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Pediatric sleep questionnaire predicts more severe sleep apnea in children with uncontrolled asthma

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ABSTRACT

Objective: While up to 35% of children with asthma have evidence of sleep disordered breathing (SDB), it is unclear if nocturnal symptoms stem from asthma itself or SDB. The Pediatric Sleep Questionnaire (PSQ) is a validated tool for identifying SDB in childhood asthma. We hypothesize children with asthma and abnormal PSQ demonstrate decreased asthma control and are at higher risk of obstructive sleep apnea (OSA).

Methods: We performed a retrospective, chart review of children and young adults referred to our tertiary children's hospital severe asthma clinic. Data collection included age, gender, BMI percentile, spirometry, PSQ, asthma control questionnaires, asthma severity, control, and impairment. These data were evaluated in the context of polysomnography, when available.

Results: 205 inner-city children were included; 37.2% female, median age 6.4 y, and mean BMI of 71.3%ile. Rhinitis ($p = 0.028$), eczema ($p = 0.002$), and reflux ($p = 0.046$) were associated with abnormal PSQ; however, overweight/obese status, spirometry, asthma severity, and serologic markers were not. After correcting for comorbidities, abnormal PSQ score was associated with poor asthma control based on validated measures ($p < 0.001$). In patients with polysomnography, we confirmed abnormal PSQ was associated with increased OSA severity (apnea-hypopnea index 9.1/hr vs. 3.6/hr; $p = 0.027$).

Conclusions: In pediatric asthma, positive PSQ was associated with significantly decreased asthma control. Additionally, children with normal PSQ demonstrated mild OSA, while children with abnormal PSQ had increased severity of OSA. This demonstrates that PSQ can be used to screen children for more severe sleep apnea.

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Introduction

Asthma is one of the most prevalent childhood diseases in the United States, affecting over six million children nationwide (1). Childhood asthma accounts for significant healthcare utilization, with an estimated cost of \$5.92 billion annually (2). Additionally, childhood asthma adversely affects quality of life as children with asthma miss over 13.8 million days of school per year. Furthermore, 30% of parents of children with asthma report missing work because of their child's condition (3). To improve these outcomes, the National Asthma Education and Prevention Program (NAEPP) guidelines were established for the diagnosis, classification, and management of asthma in children.

More specifically, these guidelines stratify asthma severity based on clinical impairment (daytime and nighttime symptoms, activity limitation, and lung function testing) and risk (requirement of systemic corticosteroids for treatment of acute exacerbations) (4). The guidelines classify asthma severity as intermittent or persistent with further classification as mild, moderate, or severe. Longitudinal asthma control can be further assessed as well controlled, not well controlled, or very poorly controlled based on similar criteria (5).

Many comorbid conditions influence perception of asthma symptoms (6–8). Sleep-disordered breathing (SDB) is a prominent comorbid condition in pediatric asthma that ranges in severity from partial obstruction

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and snoring to multiple episodes of complete upper airway obstruction leading to obstructive sleep apnea (OSA) (9). The estimated prevalence of children with SDB in the general population is between 1–5% (10,11) while self-reported SDB symptoms have been found to be as high as 20% in some adolescent minority populations (12). Children with asthma are twice as likely to develop SDB than those without asthma (13) and SDB symptoms have been found in as high as 35% of asthmatic compared to non-asthmatic children (14). Additionally, sinus problems and recurrent wheezing episodes, typically associated with asthma, increase the likelihood of developing SDB symptoms (15,16). Furthermore, children and adolescents report more frequent SDB symptoms with increasing asthma severity (17) and recent evidence demonstrates adenotonsillectomy appears to improve reported asthma symptoms (18). These findings indicate a close relationship between asthma and SDB symptoms (19).

NAEPP guidelines recommend evaluating for comorbid SDB in children with poorly controlled asthma (5). The Pediatric Sleep Questionnaire (PSQ) is a validated tool for identifying SDB in children and has been shown to be a sensitive measure for identifying obstructive sleep apnea in children with asthma (20,21); however, its association with NAEPP guideline-specific asthma related impairment has not been evaluated (22). Assessment of asthma control in pediatric patients is often times contingent on anecdotal reporting; thus, it is necessary to investigate the efficacy of PSQ as a more objective measure of SDB affecting parameters of asthma control. We hypothesize that children with SDB as defined by the PSQ (PSQ score ≥ 0.33) have decreased asthma control and are more likely to have more severe sleep apnea as defined by polysomnography.

Methods

We performed a retrospective chart review of children and young adults 1 to 21 years of age evaluated between August 2014 and November 2018 at Children's National Hospital's Pediatric Pulmonary Asthma Clinic in Washington, DC, a tertiary pediatric care center, for evaluation and expert management of persistent asthma. This study was approved by Children's National Hospital's Institutional Review Board (Pro00013309).

