Selection of Peak Flowmeters in Ambulatory Asthma Patients*

A Review of the Literature

Daniel T. Kennedy, PharmD; Ziba Chang, PharmD; and Ralph E. Small, PharmD

The National Asthma Education and Prevention Program recently published updated guidelines that stress the importance of peak flow monitoring for patients with moderate-to-severe persistent asthma. In this specific patient population, a peak flowmeter provides a simple, quantitative, objective measurement of large airway function. The purpose of this article is to describe indications for peak flow monitoring in asthmatic patients, review technical requirements for peak flowmeters as described by the National Heart, Lung, and Blood Institute, and evaluate the literature on commercially available peak flow devices to aid the health professional in selecting an appropriate meter for the patient with moderate-to-severe persistent asthma.

(CHEST 1998; 114:587–592)

Key words: accuracy; interdevice variability; National Asthma Education and Prevention Program recommendations; peak flowmeters; reproducibility

Abbreviations: ATS=American Thoracic Society; CV=coefficient of variation; NHLBI=National Heart, Lung, and Blood Institute; PEFR=peak expiratory flow rate; PFM=peak flowmeter

A peak flowmeter (PFM) provides a simple, quantitative, reproducible, and objective measurement of large airway function. The purpose of using PFM is to monitor lung function, help identify asthma triggers, and help asthmatics recognize signs and symptoms of decreased lung function. Clinical studies have shown that the routine use of a PFM, along with a self-management plan and education program, can lead to better control of asthma.1 The purpose of this article is to describe appropriate indications for peak flow monitoring in asthmatics, review the literature on the accuracy, reproducibility, and interdevice variability of PFM, and guide the health-care professional in selecting a meter that best suits the needs of the individual patient.

Indications for Peak Flow Monitoring in Asthmatics

Peak flow assessment can be used for short-term monitoring, exacerbation management, and daily long-term monitoring of patients with asthma. Short-term monitoring is recommended for patients with moderate-to-severe persistent asthma who experience an exacerbation to determine severity and to guide therapy. Short-term monitoring may also be useful in the assessment of occupational asthma. Long-term monitoring may be beneficial in patients with moderate-to-severe persistent asthma or those suspected of not perceiving airflow obstruction, but it is not recommended for patients with mild intermittent or mild persistent asthma. Patient-specific signs and symptoms should be carefully addressed in all patients, regardless of whether a PFM is utilized. Some will need to design their treatment plans based only on signs and symptoms because PFM is not sensitive enough to accurately and predictably reflect lung function in all patients with asthma.

A PFM is a relatively inexpensive device that measures airflow obstruction when a patient forcibly
worsening airway

detect small
ability
lished
best
providers
controlled
poorly
is
best
possible
or
A
effort
patient-specific
of
personal
control.2
PEFR
management
before administration of asthma medications
Reproducibility
of
Institute
3-week
monitoring
determining
to
recording
doesn’t
PEFR
is
obtained
after
flow
sibling
toom
A
Reproducibility,
Accuracy,
requirements
To
obtain
PFM
established
be assessed
patient’s
PFMs
once-daily
monitoring
to
recording
PEFR
is
obtained
after
flow
sibling.

A
PFM
is
best
in
the
PEFR
(ATS)
for
the
ATS
Waveform
24
as
the
standard
for
testing
PFMs.6
The
ATS
Waveform
24
has
a
faster
rise-time
(time
required
for
flow
to
rise
from
10
to
90%
of
PEFR)
as
well
as
a
higher
frequency
content
than
the
ATS
Waveform
24.
It
should
be
noted
that
the
studies
evaluated
in
this
review
were
conducted
when
the
ATS
Waveform
24
was
considered
the
standard
for
PFM
testing.
Additionally,
many
studies
used
the
Fleisch
pneumotachometer
to
test
PFMs.
Although
it
is
not
the
standard
for
PFM
testing
according
to
the
ATS,
the
Fleisch
pneumotachometer
is
considered
an
accurate
apparatus.7

