A Review of Portable, Electronic Spirometers: Implications for Asthma Self-Management

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ABSTRACT

Purpose of review. Although portable electronic spirometers allow for at-home lung function monitoring, a comprehensive review of these devices has not yet been conducted. We conducted a systematic search and review of commercially-available portable electronic spirometers designed for asthma patient use.

Recent Findings. All devices (N=16) allowed for monitoring of basic lung function parameters, but only 31% provided in-app videos on how to perform breathing maneuvers. Most devices (63%) provided graphical representations of lung function results, but only 44% gave immediate feedback on the quality of the breathing maneuver. Several devices (25%) were FDA-approved and cost ranged from US$99-1390. Information on data security (63%), measurement accuracy (50%), and association with patient outcomes (0%) was commonly limited.

Summary. This review found that providers' ability to make informed decisions about whether asthma patients may benefit from portable electronic spirometers is limited due to lack of patient outcome data.

Keywords. spirometry; asthma; mHealth; eHealth; self-management

Introduction

Asthma is a reversible chronic respiratory disease with an underlying inflammatory basis. It is marked by narrowing of the airways and recurrent episodes of breathlessness, wheezing, and chest tightness. Recent estimates from the World Health Organization (WHO) suggest that asthma affects the lives of more than 235 million people worldwide [1]. Studies show that patients with asthma often develop a progressive decline in lung function which is correlated with both the severity and duration of asthma [2].

Research conducted by the Centers for Disease Control and Prevention (CDC) shows that out of the 22 million Americans who have been diagnosed with asthma, 12 million have experienced an asthma episode over the past year [3]. This highlights that many patients have sub-optimally controlled asthma and may benefit from engaging in self-management behaviors. Asthma self-management refers to the daily activities that patients can undertake in order to keep their illness under control, minimize its symptoms and impact on physical health, and help cope with its psychosocial sequelae [4].

Self-management behaviors include self-observation (e.g., monitoring symptoms), self-judgement (e.g., evaluating asthma severity using information collected during the process of self-observation), and self-reaction (e.g., how an individual responds to self-observations and self-judgements) [5]. Clinicians commonly ask patients to self-monitor (or self-observe) their asthma symptoms and lung function in order to make informed decisions about whether treatment regimens are effectively controlling asthma and whether escalation of therapy is warranted [6]. Indeed, symptom self-monitoring can be extremely useful in preventing future exacerbations, reducing emergency hospital visits, and keeping asthma well-controlled [7].

Self-monitoring of lung function by measuring the peak expiratory flow (PEF) and forced expiratory volume in one second (FEV_1) is often recommended for children and adults with persistent asthma [8]. These lung function parameters are indicators of airflow obstruction and provide useful information about the patient's asthma severity [9] . Devices such as peak flow meters (PFMs) and spirometers are considered important tools for the monitoring and assessment of PEF and FEV_1. Thus, the use of such devices can result in information (e.g., lung function results) that influences how patients judge the severity of their asthma and their subsequent reactions (e.g., calls the doctor, takes rescue medications, etc.)

In recent years, the desire to facilitate patients' ability to monitor their lung function from a home setting and without clinical supervision has led to the development of handheld, portable, electronic spirometers which can measure, store, and download the results of multiple lung function tests onto personal electronic devices such as smart phones and computers [7]. The usefulness of portable spirometers for asthma self-management depends on their ability to provide patients with objective and reliable measurements of pulmonary function [7]. Lung function tests are highly effort dependent and pose challenges for many patients. Therefore, differences in spirometer features and quality of instruction on how to perform the breathing maneuvers required for spirometry may impact whether patients use the device correctly. In the past, patients have used PFMs to manually record their peak expiratory flow in paper or electronic diaries. Despite provider requests to have patients document PEF, many patients did not record PEF because they found the process burdensome or unhelpful [10, 11]. The use of electronic home spirometers may be less burdensome to patients and facilitate accurate documentation of lung function by allowing patients to electronically log data and receive

feedback on whether they performed a high-quality lung function test [12, 13].

Given the relative newness of most portable electronic spirometers, a review of the capabilities of existing spirometers is currently lacking in the published literature. Thus, our aim was to address this gap in the literature and review portable, electronic spirometers that are currently available and marketed for use with asthma patients. This review focuses on the features of the spirometers that could influence patient uptake (e.g., cost) and use (e.g., how results are displayed) in order to help clinicians make informed decisions about which spirometers may most benefit their patients.