Data was collected through the electronic medical record (Cerner Millennium, Cerner Corp., Kansas City, MO, USA) and included age, gender, body mass index (BMI), ethnicity, associated medical or surgical

problems, allergies, medications, family and social histories. Other data collected included physical examination, laboratory studies (if performed), and pulmonary function testing (PFT). NAEPP guidelines were used for diagnosis, classification and assessment of asthma control. Further assessment of asthma control included validated standardized questionnaires including either Asthma Control Test (ACT), for children 5 years of age or older (23), or Test for Respiratory and Asthma Control in Kids (TRACK), for children younger than 5 years of age (24); these two parameters were included as continuous variables as performed by the original authors. All children included in this study completed a PSQ questionnaire to screen for SDB (20). Data represented in this study are from the initial visit or the first time the specific outcome was performed (if not performed at the initial visit).

Data analysis included evaluating for associations between PSQ scores and NAEPP asthma control (including each level of NAEPP asthma guideline impairment: daytime symptoms, nighttime awakenings, normal activity interference) and asthma control based on TRACK and ACT questionnaires. Positive PSQ scoring was defined as greater than or equal to 0.33; a score less than 0.33 was considered negative (20). Additional analyses include associations between PSQ score, demographic data, serum markers (IgE, eosinophils) when available, lung function testing (spirometry and fractional exhaled nitric oxide [FeNO] in children 5 years of age and older), and self-reported comorbid conditions (rhinitis, eczema, gastroesophageal reflux, and obstructive sleep apnea). Due to non-Gaussian distribution of PSQ, log-transformed PSQ was used when correlating with markers of asthma control (ACT and TRACK). When available, polysomnography parameters were included and total AHI (apnea-hypopnea index), periodic leg movement index, hypoxia less than 90%, and hypercapnia $>50\text{mmHg}$ were analyzed. Age stratified analyses (<5 years, preschool aged; 5–11 years, pre-adolescence; 12–21 years, adolescent/young adult) were conducted given the wide range of ages included in this study (see [supplementary tables](#)). Given the smaller numbers of individuals included in each subgroup, the pooled results are included in the main tables. Results were considered significant for p values ≤ 0.05 calculated with t-test for continuous variables and Pearson's χ^2 test for binomial data; logistic regression was used for analysis of significance in both reported comorbidities and asthma severity. Statistical analysis was performed on all data collected using SPSS v25.0 (SPSS, Chicago, IL, USA).

Table 1. Demographics.

Demographic	Overall (n = 205)	PSQ < 0.33 (n = 96)	PSQ ≥ 0.33 (n = 109)	P Value
Age, Median (IQR)	6.4 (3.8, 9.9)	6.2 (3.3, 9.8)	6.7 (4.0, 10.0)	0.32
Gender, % Female (n)	37.2 (77)	38.1 (37)	36.4 (40)	0.79
Ethnicity, % (n)				0.73
African American	72.0 (149)	66.0 (64)	77.3 (85)	
Caucasian	16.9 (35)	22.7 (22)	11.8 (13)	
Other	2.9 (6)	3.1 (3)	2.7 (3)	
BMI Percentile, Mean (SE)	71.3 (2.2)	69.1 (3.3)	72.9 (3.3)	0.37
BMI Percentile ≥85, % (n)	38.6 (80)	37.1 (36)	40.0 (44)	0.78
Reported co-morbidities ^a , % (n)				
Rhinitis	78.7 (163)	75.3 (73)	81.8 (90)	0.028
Eczema	62.8 (130)	53.6 (52)	70.9 (78)	0.002
Obstructive sleep apnea	6.3 (13)	1.0 (1)	10.9 (12)	–
Gastroesophageal Reflux	15.0 (31)	10.3 (10)	19.1 (21)	0.046
NAEPP Asthma severity ^b , % (n)				0.94
Intermittent asthma	0 (0)	0 (0)	0 (0)	
Mild persistent asthma	16.9 (35)	16.5 (16)	17.3 (19)	
Moderate persistent asthma	34.8 (72)	40.2 (39)	30.0 (33)	
Severe persistent asthma	23.7 (49)	19.6 (19)	27.3 (30)	
Mod/severe persistent <5 yrs	23.7 (49)	22.7 (22)	24.5 (27)	
PSQ, mean (SE)	0.38 (0.03)	0.14 (0.0)	0.59 (0.05)	<0.001
Total ICS, Mean mcg (SE)	432 (17); n = 178	497 (30)	573 (35)	0.1

^aP Value based on Logistic Regression.

^bpatient or parent reported comorbidities present at time of visit.

P Value for continuous variables calculated based on t-test.

P Value for binomial data calculated using Pearson's χ^2 test.

IQR: interquartile range; BMI: body mass index; SE: standard error; NAEPP: National Asthma Education and Prevention Program; PSQ: Pediatric Sleep Questionnaire ICS: inhaled corticosteroids.

Results

Demographic characteristics

A total of 205 inner-city children and young adults with asthma were included in this study. Ages ranged from 1 to 21 years with a median age of 6.4 years (IQR: 3.8, 9.9) (Table 1). A total of 37.2% of the children studied were female. The majority of children included in the study were African American (72%). There was no significant association between reported race or ethnicity and PSQ in our population. PSQ did not show significant association with other demographic information including age ($p = 0.32$), gender ($p = 0.79$), or moderate/severe persistent asthma ($p = 0.94$).