Jackson8
evaluated
the
accuracy,
reproducibility
and
interdevice
variability
of
several
different
models
of
PFMs
at
sea
level.
The
brands
of
PFMs
evaluated
were
the
Ferraris
(Ferraris
Medical;
Holland,
NY),
Assess
(HealthScan
Products;
Cedar
Grove,
NJ),
Mini-Wright
(Clement
Clarke
International;
Harlow,
Essex,
UK),
and
Astem
(Center
Laboratories;
Port
Washington,
NY).
Two
models
each
of
the
first
three
brands
were
tested,
one
for
adult
use
(standard-flow
range)
and
another
for
pediatric
use
(low-flow
range).
Twenty
PFMs
of
each
model
were
tested.
Peak
flows
ranging
from
80
to
700
L/min
were
tested
based
on
whether
the
PFM
was
a
low-range
or
standard-range
model.
Five
measurements
of
each
PFM
were
made
each
of
the
peak
flow
rates.
Accuracy
was
assessed
by
the
percentage
of
error
of
the
average
measured
peak
flow.
Reproducibility
of
each
PFM
was
assessed
by
the
coeffi¬cient
of
variation
(CV)
of
the
set
of
measurements
at
each
flow
rate.
Interdevice
variability
was
assessed
by
the
CV
of
the
mean
flows
of
the
20
PFMs
at
each
flow.

In
terms
of
accuracy,
all
20
Astem
PFMs
recorded
flows
with
<10%
error
at
all
flow
rates.
The
Assess
standard-range
PFMs
were
within
the
10%
error
range
for
accuracy
except
for
one
meter
at
a
flow
of
200
L/min.
The
Assess
low-range
PFMs
were
less

**ACCURACY, REPRODUCIBILITY, AND INTERDEVICE VARIABILITY OF PFMS**

Technical
requirements
for
PFMs
were
established
by
the
National
Heart,
Lung,
and
Blood
Institute
(NHLBI)
in
1991.3
A
PFM
must
be
accurate
over
its
full
range
(100
to
400
L/min
crheture
and
from
100
to
700
L/min
for
adults)
within
±10%.
Reproducibility
of
the
devices
should
be
within
10
L/min
or
±5%
of
the
reading,
whichever
is
greater,
to
detected
small
changes
in
PEFR.
Interdevice
variability
should
be
within
±5%. All
of
the
above
parameters
can
be
tested
by
using
Waveform
24
from
the
American
Thoracic
Society
(ATS)
Standard
Test
Waveform
Set.4
Since
these
criteria
for
PFMs
were
published,
to
have
been
several
studies
implemented
to
determine
which
meter
is
superior
for
asthma
monitoring.
Following
is
a
review
of
the
literature
on
the
accuracy,
variability,
and
reproducibility
of
commercially
available
PFMs.

**EVALUATION OF THE LITERATURE OF PFMS**

Before
evaluating
the
literature,
the
different
methods
of
testing
PFMs
should
be
mentioned.
In
1992,
the
Waveform
24
was
recommended
by
the
National
Asthma
Education
Project
as
a
standard
for
testing
PFMs.5
The
ATS
recently
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the
Waveform
26
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the
standard
for
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of
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The
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less

588
accurate compared with the standard-range PFMs. Errors >10% for accuracy were noted with 15, 11, 6, 5, and 5 meters at 80, 150, 200, 250, and 320 L/min, respectively. The Ferraris standard-range PFMs were less accurate than the Astech and Assess standard-range PFMs. Accuracy errors of >10% were noted with 8, 9, 3, 3, and 4 meters at peak flows of 100, 200, 320, 500, and 700 L/min, respectively. The Ferraris low-range PFMs were slightly better than the standard-range PFMs in terms of accuracy, with 15, 4, 1, 0, and 1 meters recording flows with errors >10% at flow rates of 80, 150, 200, 250, and 320 L/min. The Mini-Wright standard and low-range PFMs lacked accuracy. The Mini-Wright standard-range PFMs showed >10% error of accuracy with all 20 PFMs at flow rates of 100, 200, and 320 L/min. The low-range Mini-Wright PFMs demonstrated >10% error of accuracy with 2, 18, 18, 19, and 19 meters at peak flows of 80, 150, 200, 250, and 320 L/min, respectively.

