

Adherence Monitoring and E-Health: How Clinicians and Researchers Can Use Technology to Promote Inhaler Adherence for Asthma

Amy Hai Yan Chan, BPharm(Hons)^a, Helen Kathryn Reddel, MBBS, PhD^b, Andrea Apter, MSc, MA, MD^c, Michelle Eakin, PhD^d, Kristin Riekert, PhD^d, and Juliet Michelle Foster, PhD^b Auckland, New Zealand; Sydney, Australia; Philadelphia, Pa; and Baltimore, Md

In the past decade, rapid technological developments have advanced electronic monitoring devices (EMD) for asthma inhalers beyond simple recording of actuations to providing adherence promotion features and detailed information about patterns of medication use. This article describes currently available EMDs, discusses their utility and limitations in assessing adherence, and describes the potential for EMD-based adherence promotion interventions in clinical settings. To date, the main use of EMDs has been in clinical research. In selected populations, simple EMD-based adherence interventions, delivered either through clinician-to-patient feedback about medication use or by direct-to-patient reminders for missed doses, can significantly improve adherence. Further work is now needed to determine the impact of EMDs on clinical outcomes and their cost-effectiveness and feasibility for different clinical settings, including in disadvantaged populations. If this evidence

can be provided, then the use of EMDs could expand into the management of asthma in populations with high health care costs, eg, severe asthma. In the future, medication monitoring could help distinguish poor treatment response from poor adherence, guide prescribing decisions, and prompt providers to discuss barriers to adherence; electronic health records may provide the gateway for integrating medication-use monitoring into digital chronic care management. © 2013 American Academy of Allergy, Asthma & Immunology (J Allergy Clin Immunol: In Practice 2013;1:446-54)

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MEDICATION ADHERENCE IN ASTHMA IS SUBOPTIMAL

Patient adherence with therapy is the necessary link between effective treatment and improved patient outcomes. However, recent asthma studies that used objective measures showed significant underuse of controller therapy in children (25%-76% of prescribed doses) and adults (1%-93%).¹ At a population level, poor adherence contributes to greater asthma morbidity, including increased symptoms, more-frequent oral steroid courses, lower lung function, poorer quality of life, greater health care utilization, and higher asthma-related mortality.²⁻⁵ For these reasons, patient adherence is a top priority area for research^{6,7} and clinical practice.⁸

WHY ARE ELECTRONIC MONITORING DEVICES FOR INHALERS NEEDED?

Medication-use monitoring can provide important information for patients, researchers, and health professionals, with the aim of facilitating improved adherence and of improving treatment prescribing, but available monitoring methods vary in quality. Patient self-report and clinician assessments of medication adherence are notoriously unreliable.⁹⁻¹¹ Assessment from a canister weight or a dose counter is limited by undetectable dose-dumping, ie, multiple actuations to conceal poor adherence.^{10,12} Increasingly, clinicians in some health systems, eg, health maintenance organizations, are able to obtain real-time or retrospective pharmacy records, which show when medications were dispensed. Dispensing data can provide an estimate of maximum overall inhaler use in a given period,¹³ but few countries have complete dispensing registers, and, unlike electronic monitoring devices (EMD),¹⁴ these records cannot confirm timing of use and have limited sensitivity to change in

^aSchool of Pharmacy, Faculty of Medical and Health Sciences, The University of Auckland, Auckland, New Zealand

^bWoolcock Institute of Medical Research, Clinical Management Group, University of Sydney, Sydney, Australia

^cDivision of Pulmonary, Allergy, Critical Care Medicine, Perelman School of Medicine, University of Pennsylvania, Philadelphia, Pa

^dDivision of Pulmonary and Critical Care Medicine, Department of Medicine, Johns Hopkins University, Baltimore, Md

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Corresponding author: Juliet M. Foster, PhD, Woolcock Institute of Medical Research, University of Sydney, PO Box M77, Missenden Road, NSW 2050, Australia. E-mail: j.m.foster@woolcock.org.au.