Self-reported, common comorbid conditions were analyzed. There were significant associations between positive PSQ and a reported diagnosis of allergic rhinitis ($p = 0.028$), eczema ($p = 0.002$), and gastroesophageal reflux ($p = 0.046$) as shown in Table 1. The mean BMI percentile was 71.3 (SE $\pm$ 2.2) and 38.6% of patients had a BMI percentile greater than the 85th percentile, indicating clinically overweight or obese status. Despite the known association between overweight/obese status and obstructive sleep apnea, there was no association between weight status and abnormal PSQ in our population ($p = 0.37$). Abnormal PSQ was not associated with NAEPP asthma severity ($p = 0.94$).

Serum studies and pulmonary function testing

When corrected for reported comorbidities, serum studies, including percent eosinophils on peripheral white blood cell differential ($n = 109$, $p = 0.23$) or total serum IgE ($n = 94$, $p = 0.23$), were not associated with positive PSQ score. Similarly, pulmonary function testing ($n = 128$), including FEV1 percent predicted ($p = 0.73$), FVC percent predicted ($p = 0.65$), FEV1/FVC ratio ($p = 0.76$), FEF25-75% percent predicted ($p = 0.87$), and FeNO ($p = 0.38$), was also not associated with positive PSQ score (Table 2) when corrected for comorbidities.

Asthma control

After correcting for presence of reported comorbid conditions, our primary analysis for association with specific aspects of NAEPP impairment demonstrated abnormal PSQ score (≥ 0.33) was significantly associated with all indices of NAEPP asthma control. Validated asthma questionnaires demonstrated a significant association with more abnormal (increasing) PSQ and worse asthma control in children ≥ 5 years old using ACT ($n = 138$; $r = -0.423$, $p < 0.001$) (Figure 1) and TRACK in children < 5 years old ($n = 61$; $r = -0.446$, $p < 0.001$) (Figure 2). Log-transformed PSQ (logPSQ) was used to account for non-normal distribution of PSQ data. This association with

Table 2. Serum Studies and Pulmonary Function Testing vs. PSQ.

Outcome	Overall (n = 205)	PSQ < 0.33 (n = 96)	PSQ ≥ 0.33 (n = 109)	P Value*
Serum Studies				
% Eosinophils, mean (SE)	5.1 (0.4); n = 109	4.7 (0.6); n = 41	6.2 (0.90); n = 32	0.45
Total IgE, mean (SE)	595 (112); n = 94	782 (271); n = 32	499 (97); n = 62	0.23
Pulmonary function testing				
FEV1 (%pred), mean (SE)	n = 128 81.4 (1.5)	n = 58 82.4 (2.4)	n = 70 81.4 (2.0)	0.73
FVC (%pred), mean (SE)	90.1 (1.3)	90.8 (2.0)	89.6 (1.7)	0.65
FEV1/FVC (Abs), mean (SE)	82.0 (0.9)	82.3 (1.3)	81.8 (1.2)	0.76
FEF25-75% (%Pred), mean (SE)	69.0 (2.7)	69.5 (4.2)	68.6 (3.5)	0.87
FeNO (ppb), mean (SE)	35.7 (3.8)	32.0 (5.2)	38.8 (5.5)	0.38

*Adjusted for reported co-morbidities.

P Value for continuous variables calculated based on t-test.

P Value for binomial data calculated using Pearson's χ^2 test.

IgE: immunoglobulin E; SE: standard error; FEV1: forced expiratory volume in 1 s; FVC: forced vital capacity; FEF25-75%: forced expiratory flow over the middle half of FVC; FeNO: fraction of exhaled nitric oxide.

