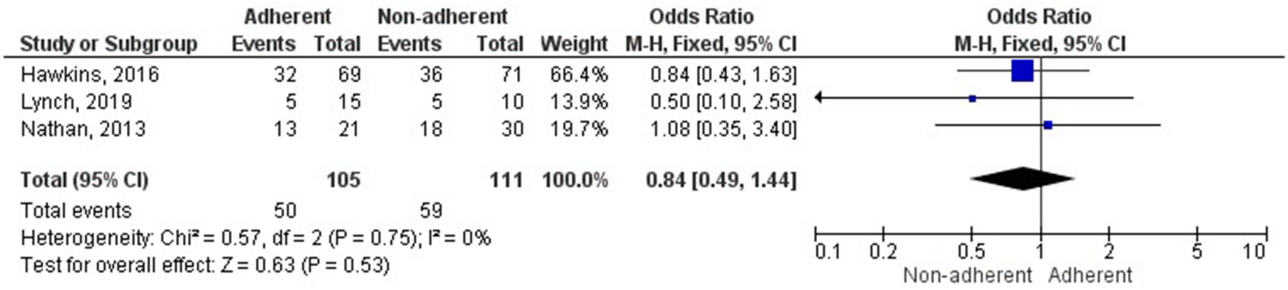

Figure 10 Calculation of severe obstructive sleep apnea (OSA) of pediatric patients with OSA on adherence of a continuous positive airway pressure machine.[43,45,46]

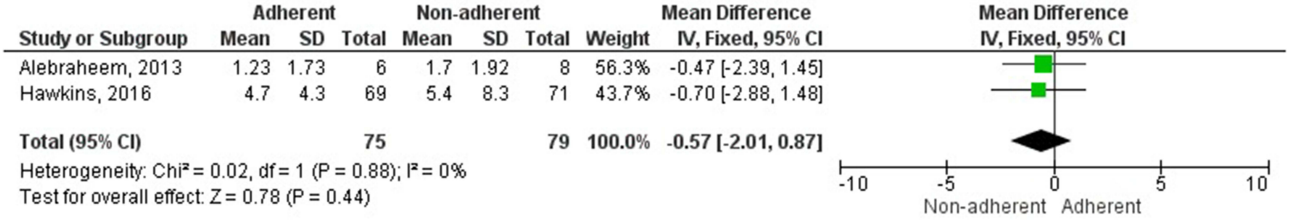

Figure 11 Calculation of residual apnea-hypopnea index (events/hour) of pediatric patients with obstructive sleep apnea on adherence of a continuous positive airway pressure machine.[40,43]

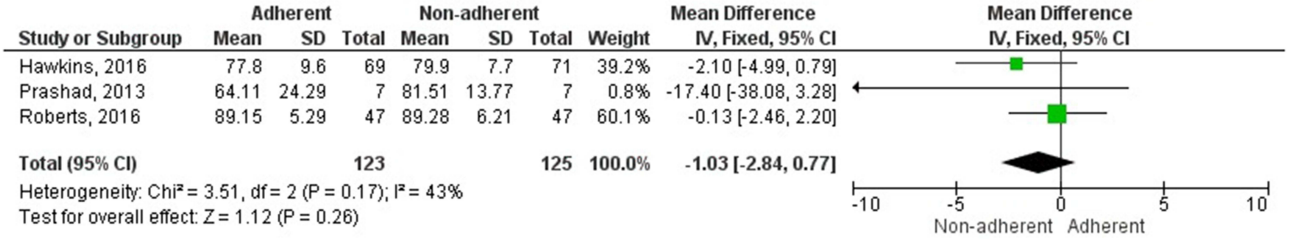

Figure 12 Calculation of lowest oxygen level (%) during polysomnography of pediatric patients with obstructive sleep apnea on adherence of a continuous positive airway pressure machine.[43,48,49]

after being adjusted for other factors. Additionally, we were unable to analyze the developmental delay factor as data were not sufficient for the calculation. Only the study by Kang et al reported findings in regard to developmental delay, while the Hawkins study had incomplete data on this factor, resulting in the inability to calculate as a meta-analysis.[25,43] Finally, this present study included only published articles, unlike the previous report, which included abstract articles.[12]

Table 5 Study Quality Evaluation by the Newcastle-Ottawa Scale Adapted for Cross-Sectional Studies of the Included Studies of Pediatric Studies with Obstructive Sleep Apnea on Compliance of a Continuous Positive Airway Pressure Machine: Included Studies for a Meta-Analysis

Study	Year	Study Design	Selection Process (4)	Comparability (2)	Outcome Measures (3)	Total (9)	Interpretation
Alebraheem	2018	Qualitative	-	-	-	-	NA
Avis	2019	Prospective	3	0	3	6	Satisfactory
Beebe	2011	Prospective	2	1	1	4	Satisfactory
Hawkins	2016	Retrospective	3	0	3	6	Satisfactory

(*Continued*)

Table 5 (Continued).