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Abbreviations used

AAD- Adaptive aerosol delivery
DSS- Data storage spirometer
EMD- Electronic monitoring device
FDA- US Food and Drug Administration
GPS- Global positioning system
ICS- Inhaled corticosteroid
LCD- Liquid crystal display
MDI- Metered-dose inhaler
PLS- Patient login system
pMDI- Pressurized metered-dose inhaler

adherence patterns. For example, despite regular dispensing of controller medication, a patient may take large amounts during symptomatic periods then take nothing for weeks. EMDs capture this level of detail by recording the time and date of every puff and provide precise, personalized data to support the adherence promotion strategies of patients, researchers, and health professionals.

In this article, we review the state of the art of EMDs for inhaled medications. We describe the features, reliability, and limitations of currently available EMDs, review evidence for their effectiveness in monitoring and promoting adherence, discuss emerging roles for EMDs, and identify the changes needed to move electronic monitoring from the research arena into clinical practice.

FEATURES AND RELIABILITY OF CURRENTLY AVAILABLE EMDs

EMD features and functions

Most currently available EMDs (Table 1) are designed for pressurized metered-dose inhalers. Because of the wide variation in inhaler design, the majority of EMDs only function with 1 specific inhaler type. Most EMDs are retrofitted to commercial inhalers, with only 2 electronic nebulizers (not used routinely for asthma) with integrated adherence monitoring. With some EMDs, data collection may be concealed; ethical issues should always be considered in this context.¹⁵

EMD functionality is no longer limited to actuation recording. Some devices record inspiratory flow data (eg, the Turbuhaler [AstraZeneca, Sodertalje, Sweden] or pneumotachograph device), which may be useful for exploring relationships between inhaler technique and poor outcomes in patients with good adherence, although it cannot substitute for a face-to-face check of inhaler skills.¹⁶ Some EMDs offer interactive features such as customizable ringtone reminders for promoting adherence (eg, SmartTrack; Nexus 6, Auckland, New Zealand)¹⁷ and direct data uploading to a secure Web site or via Bluetooth [Bluetooth SIG, Kirkland, Wash] connection to a cellphone (eg, Asthmapolis [Madison, Wis], which also allows global positioning system tracking) (Figure 1). Remote data uploads reduce data loss and allow patients and/or providers to monitor adherence data without the need for clinic visits.

Accuracy and reliability of EMDs

As with any technology, accuracy and reliability are important considerations. Under laboratory conditions, EMD recording accuracies compared with written diaries are 90% or higher, and close to 100% for newer devices (Table 1). Reported failure rates, eg, due to device malfunction, vary between 0% and 21%.

However, the rapidity of technological development means that published performance data become quickly superseded.

THE ROLE OF EMDs IN MONITORING ADHERENCE WITH ASTHMA INHALERS

At a population level, research results have shown that stopping treatment can leave patients at serious risk,⁵ but understanding patients' patterns of inhaler use may become paramount,^{18,19} because analysis of recent evidence indicates that intermittent or as-needed controller use may be as effective as regular regimens for some patients.^{20,21} EMDs produce detailed data about temporal changes in patterns of inhaler use,^{18,22} even over relatively short time periods,^{23,24} and can support the identification of patients who may benefit from intermittent regimens.^{19,25} Because improved adherence is most likely to benefit those with the poorest adherence, EMDs may allow identification of patients who require more intensive interventions.²⁶ If used reliably, EMDs can also help clarify the relationship between patient attitudes and adherence,²⁴ explain heterogeneity in treatment response,²⁷ and plot the time course of adherence change.^{2,28}

THE ROLE OF EMDs IN ADHERENCE PROMOTION IN ASTHMA

Two different approaches have been used for EMD-based adherence promotion studies: health professional-to-patient discussion based on EMD data and direct-to-patient EMD reminders for missed doses. Relatively few publications exist, but early data are promising.

