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Peak Flow Measurements in Children with Asthma: What Happens at School?

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Abstract

Background—Self-monitoring of symptoms or peak flow monitoring (PFM) is recommended for all asthma patients and is commonly included in asthma management plans. Limited data are available documenting PFM outcomes in school settings.

Method—Three hundred twenty-three urban children with persistent asthma were enrolled in a school-based study that implemented an internet-based asthma monitoring and data collection system. The mean age of the children was 10.0 (SD 2.1) years; 57% were male and 91% were African American. Children logged in daily to an internet-based program to record their asthma symptoms and PFM reading. Teachers logged in daily to confirm the PFM readings. School staff responsible for student health reported actions taken for low PFM readings.

Results—A total of 12,245 child reports were completed; 98% (n=11,974) had corresponding teacher reports, confirming the peak flow meter readings reported by the children. The prevalence of reported asthma symptoms varied across PFM readings; the highest prevalence occurred in the setting of red zone readings, with intermediate prevalence in the setting of yellow zone readings, and lowest prevalence in the setting of green zone readings. The actions reported in response to children's symptoms and peak flow results similarly varied; however, instances of no action were reported in the setting of yellow and red zone readings. When comparing the "worst days" of children who had ever had a red or yellow PFM reading with those of children who only had exhibited green, there was a nonsignificant trend toward fewer symptoms in the green-only group. Additionally, there was a nonsignificant trend toward a greater likelihood of being sent to the office or school nurse with greater symptoms in the setting of a yellow or red zone reading.

Conclusions—On the whole, peak flow readings tended to correspond to asthma disease activity. However, the data indicate that school staff may be more inclined to take action based on their own perceptions of a child's asthma or respond to children's subjective reports of asthma symptoms rather than using a more objective measure of disease activity provided by a peak flow meter.

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Keywords

asthma; peak flow; school; children; wheeze

INTRODUCTION

Asthma management guidelines recommend ongoing monitoring of disease activity to help optimize control (1). Peak flow monitoring affords patients a quantitative measure of impairment due to asthma and can help detect early changes in disease status requiring treatment and evaluate responses to changes in therapy (1). Current asthma management guidelines acknowledge that peak flow monitoring during exacerbations of asthma help determine the severity of these flares and can be useful to guide therapeutic decisions at school (1). Yet, patients' difficulty maintaining adherence and the potential for incorrect readings have been recognized as limitations to long-term peak flow monitoring. Indeed, a review of the limited evidence suggests that a peak flow monitoring–based action plan is not clearly better than one based on symptoms alone in improving asthma outcomes (1).

Peak flow monitoring (PFM) used during asthma exacerbations at school may be helpful to inform decisions and provide guidance to school staff. In recognition of this, the availability of PFM at school has become a benchmark measure in evaluating the adequacy of asthma care in school settings, and comprehensive school-based asthma programs regularly incorporate PFM into their asthma action plans. Additionally, the capacity to perform PFM has been designated as a recommended responsibility of school nurses (2,3). Yet, surveys have demonstrated that at most, a little over half of the children with asthma have access to a peak flow meter at school (4–6).

School-based supervised asthma treatment programs in inner-city schools that incorporate PFM recommendations into their operations have the potential to optimize pediatric asthma outcomes, help children make PFM a daily habit, and lessen asthma disparities. (7) In one such program implemented in Dallas, Texas, peak flow readings were measured twice a day in 22 children. School personnel were provided standard protocols to guide responses to yellow (50%–80% of target) and red zone (0%–50% of target) readings (8). Over the 13 weeks of the study, most children demonstrated improvements in peak flow readings, as well as reductions in the use of inhaled bronchodilator, and in nocturnal symptoms. Data were not presented regarding the frequency of red or yellow zone readings or of the actual response of the school personnel to such readings (8). An expanded study in the same school district yielded similar findings (7). Again, the frequency of yellow and red zone readings and the response of the school personnel were not noted. We previously reported on a 17-week pilot study of internet-based asthma monitoring in 42 children in urban Midfield and Tarrant, Alabama, in which 2,695 peak flow readings were obtained in total, of which 5% were in the yellow zone and 1% in the red. The school nurses reported follow-up for 90% of the yellow and red readings; the child's parent or guardian was contacted 15% of the time, medication given at school 55% of the time, and emergency services called 2.5% of the time (9). No data were collected on the reasons why the nurses did not report follow up for the remaining 10% of the low peak flow readings.