Study	Year	Study Design	Selection Process (4)	Comparability (2)	Outcome Measures (3)	Total (9)	Interpretation
Katz	2020	Prospective	1	0	3	4	Satisfactory
Lynch	2019	Prospective	3	0	3	6	Satisfactory
Nathan	2013	Retrospective	4	0	3	7	Good
Nixon	2011	Retrospective	3	0	3	6	Satisfactory
Prashad	2013	Qualitative	-	-	-	-	NA
Roberts	2016	Retrospective cohort	3	0	3	6	Satisfactory
Simon	2012	Cross-sectional	1	0	2	3	Unsatisfactory
Tovichien	2022	Prospective	3	0	3	6	Satisfactory

Note: NA, not available due to qualitative study design.

As previously reported, children with OSA who were younger were adherent with CPAP. The adherent group was −1.85 years younger than the non-adherent group. The younger patients may have had caregivers, usually their mother, who facilitated their CPAP treatment. By contrast, older children may have more barriers to wearing the CPAP device during sleep. A study conducted with adolescent patients with an average age of 13.2 years found that older children may have several barriers to CPAP use because they are away from home more often (47%); they may simply want to forget about having OSA (43.1%); they may not feel well (42.0%); or they may forget to use the device (39.2%).[50] In addition, a lack of help from a parent or other caregiver to use CPAP at night represented another barrier in 31.4%.[50]

Similar to age, BMI was negatively correlated with CPAP adherence (Figure 5). In other words, those with lower BMI had better CPAP adherence than those with higher BMI. As shown in Figure 5, the significance of BMI was driven by the study by Lynch et al.[45] A previous report found that high BMI was related to mask leakage ($r = 0.579$; $p < 0.001$) resulting in poor CPAP adherence.[52] Obese children may have a higher risk for mask leakage, leading to poor adherence as high mask leakage was correlated with poor adherence ($r = -0.376$; $p = 0.008$).[52]

Regarding polysomnographic factors, only AHI was related to CPAP adherence in children with OSA. Previous studies in adult patients with OSA found that lowest oxygen saturation differed significantly between the adherence group and the non-adherence group (80.33% vs 85.18%; p value = 0.017) as well as duration of oxygen saturation lower than 90% (10.0% vs 5.0%; $p = 0.013$).[53,54] Four studies showed that AHI was related to CPAP adherence in adult patients.[53–56] Adult patients with oxygen desaturation index (ODI), an index comparable to AHI, of over 60 times/hour had a CPAP adherence rate of 90.8% at 10 years. The ODI or AHI also had an adjusted hazard ratio for CPAP adherence of 0.97 ($p < 0.001$). As previously reported,[57] severity of OSA may be associated with more sleepiness, leading to better adherence to CPAP but not other polysomnographic factors such as oxygen level or sleep efficiency (Figures 11 and 12).

Above, we have discussed why AHI was associated with CPAP adherence in adults. In children, our analysis found that six of seven studies in the meta-analysis calculation had non-significant higher AHI in the adherent group than the non-adherent group; the study by Alebraheem et al was the exception (Figure 9). Additionally, another study identified non-significant higher AHI in the adherent group as well (20.5 vs 17.5 events/h; p 0.651).[51] Note that the study by Tovichien et al was not included as they reported median AHI. After totaling up, the adherent group had greater significant value than the non-adherent group. Unlike in adults, further studies may be required to explain why AHI is significantly related to CPAP adherence. One study found that less severe OSA was related to low adherence to CPAP with a relative risk of 0.97.[19]

This study also added data about the adherence rate in children with OSA in a large sample (n = 22,075), which was not reported in the previous meta-analysis. The adherence rate was almost 50% but may be higher in specific populations,

eg, 90% in children with developmental delays,[25,43] 87% in children with obesity or craniofacial anomalies,[28] or in those using BPAP (91–100%).[27,46] This adherence rate was slightly lower than that previously reported at 56.9%.[11] These differences may be due to sample size numbers and included studies. The previous study had 1,079 participants from 20 studies, while this study had 22,075 participants from 34 studies.[11] Several studies conducted with adults found that CPAP adherence rate ranged from 34% to 83%.[58–62] Similar to children with OSA, there are several predictors of good adherence, such as age, sex, education level, and AHI.[61–65]

This study has several limitations. First, there are no standard criteria for CPAP adherence in children with OSA, resulting in different adherence criteria (Table 2). Second, some factors are not analyzed as they do not meet the calculation criteria for meta-analysis and data are not available for some populations, for example, Black children or children with asthma.[18] Finally, interventions to facilitate CPAP adherence or OSA consequences or related conditions such as quality of life or cardiovascular diseases were not studied.[66–72]

Conclusions

Young age, low BMI, and high AHI are associated with satisfactory CPAP adherence in children with OSA. Although these factors were significant, the overall quality of evidence was fair, and the duration of study was generally about six months with no interventions. Further studies with longer durations or interventions should be considered. However, these factors may be helpful for clinicians in order to initiate CPAP therapy in potential patients for satisfactory adherence. Additionally, further interventions may be important for these groups of patients to facilitate CPAP adherence. Based on the large sample size, the CPAP adherence rate for children with OSA was 46.56%.

Patient and Public Involvement

Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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