Regarding reproducibility, all 20 Astech PFMs had a CV of <5% at each of the flow rates tested. Three Assess standard-range PFMs and four of the Assess low-range PFMs had a CV greater than the 5% allowed for reproducibility. The low reproducibility of the Assess PFMs could be attributed to the discovery that these devices malfunctioned after several uses. All 20 of the low-range Ferraris and low-range Mini-Wright PFMs had a CV <5% at each of the flows tested and therefore met the guidelines for reproducibility. Only one meter of the Ferraris standard-range PFM and the Mini-Wright standard-range PFM had a CV greater than the ±5% range for reproducibility. Interdevice variability of the PFMs was ≤5% for all PFMs from each of the manufacturers. In summary, the Astech PFM was concluded to be the only device to meet all the guidelines for accuracy, reproducibility, and interdevice variability. It should be noted that Jackson8 may have an association with Center Laboratories, the manufacturer of Astech PFMs.

Evaluation of this study reveals that the results are valid. The use of 20 PFMs from each manufacturer reduces the possibility of false results due to instrument error. In addition, the requirement of five peak flow measurements made at each of the peak flow levels decreases the chance of invalid results. Lastly, the use of the Waveform 24 instead of actual human subjects eliminates variability of results due to inappropriate technique. The well-designed Jackson8 study can be considered the “gold standard” compared with the other studies that evaluate PFMs.

Gardner and colleagues9 evaluated the accuracy and reproducibility of Assess, Ferraris, Spira, Vitalograph (Vitalograph, Inc; Shawnee Mission, Kan), Vitalograph low-range, Wright standard, Mini-Wright, and Mini-Wright low-range PFMs. Five PFMs of each manufacturer were used for the study with the exception of the Ferraris and the Wright PFMs that used only four and two devices, respectively. One PFM of each manufacturer was randomly selected to test reproducibility. Twenty repetitions at each selected waveform were tested by each of the randomly chosen PFMs representing each manufacturer. The authors concluded that the eight models tested were accurate and gave reproducible results; however, the test did not clearly state the percentage of error regarding accuracy in the results. Based on the figures and tables, Vitalograph low-range and the Mini-Wright low-range PFMs’ measurements for accuracy all fell within the 10% accuracy range of error. The Ferraris, Wright, and Mini-Wright PFMs overestimated their flows in mid-range. The study followed the NHLBI standards of accuracy, reproducibility, and interdevice variability. One flaw of the study is that measurements were taken at 1,400 m altitude, possibly underestimating peak flow measurements by 6% compared with sea level. Although the study was well designed, the results’ section failed to mention specific differences among the PFMs.

Miller and associates10 evaluated the accuracy and reproducibility of six Mini-Wright, Ferraris, and Vitalograph PFMs. Each device was tested five times at flow rates between 60 and 720 L/min. Results showed the Vitalograph meters were significantly closer to the true flow, compared with the Mini-Wright meters, for flows <600 L/min. The Ferraris meters were significantly closer to the true flow, compared with the Mini-Wright meters, for flows up to 300 L/min. Beyond the flow of 300 L/min, there was no significant difference between the two brands of PFMs. In conclusion, the authors stated the Mini-Wright, Ferraris, and Vitalograph gave reproducible results, but the accuracy error profiles for the full-range meters would lead to possible incorrect diagnosis and affect treatment strategies. As previously stated, the diagnosis of asthma should not be based on PFM results.1 Changes in therapy are based on the percent of the patient’s personal best peak flow reading. Reproducibility, rather than accuracy, may be considered the more crucial determinant of altering drug therapy based on PFM results. Additionally, it should be noted that the ATS Waveform 24 was not used for testing the PFMs because of concern for possible distortion of flow due to gas compression. Flows were generated by computer-driven pumps which, unlike human generated flows, allowed for less variability. Although the test results did not mention accuracy according to NHLBI guidelines, figures illustrating absolute accuracy error enabled readers to evaluate accuracy.
of the PFMs according to these guidelines. It is fair to say that the results of this study are valid, although conclusions drawn by the authors could be debated.