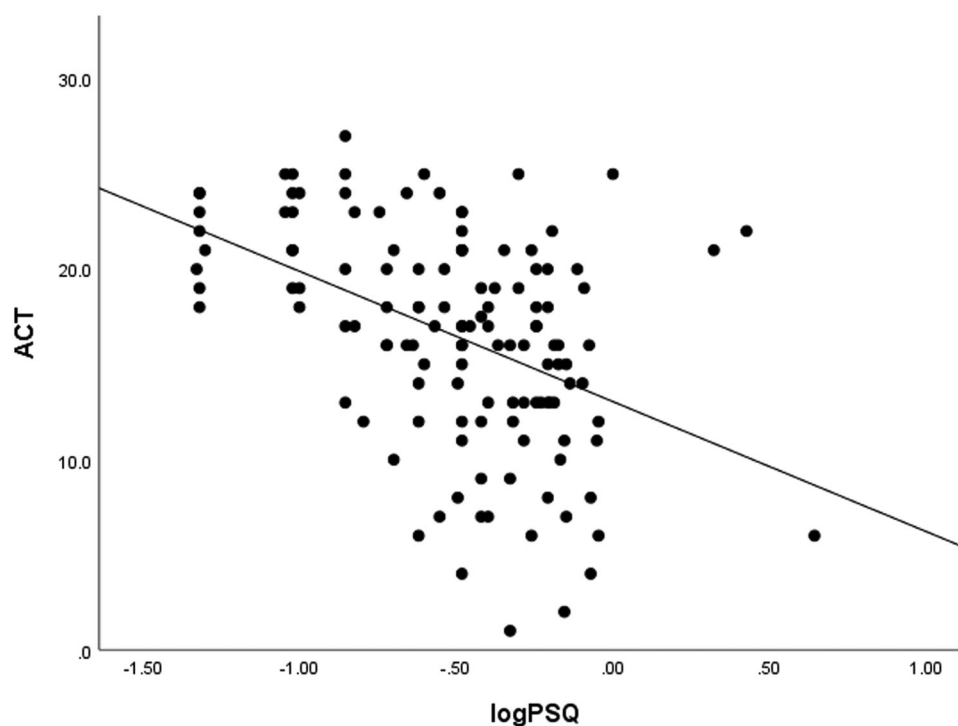


Figure 1. ACT vs. logPSQ. Significant correlation demonstrating decreased asthma control in subjects >5 years old based on Asthma Control Test (ACT) as PSQ increased. PSQ log transformed due to non-Gaussian distribution.

poor asthma control was confirmed with similar results between PSQ and ACT or TRACK questionnaires, respectively, based on age (Table 3). More specifically, children less than 5 years, as well as those 5–11 years (Supplementary material, Table 3) appear to drive these results for TRACK and ACT, respectively, while we see a similar trend toward significance for both NAEPP control and ACT in the 12–21 age group.

Polysomnography

A subgroup ($n=47$) of our study population had completed polysomnography during the study

period. An abnormal PSQ was associated with higher average Apnea-Hypopnea Index (AHI). In those with an abnormal PSQ, the mean AHI was significantly higher (9.1 events/hr [SE $\pm$ 2.3], moderate OSA range) than in those with a normal PSQ (mean AHI 3.6 events/hr [SE $\pm$ 0.7], mild OSA range) ($p=0.027$). There was no significant association between PSQ and periodic limb movement index ($p=0.58$), oxygen desaturation less than 90% ($p=0.87$), or hypercapnia above 50 mmHg ($p=0.61$) (Table 4). In our age-based sub analysis, the most significant difference in AHI is appreciated in the 5–11 age group (Supplementary material, Table 4).

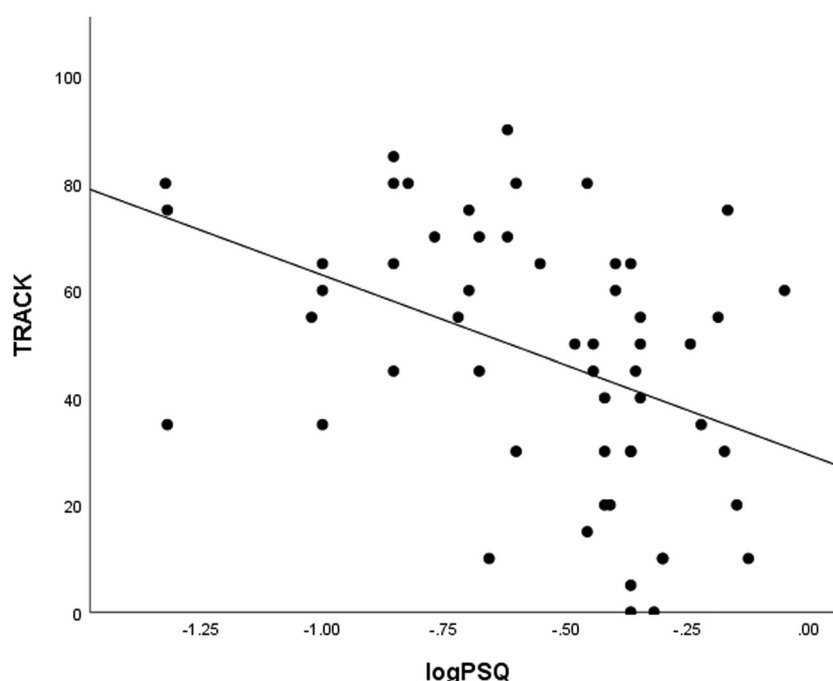


Figure 2. TRACK vs. logPSQ. Significant correlation demonstrates decreased asthma control in subjects <5 years old based on TRACK as PSQ increases. PSQ log-transformed due to non-Gaussian distribution.

Table 3. Asthma Control vs. PSQ.

Outcome	Overall (n = 205)	PSQ < 0.33 (n = 96)	PSQ ≥ 0.33 (n = 109)	P Value*
NAEPP Control, % (n)	42.0 (87)	57.7 (56)	28.2 (31)	<0.001
Daytime Symptoms		33.3 (32)	66.1 (72)	<0.001
Nighttime Awakening		33.3 (32)	69.7 (76)	<0.001
Albuterol Use		29.2 (28)	61.5 (67)	<0.001
Activity Limitation		51.0 (49)	70.0 (73)	0.006
ACT, Mean (SE)	17.1 (0.6); n = 138	19.1 (0.6); n = 61	14.7 (0.6); n = 75	<0.001
TRACK, Mean (SE)	48.9 (3.3); n = 61	61.5 (4.1); n = 31	37.1 (4.0); n = 31	<0.001

*Adjusted for reported co-morbidities.

P Value for continuous variables calculated based on t-test.