We recently have completed a randomized trial of supervised asthma therapy in 36 urban elementary schools in and around Birmingham, Alabama (10). Internet-based monitoring of peak flow and asthma symptoms was conducted on days that school was in session. This article reports school staff responses to yellow and red zone peak flow readings, in conjunction with the symptoms manifested by the children at the time of the readings.

METHODS

Data were collected during the baseline period of the randomized trial, between October and December, 2005. Data were collected from 323 elementary school children (ages 6–12 years of age; mean age 10, SD 2.1 years); 57% of the children participating in this study were male and 91% were African American. The study was conducted in five urban school districts located in the greater Birmingham area of Alabama. Children were recruited from the pulmonary and allergy clinics of The Children's Hospital of Alabama, from local health department pediatric clinics, and by word-of-mouth and flyers distributed to parents through the schools. All recruitment materials announced that participants would receive two peak flow meters, spacers, and controller and rescue medications for use in the home and the school at no cost.

Children were eligible to enroll in the study if they had a physician diagnosis of persistent asthma that required daily administration of an inhaled steroid and could tolerate a switch to the medication budesonide available through the study. Before enrollment, each child was medically evaluated by a board-certified pediatric pulmonologist in a clinic conducted at the Lung Health Center (LHC) at the University of Alabama at Birmingham (UAB). Any child being treated for asthma whose disease was judged too severe to attempt a switch to budesonide was excluded. When a caregiver identified a medical home for their child, a letter outlining study activities, each child's medication prescription, a summary of the study physician's physical examination, and contact information for the UAB LHC was sent to the healthcare provider. Written informed consent was obtained from the parent or legal guardian of each child before his or her enrollment into the study. Additionally, assent was obtained from the children. The study was approved and monitored by the institutional review board for human studies at the University of Alabama at Birmingham.

After their enrollment into the study, children were oriented to the daily monitoring program with a computerized interactive educational program. This educational program reviewed the nature of asthma, asthma triggers, the proper use of a metered-dose inhaler and a breath actuated device, PFM technique, and interpretation of PFM readings. After completing the educational program, children were asked to demonstrate their PFM and inhaler skills to the study nurse. Children then began logging in to an interactive internet-based asthma monitoring and data collection system at school. Children were asked to report asthma symptoms (choices included "fine," "coughing," "wheezing," "chest tightness," and "trouble breathing"; children could choose more than one symptom) and PFM reading (9,10). Based on reported PFM readings the system provided each child with feedback. In the event of a "green zone" reading, children were told "it is a good day–go play"; a reported "yellow" reading yielded instructions to "slow down and talk to an adult"; while a reported "red" zone reading instructed a child to "stop and talk to an adult right away." Teachers also logged in each day to confirm children's reported readings and record actions taken for low PFM readings or to report a child absent.

At the start of the study, school staff involved in the project attended a 60-minute in-service that included basic asthma education, instruction in proper use of the PFM and asthma action plans, and orientation to the computer program. The target PFM readings for each child were set and recorded by the study staff during each child's recruitment visit with the study physician. These target readings were reassessed every 12 months, with upward adjustments made if PFM readings consistently topped the previously determined green zone top reading. The study physician was available for consultation when questions arose related to target PFM levels or in the event a child reported red PFM readings with symptoms for 3 days in a row or reported yellow PFM readings with symptoms for 5 days in a row.

