

Strategies for Improving Inhalation Technique in Children: A Narrative Review

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Abstract: Inhaled medicines are commonly utilized by children for various respiratory conditions and must be used effectively for the medication to reach the airways. Poor inhaler technique contributes to poorly controlled asthma with significant associated morbidity. Given the significant consequences of improper inhaler use in children, the goal of this review is to comprehensively describe existing and potential solutions to improve inhaler technique. Because children move through various settings, including clinical practices, schools, pharmacies, and homes, in their daily routine, there is great opportunity to teach and reinforce proper inhaler technique across settings. Within each setting, in-person and technology-based interventions have shown promise to improve technique. These solutions need to be more broadly adopted to deliver tailored education with support for provider training, team-based care, communication structures, and reimbursement. Such solutions hold the potential to improve inhaler use among children, with potential for decreasing morbidity and costs.

Keywords: asthma, devices, inhalers, pediatric

Introduction

Inhaled medicines are commonly utilized by children for various respiratory conditions, such as asthma, cystic fibrosis, and chronic lung disease/bronchopulmonary dysplasia. Delivered via nebulizer machines and inhaler devices (“inhalers”), these medicines are fundamental to effective disease management and offer many clinical advantages. One key benefit is that inhaled medicines act locally in the lungs, thus minimizing their systemic effects on the rest of the body.

Inhalers are shown to be at least as effective as nebulizers and have the added benefits of portability and access.¹ However, for inhaled medications to be effective, their fine particles must be delivered directly into the airways. It is critical that each person with a respiratory condition is able to use their inhaler correctly to support disease management. Improper inhaler technique (also termed inhaler misuse) is a key reason that inhaled medicines are not effective, as the medicine does not reach the airways.^{2–4} Inhaler misuse contributes to poorly controlled asthma with resultant exacerbations, steroid use, acute care utilization (urgent care and emergency department visits), as well as hospitalization.^{3,5–7} In addition to negative clinical outcomes, improper inhaler use leads children to miss school and parents to miss work. The financial cost of inhaler misuse is estimated at \$7–15 billion annually.⁸ Indirect effects of inhaler misuse include patient or caregiver loss of confidence in their medications and

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treatment plan, worse medication adherence, as well as escalation of therapy with associated potential side effects.⁷

Research indicates that poor inhaler technique is common among children.⁹ Specifically, observational studies have found that only 8–22% of children with asthma use their inhalers correctly.⁹ High rates of inhaler misuse are present across ages, race/ethnicity, geographic variation, places in care, and conditions.^{9,10} As a result, guidelines recommend that healthcare professionals educate about proper inhaler use at each patient encounter.^{11,12} Despite these guidelines, a sizeable (25%) proportion of patients who use inhalers do not receive inhaler instruction.¹³ Among children, one study found that only 10% had their inhaler technique assessed by their provider during an office visit.¹⁴ This limited education represents missed opportunities to improve asthma outcomes among children.

Effective Inhaler Technique

Proper inhaler technique involves knowing each step for effective use and implementing maintenance and cleaning procedures to ensure that the devices continue to work effectively. Inhaler technique varies by device (eg, metered dose inhalers (MDIs), diskus, turbobhalers), with each inhaler type requiring different steps for correct use.¹³ There are no set standards for proper or effective technique; however, a variety of checklists or review criteria have been published.¹⁵ Within this literature, evidence is emerging about the importance of “critical” errors, defined as errors that have the greatest impact on effective medication delivery on clinical outcomes.¹⁶ Further, proper technique varies according to patients’ age and abilities. For instance, younger patients require both a mask and spacers with MDIs, while older patients can effectively use just a spacer with MDIs.¹⁷ No guidelines establish what factors should drive this change or at what age this change should occur, though it is typically posited to be around 5 years of age.¹⁷