Methods

Search strategy. A systematic review was conducted in December 2017 to identify portable electronic spirometers available on the market which are capable of monitoring lung function and providing asthma patients with feedback on their lung function tests. We searched for electronic spirometers using both PubMed and Google.

First, a PubMed search without any publication data restrictions was conducted using the following search terms:

("electronics"[MeSH Terms] OR "electronics"[All Fields] OR "electronic"[All Fields]) AND portable[All Fields] AND spirometer[All Fields] AND ("patients"[MeSH Terms] OR "patients"[All Fields] OR "patient"[All Fields])

Abstracts were reviewed for relevance and excluded from further review if they did not reference: a) electronic spirometers; b) lung function monitoring; c) asthma monitoring devices; or d) names of devices/apps associated with asthma monitoring. Full texts of potentially relevant articles were then obtained and reviewed in detail. Additionally, the references of those articles were examined to determine if there were additional devices that were not captured during the original PubMed search.

Given the low yield of the PubMed search, we then conducted a Google search to identify portable electronic spirometers that may have been developed but not yet reported in the academic literature. The Google search was conducted by two researchers (RJ and CR) who independently reviewed the first 100 search results. The researchers used the following search terms: “spirometer AND Asthma AND portable OR handheld AND electronic.” Search results were flagged for further review if they referenced: a) electronic spirometers; b) lung function monitoring; c) asthma monitoring devices; and d) names of devices/apps associated with asthma. The two researchers (RJ and CR) then met and reached consensus on which devices should be included for further review.

Last, because many of the electronic spirometers identified during the Google search had associated mobile applications (apps), two researchers (RJ and CR) also reviewed all search results on Apple’s App Store and Google Play using the following search terms ‘’spirometry’’ and ‘’spirometer’’ to identify additional devices that may not have populated during the Google or PubMed searches.

Inclusion criteria. Two coders met to reach consensus on which devices met the inclusion criteria. Devices met inclusion criteria if they: 1) were electronic; 2) were handheld/portable or “pocket-sized”; 3) could be used with mobile devices/tablets/health apps; 4) were indicated for asthma; 5) were intended for patient use; 6) were interactive (i.e., provided patients with feedback/videos/alerts/instructions); 7) allowed data syncing of results onto personal devices; and 8) measured lung function parameters relevant to asthma such as PEF and FEV_1. Devices were excluded

if they were: 1) not used for asthma (for example, devices exclusively for Chronic Obstructive Pulmonary Disease (COPD) or Cystic Fibrosis (CF)), or 2) intended solely for use by healthcare professionals (e.g., physicians, nurses, respiratory therapists).

Data extraction and analysis. For those devices that met inclusion criteria, two coders (RJ and CR) independently extracted the following information: 1) name of device; 2) other non-asthma indicated diseases (COPD, CF, other); 3) target users (i.e., patient, provider, other); 4) lung function tests performed; 5) type of feedback provided to users; 6) whether the device's app included instructional videos on how to perform breathing maneuvers correctly; 7) additional device features; 8) data on the relationship between use of the device and patient outcomes as reported in peer-reviewed publications; 9) operating platform (i.e., iOS, Android); 10) FDA approval status; 11) whether data are stored in a secure manner; 12) and the measurement accuracy of the device. The two coders discussed coding discrepancies and reached consensus on data that were extracted for all devices.

Results

The search strategy yielded 36 devices, 16 of which met inclusion criteria (Figure 1). Table 1 presents an overview of the data that were coded from the 16 devices.

Indicated diseases**.** Although all 16 devices were designed for use with patients with asthma, most were also designed for use in patients with other respiratory diseases. For instance, ten devices (62.5%) also targeted COPD, six devices (37.5%) targeted CF, and five (31.3%) targeted other pulmonary disorders such as bronchitis and emphysema. Three devices (18.8%) were also marketed to patients to monitor lung function after lung transplant surgeries.

Target user. Only three devices (18.8%) were targeted specifically to patients. The remaining 13 devices (81.3%) were targeted to both patients and their healthcare providers. Out of those thirteen devices, one device (Wing) also targeted athletes, runners, swimmers, and musicians who were interested in monitoring their lung function.