Asthma action plans were provided for all children. When a child reported a low PFM reading, action plans were implemented according to school policy. In a few schools teachers or school nurses were responsible for implementing a child's asthma action plan; however, in most schools central office staff who had undergone district-wide training for medication administration were responsible for executing the action plans. These plans instructed staff to administer albuterol by pressurized metered-dose inhaler and to repeat the peak flow reading 10 to 15 minutes afterward. If the child's PFM did not improve, a second dose of albuterol was to be given. If, after the second administration of albuterol there was no improvement, or if at any time school staff were concerned that the child needed medical attention, the action plan instructed staff to call for emergency medical services. Reported yellow and red zone PFM results caused the computer program to generate automatic e-mails containing both the PFM results and any reported asthma symptoms to the study coordinator and the study nurse, thereby allowing for timely follow-up by both the school and study staff. This asthma action plan protocol was approved and monitored by the Data Safety and Monitoring Board for this study.

We examined the distribution of PFM readings and the actions taken by the school teacher in response to yellow or red zone readings. Serious adverse events, as defined by the FDA, were noted as they occurred in participants (11).

STATISTICAL ANALYSIS

The statistical analyses are mostly descriptive, with frequencies and percents computed. The data were collected on a daily basis from the subjects. Most statistical tests of interest are based on independent data; therefore, many standard statistical tests were not appropriate in this analysis. Therefore, conclusions drawn are based on trends observed, without the utilization of inferential procedures.

In addition, we selected the "most extreme" day for each child, and then were able to assess statistically whether differences in specific symptoms, and number of symptoms, existed between children with at least one red or yellow zone PFM reading and children with only green zone readings. We used a chi-square test of association to determine whether differences exist between these groups. We also examined the differences in the actions taken by the teachers among children with at least one red or yellow PFM reading with a chi-square test of association. All analyses were performed using SAS, version 9.0 (SAS Institute, Inc., Cary, NC).

RESULTS

A total of 12,245 child reports were completed, 98% of which (n = 11,974) had corresponding teacher reports. Given the number of days that school was in session, 13,855 reports were expected during this time. Thus, of the expected reports, child reports were observed 88% of the time, while teacher reports were observed 95% of the time. There were 1,198 instances for which reports were not completed. Incompletion of these reports included the following reasons: absence (94%), field trips (2%), late to school (1%), and standardized testing (<1%). For 27 instances (2%), the reason that the report was not completed was not known. The teachers validated ninety-eight percent of the PFM readings entered by the student. Teachers reported 26 red, 459 yellow, and 11,489 green PFM readings. The 485 abnormal (yellow and red) peak flow meter readings occurred among only 131 children. The occurrence of at least one symptom was reported 1,964 times, among 216 unique children. Table 1 below details the type and number of symptoms reported at the times that red, yellow, and green readings were recorded as well as the responsive actions taken by the teacher.

Children with red zone readings appeared to have the highest prevalence of individual symptoms; children with yellow zone readings had an intermediate prevalence; and children

with green zone readings had the lowest prevalence of individual symptoms. Additionally, children with red zone PFM readings appeared to report a higher total number of symptoms; children with yellow zone readings an intermediate number, and children with green zone readings a low number of symptoms. Because individuals provided data on multiple occasions, the ability to test this relationship statistically is limited. It is interesting to note that in 38% of the red zone readings and 44% of the yellow zone readings, no symptoms were reported.

Most of the children who had low PFM readings were sent to the school office for further management. The teachers did not report giving albuterol to any children with red PFM readings, while they reported administering albuterol to treat 11% of the yellow PFM readings. Interestingly in 25% of the yellow and 12% of the red zone peak flow readings, the teacher took no action.

Table 2 and Table 3 below detail the actions taken by the teacher in response to yellow and red PFM readings among all yellow and red readings, respectively, broken down by the number of presenting symptoms.

The teachers appeared to respond more aggressively to children exhibiting more symptoms and lower PFM readings. On 63 yellow PFM occasions (14% of the yellow PFM readings), the teacher took no action, although symptoms were present. For 3 red PFM readings, no actions were taken.