P Value for binomial data calculated using Pearson's χ^2 test.

NAEPP: National Asthma Education and Prevention Program; SE: standard error; ACT: Asthma Control Test; TRACK: Test for Respiratory and Asthma Control in Kids.

Table 4. Polysomnography vs. PSQ.

Parameter	Overall (n = 47)	PSQ < 0.33 (n = 15)	PSQ ≥ 0.33 (n = 32)	P Value
Apnea-Hypopnea Index, mean (SE)	7.3 (1.6)	3.6 (0.7)	9.1 (2.3)	0.027
Periodic Limb Movement Index	1.7 (0.7)	2.7 (1.5)	1.4 (0.8)	0.58
O ₂ saturation <90%, %	29.8% (14)	31.3% (5)	28.1% (9)	0.87
CO ₂ > 50mm Hg, %	4.2% (2)	6.3 (1)	3.1 (1)	0.61

P Value for continuous variables calculated based on t-test.

P Value for binomial data calculated using Pearson's χ^2 test.

Discussion

Our study explores the association between poorly controlled asthma and SDB. The goal of this study is to help general practitioners identify when to use a screening tool, such as the PSQ, in children with asthma, and to demonstrate an association with asthma control. To this end, we focused on currently accepted guidelines for evaluating asthma control and impairment. Recently, it was found that SDB

symptoms remain prevalent in adolescents when controlling for nocturnal asthma symptoms (12) and that SDB and adenoid hypertrophy contribute to uncontrolled asthma (25). Our findings are consistent with these as a positive PSQ score was associated with decreased control across all NAEPP impairment criteria, which supports our hypothesis. This emphasizes the importance of exploring common symptoms of both asthma and SDB affecting the upper airway to

achieve optimal control and improve quality of life by addressing both conditions concomitantly (26).

Our findings suggest that when screening for asthma control at routine visits, the presence of uncontrolled symptoms across all indices is associated with SDB. Based on these findings, the use of a screening tool for SDB should be considered among all children with uncontrolled asthma given the low risk and high potential benefit of screening. Recent studies have indicated that, while adenotonsillectomy can improve asthma control (18), children with asthma are at higher risk of continuing to have severe OSA requiring continuous positive airway pressure (CPAP) therapy when compared to their non-asthmatic peers (8). Therefore, early detection of underlying SDB symptoms concurrent with poorly controlled asthma may be critical in preventing the development of severe OSA later in life.

Sleep disordered breathing symptoms can influence perceived asthma control by patients and families, as suggested by all asthma control measures included in this study (NAEPP, TRACK and ACT). Patients with both positive and negative PSQ had a significant degree of uncontrolled asthma based on NAEPP guidelines (42.3% vs. 71.8%) across all indices. Our study revealed that patients with positive PSQ had significantly worse control based on ACT and TRACK questionnaires. When broken down by age, these results were most striking in the less than 5 year and 5–11 year age group; these parameters trend toward significance in the 12–21 year old age group, though due to a small *n* was not significant ([Supplementary material, Table 3](#)). These differences were not associated with baseline asthma severity, going against what had been demonstrated in Ross et al. correlating worse control measures with more severe asthma (17). Both ACT and TRACK, while typically used with discrete cutoff values for sensitivity and specificity purposes in clinical settings, were developed as continuous variables and demonstrate decreased asthma control as scores decline (23,24,27), with the lowest scores associated with the poorest control. In utilizing ACT and TRACK as originally intended we are able to evaluate the continuum of asthma control in relation with additional scoring measures, as we did with PSQ. With this in mind, we demonstrated worsening sleep symptoms based on PSQ scores correlate with worsening asthma control, as noted in [Figures 1 and 2](#).

Despite significant differences in these questionnaires, our populations showed no significant difference in objective diagnostic testing often used to evaluate asthma control and disease severity, including

serum studies (eosinophils, IgE), spirometry, or FeNO. This highlights the importance of using multi-modal evaluations of patients, especially those with poorly controlled asthma symptoms. Based on the absence of clear association between objective measures of asthma disease severity and obstructive sleep apnea, the PSQ may be the best tool to use as screening for SDB in poorly controlled asthmatic children as our study suggests validated questionnaires may be more sensitive in identifying differing degrees of impairment.

The PSQ may be useful for evaluating the presence and degree of SDB in practices where there are few other tools for clinical evaluation. In Ramagopal et al., it was seen that patients referred for adenotonsillectomy had significantly increased AHI if they had a history of uncontrolled asthma (28). In our subgroup of patients who underwent polysomnography, those with positive PSQ had more severe OSA (AHI 9.1 vs. 3.6). More specifically, all eight subjects with severe OSA (AHI > 10.0/hr) were in the abnormal PSQ group. This data is most significant in the pre-pubertal children included in our study with greater than 5 times increase in AHI ([Supplementary material, Table 4](#)), though further study on adolescents is warranted given low *n* in our population. Based on this, PSQ may be the best noninvasive tool to identify moderate and severe OSA among uncontrolled children with asthma. This stratification can help identify higher risk patients and determine next steps in workup or appropriate treatment of comorbid conditions.