Face-to-face adherence feedback studies when utilizing EMDs

Objective, personalized, feedback data on patterns of medication use provided by EMDs can open discussions between the health professional and the patient,²⁴ and when feedback is given sensitively and with respect for the patient's autonomy,^{15,29} it can facilitate shared decision making and optimize treatment routines.³⁰ A number of trials, from 2 to 18 months' duration, have examined the use of adherence feedback as a strategy to improve adherence of patients with asthma, either alone or in conjunction with a behavioral intervention.^{2,10,23,31-34} Feedback generally took the form of reviewing printouts of inhaler use, with constructive and positive discussion and suggestions, and with problem-solving or goal-setting sessions. The impact of adherence feedback on asthma outcomes such as asthma control and emergency department visits across these studies was inconsistent. Most studies demonstrated improvement in adherence during the feedback intervention. One exception was a study that compared asthma education with adherence feedback plus problem solving among disadvantaged inner-city adults with moderate-to-severe asthma,³⁴ with whom electronically monitored adherence did not differ among groups. This may have been due to complex issues that are difficult to address in disadvantaged populations.

Limitations of existing studies include high adherence in some control groups, possibly due to self-selection of motivated volunteers in research environments, free medication, and/or frequent study visits. Awareness of adherence monitoring may inflate adherence, and, although analysis of early evidence suggests that this lasts only for approximately 7 days,²⁴ more data are needed. Collection of run-in EMD adherence data would be beneficial to ensure that baseline adherence is comparable among randomization groups and to allow monitoring awareness to

TABLE I. The features and reliability of currently available electronic monitoring devices.

Device name/Ref. no.	Manufacturer	Device compatibility	Description	Actuation recording	Data transfer	Reliability/accuracy	Features/ limitations	Device cost*	Reusable†
Commercially available EMDs									
Asthmapolis ⁵⁰	Asthmapolis, Madison, Wis	Standard pMDI	Disposable adapter cap that mounts onto the end of a canister of a standard pMDI; combines a GPS tracking device with a mobile smartphone application.	Uses GPS to determine the time and location of inhaler use; lights on the device show actuation recording, charging, and battery level; the device can store >100,000 logs.	Data stored on the device can be sent to a remote server or computer via a USB port or Bluetooth to a cellphone; usage patterns can be provided to patients via weekly e-mail and portal reports.	No published data are available.	(1) Battery life, 2-3 days; the device recharges with a wall charger or USB power source; (2) easily transferable to a new canister, does not modify drug delivery or actuation; (3) engages patients via text reminders and education content; and (4) able to track rescue inhaler usage when and where it happens.	US\$230/y	Yes
Doser ^{11,51-53}	Meditrac, Inc, Hudson, Mass	Standard pMDI; compatible with use of a spacer but not Haleraid (a lever aid to assist actuation of pMDIs).	A round, flat device secured to the top of a MDI canister; has a small LCD screen to view results.	When pressure is applied to actuate the inhaler, an electromechanical switch records the actuation; records total daily use (no. puffs each day) for up to 30 d.	Data can be read from the device screen but cannot be uploaded; history of actuations is obtained by scrolling through the display.	Actuation recording accuracy 94%-97% ⁵³ ; failure rate 63/301 ¹¹ ; 2/101 ⁵⁴ ; 8% ⁵⁵	(1) Has covert and overt modes so feedback on usage can be displayed or hidden; (2) stores data for only 30 d; (3) data cannot be uploaded; (4) counts down to when inhaler is empty; (5) beeps when fewer than 20 actuations remain in the canister; (6) detects actuations more than 1 s apart, therefore, cannot detect puffs performed in quick succession; (7) may not fit some newer pMDIs; (8) the battery lasts for 13 mo; and (9) an FDA-approved device.	US\$28 per unit	Yes
Smartinhaler Tracker ^{36,37,56}	Nexus6, Auckland, NZ	pMDI; different Smartinhaler moldings for different medications; inhaler cap may not necessarily fit.	Monitoring device situated in a plastic case into which the inhaler canister is placed.	Incorporates a switch that is activated when the canister is depressed and records time and date stamp of actuation; stores up to 1600 logs.	The date may be uploaded to a computer via a serial cradle and communication link; Web-based program is used to set up the device.	Actuation recording accuracy up to 100% ^{36,56} ; failure rates of 0/10 ⁵⁶ ; 13/99 ¹ ; 2/10 ⁵⁷ ; 9% ⁵⁸ ; 1.9% ⁵⁹ .	(1) Records time and date of actuation; (2) can incorporate an audiovisual reminder for missed doses and provide visual feedback about inhaler use; (3) the time stamp is accurate to 1 second precision; (4) USB or cellphone upload available on request.	US\$120 per device	Yes; potential issues with blocking of the nozzle.