Lung function tests performed**.** All 16 devices provided testing for PEF and FEV_1. Thirteen devices (81.3%) also allowed patients to measure Forced Vital Capacity (FVC), which is another measure of airway obstruction. Half of the devices measured FEF_{25-75}, which is an indicator of how the smaller airways have been affected by asthma. Furthermore, seven devices (43.8%) measured the FEV_1/FVC ratio, three devices (18.8%) measured FEV_6 (Forced Expiratory Volume in 6 seconds), two devices (12.5%) measured the FEV_1/FEV_6 ratio, and one device (6.3%) measured Slow Vital Capacity (SVC).

Feedback given. Ten devices (62.5%) provided graphical representations of lung function results. Seven (43.8%) gave patients immediate visual or audio feedback on whether they had performed the test correctly. Six devices (37.5%) had a traffic light system indicating whether patients' pulmonary status was in the red (danger zone), yellow (caution), or green (safe) zone.

Instructional videos. Only five devices (31.3%) had instructional videos available within the app to provide patients with guidance on how to use the device and how to perform the breathing maneuvers correctly. The remaining 68.8% did not have instructional videos available directly on the device or app. Instead, some had graphical or text instructions or posted videos on the manufacturer's website or YouTube.

Additional features. Nearly all devices (75%), either directly or via their associated apps, allowed patients to share lung function test results with their healthcare provider. Four devices (25%) included incentive features such as games to motivate patients to perform their lung function test correctly. Six devices (37.5%) had other self-management features, such as a medication tracking feature as well as symptom monitoring and asthma trigger alert features. Three devices (18.8%) had an additional oximetry option which allowed for the monitoring of oxygen saturation.

Patient outcome data. Data on the relationship between use of these devices and patient outcomes have not yet been published in peer-reviewed journals. However, a 6-month trial on the use of the mSpirometer in conjunction with an inhaler monitoring device and medication reminder system has been reported and found a positive association with medication adherence [14].

App platform. The MIR Spirobank Smart and Spirotube both had two apps that could be used with the device. Six of the spirometer apps (33.3%) were designed exclusively for iOS platforms and six of the apps (33.3%) were exclusively for Android platforms. The other six apps (33.3%) were available on both iOS/Android platforms.

FDA approval. Four devices (25%) had been approved by the FDA. Seven devices (43.8%) were not FDA-approved, two (12.5%) were pending FDA approval, and three devices (18.8%) were currently seeking FDA approval.

Data security. Ten devices (62.5%) did not provide any information regarding how data security was addressed. Four devices (25%) used Health Insurance Portability and Accountability Act (HIPAA) compliant servers and two (13.8%) provided password-based protection of data. Others claimed to have ‘’secure databases’’ or ‘’secure bi-directional transfer of data‘’ but did not specify how data were protected.

Cost. Information on cost was only available for seven devices. The prices ranged from US$99 to $1,390. The majority (6 out of 7) cost less than $200. The apps associated with the devices were available for free, with the exception of one app (Aeres) which required a $10/month fee.

Measurement accuracy. The accuracy of eight devices (50%) was not publicly available. However, four of the eight devices claimed that the device met hospital and clinical grade accuracy. Two devices (12.5%), AirSmart and MIR Spirobank Smart, claimed the following: Volume accuracy ± 3% or 50mL and Flow accuracy ± 5% or 200mL. Another device, Wing, claimed to meet American Thoracic Society (ATS) standards for measuring FEV_1 and Peak Flow (FEV1: ±0.1L or ±5%, Peak Flow: ±20L/min or ±10%). The remaining devices had varying accuracy values (Table 1). Studies have been published that compare the accuracy of several devices (MIR Spirobank [15], MobileSpiro [16], AimSmart [17], Wing [18]) with standard spirometers.

Discussion

This review is the first to summarize the key features of portable electronic spirometers that have been developed to help patients with asthma monitor their lung function at home. Portable technology that uses sensors and smartphones to measure lung function is becoming increasingly prevalent [19], and home spirometry is acquiring more acceptance because of its potential to help patients detect exacerbations, manage their condition, and improve the overall outcomes of chronic lung conditions.

This review highlights both the promise and current shortcomings of portable electronic spirometers to enhance at-home monitoring of lung function.