In addition to age as a factor for proper technique, inhaler devices differ in terms of how easy or difficult it is to use them.¹⁸ Devices that are generally considered easier to use include diskus, turbobhaler, and ellipta, because the steps required for effective use are more obvious and/or it is more difficult to conduct critical errors.^{9,14,18,19} Metered dose inhalers, despite being the first device developed to deliver inhaled medications to the lungs, are considered more challenging to use than

most other devices.^{19,20} This is in large part due to the difficulty, if not near impossibility, of effectively “coordinating” the breath in after device activation such that the medication reaches the lungs rather than the gastrointestinal tract. Common teachings include instructing patients on how to coordinate this breath in; however, the speed at which the medication leaves the device after actuation is simply too fast for a person to be able to effectively inhale most of the medication without the use of a spacer. Spacers are separate devices that require a prescription and money to purchase. Also, adolescents often report that using a spacer is inconvenient, creating an additional barrier to proper inhaler technique in pediatric patients.²¹ Further complicating matters is the fact that many patients require more than one inhaler device to manage their asthma. Some data suggest that multiple devices can lead to worse technique,^{22,23} though at least one study did not find these results.²⁴ Finally, with every inhaler a patient is prescribed, risk of misuse is increased.²⁵

According to the national asthma guidelines, factors that promote good technique include clinician assessment of patient technique and provision of technique education at all healthcare encounters.¹¹ Multiple options exist for inhaler technique education and the type of education that clinicians use to teach patients about inhaler technique matters. For example, in one study of hospitalized adults with obstructive lung disease, inhaler education that utilized an active learning approach with assessment and teach-back, termed teach-to-goal, was found to be more effective at reducing acute care utilization (ED visits and/or re-hospitalizations) within 30 days after hospital discharge compared to simply providing brief verbal instructions.²⁶ Also, education is critical and cannot be substituted by assessing a child’s or parent’s confidence in technique, as studies show that confidence and proper technique are not aligned.²⁷ However, assessing patients’ confidence in their technique is important because patients’ adherence to their regimen is predicted by confidence.²⁸ Further, when patients have low confidence in their technique, they also report worse adherence.²⁹ Providing repeated education on correct inhaler technique has been found to improve adherence.³⁰

Given the significant consequences of improper inhaler use in children, the goal of this review is to comprehensively describe existing and potential solutions to improve inhaler technique. This paper first describes solutions to improve technique and explores existing solutions and future directions by the healthcare delivery setting. For this narrative

review, relevant English language articles from any year were identified from PubMed, Google Scholar, and Embase databases using keyword searches for “inhaler technique”, “inhaler competence”, “inhaler misuse”, “diskus technique”, “metered dose inhaler technique”, and “inhaler education”, “children”, and “pediatric”. The references of relevant articles were reviewed for additional papers.

Results

Measuring Inhaler Technique

Instruments, such as questionnaires or checklists, are utilized to measure inhaler technique in research studies in order to quantify the adequacy of inhaler technique. However, no standard tool is used for asthma education in routine clinical delivery. Part of the challenge may be attributed to the numerous inhaler technique instruments available. In a systematic review of 24 available instruments to measure pressurized MDI technique among children with asthma, four instruments were designated as higher quality based on appropriateness of measurement and evidence of validation.³¹ The conclusion, however, is that no single instrument has been fully evaluated to ensure appropriate validity and reliability for adoption into clinical practice. Most experimental or observational studies for MDI technique used an 8-step reference to measure correct use.⁹ Other researchers have suggested that not all steps in inhaler technique should be weighted equally and it may be more meaningful for practicing clinicians to distinguish whether the step is a critical error (eg, not taking the cap off the inhaler) versus a non-essential error (eg, not holding the inhaler upright).^{9,32}

Solutions to Improve Inhaler Technique

Because children move through various settings, including clinical practices, schools, pharmacies, and homes (Figure 1), as part of their daily routine, there is great opportunity to teach and reinforce proper inhaler technique across these settings. Within each setting, several interventions can be implemented to support children’s asthma management and inhaler technique. Also, some of these solutions can be implemented across settings. We outline these solutions by setting below and note when interventions overlap across settings (Table 1).