Considering the yellow zone readings, the 111 “no action” responses were distributed among 39 unique children (range 1–15 occurrences per child), the 47 “medication by teacher” responses were distributed among 28 unique children (range 1–6 occurrences per child), and the 270 “sent to the nurse” responses were distributed among 92 unique children (range 1–27 occurrences per child). Considering the red zone readings, the 3 “no action” responses were distributed among 2 unique children, and the 23 “sent to the nurse” responses were distributed among 13 unique children (range 1–4 occurrences per child). Of the 131 unique children with either red or yellow readings, 13 experienced at least one of both red and yellow readings, 117 children experienced yellow readings only, and only 1 child experienced only a red reading. In 100 of the 115 cases where no action was taken, the PFM reported by the child was validated by the teacher. In the remaining 15, on 14 occasions the teacher reported yellow while the child reported green. On one occasion, the teacher reported yellow and the child reported red. Of 131 children with either red or yellow readings, 16 never had any action taken, 80 always had action taken, 20 sometimes had action taken and sometimes not, and in 15 there were missing data that precluded our knowing whether the response by the teacher was consistent across all low readings.

We examined the circumstances surrounding the 25 serious adverse events (SAEs) that were reported to us during the time period of these observations. Twenty-three of these events were related to a worsening of the child’s asthma. On 2 of these 23 occasions, the SAE occurred during the Christmas break, therefore no data are available covering the days immediately before the SAE. Two children each had 2 SAEs; all related to worsening of the child’s asthma. On 7 occasions, SAEs were preceded by decreases in peak flow; the child was sent to the office or school nurse on all of these occasions. On 15 occasions, all of the PFM readings leading up to the SAE were in the green zone. On one occasion, PFM were not recorded the 4 days leading up to the event. On 10 occasions, the child reported asthma symptoms anywhere from 1 to 8 days before the SAE. On each of the occasions where the child reported symptoms on the day of the SAE, the child was sent to the office or school nurse. On 10 occasions, the child did not report symptoms before the SAE. On one occasion, there was no report of the presence or absence of symptoms in the 4 days leading up to the SAE, and before that time period the child

reported no symptoms. Thus, no SAEs were associated with a lack of action following a yellow or red zone PFM reading or symptoms on the day of the SAE.

For each child, we identified the single day with the most symptoms reported and compared these "worst days" between children who had ever had a red/yellow PFM reading and those who had only green readings for the duration of the observation period. This allowed us to compare the frequency of symptoms between two independent groups, and thus get *p* values that are meaningful. Table 4 details this difference.

The children who always exhibited green peak flow meter readings trended toward fewer symptoms on their "worst' days; however, none of these differences were statistically significant.

For the children who had ever had a red/yellow PFM reading, we looked at the number of symptoms on their worst day and the likelihood of their being given medication by the teacher or sent to the school office. Table 5 examines the relationship between the number of observed symptoms on the day selected and the action taken by the teacher.

As the number of symptoms increased, there was a trend toward an increased likelihood of being sent to the office or school nurse; however, this was not statistically significant ($p = 0.61$).

DISCUSSION

Our data demonstrate that PFM readings at school are feasible, and that, qualitatively, they do appear to track disease symptom activity. Our "worst days" analyses failed to show a statistical difference in the frequency of symptoms between those who exhibited only green zone readings and those who exhibited yellow or red zone readings. By selecting the day with the largest number of reported symptoms, our analysis may have been biased toward the null hypothesis. The lack of symptoms in 38% of the red zone readings and 44% of the yellow zone readings was striking. Sly et al. have documented the occurrence of false-positive decreases in peak flow as recorded by PFMs, reductions considered to be clinically important but not borne out by the peak flow reading simultaneously obtained by a spirometer (12). Conversely, "poor perceivers" may not report symptoms in association with significant decreases in peak flow and thus are at risk for severe exacerbations of their disease. Anecdotal evidence in our population suggests that some students seek attention through reporting of symptoms and/or incorrect PFM readings. Peak flow is effort-dependent, and malingering can easily yield falsely low PFM readings. It is possible that teachers are able to identify these students and thus respond less frequently to them. Our data showing a lack of statistical association between the number of symptoms and the action taken in the setting of yellow and red zone readings, coupled with the observations that some of the children with yellow or red peak flow readings never had action taken, as well as a lack of SAE following inaction on the part of the teacher, would support this hypothesis. The occasional inaction of teachers in the setting of a low peak flow reading and reported symptoms is potentially concerning because prompt attention to developing asthma flare-ups can potentially reduce the likelihood of life-threatening exacerbations. A review and meta-analysis of the evidence of the various components of asthma action plans in adults demonstrated that plans using the personal best peak flow resulted in reduced emergency department visits, hospital admissions, and an improvement in airway caliber (13). Further work aimed at understanding the determinants of actions taken by teachers in their pupils with asthma would be helpful in the development of strategies to reduce asthma risks in schoolchildren.