Effectively treating residual OSA symptoms in these patients may further improve perceived nocturnal symptoms, asthma control, and fragmented sleep. Kheirandish-Gozal et al. demonstrated that treatment of OSA with adenotonsillectomy reduced frequency of symptoms and rescue inhaler use (29), emphasizing the importance of detecting and intervening on clinically significant OSA for both sleep and asthma benefits. The connection between the two entities is still unclear, but thought to be secondary to bidirectional mechanical and molecular inflammatory pathways (30,31). Controlling for one can help reduce the severity of the other when the more contributory underlying issue is identified and addressed effectively (32). There is also a large body of evidence suggesting a distinct phenotype in asthmatic children owing to alteration in respiratory muscle tone during sleep stages, specifically rapid-eye movement (REM) sleep, with increased bronchial reactivity (33). Further study conducted by Kilaikode et al. demonstrated that asthma was an independent risk factor for needing CPAP therapy even after therapeutic adenotonsillectomy (8). These highlight

the importance of identifying and following comorbid conditions, which makes PSQ an even more useful tool in the setting of outpatient care, particularly for general pediatricians who may not have immediate access to a sleep center, offering an inexpensive, effective screening tool to aid in deciding if a formal sleep study is warranted.

There are a few limitations with our study. First, as a retrospective study we can only identify associations and cannot assume causality between findings in questionnaires and actual underlying diagnoses. Second, sleep studies were not performed on all subjects included in this study, and the decision to obtain a sleep study was not determined by nighttime symptoms or positive PSQ scores. Interestingly, there was no significant association between PSQ score and report of sleep apnea as a comorbid condition. This may be due to a bias toward reporting nighttime asthma symptoms, and not recognizing sleep symptoms. Ultimately, a prospective analysis in a larger cohort with polysomnographic data would be the next logical step to further evaluate and validate these findings. It would be prudent to include a larger number of adolescent patients in future study as much of our data is driven by the larger number of younger children (under 12 years). Finally, it would be important to follow patients undergoing intervention for their OSA and determine response in both PSQ and asthma control questionnaires.

Overall, our observations are consistent with previous epidemiologic and clinical studies of pediatric asthma and sleep disordered breathing. However, our study is the first to associate abnormal PSQ in the setting of poorly controlled asthma with significant differences in polysomnography despite similar conventional measures of asthma burden (serum studies, spirometry) which again validates our hypothesis. Building on these recent studies, our results suggest that using the Pediatric Sleep Questionnaire when evaluating children with asthma and poorly controlled symptoms, regardless of weight status, will help practitioners determine whether further evaluation for sleep apnea or step-up therapy for asthma symptoms is indicated.

Conclusion/key findings

While the association between asthma and SDB is well described, this is the first study which shows there is a significant association between PSQ scoring and NAEPP guideline based indices of asthma control. Our finding of poor asthma control based on NAEPP

guidelines with abnormal PSQ score were confirmed with ACT and TRACK, two validated, age-specific asthma control questionnaires. Additionally, our PSQ results were confirmed in our subgroup that completed polysomnography and suggest abnormal PSQ is associated with moderate and severe OSA while normal PSQ can still be associated with mild OSA. We recommend that pediatricians regularly screen for SDB with PSQ in children with asthma, especially when poorly controlled.

Declaration of interest

The authors report no conflict of interest

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Supplemental Table 4. Polysomnography vs. PSQ, Age Specific Groups

Parameter	Age <5 Years				Age 5 – 11 Years				Age 12 – 21 Years			
	Overall (n=18)	PSQ<0.33 (n=7)	PSQ≥0.33 (n=11)	P Value	Overall (n=22)	PSQ<0.33 (n=7)	PSQ≥0.33 (n=15)	P Value	Overall (n=8)	PSQ<0.33 (n=1)	PSQ≥0.33 (n=6)	P Value
Apnea-Hypopnea Index, Mean (SE)	4.8 (1.2)	4.4 (0.9)	4.9 (1.9)	0.84	8.8 (2.8)	2.1 (0.9)	11.8 (3.8)	0.026	9.7 (5.7)	8.2 (0)	9.9 (6.7)	-
Periodic Limb Movement Index	1.3 (1.2)	0.07 (0.07)	2.1 (2.05)	0.45	2.0 (1.0)	3.4 (2.9)	1.4 (0.7)	0.53	1.7 (1.4)	9.8 (0)	0.35 (0.2)	-
O2 saturation <90%, %	27.8 (5)	14.3 (1)	36.3 (4)	-	23 (5)	29 (2)	20 (3)	0.66	43 (3)	100 (1)	33 (2)	-
CO2 >50mm Hg, %	0 (0)	0 (0)	0 (0)	-	9 (2)	14 (1)	7 (1)	0.56	0 (0)	0 (0)	0 (0)	-

P Value for continuous variables calculated based on t-test

P Value for binomial data calculated using Pearson’s χ^2 test

P value excluded if n<5 for any comparison group

Supplemental Table 2. Serum Studies and Pulmonary Function Testing vs. PSQ, Specific Age Groups