SmartTrack ¹⁷	Nexus 6, Auckland, NZ	pMDI; different SmartTrack moldings for different medications.	The monitor fits around a pMDI; has an LCD screen to display time, date, battery level, and other user feedback as desired.	Records time and date of actuation by optical sensor (no mechanical parts); able to record actuations with a time and date stamp accurate to 1 second precision; stores up to 3200 logs.	Optional remote data upload by SIM card to a secure Web site available or upload manually to computer via a docking station and USB cable; option to communicate with Smartinhaler Live software.	Mean accuracy of actuation logs reported to be 97%-99%; reminders were 100% accurate ¹⁷ ; failure 1/10. ¹⁷	Uses a standard AAA battery; Optional features include (1) visual and/or audio adherence feedback (overt and covert mode selections); (2) graphic and numerical adherence data can be viewed and/or uploaded from secure Web site or on desktop software; (3) audio reminders tailored to weekday and weekend routine; (4) personalized ringtone selection; (5) battery installation and removal logging; (6) audio reminder on-off logging; (7) security screw to ensure that the inhaler cannot be taken out during monitoring.	US\$220	Yes
Custom-built EMDs									
Device linking Turbuhaler with a pneumotachograph ¹⁶	AstraZeneca, Sodertalje, Sweden	Budesonide Turbuhaler dry powder inhaler.	The Turbuhaler is connected in line with the pneumotachograph via a spacer, which consists of an adapter and sealing cap; any flow generated via inhalation is detected by the DSS.	A spirometer (DSS) records the peak inspiratory flow via the device each time a dose of medication is inhaled; the DSS consists of a pneumotachograph and a computer.	After each inhalation and exhalation, values are shown on the DSS display and are uploaded at study visits.	Missing data due to malfunction of the DSS are reported on 2.5% of the study days during the treatment period ¹⁶	Records date and time of inhalations; assesses peak inspiratory flow; reduces handling errors with the Turbuhaler; bulky.	Data not available	Yes
Diskus Adherence Logger, DAL ^{60,61}	Daniel Bogen, PhD Philadelphia, Pa; not in commercial production.	Diskus (Accuhaler) dry powder inhaler.	Attaches externally to the patient's Diskus, consists of 3 subsystems: a data collection module that detects doses, an interface module to allow uploading to a computer, and computer software to initialize the data collection.	Senses motion of the dose delivery lever of the Diskus and records date and time of lever motion; operates via an electromagnetic system.	Adherence data are able to be uploaded onto a computer via a USB port and connecting cable.	Three of 40 monitors (7.5%) failed to download in 1 study ⁶⁰ ; 100% accuracy reported in another study. ⁶¹	(1) Expected battery life of 5.8 mo ⁶¹ ; (2) time logs are accurate to 1 min; (3) no interference with normal inhaler function ⁶¹	Available through collaboration with D. Bogen.	Yes
INCA study device ⁶²	Trinity Centre for Bioengineering, Trinity College, Dublin	Diskus dry powder inhaler	Device that stores an audio recording of each inhaler event; software program checks time and date of audible steps in inhaler use.	Adherence device that records an audio signal with each inhaler use.	Database of audio recordings of inhalations generated; data are transferred from the device to a computer for local processing.	5% (unpublished).	Detects actuation and inhalation.	Not commercially available.	Data not available.