Peak flow is commonly used as a surrogate for forced expiratory flow (FEV_1) because it is easier and less expensive to monitor in the non-clinical setting. However, peak flow reflects

large airway caliber, whereas FEV_1 reflects that of large and medium-sized airways (14). Children with asthma have increased lability of peak flow readings and decreased repeatability compared with healthy children and adults (15). Meltzer et al. have shown in asthmatic children who are clinically stable, that while percent predicted PFM and FEV_1 are strongly correlated, individuals may exhibit a large discrepancy in circadian variation of percent predicted PFM compared with that of FEV_1 (16). Furthermore, many exhibit greater variation in PFM percent predicted than in FEV_1 (16). In research studies in adult asthma, no indices of peak flow are adequate to discriminate those subjects with a 20% or greater decrease in FEV_1 (17). Our peak flow action plan called for a response when the peak flow fell below 80% of personal best. Data in adults suggest that if this plan is followed meticulously, many would increase asthma therapy during stable periods, as 47% of patients may have peak flow values <80% during stable periods (18). Thus, it is possible that some of our yellow zone readings reflected normal variability for that specific child. Individualized action points based on that person's variability during periods of clinical stability may be more useful indicators of asthma exacerbation (18).

Peak flow meters are commonly issued to children and families for daily use at home. Action plans are provided along with the meters, with guidance on how to respond to abnormal PFM readings. Adherence to PFM monitoring at home by inner-city children enrolled in a research study has been shown to be poor (19). Of children presenting to an urban emergency room with an acute asthma flare, two thirds of those who owned a PFM reported that they did not use it (20). When parents of children who had been hospitalized for asthma at an inner-city medical center were presented with a hypothetical scenario of an acute asthma flare, no one mentioned that he or she would refer to a written asthma action plan, and only 1 of 143 parents would even measure peak flow (21). Thus, in the "real world," PFM monitoring, even during exacerbations of disease, is spotty at best. Our students monitored PFM daily, regardless of whether they reported symptoms. Ninety-six percent of the PFM readings were green zone; abnormal PFM readings occurred in this population at a rate of 1 in every 24. PFM involves constant vigilance to ensure good technique, recording of the data, adjustment of zones as children grow and their flows increase, and maintenance of the PFM device. Finally, even when PFM monitoring is performed faithfully, data in both adults and children suggest that PFM decreases of 20% are insensitive at detecting exacerbations early on; changes in number of symptoms precede changes in peak flow (22). This is consistent with our finding that 16 of the 25 SAEs noted were not preceded by decreases in peak flow. In a study of adults randomized to PFM-based monitoring and management of their asthma, therapy was escalated in only 37.5% of exacerbations (23). In a multicenter study of children living in the inner city, a population similar to ours, participants were asked to complete three 2-week symptom and PFM diaries over a 1-year period. Forty-three percent completed all three diaries, 31% completed two, and 25% completed just one. In this population, measures of peak flow lability did not add substantially to a model of symptoms and demographics (asthma persistence, season, or family income) in predicting asthma hospitalizations or unscheduled visits (24). Conversely, Yoos et al. demonstrated long-term (to one year) improvements in asthma composite severity scores and symptom days most noted in African American children who monitored symptoms and used a peak flow meter when increases in symptoms occurred. There was no additional benefit to daily PFM (25). For a monitoring tool to be useful, it should maximize sensitivity and specificity and should be acceptable to the population being monitored, cost-effective, and continuously used (26). Furthermore, there should be evidence that abnormal results are appropriately evaluated and treated. Our data would thus support those of others suggesting that PFM monitoring likely adds little to symptom-based management at home or at school.