A variety of portable electronic spirometers are commercially available, and lung function test capabilities of these spirometers commonly include PEF and FEV_1. However, lung function test results have little meaning to patients and providers unless they are compared against specific reference values [20] since these reference values allow one to determine the extent of airway obstruction [21]. To be most useful, lung function tests should present results in relation to what would be predicted given the user's age, ethnicity, gender, and smoking status. Hence, portable spirometers should allow users to enter their demographic data in order to get customized lung function results, rather than using a "one size fits all'' referencing approach. However, this recommendation comes with the caveat that all data should be stored securely so that the user's personal health information is not at risk of being stolen. Many devices did not address how data were secured, which is a major shortcoming that needs to be addressed by device manufacturers.

Although many devices provided patients with graphical representations of their lung function results, in many cases, these data were not in a form that would be easy to understand for a layperson. An exception are those devices that incorporated a ''traffic light system'' feature which could facilitate patients' ability to self-judge whether their asthma is within the green (safe) zone, yellow (caution), or red (danger) zone based on their lung function test results. This can not only motivate patients who have their asthma under control to continue engaging in self-monitoring behavior, but it also can alert patients who fall under the yellow or red zones that they are at greater risk of an asthma exacerbation.

Almost half of the devices included in this review provided patients with feedback on the quality of their test performance, allowing users to know when they have performed a "poor blow'' or if they needed to repeat the test. Without adequate feedback, patients may not be aware of when they performed a lung function test incorrectly, which may in turn lead to inaccurate results, inappropriate action, or further confusion. Thus, it is important for devices to provide patients with feedback on the quality of their test performance. In addition to ensuring that the quality of results is not jeopardized, the integration of feedback and coaching features could potentially improve patient adherence if they see that their lung function improves when they adhere to their treatment regimen. For example, some of the devices included messages such as: "Your asthma is doing great! Continue taking your daily medicines as prescribed.'' However, apps that include treatment recommendations need FDA approval, which may limit the number of devices that provide guidance on what actions to take when a test reveals poor lung function results.

Studies have highlighted differences in the quality and accuracy of lung function measurements collected with portable electronic spirometers, with some devices providing more reliable and accurate data than others [15-18, 22]. Accuracy of lung function data is especially important given that valid spirometry testing requires substantial effort whilst exhaling to yield accurate results. Even though some of these devices offer games and incentives to encourage accurate test performance, most fail to take into account some factors that may affect patients' ability to perform a test correctly, such as age or asthma severity. For example, children may have more difficulty performing a PEF or FEV_1; thus, they may need additional guidance to ensure a high quality test. Therefore, additional modifications to the devices may be required to create suitable coaching methods for specific patient groups who might find spirometry more challenging [19].

The convenience and accessibility of a personal portable spirometer may encourage patients to self-monitor (or self-observe) their lung function more often. Most of the asthma apps associated with the spirometers were free to download. Moreover, mobile phones are generally affordable, widely used, and discrete, which makes regular monitoring of lung function more accessible and convenient for patients than ever before. This is especially true given that traditional spirometers are generally larger, more expensive, require calibration, and cannot be easily used outside a clinical setting [23]. Also, the apps associated with these spirometers allow patients to collect lung function data themselves, which in turn seems to be slowly disrupting the traditional practice of office or clinic-based monitoring of lung function [23]. Indeed, the majority of these devices enable patients to transfer their lung function test results directly to their healthcare providers, which could facilitate patient-provider communication about asthma by allowing providers to track their patients' overall pulmonary status without the necessity of an appointment. For example, data collected from the symptom diary features of the mobile phone apps can be used to determine the effectiveness of treatment [24]. As with most long term diseases, healthcare professionals have begun to explore the concept of mobile technology as a means of communicating with patients and collecting health information more efficiently [25].

Although these devices are convenient to use, patients may not use them on a regular basis over longer periods of time. In the past, patient adherence to peak flow monitoring was often low due to perceived burden of testing or low perceived usefulness [10, 11]. Currently, only 25% of devices included motivational features to encourage patients to perform the test correctly. Additional motivational features, such as games or incentives, may be needed to promote long-term self-monitoring with portable electronic spirometers.