Hegewald and coworkers\textsuperscript{11} conducted a study that evaluated intraindividual variability and instrument variability of PFMs. Twelve Assess PFMs were used at each of the four study sites. All 45 Assess PFMs met the NHLBI guidelines for accuracy and reproducibility when tested with the ATS Waveform 24. A total of 301 healthy subjects were involved with the testing of the PFMs to assess intraindividual variability. A minimum of five measurements was made by all subjects. Evaluation of PFM variability by the authors involved the testing of three Assess PFMs with the ATS Waveform 24 ten times at each peak flow of 200, 400, 600 L/min at sea level and 1,400 m altitude. Regarding reproducibility of the human subjects, 12.6% of the subjects failed to meet the Burge\textsuperscript{12} criteria of accuracy (best two values within 20 L/min of each other), 9.6% failed to meet the European Respiratory Criteria\textsuperscript{13} (best two values within 5% or 20 L/min, whichever is greater), and 3% failed to meet Dahlquist and colleagues\textsuperscript{14} criteria (best two values within 10% of each other). Results from the three Assess PFMs tested on the ATS Waveform 24 demonstrated meter variability to be small. It was apparent from the tables provided in the results that the flow rates were all within the ±10% accuracy range of error using the Waveform 24. The design of the study was acceptable. Although human subjects were used in the study, the PFMs all met the NHLBI criteria for accuracy and reproducibility prior to the study according to the manufacturer. Additionally, the study did use the ATS Waveform 24 to evaluate instrument variability and accuracy. One flaw of the study is that the use of healthy subjects in the study makes it difficult to extrapolate the results to the asthmatic population. It should be noted that the study was supported by Health Scan Inc, the makers of Assess PFMs.

Shapiro and colleagues\textsuperscript{15} evaluated the accuracy of the Assess and Mini-Wright PFMs. Ten PFMs from each manufacturer were evaluated before (new) and after (used) 200 uses to assess the accuracy by a calibrated pneumotachometer. The new Assess PFMs generally underestimated peak flow at values <350 L/min and overestimated at values >350 L/min. The new Mini-Wright meters were accurate for flows >400 L/min, but consistently overestimated flow rates <400 L/min. After 200 uses, the Assess PFM showed no significant change in accuracy. The accuracy of the Mini-Wright after 200 uses was noted to have diminished. The investigators concluded that the Assess meters were more accurate than the Mini-Wright meters at flows of <300 L/min, while at flows >400 L/min, the Mini-Wright PFM was more accurate. According to the authors, ranges <300 L/min are clinically important since decisions regarding therapies will be made at this range. Changes in asthma therapy today are based on the percent of the patient’s personal best peak flow reading, not a set peak flow measurement of <300 L/min. Another flaw of the study is that the assessment of accuracy was not defined according to the guidelines established by the NHLBI in 1991. In fact, the average percentage of error usually did exceed 10% with the exception of the new Mini-Wright meters at flow rates >300 L/min and the used Mini-Wright meters at rates >450 L/min.

Quirce and associates\textsuperscript{16} evaluated the accuracy, reproducibility, and interdevice variability of the VMX Mini-Log (Clement Clarke Inc; London, UK), a flowmeter with a built-in microprocessor that allows data to be retained for a 1-month period. Accuracy was expressed as percent error, while reproducibility was defined as the average CV of the observed values for each PFM. Interdevice variability was expressed as the average CV of mean flows recorded at each flow rate for all devices. Each of the nine devices was tested six times at flow rates of 100, 200, 300, 400, 500, 600, and 700 L/min using a pneumotachometer. At flow rates between 200 and 600 L/min, all nine VMX Mini-Log PFMs tested were within 10% error of accuracy. At the flow rate of 100 L/min, only one device did not exceed 10% error of accuracy. At the flow rate >700 L/min, five PFMs showed >10% error of accuracy. In terms of reproducibility, the CV was within 5% for all PFMs except three at 100 L/min and one at 700 L/min. Interdevice variability results showed that all the VMX peak flow meters had a CV <±5% at all flow rates tested except 100 L/min. It can be concluded that the VMX PFM satisfies the NHLBI guidelines of accuracy, reproducibility, and interdevice variability between peak flows of 200 and 600 L/min.