The strength of our study rests in the large number of observations recorded in real time on the computer and the "real world" setting in these inner-city schools. Several limitations exist that

may affect the external validity of our study. First, the teachers themselves were not asked to record the presence or the severity of asthma symptoms in the children. In examining reasons for action or inaction in response to low peak flow readings, it would have been helpful to note their perceptions of the children's disease status. However, this would have been impractical in a busy school setting. Second, we do not have real-time validation of the peak flows with spirometry. This too would have been impractical in the setting of the study. Third, the setting of the study, while in the inner-city where asthma morbidity is high, is not reflective of the "real world" as the staff had a relatively high degree of training before initiation of the study, which would be unlikely to happen in most day to day settings. Certainly this type of training would ideally be incorporated into any school-based asthma case management program.

In summary, we conclude that PFM at school is feasible and generally tracks disease activity. However, symptom-based interventions may be more time and cost-effective. Further work designed specifically to answer this question is warranted.

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TABLE 1

Number and type of symptoms reported by PFM reading.

	Red (n = 26 readings among 14 children)	Yellow (n = 449* readings among 130 children)	Green (n = 11489)
Symptoms			
Cough	15 (58%)	197 (44%)	1232 (11%)
Wheeze	11 (42%)	119 (27%)	496 (4%)
Tightness in chest	10 (38%)	107 (24%)	419 (4%)
Trouble breathing	10 (38%)	91 (20%)	385 (3%)
Number of symptoms			
None	10 (38%)	198 (44%)	9708 (86%)
1–2	5 (19%)	168 (37%)	1403 (12%)
3–4	11 (42%)	83 (19%)	222 (2%)
Action taken			
None	3 (12%)	111 (25%)	N/A
Albuterol given	0 (0%)	48 (11%)	N/A
Sent to office	23 (89%)	279 (64%)	N/A

*Ten teachers reported yellow PFM readings, but the child did not enter symptom or PFM data.

TABLE 2

Number of symptoms by action taken –yellow PFM readings.*

	No action taken	Given medication by teacher	Sent to office or school nurse
0 symptoms	48 (26%)	15 (8%)	121 (66%)
1–2 symptoms	46 (29%)	26 (16%)	89 (55%)
3–4 symptoms	17 (20%)	6 (7%)	60 (72%)

*Cell counts represent the number of yellow PFM readings within those categories, not the number of individual subjects; thus, proportions should be interpreted with caution.

TABLE 3

Number of symptoms by action taken –red PFM readings*.

	No action taken	Given medication by teacher	Sent to office or school nurse
0 symptoms	2 (20%)	0 (0%)	8 (80%)
1–2 symptoms	1 (20%)	0 (0%)	4 (80%)
3–4 symptoms	0 (0%)	0 (0%)	11 (100%)

*Cell counts represent the number of red PFM readings within those categories, not the number of individual subjects; thus, proportions should be interpreted with caution.

TABLE 4

Frequency of symptoms among children with red/yellow PFM readings vs. green PFM reading (each child only counted 1 time).

	Red/yellow (n = 131)	Green (n = 159)	*p* value
Symptoms			
Cough	74 (56%)	83 (52%)	0.47
Wheeze	50 (38%)	49 (31%)	0.19
Tightness in chest	55 (34%)	39 (25%)	0.09
Trouble breathing	41 (31%)	34 (21%)	0.06
Number of symptoms			
None	39 (30%)	65 (41%)	
1–2	55 (42%)	60 (38%)	0.12
3–4	37 (28%)	34 (21%)	

The children who always exhibited green peak flow meter readings trended toward fewer symptoms on their “worst” days; however, none of these differences were statistically significant.

TABLE 5

Number of symptoms by action taken (n=126, 5 children are missing the action taken).

	No action taken	Given medication by teacher	Sent to office or school nurse
0 symptoms	9 (26%)	4 (11%)	22 (63%)
1–2 symptoms	8 (15%)	10 (19%)	35 (66%)
3–4 symptoms	7 (19%)	4 (11%)	26 (70%)

As the number of symptoms increased, there was a trend toward an increased likelihood of being sent to the office or school nurse; however, this was not statistically significant ($p = 0.61$).