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Published in:
Journal of Allergy and Clinical Immunology: In Practice

DOI:
10.1016/j.jaip.2023.04.031

Publication date:
2023

Recognizing and Tackling Inhaler Technique Decay in Asthma and Chronic Obstructive Pulmonary Disease (COPD) Clinical Practice

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A poor inhaler technique continues to represent a substantial barrier to effective asthma and chronic obstructive pulmonary disease management. It can result in perceived lack of treatment effectiveness even with apparent adherence to a prescribed regimen of inhaled maintenance therapies, potentially resulting in an unnecessary change or escalation of treatment. Many patients are not trained to inhaler mastery in real-world practice; furthermore, even where mastery is initially achieved, an ongoing assessment and education are seldom maintained. In this review, we present an overview of the evidence for deterioration of the inhaler technique over time after training, investigate the factors that contribute to this deterioration, and explore innovative approaches to addressing the problem. We also propose steps forward drawn from the literature and our clinical insights. **(J Allergy Clin Immunol Pract 2023;11:2355-64)**

Key words: *Asthma; COPD; Treatment; Management; Inhaler technique; Patient education*

Inhaled maintenance therapy remains fundamental to the management of asthma and chronic obstructive pulmonary disease (COPD). A good inhaler technique is essential to achieving disease control and improving health.[1,2] However, individual studies on populations with obstructive lung diseases demonstrated that ≥80% of patients make ≥1 inhalation technique error.[3] A poor inhaler technique prevents medication from reaching areas of the lung where it is most effective;[4] consequently, it has a substantial detrimental effect on clinical outcomes and economic impacts on health systems[5] and should be assessed before any adjustment to therapy is initiated.[6,7] Despite long-standing and global recognition that the poor inhaler technique remains a major problem,[2,8-13] it persists as a significant hindrance to the effective management of asthma and COPD well into the 21st century.

A frequent assessment of the inhaler technique over time is considered crucial to successful treatment.[14-18] However, the rate of repeated assessment of the inhaler technique is low among asthma specialists (39.7% "almost always" and 44.9% "often") and primary care physicians (16.8% "almost always" and 38.7% "often").[19] The low rates of inhaler technique reassessment are further reflected by the suboptimal level of clinician knowledge

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Medical writing support for the development of this article was funded by Teva Branded Pharmaceutical Products R&D Inc.

Conflicts of interest: S. Bosnic-Anticevich reports receiving a grant and a personal fee for advisory board contribution and/or expert lectures/educational activities from GSK, AstraZeneca, Mylan, Viatris, Boehringer Ingelheim, and Sanofi; and serves as a consultant for Teva. B. Bender reports having participated in an advisory board for Teva. M. Shuler is President of the Executive Board of Directors of the Association of Asthma Educators; serves on the coordinating committee of National Asthma Education and Prevention Program-National Heart, Lung, and Blood Institute; is a rural health consultant on asthma and nonmedical drivers of health for the North Carolina Area Health Education Centers and North Carolina Department of Health and Human Services Division of Child and Family Well-Being; is a board member of WNC Lighthouse, the American Nurses Credentialing Center, and University of North Carolina Center for Environmental Health and Susceptibility; participates on advisory boards for Teva Respiratory and AstraZeneca; and is a speaker for AstraZeneca. M. Hess has participated in advisory boards and speaker bureaus for Boehringer Ingelheim, Theravance Biopharma, Viatris, and Olympus Medical. J. Kocks reports grants, personal fees, and nonfinancial support from AstraZeneca, Boehringer Ingelheim, and GSK; grants and personal fees from Chiesi Pharmaceuticals and TEVA; grants from Mundi Pharma; and personal fees from MSD and COVIS Pharma, outside the submitted work; he holds 72.5% of shares in the General Practitioners Research Institute.