Regular spirometry testing can result in earlier detection of exacerbations, quicker recovery times, earlier treatment, reduced health costs, and an overall improved quality of life [26], yet patients' ability to engage in spirometry at home could be limited by several factors, including the platform of the device's app (iOS/android), lack of FDA approval, and cost. If the patients' smartphone or tablet platform does not match the device's app, then they cannot use that device. Also, providers may feel uncomfortable recommending a device that is not FDA approved to patients.

We identified several key areas for potential future research that may lead to the development of improved electronic spirometers for the monitoring of asthma from a home setting. First, studies on the relationship between use of these devices and patient outcomes are greatly needed so that providers and patients can make an informed decision about whether these devices could be potentially beneficial for improving asthma outcomes. Data on whether using these devices results in better asthma control and less health service utilization (e.g., asthma-related emergency department visits, hospitalizations, and unscheduled office visits) as well as data on adoption and continued use of the device over time are particularly needed. Longitudinal studies that compare the effectiveness of portable electronic spirometers with usual care will help providers truly understand the impact that these devices can have on self-management and clinical outcomes. Second, only a few devices' apps included instructional videos on breathing maneuvers, which is a serious shortcoming given that significant patient effort is needed to yield a high quality test. Therefore, we recommend that all portable, electronic spirometers include instructions that are easy to access in the spirometer's app. Additionally, apps should present spirometry results in a way that is easy for patients to understand. Devices that provide feedback that is difficult to interpret could lower users' perceived usefulness of the device, especially for patients with low health literacy [23]. Moreover, patients' involvement and engagement in self-monitoring could be negatively impacted if they do not understand the results. Third, more studies should be conducted on the usability and accuracy of these devices. Often, there

was not enough published data to confirm the manufacturer's claims regarding the accuracy of their devices.

Limitations

It is likely that our search strategy did not capture all portable electronic spirometers intended for home use with asthma patients. We limited our search to PubMed and Google, as we felt non-academic search engines may yield more results because many commercial devices are not used in published studies. However, other databases such as Cochrane and EMBASE may have yielded additional devices. Also, we were unable to obtain some information (e.g., cost) on spirometers. Despite our efforts to contact different manufacturers to supplement missing information, insufficient publically-available detail may have resulted in misinterpretations of data during the extraction process. In order to minimize coding inaccuracies, two independent researchers coded all device features and met to resolve discrepancies in coding. In addition, our review did not include spirometers that did not have an associated app. We chose to focus on spirometers that had apps since these spirometers would be more likely to present lung function data to patients. Spirometers without apps may include different features that could be of great use to the patient; thus, our results should not be extrapolated to portable spirometers that do not have apps. Also, we mainly focused on whether certain device features were present rather than the actual quality of the feature. Future work could examine user ratings on the App store and Google Play store as well as collect usability data from patients to understand the quality of various spirometer and app features.

Conclusions

As the number of portable, electronic spirometers continues to increase, it is important that clinicians and patients are able to easily evaluate each spirometer's strengths and weaknesses in order to make an informed decision about which spirometer best meets the patient's needs. Although all spirometers were capable of providing patients with useful information about their lung function, many devices had several limitations related to a lack of instructions on how to perform breathing maneuvers correctly and did not provide feedback on lung function results in a way that is easy for patients to understand. Additionally, many devices may be inaccessible to patients due to high cost, app platform (iOS vs Android), and lack of FDA approval. Due to the lack of data on whether use of these spirometers is associated with improved patient outcomes, including clinical outcomes, providers may want to work with patients on an individual basis to determine whether they believe using these devices may benefit patients via increased self-monitoring of lung function at home.

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Figure 1. Overview of portable electronic spirometer selection process