(continued)

TABLE I. (Continued)

Device name/Ref. no.	Manufacturer	Device compatibility	Description	Actuation recording	Data transfer	Reliability/accuracy	Features/ limitations	Device cost*	Reusable†
Nebulizer EMDs									
AAD nebulizer system ⁶³⁻⁶⁵	Philips Respironics, Chichester, England	Nebulized medications; not currently used in routine asthma care.	Jet nebulizer connected to a PLS.	The processor collects pressure data from the nebulizer via a sensor and analog-to-digital converter, which is stored on a memory chip	Data able to be downloaded from PLS to a computer; compatible with the I-neb insight Online system, which allows uploading of data onto a server to provide remote access to data by the clinician.	12.8% of PLS units malfunctioned in one study ⁶⁵	Records date and time of each nebulizer treatment and cumulative inhalation time; gives visible and audible feedback signals to indicate when dose delivery is complete; monitors amount of drug delivered per treatment.	Data not available.	Yes
AKITA ⁶⁶	Activaero GmbH, Gemunden, Germany	Nebulized medications; not currently used in routine asthma care.	Nebulizer system including smart card technology to record adherence and breathing data; the smart card is an electronic microchip that transfers information to the AKITA control unit.	Saves data onto a microchip (Smart Card)	Data can be transferred to a computer for analysis.	Data are unavailable.	Provides information on the no. breaths per treatment; duration of treatment; timing of inhalation; inhaled drug dose (overall vs 7-d dose); inhalation with AKITA can be adapted to the patient.	Data not available.	Yes

Note. The SmartDisk, SmartTurbo (Nexus6), Turbuhaler Inhalation Computer (Medtrac Technologies, Lakewood, Ill), MicroDose with Smartinhaler Live (MicroDose Therapeutx Inc [Monmouth Junction, NJ] and Nexus6) and the Electronic Diskhaler are not included in this table due to limited data and/or early developmental status; discontinued devices that are no longer available, including the MDI Log, MDI Chronolog and Nebuliser Chronolog are also not included.

AAD, Adaptive aerosol delivery; *d*, day; *DSS*, data storage spirometer; *EMD*, electronic monitoring device; *FDA*, US Food and Drug Administration; *GPS*, global positioning system; *LCD*, liquid crystal display; *MDI*, metered-dose inhaler; *Mo*, month; *PLS*, patient login system; *pMDI*, pressurized metered-dose inhaler; *Y*, year.

*Device cost does not include cost of medication itself where relevant, or the cost of data transfer services or Web maintenance for remote monitoring.

†Reusable by the same patient with replacement medication.



FIGURE 1. Images of some electronic monitoring devices discussed in this article.

subside. Adherence tends to decrease over time in research studies, so, although adherence may be significantly higher in the intervention group at study end, the long-term duration of effect is uncertain. These limitations may impact the generalizability of study findings to clinical settings.

Direct-to-patient adherence reminder interventions utilizing EMDs

Direct-to-patient reminders about medications can help patients with chronic illness to establish medication-taking routines and increase engagement with self-management.³⁵ Two published randomized controlled studies investigated the effectiveness of inhaler reminders for improving adherence. In one 6-month study in adults with asthma, the EMD beeped for up to an hour if the dose was not taken by a patient-determined time, and a light changed color once the dose was taken.³⁶ Adherence over weeks 13 to 24 was significantly higher in the reminder group compared with the control group (93% vs 74%; $P < .0001$). The second study, in children, of 8 weeks' duration and reported only in an abstract, had twice-daily inhaler reminders that rotated through 14 different ringtones (cow mooing, movie themes etc).³⁷ Median adherence in the last 2 weeks of the study was significantly higher in the reminder group (92.0% vs 51.5%; $P < .0001$). Neither study showed significant differences in asthma outcomes.

These studies are limited by a lack of baseline adherence data and relatively high adherence in control groups, which perhaps reflects selection bias. These studies suggest the potential for

reminders to positively change adherence behavior, but much more evidence from longer pragmatically designed trials is needed to assess the clinical impact, especially in real-world practice populations.

DISCUSSION

With the rapid development of communications technology and increasing awareness of the importance of patient-centered care, interest in remote monitoring of chronic illnesses is growing among physicians and consumers.^{38,39} Technology in EMDs for inhaled asthma medications has advanced, with devices now offering customizable reminder systems, Internet and/or cell-phone applications, inspiratory flow recording, global positioning system tracking, and feedback to health professionals and patients via Web-based interfaces, e-mails, and/or text messages. However, more evidence is needed to establish the feasibility and cost-effectiveness of EMDs for use in clinical practice and to clarify the populations and clinical contexts in which they may improve asthma outcomes or reduce health care costs.