Outcome	Age <5 Years				Age 5 – 11 Years				Age 12 – 21 Years			
	Overall (n=75)	PSQ<0.33 (n=37)	PSQ≥0.33 (n=38)	P Value	Overall (n=103)	PSQ<0.33 (n=48)	PSQ≥0.33 (n=55)	P Value	Overall (n=27)	PSQ<0.33 (n=11)	PSQ≥0.33 (n=16)	P Value
Serum Studies												
% Eosinophils, Mean (SE)	3.9 (0.6); n=39	3.1 (0.8); n=16	4.4 (1.0); n=23	0.31	6.1 (0.6); n=54	6.1 (0.9); n=23	6.0 (0.8); n=31	0.92	4.8 (0.9); n=16	0.95 (0.95); n=2	5.3 (0.94); n=14	-
Total IgE, Mean (SE)	471 (164); n=34	205 (104); n=10	582 (226); n=24	0.30	757 (204); n=43	1147 (461); n=18	476 (94); n=25	0.11	434 (100); n=17	583 (234); n=4	388 (112); n=13	-
Pulmonary Function Testing	n=2	n=0	n=2		n=103	n=48	n=53		n=25	n=10	n=15	
FEV1 (%pred), Mean (SE)	96.0 (2.0)	0	96.0 (2.0)	-	81.6 (1.7)	81.7 (2.5)	81.4 (2.2)	0.93	81.8 (3.9)	85.7 (6.4)	79.2 (4.9)	0.42
FVC (%pred), Mean (SE)	99.5 (7.5)	0	99.5 (7.5)	-	88. (1.5)	89.2 (2.3)	88.4 (1.9)	0.79	94.9 (2.5)	98.4 (3.0)	92.6 (3.5)	0.26
FEV1/FVC (Abs), Mean (SE)	85.5 (3.5)	0	85.5 (3.5)	-	83.5 (0.9)	83.4 (1.2)	83.6 (1.2)	0.91	75.8 (2.4)	77.2 (4.8)	74.9 (2.5)	0.65
FEF25-75% (%Pred), Mean (SE)	82.5 (8.5)	0	82.5 (8.5)	-	69.9 (3.0)	68.6 (4.5)	71.0 (4.0)	0.68	64.7 (6.7)	74.2 (11.9)	58.4 (7.8)	0.26
FeNO (ppb), Mean (SE)	95 (0)	0	95 (0)	-	36 (5)	35.8 (5.9)	36.0 (6.9)	0.98	32 (6)	21.1 (10.3)	40.8 (7.2)	0.13

P Value for continuous variables calculated based on t-test
P Value for binomial data calculated using Pearson’s χ^2 test
P value excluded if n<5 for any comparison group
IgE: Immunoglobulin E
SE: Standard error of the mean
FEV1: Forced expiratory volume in 1 second
FVC: Forced vital capacity
FEF25-75%: Forced expiratory flow over 25% to 75% of FVC
FeNO: Fraction of exhaled nitric oxide

Supplemental Table 3. Asthma Control vs. PSQ, Specific Age Groups

Outcome	Age <5 Years				Age 5 – 11 Years				Age 12 – 21 Years			
	Overall (n=72)	PSQ<0.33 (n=32)	PSQ≥0.33 (n=35)	P Value	Overall (n=103)	PSQ<0.33 (n=48)	PSQ≥0.33 (n=55)	P Value	Overall (n=25)	PSQ<0.33 (n=11)	PSQ≥0.33 (n=14)	P Value
NAEPP Control, % (n)	48.6 (34)	68.6 (24)	28.6 (10)	0.001	39.8 (41)	52.1 (25)	29.1 (16)	0.017	44.0 (11)	63.6 (7)	28.6 (4)	0.08
Daytime Symptoms		24.3 (9)	62.9 (22)	0.001		42.6 (320)	72.2 (39)	0.003		27.3 (3)	68.8 (11)	-
Nighttime Awakening		35.1 (13)	71.4 (25)	0.002		38.3 (18)	77.4 (41)	<0.001		9.1 (1)	62.5 (10)	-
Albuterol Use		21.6 (8)	64.7 (22)	<0.001		37.0 (17)	64.8 (35)	0.005		27.3 (3)	62.5 (10)	-
Activity Limitation		37.1 (13)	84.8 (28)	0.006		64.4 (29)	67.9 (36)	0.72		63.6 (7)	64.3 (14)	0.97
ACT, Mean (SE)	18.9 (1.2); n=9	21.0 (1.0); n=3	17.8 (1.6); n=6	-	16.4 (0.6); n=101	18.9 (0.7); n=47	14.1 (0.8); n=54	<0.001	17.1 (1.0); n=26	19.3 (1.4); n=11	15.5 (1.2); n=15	0.056
TRACK, Mean (SE)	49.3 (3.2); n=62	61.4 (4.1); n=31	37.1 (4.0); n=31	<0.001	0	0	0	-	0	0	0	-