Clinical: Outpatient and Inpatient

The outpatient setting, either primary care or specialty clinics (pulmonary or allergy), remains the most common location to provide comprehensive, high-quality, longitudinal care for



Figure 1 Settings in which inhaler technique solutions can be implemented.

children with asthma.³³ National Heart, Lung, and Blood Institute guidelines that recommend healthcare professionals check inhaler technique at every opportunity seems most apt for the outpatient clinical setting.¹¹ However, evaluations of outpatient asthma visits found that most health providers, particularly physicians, do not take the time to review and assess the use of inhalers with their pediatric patients with asthma.¹⁴ Additionally, patients have a low return rate for preventive asthma visits, which necessitates that other clinical settings, such as the emergency department or urgent care, must be considered as settings for education and reinforcement of proper inhaler technique.³⁴ Further, a hospitalization represents a critical event and important opportunity for education. Thus, we review solutions for assessment and education of inhaler technique that are used in various clinical settings, including office-based visits, emergency departments, and inpatient settings.

Educational interventions focused on inhalation technique generally improve children’s technique significantly regardless of whom (ie, nurse, physician, asthma educator) provides the education.⁹ While some educational interventions were delivered during scheduled clinic visits, others were done at follow-up clinic visits 1 to 12 months after the initial assessment. Most importantly, frequent opportunities to observe and correct technique are needed for children and caregivers to maintain proper technique. Educational interventions can use face-to-face support, multimedia delivery (eg, apps, games), and technology-enhanced feedback devices. Each educational modality

Table 1 Solutions, Educators, Themes, and Future Directions to Improve Inhaler Technique in Children

Solutions	Educators	Themes	Future Directions
Education types: • Written material – eg paper, pamphlet • Videos - • In-person – with demonstration and teach-back • Technology-enabled supports – device-based and telehealth education	• Doctors • Advanced practice providers • Pharmacists • Nurses • Respiratory therapists • Medical assistants • Community health workers	• Most education can be implemented in multiple settings by various educators • Many inhaler technique education modalities are evidence-based and can be used in alone or in combination • Education should be tailored to individual's knowledge and skill • Active learning methods are most effective and can be supplemented by written and videos to reinforce education • Team-based approach is crucial for delivering education	• Provide reimbursement for inhaler technique education for all patient ages and various health professionals • Expand scope of practice of team members • Ensure consistent coverage for telehealth services • Advance communication systems between health professionals to enable easy bi-directional information flow • Change appearance and structure of inhaler devices to support effective use, including consistent colors, built-in spacers, and real-time feedback • Adopt training about proper inhaler technique for health professionals broadly • Support research on improve inhaler use, such as epidemiology and impact of misuse, standardized assessment tools, practical interventions, and implementation

Notes: Education can be provided synchronously or asynchronously. Checklists can be helpful to assess technique.

improves technique in adults and children in comparison to usual care.³²

In-person education, defined as live instruction typically with a health provider, is the most common approach for educational interventions on inhaler technique in clinical care. Studies often describe hands-on demonstration with patients and verbal instruction to reinforce technique with patients.³⁵ Educational approaches have also included a “teachback” process from patients, such as Teach-to-Goal (TTG). This standardized in-person educational intervention is one evidence-based approach to improve inhaler technique. In TTG, learner’s skills and knowledge of inhaler technique are assessed and tailored education is provided. The learner then re-demonstrates technique as “teachback”. The cycle is repeated until learners demonstrate skills mastery.³⁶ TTG has been effective among 8–14-year-old children, with one study showing improvement in the number of correct steps performed, an increase in the proportion of children with mastery (all steps correct), and a decrease in the proportion of children with inhaler misuse.³⁷

Multimedia Interventions

Videos are an additional education tool that can be used to provide step-by-step physical demonstrations of how to use inhalers. Videos have the advantage of demonstrating proper inhaler technique while ensuring high fidelity (ie, the process is taught the same way to different patients);

however, they do not allow for a teach-back process. Videos have been created for different inhalation devices, age groups, genders, and even languages, thus creating a tailored experience for the child. Various organizations have developed videos that are readily accessible online.^{38,39} Benefits of videos include the ability to integrate them in clinical workflows, the ease of access in clinical environments and at home, the opportunity to deliver training to additional caregivers or family members, as well as cost-effectiveness and sustainability.⁴⁰