EMDs have a unique role in monitoring adherence and in investigating related health outcomes by providing information about the pattern of medication use that is unobtainable from other methods. This is important in light of recent evidence that intermittent use could be as effective as regular inhaled corticosteroid (ICS) use for asthma control in some patients.^{20,21} In addition, EMDs can contribute to adherence promotion, either through direct reminders or as part of a behavioral intervention,

with benefits remaining up to 2 years,³¹ although benefits may not be sustainable once feedback is removed.² EMD intervention studies have been conducted in a variety of populations, ranging from research volunteers to inner-city minorities with major socioeconomic disadvantage, but there is still a paucity of studies outside research settings that can assess acceptability and feasibility in real-life practice.²² Most EMD intervention studies to date have not been able to demonstrate changes in clinical asthma outcomes or have been unable to link improved adherence with better health outcomes.³⁴ This may partly relate to the brevity of the interventions, differing asthma phenotypes that require differing treatment intensities,⁴⁰ inappropriate prescribed doses, a potential lag of several months between poor adherence and negative asthma outcomes,⁴¹ “ceiling” or threshold effects in response to ICS,²⁶ and the tendency for improved adherence in the lead up to an exacerbation.⁴ Population-based evidence tends to support the relationship between poor adherence and poorer asthma outcomes,^{3,5} but the current evidence from intervention studies remains weak.

What are the evidence gaps?

Existing EMD studies have essentially represented proof-of-concept studies for their use in adherence monitoring and promotion. Most have been conducted in research environments with technical support for device checking and data handling, with trained clinicians having time to deliver appropriate counseling. Feasibility data are needed from normal clinical settings because significant barriers to implementation of adherence feedback interventions may be concealed in research studies in which patients and clinicians are actively recruited and reimbursed for participation. Patients, particularly those from disadvantaged populations, may fail to attend clinic visits and lose EMDs, and health care professionals may lack the resources and time to review patients' adherence data and provide counseling.²² Longer-term, larger studies are needed to determine whether adherence improvements can be sustained and to demonstrate which feedback interventions can reliably improve asthma outcomes to ensure that these relatively costly interventions produce useful outcomes beyond the research setting.⁴²

At the present time, a key barrier to implementation of adherence interventions is the lack of evidence for sustained improvements in asthma outcomes. Longer, larger, or more-targeted studies may show clinical benefit in those patients for whom poor adherence drives poor asthma control, so EMD research will be important for facilitating the identification of patients who would benefit from adherence interventions.

What are the most promising areas for use of EMDs?

The greatest potential use for EMDs in coming years appears to lie in 3 main areas: personal patient-driven use, clinical management of difficult-to-treat asthma, and clinical research. Results of recent surveys indicate a substantial appetite for personal patient-driven health monitoring in populations aware of e-health and technological developments.³⁸ Several EMD manufacturers report engaging in direct-to-patient marketing, and their customers use EMDs as dose counters, to monitor controller medication use, or to set inhaler reminders. This market is likely to largely comprise patients with high health literacy⁴³ and to exclude disadvantaged and minority populations, but its existence may facilitate progress on hardware and software design and connectivity issues.

In clinical practice, the most promising indications for EMDs lie in the management of severe asthma,⁴² which is associated with high health costs. In particular, EMD data could help identify asthma that is poorly controlled due to poor adherence with ICS.¹ These data could generate cost savings by better informing prescribing of expensive add-on therapies, such as biologic agents, in which the EMD cost may be less than 1 month's treatment. EMD data could prompt discussion of adherence barriers and identify who might benefit from flexible ICS dosing strategies.^{1,44} However, feasibility issues in populations with diverse medical and social problems, complicated by poverty and low health literacy, must be investigated, including the patient's ability and willingness to use EMDs and appropriately engage with interventions, and the design of acceptable feedback strategies.²²

Asthma is an area of major health disparity. The worst asthma outcomes and adherence are seen among those who have difficulty obtaining even basic medical care and who are unlikely to have access to EMD interventions.^{45,46} Benefits to these populations from EMD utilization will most likely stem from the information gathered from EMD research to inform public health initiatives that target these disparities.