P Value for continuous variables calculated based on t-test

P Value for binomial data calculated using Pearson's χ^2 test

P value excluded if n<5 for any comparison group

NAEPP: National Asthma Education and Prevention Program

SE: Standard error of the mean

ACT: Asthma Control Test

TRACK: Test for Respiratory and Asthma Control in Kids

Supplemental Table 1. Demographics, Specific Age Groups

Demographic	Age <5 Years				Age 5 – 11 Years				Age 12 – 21 Years			
	Overall (n=75)	PSQ<0.33 (n=37)	PSQ≥0.33 (n=38)	P Value	Overall (n=103)	PSQ<0.33 (n=48)	PSQ≥0.33 (n=55)	P Value	Overall (n=27)	PSQ<0.33 (n=11)	PSQ≥0.33 (n=16)	P Value
Age, Median (IQR)	2.8 (2.0, 4.0)	2.8 (2.0, 3.8)	3.0 (2.0, 4.0)	0.62	7.4 (6.3,9.8)	7.1 (6.2,9.9)	8.0 (6.4,9.6)	0.53	14.8 (12.9, 17.5)	14.0 (12.9, 17.6)	15.5 (12.8, 17.8)	0.75
Gender, % Female (n)	30.7 (23)	27.0 (10)	34.2 (13)	0.50	40.7 (42)	47.9 (23)	34.5 (19)	0.17	40.7 (11)	36.3 (4)	43.7 (7)	0.7
Ethnicity, % (n)				0.83				0.10				0.17
African American	73.3 (55)	73.0 (27)	73.7 (28)		72.8 (75)	64.5 (31)	80.0 (44)		62.9 (17)	45.4 (5)	75.0 (12)	
Caucasian	12.0 (9)	13.5 (5)	10.4 (4)		4.8 (5)	6.2 (3)	3.6 (2)		7.4 (2)	9.1 (1)	6.2 (1)	
Other	5.3 (4)	5.4 (2)	5.3 (2)		22.3 (23)	29.1 (14)	16.3 (9)		29.6 (8)	45.4 (5)	18.7 (3)	
BMI Percentile, Mean (SE)	65.6 (3.9)	62.8 (6.0)	68.4 (5.0)	0.47	71.2 (3.0)	69.5 (4.5)	72.5 (4.1)	0.62	82.2 (4.7)	82.4 (7.4)	82.1 (6.9)	0.98
BMI Percentile ≥85, % (n)	21.3 (16)	21.6 (8)	50.0 (19)	1.0	44.7 (46)	43.7 (21)	45.4 (25)	0.98	62.9 (17)	63.6 (7)	62.5 (10)	0.95
Reported Co-Morbidity ^a , % (n)												
Rhinitis	62.7 (47)	54.1 (20)	78.9 (30)	0.004	88.3 (91)	91.6 (44)	85.4 (47)	0.78	74.0 (20)	72.7 (8)	75.0 (12)	0.71
Eczema		54.1 (20)	71.1 (27)	0.08	66.0 (68)	58.3 (28)	72.7 (40)	0.046	48.1 (13)	27.2 (3)	62.5 (10)	-
Obstructive Sleep Apnea	4.0 (3)	2.7 (1)	5.3 (2)	-	5.8 (6)	0 (0)	10.9 (6)	-	14.8 (4)	0 (0)	25.0 (4)	-
Gastroesophageal Reflux	21.3 (16)	18.9 (7)	23.7 (9)	0.48	9.7 (10)	2.0 (1)	16.3 (9)	0.01	11.1 (3)	9.1 (1)	12.5 (2)	-
NAEPP Asthma Severity ^a , % (n)				0.28				0.93				0.56
Intermittent	0 (0)	0 (0)	0 (0)		0 (0)	0 (0)	0 (0)		0 (0)	0 (0)	0 (0)	
Mild Persistent	22.7 (17)	27.0 (10)	18.4 (7)		14.5 (15)	8.3 (4)	20.0 (11)		11.1 (3)	18.2 (2)	6.2 (1)	
Moderate Persistent	6.7 (5)	8.1 (3)	5.3 (2)		51.4 (53)	64.6 (31)	40.0 (22)		51.8 (14)	45.4 (5)	56.2 (9)	
Severe Persistent	5.3 (4)	5.4 (2)	5.3 (2)		33.9 (35)	27.0 (13)	40.0 (22)		37.0 (10)	36.3 (4)	37.5 (6)	
Mod/Severe Persistent <5yr	65.3 (49)	59.5 (22)	71.1 (27)		-	-	-		-	-	-	
PSQ, Mean (SE)	0.33 (.03)	0.13 (0.02)	0.42 (0.05)	<0.001	0.43 (.05)	0.16 (.01)	0.67 (.08)	<0.001	0.34 (.04)	0.11 (.02)	0.49 (.04)	<0.001
Total ICS, Mean mcg (SE)	346 (23); n=64	382 (44)	497 (51)	0.28	458 (34); n=92	450 (39)	465.1 (53)	0.94	581 (65); n=20	537 (94)	700 (83)	0.26

^aP Value based on Logistic Regression
P Value for continuous variables calculated based on t-test
P Value for binomial data calculated using Pearson’s χ^2 test
P value excluded if n<5 for any comparison group
IQR: Interquartile Range
NAEPP: National Asthma Education and Prevention Program
BMI: Body Mass Index
SE: Standard error of the mean
PSQ: Pediatric Sleep Questionnaire
ICS: inhaled corticosteroid