Technology-enabled supports have emerged as additional tools in asthma education in the clinical setting. Various types of technology-enabled devices or programs are available for teaching inhaler technique, including device-based interventions and telehealth for enhanced education. Electronic devices often externally attach to the inhaler and detect when the patient activates (or uses) the inhaler. For example, Ammari et al conducted a trial where children used a device designed to support their coordination with slow, deep breaths to improve the manual delivery of inhaled medication via MDI.⁴¹ In the study, the device proved equally effective in helping children master MDI technique when compared with traditional verbal counseling about technique. In addition to qualitative feedback typically given to patients about inhaler technique, a mobile spirometer, a machine for pulmonary function testing, has been studied to also give patients quantitative feedback about technique.⁴² These are two

examples of the various devices available to support inhaler technique. Notably, a recent review found that many devices do not include all the evidence-based steps for inhaler technique and have limited real-time feedback.⁷

Telehealth educational sessions have been increasingly adopted to further connect with patients with clinicians without requiring in-person visits. Since the COVID-19 pandemic, telehealth approaches have accelerated within clinical practice.^{43,44} Despite the limited evidence on using televideo visits for children with asthma, they might become more prevalent due to changes in practice norms and capacity. Further, they enable chronic disease management without requiring families to attend office-based visits, thus overcoming barriers with transportation or missed work/school. In a prospective 12 month randomized trial using asynchronous, in-home asthma monitoring, pediatric patients in the virtual group demonstrated improved MDI technique compared with the office-based only group at 52 weeks. There was no difference in dry-powder inhaler technique in the trial between the two groups.²⁴ Notably, to overcome technology and equipment barriers, families were provided a home computer, camera, and internet access in the trial. The limited evidence suggests that telemedicine was non-inferior to office-based visits for asthma.⁴⁵

Community Pharmacies

Across the United States, there are over 68,000 pharmacies, many of which have convenient hours and offer free medication counseling services without the need for an appointment.⁴⁶ These factors mean that pharmacies have an important role in play in educating children about their inhaled medications. In fact, pharmacists are uniquely positioned to assess inhaler technique and deliver education each time an inhaler prescription is filled. Studies suggest that both children and their caregivers are receptive to receiving medication education from pharmacists.⁴⁷ Although pharmacies offer distinct advantages for inhaler technique education, many children do not accompany caregivers when they pick up their prescriptions.^{7,48} Despite this barrier to pharmacist assessment of technique, several viable inhaler technique education solutions are currently offered in pharmacies. Indeed, a recent review found that inhaler technique education was a common component of pharmacist-delivered asthma interventions.⁴⁹ We describe various pharmacy-based solutions below.

In-person assessment and education is the most common intervention implemented in community pharmacies. Face-

to-face demonstration and assessment have been described previously in the clinical settings section, and the same teaching principles apply in the community pharmacy setting. Face-to-face instruction has shown benefits at both the patient and pharmacy level.⁵⁰⁻⁵² For example, one study found that when pharmacists asked patients to demonstrate inhaler technique, patients were more likely to return to the pharmacy as compared to when pharmacists did not ask patients to demonstrate technique.⁵⁰ Additionally, pharmacy-based face-to-face demonstrations have led to greater improvements in patient inhaler technique when compared to written materials or videos.⁵²

Face-to-face interventions have ranged from simple one-time assessments that led to short-term reductions in inhaler technique errors to more comprehensive interventions that are associated with long-term technique improvements.^{53,54} Specifically, one multifaceted intervention involved pharmacists: (1) asking patients with chronic obstruction pulmonary disease to demonstrate inhaler technique using a placebo device; (2) providing verbal one-on-one instruction with a physical demonstration of correct technique; (3) asking the patient to teach-back correct technique after the pharmacist demonstration; and (4) attaching a reminder label with the steps for correct technique to the patient's device.⁵⁴ Pharmacists repeated this intervention at 1, 3, and 6-month follow-up. The authors found that patients had sustained statistically significant improvements in technique at 12-month follow-up, illustrating the effectiveness of repeated inhaler technique assessments by pharmacists. Further research is needed to determine whether this strategy would be an effective method for providing education to children and their parents.