Received for publication September 21, 2022; revised February 22, 2023; accepted for publication April 11, 2023.
Available online May 3, 2023.
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2213-2198

https://doi.org/10.1016/j.jaip.2023.04.031

Abbreviations used
COPD- Chronic obstructive pulmonary disease
HCP- Health care professional
INCA- Inhaler Compliance Assessment
MDI- Metered-dose inhaler

of the inhaler technique of health care providers reported over the past decade.[20,21]

Specific common technique errors and device-specific errors also warrant attention. Certain errors have been identified as being "critical" due to their impact on treatment effectiveness and/or their potential to affect drug delivery or lung deposition (Figure 1).[5,22] Critical errors have been reported to be associated with poor disease outcomes (eg, increased frequency of exacerbations) and increased health care resource utilization in asthma and COPD.[5,22,23] Such errors may be device-specific, or common among different device types (Table E1, available in this article's Online Repository at www.jaci-inpractice.org).[23]

Individual factors can add to the challenge of inhaler use, such as physical limitations (eg, coordination, manual dexterity, and inhalation capacity) and comorbidities (eg, age-related cognitive conditions and visual impairment).[24,25] Patient-specific device selection is therefore crucial and should acknowledge skill and device preference[26] while being repeatedly reviewed over time.

Where does this leave us with regard to inhaler use and disease management in the 21st century, especially given the prolonged narrative that has surrounded this concept over many years? We explored this question by conducting a literature search to identify relevant clinical trials reporting the rate and degree of inhaler technique decay in patients with asthma and COPD, following various technique training interventions (the "Methods" section in this article's Online Repository at www.jaci-inpractice.org). The full lists of search terms used are in Tables E2 and E3 (available in this article's Online Repository at www.jaci-inpractice.org).

Our objectives were to (1) examine the health behaviors and educational factors associated with deterioration in patients' inhaler technique, (2) underscore possible strategies to arrest that deterioration, and (3) highlight areas for further research including their implementation in real-world settings (eg, clinics and hospitals). Only once we overcome these fundamental challenges can we advance the management of chronic obstructive respiratory conditions and improve outcomes for patients.

IDENTIFYING THE PROBLEM: HOW QUICKLY AND TO WHAT EXTENT DOES THE INHALER TECHNIQUE DECAY?

It is abundantly evident that the inhaler technique declines/decays over time, as shown across many studies in asthma and COPD, using various inhaler types and methods of identifying the poor technique (Figure 2).

After inhaler training, an improved technique is typically observed in the short term as the correct inhaler technique is mastered. However, this mastery is rarely maintained, and substantial technique decay occurs somewhere within a 12-month period after single- or multiple-session educational interventions.[27-32] This clearly indicates that a single training intervention (either as a single session or short program of sessions) does not ensure durable inhaler technique mastery. Indeed, there is complete consistency across all studies exploring this concept, regardless of the checklists used to assess the technique or the different thresholds used to define a good inhaler technique. Although some studies reported patients' performance in terms of the number or proportion of correct or incorrect steps performed, whereas others required completion of a minimum number of steps (or a perfect performance) to qualify as a good technique, all lead to the same conclusion: inhaler technique mastery is not maintained over time.

OBJECTIVE 1: FACTORS IMPACTING DETERIORATION IN THE CORRECT INHALER TECHNIQUE OVER TIME

Factor 1: timing of inhaler education and retraining

If the positive effects of single interventions on the inhaler technique are accepted to be temporary, repeated instruction is a logical step to achieve a longer-lasting effect.

However, one-off re-education interventions have been shown to provide only a temporary improvement in the technique,[29] and although repeated one-to-one inhaler technique retraining at monthly intervals can sustain device mastery, technique decay still occurs after longer than 2 to 3 months without further assessment or instruction.[29,31]

Passive inhaler technique support via reminder labels applied after face-to-face training interventions does not completely ameliorate inhaler technique decay over 1 to 6 months,[28,31,33] indicating that regular, active, repeated intervention could be necessary for long-term inhaler technique improvement. Regular health care professional (HCP) interaction with patients also provides opportunities to promote adherence, which may in turn improve clinical and quality of life outcomes.[34,35]

Factor 2: type of device and ease of use

Different devices are associated with different inhaler technique errors, but hand-breath coordination/dose administration is a key problematic step, alongside appropriate breathing. Important technique failure points differ according to the device; these include exhalation preactuation, followed by slow deep inhalation (metered-dose inhaler [MDI]), forceful deep inhalation (Turbuhaler), or steady deep inhalation (Accuhaler), and holding breath afterward before exhaling away from the device.[33] Individualizing training according to device requirements is important and can impact technique maintenance.[18] Recently, a dedicated inhaler technique optimization service implemented on a respiratory ward in the United Kingdom found that improving patients' inhaler technique and advising on inhaler device changes resulted in significant reductions in exacerbations, admissions, and a measurable reduction in length of stay and admission costs.[36]