Lefkowitz and colleagues\textsuperscript{17} compared a portable, hand-held, electronic PFM (Airwatch; Enact Health Management Systems Inc; Mountain View, CA) with a conventional PFM in 28 patients with mild-to-severe asthma. The Airwatch Airway Monitoring System was evaluated vs the “conventional” Assess PFM in this study funded by Enact Health Management Systems Inc. The Airwatch is capable of storing several months of test results (PEFR and FEV\textsubscript{1}) in memory that can be transmitted via telephone connection to the health-care provider to monitor the patient’s asthma status. The authors state the purpose of the article was to discuss the accuracy of the Airwatch as well as patients’ and physicians’ level of acceptance of the device. Accuracy was evaluated comparing the FEV\textsubscript{1} of the Airwatch with office-based spirometry and comparing peak expiratory
flow measurements of the Airwatch with the Assess PFM. Although the authors concluded that there was “good agreement” between the FEV₁ measured by the Airwatch and office-based spirometry, no data were presented to support this. The mean peak expiratory flow measurements between the Airwatch and the Assess in the 28 patients were found to be not significantly different. However, these measurements were not compared with a standard, such as the Waveform 24, which makes comment on accuracy anecdotal. Also, the age range of patients in this study was wide (4 to 52 years) and it was not clear which Assess model (standard-range vs low-range) was used in the younger patients. The authors also concluded that patient and physician acceptance of the Airwatch was adequate; however, compliance with the use of either device was not significantly different. Overall, the main conclusion of the authors that “the Airwatch device can be expected to reduce the cost of asthma care” is not supported by the data within the study. The Airwatch PFM has the potential to be innovative in the management of asthma with its ability to capture and transmit data; however, a well-designed trial comparing NHLBI standards of this electronic device with conventional PFMs is necessary to determine its place in asthma therapy. The suggested retail price of the Airwatch device along with 1 year of telecommunication service is $295 (Enact Health Management Systems [800] 267-9452).

A number of other studies have evaluated accuracy, reproducibility, and/or interdevice variability of PFMs.7,18–22 The validity of these studies is questionable for several reasons, including the use of human subjects with varying degrees of asthma, determination of peak flow rates by machines other than the ATS Waveform 24, and assessment of accuracy, reproducibility, or interdevice variability not adhering to the NHLBI guidelines.

**DISCUSSION**

Results from the evaluated studies for selected PFMs have been condensed in Table 1. According to NHLBI guidelines, the Astech PFM gained the highest marks in the well-designed study by Jackson;6 however, it is important to consider the NHLBI criteria in selecting a PFM for ambulatory asthma monitoring. Accuracy, reproducibility, and interdevice variability standards do not carry equal weight in this determination process. For example, accuracy of a PFM compared with that of a spirometric device such as the Waveform 24 is meaningless when a patient’s personal best peak flow is used to calculate zone therapy for an asthma action plan. A PFM should not be used as a diagnostic tool, but as a means for monitoring asthma exacerbations in an ambulatory setting. Interdevice variability has a similar role in the asthmatic patient who is counseled on the importance of using the same PFM daily. If a new or different brand of PFM is pur-