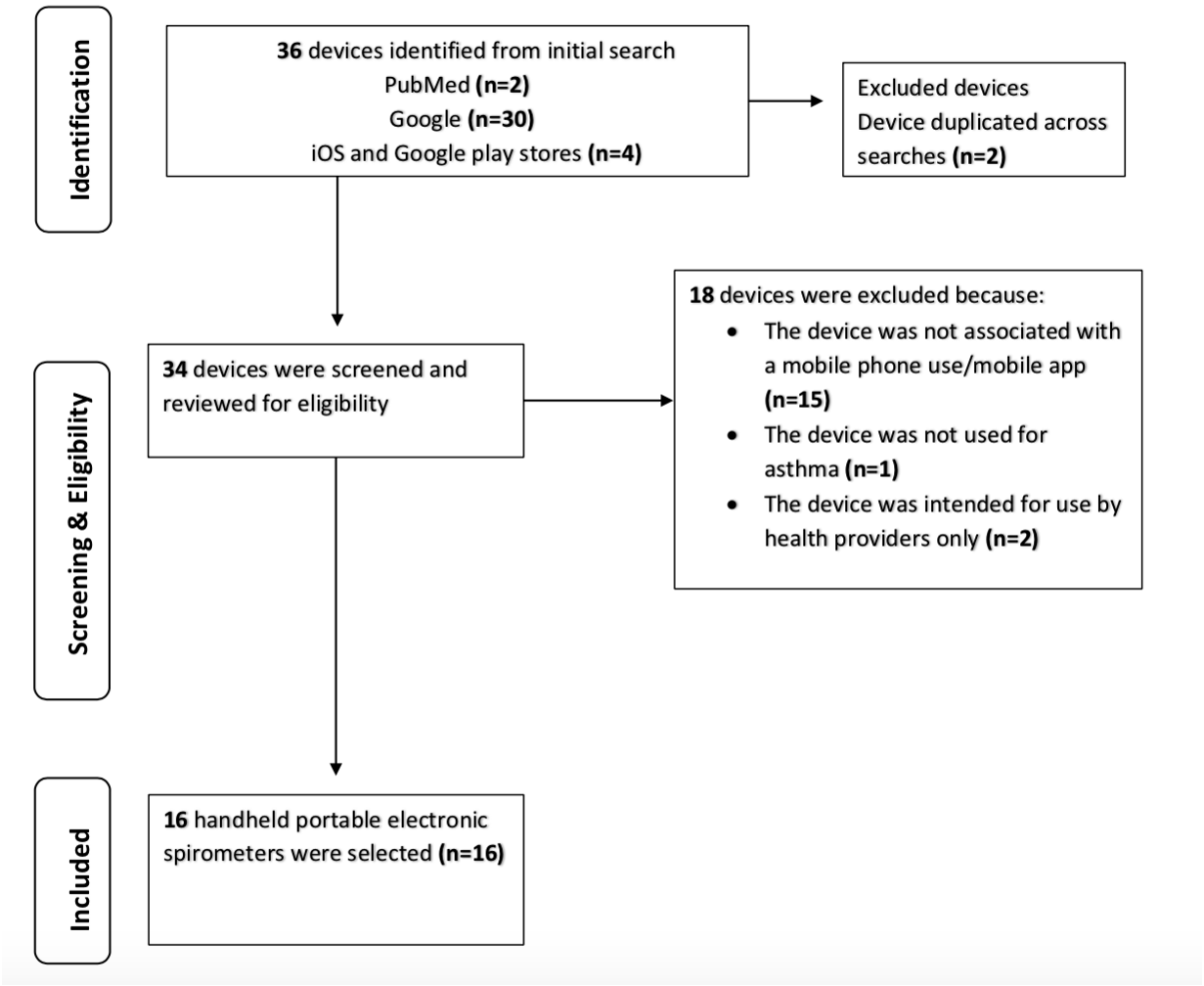

Table 1. Key aspects of electronic portable spirometers capable of monitoring lung function from home.

Name of Device	Indicated Diseases	Target User	Commonly Used Asthma-Related Lung Function Tests	Feedback Given	Instructional Videos	Additional Features	Patient Outcome Data	Associated App & Platform	FDA Approval	Data Security	Cost	Accuracy of Device
GoSpiro	Asthma, COPD,CF,IPF, and other pulmonary disease	Patients & Health providers	FVC, FEV_1, PEF, FEF_{75}, FEF_{25-75}, FEV_6, SVC; and others	-Real time patient coaching on technique -Test results dashboard with patient feedback for comparison -Immediate feedback provided on quality of patient test performance	**No**	-Portal connects patients to physicians -Automated medication and appointment reminders -Asthma questionnaire	**No**	GoSpiro (Android & iOS)	**Yes**	-No personal info stored on device; password-protection. - Secure bidirectional transfer of data between patients and physicians	Spirometer: Not available App: Free	Volume accuracy: ±3% of reading, or .05 liters; Flow sensitivity: better than .025 l/s
Aeres	Asthma	Patients	FEV_1, FVC, PEF	-Graphs as well as yellow, red, and green lights for pulmonary status; -‘’poor blast’’ alert to notify patient of poor performance -Results compared to reference	**Yes**	Game available to guide patients through pulmonary test maneuver (hot air balloon)	**No**	Aeres (iOS) –currently unavailable	**Pending**	Data not available	Spirometer: $180 App: $10 monthly fee	FEV_1 accuracy: ±3% PEFR accuracy: ±3%