Although device type and inherent ease of device use are obvious factors to consider, all device types are associated with an incorrect technique.[28,31,33,37] Furthermore, the number of different devices used, and whether patients switch from one device to another, also appears to impact correct inhaler use. In a study including patients using a Diskus (Accuhaler) and an MDI, 21 of 32 patients misused at least one device and 13 of 32 patients misused both devices at 90 days after education.[38] The use of mixed device types may also have a negative impact on outcomes in patients with COPD, particularly if these require different inhalation techniques.[39]

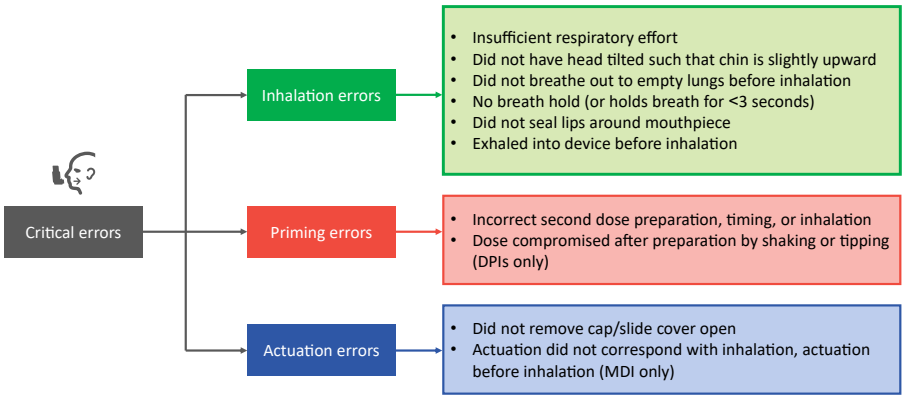

FIGURE 1. Critical inhaler technique errors associated with clinical outcomes of disease control in asthma or COPD.[22] *COPD*, Chronic obstructive pulmonary disease; *DPI*, dry powder inhaler; *MDI*, metered-dose inhaler.

On-device features can assist inhaler technique maintenance via immediate feedback or monitoring. Audible signals to assist the inhalation/dose administration process and enable self-monitoring between routine clinic visits can improve the inhaler technique compared with verbal training only in the community pharmacy and outpatient clinic settings.[27,40] More sophisticated audio inhaler technique data collection is possible: the Inhaler Compliance Assessment (INCA) device enables an accurate assessment of the inhaler technique and identification of critical errors.[41] In one study of 62 patients with asthma and/or COPD, 89% made at least 1 critical technique error as identified by the INCA device despite having received training by an expert.[41] In a separate study, data on critical errors (incorrect device priming, exhalation into the inhaler after priming but before inhalation, and insufficient inspiratory flow) detected by the INCA device were used alongside individualized, goal-based behavioral education for patients with uncontrolled asthma and were found to prevent an increase in inhaler technique errors during the month after the intervention.[32]

Factor 3: mode of inhaler education

The standard mode of inhaler technique education is via written materials or verbal instruction, which serves as a control intervention in many studies. Single-session verbal instruction has only a transient effect on improving the inhaler technique.[27] One-to-one single session training with physical demonstration of inhaler use was significantly more effective than written instruction alone for initial improvement of the technique.[28,29,42,43] However, across several studies, inhaler technique decay after physical demonstration was apparent over 1 to 3 months after a single training session.[28,30,33,37,42,43]

Inhaler technique assessment and training is typically performed using checklists for different inhaler types.[27-30,33,37,38,43-45] Checklist assessment presents several potential challenges, including the variety of checklists used, and the use of different measures and thresholds to quantify the adequate technique across studies. It could be useful to identify a minimal number of "essential" steps.[28,42] Even so, improvement of the technique identified by checklists may still not guarantee the ideal use of devices in terms of characteristics such as peak inspiratory flow.[27]