Written materials have also been used to teach inhaler technique in pharmacy settings. Pharmacists use written materials independently and/or to reinforce verbal instruction about proper technique. Common written materials include handouts and pamphlets with detailed instructions. Another simple, innovative intervention involves having the pharmacist place a label on the inhaler with step-by-step instructions for correct use.⁵⁵ This intervention provides a visual cue to think about proper technique each time the individual uses their inhaler.

Multimedia and Telehealth Interventions

Pharmacists have also used multimedia and telehealth interventions to deliver inhaler technique education to patients. Multimedia interventions typically include videos,⁵² while telehealth interventions include phone

calls or video visits. One small study found that three telepharmacy visits from a pharmacist led to significantly improved MDI technique among 36 adolescents when compared with a control group.⁵⁶ The pharmacist used a checklist to assess technique, provided verbal demonstrations and instruction on how to correct errors via a video visit. Additionally, a study in which rural patients had three to four video telehealth visits with a pharmacist demonstrated sustained improvements in inhaler technique at 2-month follow-up.⁵⁷ Given that multimedia and telehealth interventions show promise, future studies should evaluate the effect of these pharmacy-based interventions on children's inhaler technique.

Schools

Children spend more than half of their waking hours in school. As such, there are several benefits to offering inhaler technique education in schools, including access to children who attend schools; on-site school nurses who can assess and educate about technique; opportunity to conduct periodic follow-up assessments and education throughout the school year; and no need for parents to miss work days and children to miss school.

Face-to-Face Assessment and Education

Research has shown that school-based asthma education improves children's knowledge of asthma, self-efficacy, and self-management.⁵⁸ Unfortunately, a review of school-based asthma education programs found that the methods used to teach technique are poorly described, and only two studies used a validated measure to evaluate whether participation in the program improved children's inhaler technique.⁵⁹ Of the articles that described inhaler technique education in greater detail, inhaler technique was typically addressed only once in the curriculum, with 10 minutes or less dedicated to teaching technique. Thus, there is great opportunity to augment inhaler technique instruction in these comprehensive school-based programs that address other important asthma self-management behaviors, such as environmental control, symptom monitoring, and medication adherence.

Multimedia, Telehealth, and Technology-Enabled Interventions

School nurses have used tailored inhaler technique videos to improve children's inhaler technique.⁶⁰ Additionally, emerging evidence suggests that school-based asthma telehealth programs can reduce emergency department visits

for children with asthma. Perry and colleagues (2019) have provided a recent, comprehensive review of school-based asthma telehealth programs and their potential benefits.⁶¹ However, the extent to which inhaler technique is addressed during school-based telehealth visits is unknown. Although inhaler technique has not been a focus of existing school-based telehealth programs, the potential to deliver inhaler technique education during telehealth visits is great. Additionally, school nurses can reinforce proper technique in between telehealth visits and share children's inhaler technique assessments with their providers during telehealth visits, expanding the opportunities to provide team-based care. One pilot study demonstrated that children who received school-based telehealth visits with an asthma specialist and adherence psychologist combined with inhaler use monitoring via the Propellor device demonstrated improvements in asthma symptoms and medication adherence.⁶² Taken together, these studies suggest that assessing and educating about inhaler technique during school-based telehealth visits is a worthwhile area for future study.

Home Environment

Supporting families with children with asthma directly in their home environment is also an evidence-based, effective approach.⁶³ In the home, education can occur synchronously or asynchronously, thus expanding access to inhaler technique education for children, their parents/guardians, and additional caregivers in the home. Synchronous education can occur in person or via telehealth. Also, asynchronous education can utilize videos or websites with reputable information, for example from health systems, community coalitions, or pharmaceutical companies, can deliver education at a convenient time and can allow for repetition of education.