				values								
VitalFlo	Asthma	Patients & Health providers	PEF, FEV_1, FVC, FEF_{25-75}	-Detects poor blows -Coaches patients to perform test correctly -Real time asthma risk prediction -Green, yellow, red zone	**No**	-Asthma trigger monitoring -Connecting to doctor, -Asthma control survey -Medication use survey	**No**	App for iOS	**Seeking**	HIPAA-compliant servers	To be determined	"Clinical grade accuracy''
mSpirometer	Asthma, COPD	Patients & Health providers	PEF, FEV_1, FVC	Chart/graph, instant messages such as "your asthma seems under control," and real time feedback to ensure appropriate technique	**No**	-Medication reminders -Symptoms & environmental trigger recording -Track inhaler use, and sync with healthcare providers and caregivers -Instant messaging with provider	**No**	Asthmahero mobile app BreatheSmart® mobile app [14] (Android & iOS)	**Yes**	HIPAA-compliant cloud server upload	Spirometer: Not available App: Free	"Clinical grade accuracy''
Wing	Asthma, COPD,CF	Patients & Health providers, athletes, musicians, singers.	FEV_1, PEF	Green, yellow, and red zone (tracking and graphical trends); -messages such as "Your asthma is doing great! Continue taking your	**Yes**	-Tracks medications & medication reminders, triggers, and symptoms (questionnaire); -Estimates personal best goals (peak flow and FEV_1 goals based on age, height,	**No**	Wing (iOS)	**Yes**	Synced to cloud with 256-bit encryption	Spirometer: $99 App: Free	Meets ATS standard for measuring FEV1 & Peak Flow Automatic reproducibility checks FEV1: ±0.1L or ±5% Peak Flow: ±20L/min or ±10%

				daily meds as prescribed."		gender, and ethnicity) -Monthly report sent to physicians, family, and friends; -Game						
MIR Spirobank Smart [15, 27]	Asthma, COPD, CF, lung transplant	Patients & Health providers	PEF, FVC, FEV_1, FEV_1/FVC, FEV_6 FEV_{25-75}	-Indication of "good blow" -Test messages such as "test in progress, blow out faster" -Motivational graphics; -Green, yellow, and red alerts (traffic light health indicators) -Graphs and charts	**Yes**	-Scores symptoms and add notes to each section (e.g. "starting to feel well, getting over the cold") -Sharing notes with doctor - Game for starting spirometry (incentive); -Oximetry -Pediatric incentive	**No**	iSpirometry (Android and iOS) MIR Spiro (iOS)	**Yes**	Data not available	Spirometer: $1,390 App: Free	Flow range: ±16L/s Volume accuracy: ±3% or 50 mL Flow accuracy: ±5% or 200 mL/s
MySpiroo[28]	Asthma, COPD	Patients & Health providers	FVC, FEV_1, PEF, FEF_{25-75},	Graphical display -Green for normal FVC status	**Yes**	-Warnings for triggers -Inhaler management -Send data to doctor (possible video consultations) -Temperature sensor, pressure sensor,	**No** (unpublished data are publically available)	MySpiroo Clinic (iOS and Android)	**No**	Data not available	Spirometer: Not available App: Free	''Equivalent to hospital spirometers''