Regarding teaching style, although different modes of inhaler education may initially differ in terms of effectiveness, the long-term outcomes are similar, that is, a decline in the inhaler technique over 1 to 3 months after achievement of device mastery.[28,33,37,38,43,45] Video instruction is more convenient than one-to-one teaching and can be as effective in improving the inhaler technique immediately after training.[44] However, technique decay still occurs and is apparent by 1 to 3 months after training.[42,44] Multidimensional education interventions, including education, face-to-face demonstration, and regular follow-up, are also effective in the short term.[46]

Video education for the inhaler technique has potential to meaningfully improve access to inhaler training at the convenience of the user, but lacks the interactivity of one-to-one training. Home monitoring of the inhaler technique may also increase the convenience of inhaler use education. Although monitoring via smartphone videos sent to a remote pulmonologist did not prevent technique errors from the day after initial education and during the next month,[45] live-remote assessment and instruction via video telemedicine has been shown to effectively improve the inhaler technique[47] and may provide a convenient alternative to in-person training, especially for people without convenient or regular access to HCPs. Most recently, approaches such as on-demand online videos and smartphone apps have been explored for individualized inhaler training.[48,49]

Factor 4: personnel and venue for inhaler education

Although not specifically studied, given the fact that at any one time a patient may be receiving health care from a number of different health care providers, it may also be important to consider the venue in which the inhaler education is being conducted and the specific personnel administering the training.

Training delivery has been studied in various settings, including hospital clinic,[27,28,38,43] university campus or hospital,[32,42] doctor's office,[44] and monitoring at the patient's home.[45] The community pharmacy has been frequently used as a training venue, as these are a convenient and available venue for regular HCP contact.[29,31,33,37] Similarly, training delivered by different specific personnel has been investigated, including pharmacists or pharmacy student researchers,[29,31,33,37,50] respiratory therapists,[51] pulmonologists,[30,45] specialist nurses,[34,52] or trained researchers/research assistants.[28,38,44] However, post-training inhaler technique decay has been identified in all of