Home-based programs have been studied as multicomponent interventions that evaluate home environmental triggers, assess knowledge and challenges with asthma self-management, and support asthma control.^{64,65} Less explicitly mentioned in these studies is whether asthma basics or self-management education includes review of inhaler technique in these home-based programs.

In a study of in-home assessment of urban minority youth with asthma, evaluations found that participants had a lack of asthma medications and devices as well as improper asthma management.⁶⁶ These findings point to the advantage of having in-home evaluations to offer a more accurate picture of what patients and families

experience. Intervening on inhaler technique in this setting then seems appropriate. For example, a feasibility study using community health workers (CHW) for children with comorbid obesity and asthma found that inhaler technique can be improved even in a combined intervention focused on two conditions among high-risk children.⁶⁷

Discussion

Themes

Several patterns emerge as we examine existing solutions across settings (Table 1). Strategies to improve inhaler technique among children range from in-person to technology-based, both synchronously and asynchronously. These strategies enable children and their caregivers to be reached where they are at, both in terms of location and skill. Written materials are available but have been proven to have limited effectiveness when compared to more intense teaching methods. With both in-person and technology-based approaches, opportunities exist to tailor education to the individual's knowledge and skill by making assessments and adjustments in real-time. Further, a tailored approach allows the education to be modified for different learning styles. These active learning methods can be supplemented by written materials and videos for reinforcement, which is critical to maintain effective inhaler technique.

With each strategy, education can be delivered by various individuals – physicians, advanced practice providers, pharmacists, nurses, respiratory therapists, medical assistants, community health workers, and others. Primary care doctors can teach effective technique in their clinics as well as refer to subspecialists for teaching and reinforcement. Advanced practice providers, pharmacists, nurses, and respiratory therapists can teach and reinforce proper technique in their encounters and interactions with the patient, either with the physician or separately. Expanding the scope of work of medical assistants and community health workers provides enhanced opportunities for education and reinforcement across settings, particularly by diverse team members with varying time availability and day structures. This team-based approach is often applied in cystic fibrosis models of care and lessons learned can be applied to other respiratory diseases. Further, this diffusion of responsibility also ensures that the burden is not on one person to deliver education but rather on all individuals. It also enables more frequent

education for children, which proves crucial as children develop and their knowledge and skills change.

Notably, with a team-based approach, it is critical to ensure that everyone is aware of their role in teaching inhaler technique, as there is a risk that one clinician believes that another is doing the teaching. In addition, there must be a high level of skill among clinicians who are teaching proper technique and consistency in the technique taught across clinicians and clinical settings, as inconsistencies have the potential to lead to confusion and distrust among children and caregivers.

Future Directions

Building upon existing work, we propose solutions that could enhance inhaler technique education (Table 1). At the policy level, reimbursement is fundamental to ensure that healthcare professionals are better able to implement inhaler technique assessment and education for children with asthma. Currently, reimbursement varies widely by patient age, insurance, state, and clinical setting.⁶⁸ In the United States, Medicare, a public insurance option for individuals over 65 years, reimburses clinicians for delivering inhaler technique education. This model could be replicated with children in clinical settings, community pharmacies, and homes to encourage more frequent inhaler technique education. Further, reimbursement needs to occur for various health professionals, not just physicians or advanced practice providers. For example, pharmacists, medical assistants, and school nurses are commonly not reimbursed for providing inhaler technique education, and, pharmacists, for example, may prioritize reimbursable services to ensure the financial viability of the pharmacy. Alternatively, there is preliminary evidence that trained pharmacy technicians and community health workers can identify and correct inhaler technique errors.⁶⁹ Thus, they may represent an economically feasible method for providing inhaler technique education. Another potential solution is to expand the scope of practice of certain team members, for example allowing pharmacists to prescribe spacers and make adjustments to the child's inhaled medication type if the child repeatedly fails to demonstrate correct technique. Because pharmacists can assess technique on a monthly basis when the child's inhaler prescriptions are filled, they are well positioned to conduct regular technique assessments. To make the expansion of their scope of work feasible and sustainable, it is critical to match reimbursement to work.