						humidity sensor, -pulse oximetry sensor						
SmartOne	Asthma, COPD, Lung Transplant, CF	Patients & Health providers	FEV_1, PEF	-Green, yellow, and red zone; -Traffic light health indicator -Feedback on blow and performance	**Yes**	-Support in different languages -Includes an incentive program for adults and children. -Symptom monitoring -Medication reminder -Allows result sharing with doctors	**No**	MIR SmartOne (iOS and Android)	**Pending**	Data not available	Spirometer: $155 App: Free	Data not available
Spiroedge	Asthma	Patients	FVC, FEV_1, FEV_1/FVC, $FEF_{25-75,}$, PEF	-Results for lung function test provided within 15 seconds	**No**	-Buzzer to coach beginning and end of tests -Oximetry	**No**	App for Android	**No**	Personal Bluetooth code to ensure safe connection. HIPAA-compliant	Not available	Data not available
MobileSpiro	Asthma and other respiratory diseases	Patients & Health providers	PEF, FVC, FEV_1, FEV_1/FVC, FEF_{25-75}	-Gives patient direct feedback on how to blow and exhale to ensure quality test. -Real-time graph of flow and volume versus time, which serves to motivate	**No**	-Allows self-tracking of symptoms -Allows physicians to monitor patient performance	**No**	App for Android	**No**	Data not available	Not available	94%; with an inter-device deviation in flow reading of less than 8%, and detects more than 95% of erroneous cough maneuvers in a public CDC dataset.

				the patient to give his or her best effort. - Traffic light system placing patients in different zones								
Spiromagic	Asthma, COPD, or others interested in home fitness monitoring	Patients & Health providers	FEV_1, FEV_6, PEF, FEV_1/FEV_6	-Graphical display of results	**No**	-Allows multiple profiles -Family sharing of results -Provides trigger alerts and alerts on external factors (temperature and humidity)	**No**	Spiromagic for iOS	**No**	Results are stored in a ‘’secure database.’’	Spirometer: $187 App: Free	Data not available
AirSmart	Asthma, COPD CF, Bronchitis, Emphysema, Lung transplant, and many more respiratory diseases	Patients & Health providers	FEV_1, FVC, FEV_1/FVC, PEF	-Graphical display and coaching to ensure quality test (e.g. “it seems like you started your exhale a bit too slow. Exhale faster, don’t hesitate”, A, B,C, D, and F (very good, good, poor, not	**No**	-Multiple profiles -Family sharing of results -Provides ethnicity-specific results	**No**	Air Smart Spirometer (iOS and Android)	**No**	HIPAA and GDPR compliant	Spirometer: $231 App: Free	Clinical grade accuracy Volume accuracy ± 3% or 50mL Flow accuracy ± 5% or 200mL

				acceptable)								
SpiroSmart[29]	Asthma & other pulmonary & respiratory diseases	Patients	PEF, FEV_1, FVC, FEV_1/FVC	-Blowing game to guide users	**No**	-	**No**	App for iOS	**Seeking**	Data not available	''Low cost to be determined''	Spirosmart app at 5.1% accuracy of commercial spirometers. FVC is within the range of expected variability almost 80% of the time and PEF over 90% of the time
Spirotube	Asthma, COPD	Patients & Health providers	PEF, FEV_1, FEF_{25-75}, and others	- Number, graph and voice feature such as "you have mild restriction" with mild restriction written on screen	**No**	-Database synchronization with PC PDF Export -Diagnostic decision support system for general practitioners and physicians	**No**	SpiroID (Android) ThorSoftME (Android)	**No**	Data not available	Spirometer: Not available App: Free	Flow precision: 2% Flow range: ±18L/s
SpiroHome	Asthma, COPD, CF	Patients & Health providers	PEF, FEV_1, FVC, FEF_{25-75}	-Graphical display, animation (frowny face with "you did not perform test correctly")	**No**	-Track medication use, get feedback on inhaler technique, share info with medical provider through app	**No**	Spirohome (Android)	**Seeking**	Secure cloud-based storage	Spirometer: Not available App: Free	"Hi-accuracy"; "as accurate as a spirometer you would see in a hospital"
Pulmo	Asthma	Patients & Health providers	FEV_1, FVC, PEF	-Graphical display of results	**No**	- App allows sharing of medical information with physician -Symptom	**No**	Pulmo App for Android	**No**	Data not available	Spirometer: $128 App: Free	Data not available

						monitoring						

Table Note: COPD= chronic obstructive pulmonary disease; CF= cystic fibrosis; IPF= idiopathic pulmonary fibrosis
FEF_{25-75}= mean forced expiratory flow during the middle half of the FVC curve; FEV_1= forced expiratory volume in 1 sec; FEV_1/FVC = ratio of FEV_1 to FVC; FEV_6= forced expiratory time in 6 sec; FVC= forced vital capacity; PEF= peak expiratory flow; SVC= slow vital capacity

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