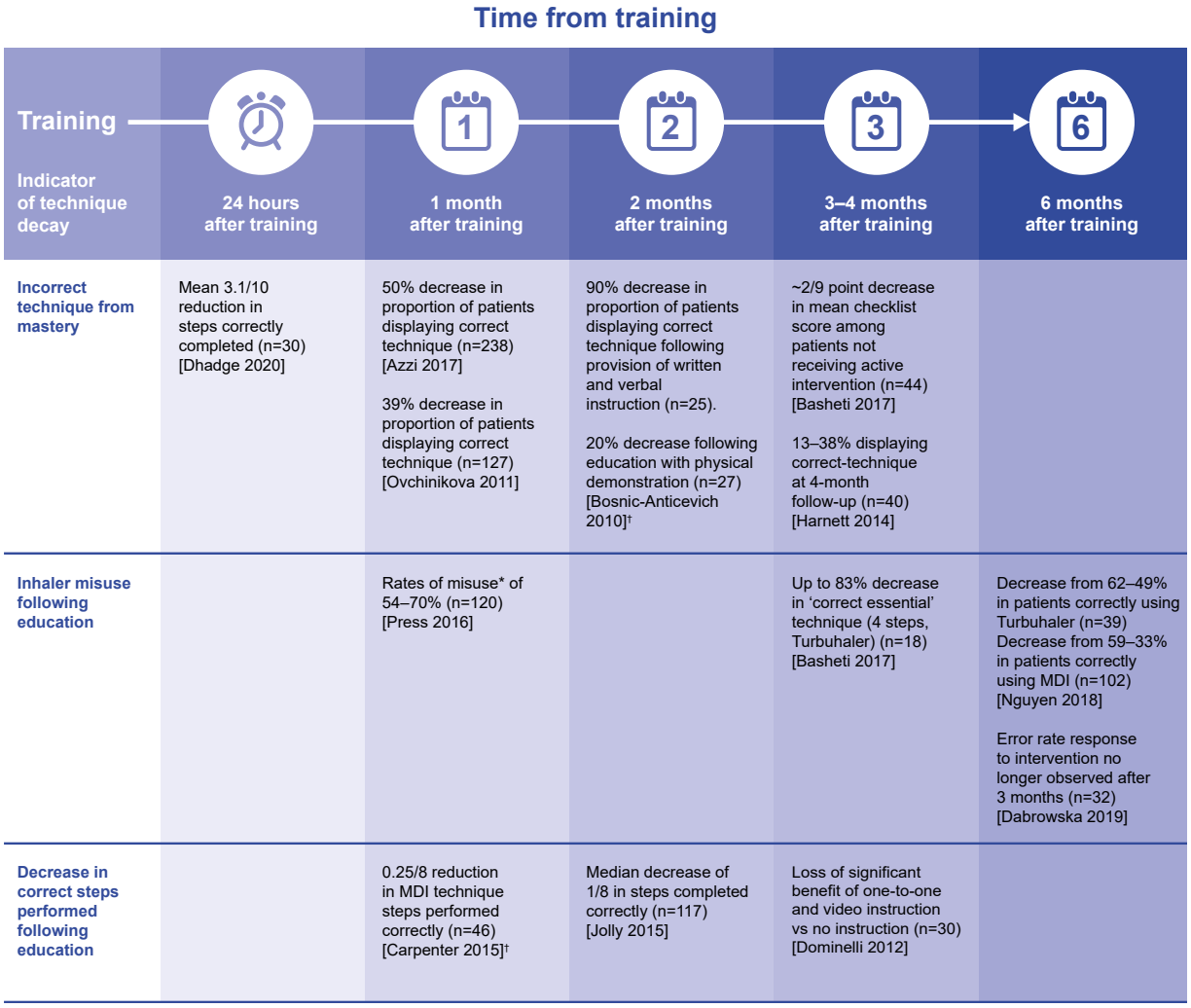

FIGURE 2. Summary of reported findings on inhaler technique decay during the 6 months after training. *Defined as completing ≤75% of steps correctly; †Pediatric study. *MDI*, Metered-dose inhaler.

these studies and does not appear to be consistently influenced by training venue or personnel.

OBJECTIVE 2: CONSIDERATIONS FROM SUCCESSFUL INTERVENTIONS FOR POSSIBLE STRATEGIES TO ARREST INHALER TECHNIQUE DETERIORATION

An overview of key learnings for inhaler technique education is provided in Figure 3. Several recurrent themes were apparent across the breadth of inhaler technique research, allowing us to identify aspects of interventions associated with long-term effectiveness. In no particular order, these include:

(1) *Clear need for repeated retraining*, with ongoing technique reminders, feedback, and/or coaching (written or via technology), is necessary to improve/maintain the technique over time.[27-29,31,32,43]

(2) *In-person inhaler technique retraining can be successfully delivered by a wide range of HCPs*, including pulmonologists, respiratory therapists, nurses, and pharmacists.[29-31,33,45,51,52]

(3) *Effectiveness of practical demonstration* for initial retraining,[29,43] while acknowledging that on-demand video and telehealth counseling are also effective methods to deliver ongoing long-term education.[45,47] Different patient populations may benefit from different modes of education.

(4) *Patient motivation* is a key factor in the practice of a good inhaler technique and good adherence to therapy.[33,37] An individualized or personalized element to educational interventions (whether face-to-face or via technology) may be key to achieving durable improvement for certain patients.

(5) *Allowance for social determinants of health* by tailoring educational interventions to suit different cultures and levels of health literacy, which may be essential for successful interventions in specific populations.[11,53] The wider appreciation of individual patients' situations and settings should underpin all health interventions.

(6) *Development of novel technological solutions* for monitoring and improving the inhaler technique, incorporating the concepts of acceptability and utility for individuals of different races, ethnicities, socioeconomic groups, ages, genders, and literacy levels, is an important consideration for

FIGURE 3. Overview of key learnings for inhaler technique education.

digital health platforms and applications.[54] Although there is evidence for acceptance of, and positive perception toward, electronic medication monitoring devices among patients with asthma and their caregivers,[55-57] their design and utility must be adaptable to the different socioeconomic, educational, and cultural circumstances of the intended users.

Suggestions for critical aspects of approaches to improve and/or maintain patients' inhaler technique are provided in Figure 4.

OBJECTIVE 3: IMPLEMENTING RETRAINING AND AREAS FOR FURTHER RESEARCH

Although a good inhaler technique is commonly acknowledged as a fundamental part of inhaler therapy, there is little guidance for clinicians on the optimal ways to educate patients, to help them maintain a good technique beyond "monitor regularly," and on the individualization of inhaler technique education to account for socioeconomic and psychosocial factors. Standardized, actionable guidelines are urgently required so physicians are confident about the general need for inhaler technique optimization with their patients and about how and when to go about it. Focusing monitoring and in-person retraining on specific patients according to the need may also help alleviate time pressure on HCPs and health care system capacity, which is a finite and valuable resource.