Also, in terms of policy, the shift from traditional clinic-based care to home and telehealth settings indicates that the landscape of care delivery for asthma is likely shifting. Telehealth is changing the paradigm about how we deliver care. How rapid or responsive systems are to this change depends partly on aligning reimbursement with health care services in these non-traditional settings. For example, with the COVID-19 pandemic, Medicare expanded its list of covered services via telehealth and modified the process to add covered telehealth care services in a more expedited way.^{70,71} Nevertheless, more US children are covered under Medicaid than private insurance, and the policies for covered telehealth services and remote monitoring are varied.⁷² Medicaid policies at the national level should be aligned broadly around coverage for telehealth services, which will directly affect coverage for asthma care telehealth services. Further, reimbursement for inhaler education, specifically, by Medicaid and private insurance should be advised, similar to the Medicare code,⁷³ to encourage health professionals to educate about inhaler technique. Reimbursement could encourage provider adherence to national guidelines that recommend assessing and educating about technique at every visit.

As a team-based model that spans in-person and telehealth is increasingly adopted for asthma care, it is critical to advance communication systems. Health professionals currently work in silos and those individuals in different locations have limited, if any, communication. When team members span many different settings, effective communication infrastructure is essential. Implementing a shared medical record enables easy bi-directional information flow without barriers such as waiting on the phone or faxing papers. Such systems would allow a pharmacist, for example, to share suggested medication changes with a medical professional when a child repeatedly demonstrates suboptimal technique and allows the clinician to comment on the appropriateness of the changes. Additionally, school nurses could communicate the need for medication and device refills or the increase of medication use that may require adjustment in the treatment plan. These communication systems are foundational to enhance the delivery of child-centered team-based asthma care.

At the systems level, changes to the appearance and structure of inhaler devices can support effective inhaler use. Pharmaceutical companies can start by simplifying the colors of devices, such as making all quick-relief inhalers one color and controller inhalers another color.

While it seems simple, such a change would reduce confusion that impacts inhaler use. Future efforts should focus on developing inhalers with built-in spacers to minimize barriers to proper inhaler use, including prescriptions and costs. In addition, devices that provide real-time feedback about technique hold potential to be more influential than those that deliver feedback at a later time. Pharmaceutical companies should engage children and parents in a user-centered design process to ensure their representation and experience are accounted for as inhalers are developed or redesigned. Finally, broad adoption of training for health professionals – including clinicians – about proper inhaler technique is necessary, as their limited knowledge, poor skills, and low confidence may preclude inhaler education for children and families.⁷⁴ This need for education is particularly true as novel inhalers are developed and approved for clinical use.

Along with the adoption of solutions in the clinical, community, and policy realms, more research is also needed to broaden effective inhaler use among children with asthma. Racial and geographic disparities are well described among children with respiratory conditions; however, few studies have focused on disparities related to inhaler use. Research is needed to understand the prevalence and impact of inhaler misuse across children of different races/ethnicities as well as living in different geographic regions. For these studies to be effective and applicable to real-world practice, the tools for the assessment of inhaler technique should be standardized. Also, work must be done to identify practical, high-fidelity interventions to improve and maintain effective inhaler technique, including how best to adopt them in busy clinical settings and among competing demands. Research about asthma self-management and inhaler technique education suggests its benefit for children; however, issues exist with rigor and design of interventions across all settings. For example, studies do not detail the specifics of self-management education, thus making it hard to understand the amount and type of inhaler education provided. Specific efforts must focus on detailing the inhaler education delivered to compare studies and ascertain educational components that should be more broadly adopted.

Conclusion

Poor inhaler technique is common among children and the effects of poor technique are broad. In-person and technology-based interventions have shown promise to improve technique. These solutions need to be more broadly

adopted with support for provider training, team-based care, communication structures, and reimbursement. Such solutions hold the potential to improve inhaler use among children, with potential for decreasing morbidity and costs.

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