In research, use of EMDs may allow greater insight into heterogeneity of treatment response to controller medications and risks associated with overuse of reliever medications,¹⁹ particularly in real life rather than select populations. Other high priorities for research include identifying the impact of the pattern of inhaler use (eg, regular, irregular, intermittent),^{4,18,25} on adverse events (eg, overuse when symptomatic), particularly in early-phase trials of inhaled medications, and clinical asthma outcomes.

Limitations of current EMDs

Health care consumers need to be aware of potential pitfalls when using new gadgets. There is only a small range of reliable EMDs, particularly for dry powder inhalers, and some devices are vulnerable to changes in inhaler design. EMDs need to be reliable and user friendly, but technology develops quickly, and it may not be feasible to publish performance data for every model; standardized quality-control processes, performed prior to EMD issue to patients and after return, are necessary to identify faults and to reduce the risk of device failure.^{22,47} Other current limitations include the cost of the device and data transfer services,⁴² and the diverse software and Web platforms used by different manufacturers, which make it difficult to assess adherence across available medications. EMD data can be complicated to synthesize. Manufacturers are increasingly offering analytic options with their software, but there is a need for standardized evidence-based adherence metrics to facilitate consistent analysis and reporting. Finally, EMD data are only useful if the EMDs are used as intended by patients; however, people may share medications and may break, lose, or tamper with the EMD, which renders the data less useful.

Moving EMDs from research into clinical practice: what is needed?

EMDs are considered to be too complicated and expensive to incorporate into routine clinic practice,²² but, with rapidly improving technology, the cost and complexity should decrease while reliability increases. Cost may be offset by savings seen with improved asthma outcomes, particularly in severe asthma when

the cost of increased health care is extremely high.⁴² Other barriers to the use of EMDs in the clinic include the lack of reimbursement for devices, staff time, training, and patient counseling.²² A useful model may be the reimbursement of continuous glucose monitors for juveniles with diabetes, where increasing research evidence for effectiveness is leveraging insurance coverage.⁴⁸

Given the existing evidence for effectiveness of EMD-based interventions in improving adherence and the limitations identified above, further well-designed studies are needed to strengthen this evidence, particularly to clarify the link between improved adherence and improved asthma outcomes. Large-scale implementation studies in a range of populations and health contexts are needed for a robust examination of EMD cost-effectiveness, feasibility, and acceptability. Such evidence would potentially support EMD interventions as a reimbursable clinic-based or self-management activity.

Initial implementation data from the Cincinnati Children's Hospital Medical Center, where adherence feedback is routinely delivered in a specialized adherence unit for adolescents show that it is feasible to use EMD data within these specialist appointments and that the approach is accepted well by patients and families.⁴⁸ However, more EMD studies are needed to build an evidence base around the most-effective feedback formatting. Further, it is plausible that conflict situations may arise if the patient's self-reported adherence does not concord with feedback data. In research studies that used EMD feedback, the staff was trained in nonthreatening, supportive adherence communication^{2,10,23,31-33} and had time for such counseling. Development of suitable tools and training for clinical settings will also be needed, both for optimal device management and to facilitate health professional-patient communication. Health professionals should already have many communication skills needed to facilitate conversations about medication adherence, but formalized training is often necessary to understand when and how to use specific skills most effectively; indeed, in a recent meta-analysis the odds of patient adherence were 1.62 times higher in patients of trained than of untrained physicians.⁴⁹

Governments and health care organizations must ensure that budgets, systems, and staff are ready for an increasingly digital environment to take advantage of this new era of personalized health care management,³⁹ and the introduction of electronic health records may provide a gateway. Data from EMDs may be interfaced with electronic records to allow the seamless transition of care between different health settings, development of management plans personalized for the patient based on his or her adherence data, and promote patient autonomy over his or her own health care. In the meantime, EMDs already offer stand-alone adherence monitoring, personal computer software, and Internet applications that can be used by clinicians and researchers to better support and understand patients' asthma self-management. More research is needed to identify the clinical contexts in which this can be both feasible and cost effective.

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