<table>
<thead>
<tr>
<th>Brand Name/Manufacturer</th>
<th>Suggested Price†</th>
<th>Accuracy‡</th>
<th>Reproducibility‡</th>
<th>Interdevice Variability‡</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assess</td>
<td>$26.59 (sr)</td>
<td>++ (sr)</td>
<td>+++ (sr)</td>
<td>+++ (sr and lr)</td>
<td>May retain accuracy after extensive use (&gt;200 uses)12</td>
</tr>
<tr>
<td>(800)962-1266</td>
<td>$29.29 (lr)</td>
<td>+ (lr)</td>
<td>+++ (lr)</td>
<td></td>
<td>Met all NHLBI guidelines for accuracy, reproducibility, and interdevice variability6</td>
</tr>
<tr>
<td>Astech full-range model</td>
<td>$21.25</td>
<td>+ (sr)</td>
<td>+++ (sr)</td>
<td>+++ (sr and lr)</td>
<td>May overestimate flows in midrange9</td>
</tr>
<tr>
<td>(800)527-4278</td>
<td>$19.95 (lr)</td>
<td>+ (lr)</td>
<td>+++ (lr)</td>
<td></td>
<td>May be more accurate vs Mini-Wright for peak flows up to 300 L/min10</td>
</tr>
<tr>
<td>Ferraris</td>
<td>$21.95 (sr)</td>
<td>+ (sr)</td>
<td>+++ (sr)</td>
<td></td>
<td>Accuracy may deteriorate after 200 uses15</td>
</tr>
<tr>
<td>(800)205-7187</td>
<td>$21.95 (lr)</td>
<td>+ (sr)</td>
<td>+++ (sr)</td>
<td></td>
<td>May be more accurate vs Mini-Wright for peak flows &lt;600 L/min10</td>
</tr>
<tr>
<td>Mini-Wright</td>
<td>$29.95 (sr)</td>
<td>+ (lr)</td>
<td>+++ (lr)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(800)488-9023</td>
<td>$19.95 (lr)</td>
<td>+ (lr)</td>
<td>+++ (lr)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vitalograph</td>
<td>$11.00 (sr)</td>
<td>+ (sr)</td>
<td>+++ (sr)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(800)255-6026</td>
<td>$11.00 (lr)</td>
<td>+ (lr)</td>
<td>+++ (lr)</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>Colored Zone PFMs</td>
<td>$14.00 (sr)</td>
<td>+ (lr)</td>
<td>+++ (lr)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VMX Mini-Log</td>
<td>$699.00</td>
<td>+ (lr)</td>
<td>+++ (lr)</td>
<td></td>
<td>Satisfies NHLBI guidelines between peak flows of 200 to 600 L/min15</td>
</tr>
</tbody>
</table>

*sr=standard range; lr=low-range; AWP=average wholesale price; n/a=unable to evaluate; ++=unsatisfactory; +++=below average; ++++=good; ++++=excellent.

†Obtained from the manufacturer and/or distributor.
‡As defined by the NHLBI.
chased, personal best peak flow should be reevaluated in the patient with moderate-to-severe persistent asthma. In contrast to accuracy and interdevice variability, reproducibility of a PFM is crucial for detecting changes in a patient with asthma that may lead to a life-threatening exacerbation. If the clinician can rely on the technique of the patient using a PFM and the reproducibility of the device, the action plan based on personal best peak flow can be successfully applied to alter drug therapy. With this concept in mind, the reproducibility of all PFMs listed in Table 1 may be adequate to monitor impending exacerbations for patients with moderate-to-severe persistent asthma. If accuracy decreases over an extended period of time in any given PFM, reproducibility may also be compromised. This phenomenon has been demonstrated in the Mini-Wright PFM by Shapiro and colleagues and may be present in other PFMs that have not been tested over extended periods.

CONCLUSION

Application of the NHLBI guidelines in the evaluation of the literature of PFMs reveals that there are significant differences in accuracy between meters used in the ambulatory asthmatic setting; however, reproducibility and interdevice variability are relatively consistent between PFMs. Reproducibility is the most important aspect of a PFM as it pertains to the latest asthma recommendations. For these reasons, any of the PFMs described in Table 1 may be adequate to monitor impending exacerbations in patients with moderate-to-severe persistent asthma. The question remains if accuracy and reproducibility of these PFMs are maintained over extended periods of time.

REFERENCES


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