Rural populations have been inadequately studied despite asthma prevalence that may be comparable to that observed in inner cities, and further investigation is required in this setting. Remote access to

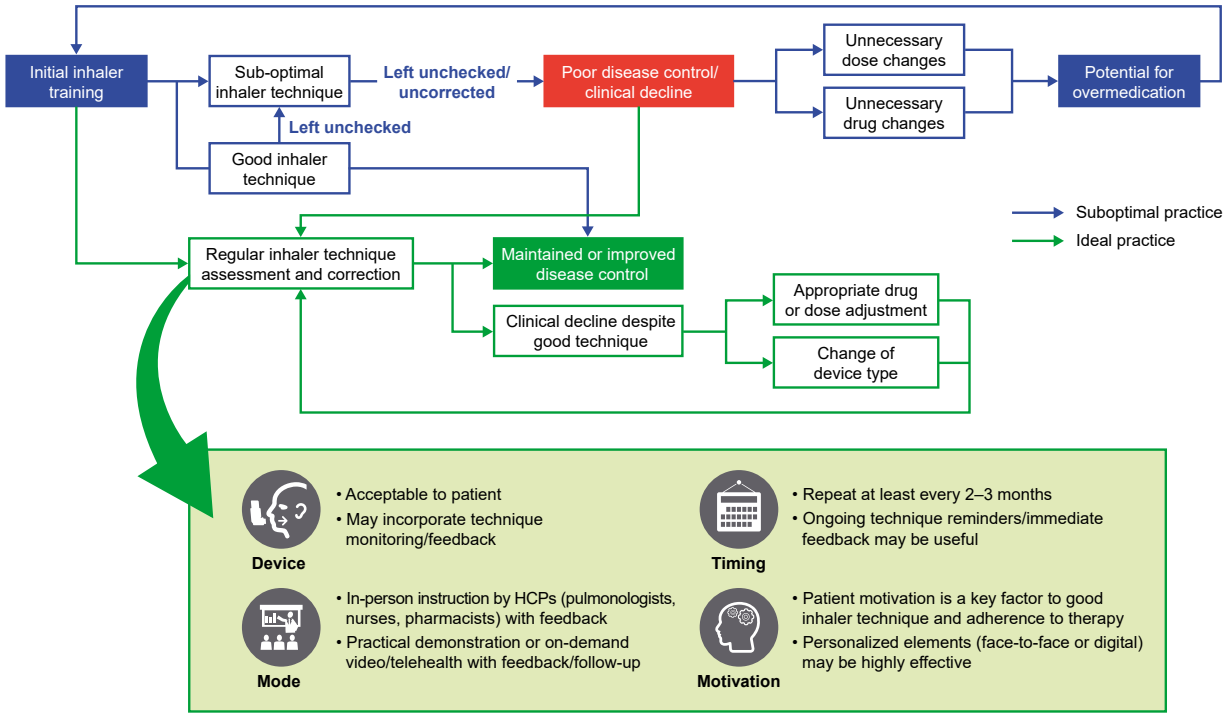

FIGURE 4. Overview of factors informing need for ongoing inhaler technique education and contributing to effective maintenance of a good inhaler technique. HCP, Health care professional.

education and counseling has obvious benefits for patients (both rural and inner-city) who have difficulty in traveling or arranging face-to-face appointments. Inhaler training via video has demonstrated high acceptance among rural patients with COPD or asthma.[58] Patients have been shown to maintain the improved inhaler technique and adherence 1 month after video training.[59,60] The findings of these studies reflect the value of digital technology to support and potentially expand access to individualized inhaler training; however, they did not address ways to sustain adherence and mitigate technique decay over the long term.

Evolving digital technologies might potentially help overcome barriers to inhaler technique education and monitoring for patients. Video-based checking of the technique via smartphones is a practical intervention that can highlight technique errors[45] and could be done on a remote, ongoing basis, with checks decreasing in frequency as a consistent correct technique is demonstrated. Digital health platforms have been associated with improvements in the inhaler technique in patients with COPD[61] and asthma[62] and are capable of providing feedback and support at every dose. Smart health platforms and digital inhalers with integrated sensors capable of identifying specific problems with inhaler use and supporting individualized counseling are likely to gain greater uptake in the future. However, the design and implementation of these interventions must be individualized to maximize the chances of effective uptake. Furthermore, overcoming practical barriers to the utility of digital interventions in the clinic, and ensuring that these technologies decrease the burden associated with chronic respiratory disease and its treatment rather than adding to it, will entail the development and execution of innovative implementation strategies.[63,64]

CONTEXTUALIZING INHALER TECHNIQUE EDUCATION

Asthma outcomes are strongly influenced by patients' social and economic situation.[65] The inhaler technique is no exception, and disparities in opportunities to receive training and retraining are clearly an important factor. A poor inhaler technique in patients with asthma and COPD has been linked to lower socioeconomic class,[66,67] lower educational level,[68,69] joblessness,[69] and age and age-related comorbidities.[67] For children, higher levels of parental education are associated with a better inhaler technique and better asthma control in combination with lower levels of stigma.[70] A poor inhaler technique may also result from inadequate communication between patients and clinicians,[71] along with insufficient time available for physicians to train patients.[72,73]

A poor inhaler technique impacts treatment efficacy and treatment adherence. Unintentional nonadherence (eg, through lack of skill and/or knowledge, or lack of access to treatment or training) can be approached using better educational interventions, regimen adjustments, or adherence aids. Intentional nonadherence is harder to address as it encompasses patients' behaviors, motivations, and personal beliefs regarding disease and therapy. In particular, patient motivation may have a considerable impact on correct inhaler use.[33] The quality of physician-patient communication and the strength of the relationship are key to improving patient outcomes including adherence, self-efficacy, and satisfaction.[74-76] Motivational interviewing, as part of a multicomponent intervention, has been associated with improvements in adherence and inhaler skills, though the level of certainty is low.[77]

TABLE I. Characteristics of highly relevant articles

Reference	Patients	Inhaler device type(s)	Training method	Re-evaluation dates	Study length	Decline date	Conclusion
Dhadge et al[45]	Asthma or COPD	MDI ± valved holding chamber DPI (unit dose) DPI (breath-actuated)	Pulmonologist training	Days 1, 7, 14, and 28	28 d	Day 1	Smartphone video monitoring of the inhaler technique; inhaler technique errors appeared from day 1 after training
Ammari et al[27]	Asthma (18-60 years old)	MDI	Verbal inhaler training vs Trainhaler or Flo-Tone CR	1 h and 6-8 wk after training	6-8 wk	6-8 wk	Both verbal training and technique aids improved the inhaler technique, but the effect deteriorated over 6-8 wk
Dabrowska et al[30]	Asthma or COPD	MDI Aerolizer Handihaler Accuhaler/Diskus Turbuhaler	Individual inhalation training vs sham procedure	3 and 6 mo	6 mo	6 mo	Significant reduction in inhaler errors with individual training at 3 mo, but not at 6 mo
Bosnic-Anticevich et al[18]	HCPs with no current or past asthma diagnosis	Turbuhaler Spiromax	Training by expert assessors	4 and 8 wk	8 ± 2 wk	4 wk (visit 2)	Significant differences in the nature and extent of training required to achieve and maintain mastery with different DPIs
Sulaiman et al[32]	Severe asthma	Accuhaler/Diskus + INCA device	Intensive education with/without biofeedback from device	3 mo	3 mo	3 mo (no biofeedback)	Repeated, ongoing interventions with patients were more effective when incorporating data collected by the inhaler device
Nguyen et al[31]	COPD	MDI Turbuhaler	Face-to-face training, vs teach-back vs technique reminder label	1, 3, 6, and 12 mo	12 mo	12 mo	Improvement of the inhaler technique during repeated intervention, but decay in technique after a gap of >3 mo
Azzi et al[37]	Asthma	MDI Turbuhaler Accuhaler/Diskus	Patients with incorrect technique at baseline trained to mastery	1 mo	1 mo	1 mo	Initial improvement of the inhaler technique decayed over 1 mo
Basheti et al[28]	Asthma	Accuhaler/Diskus Turbuhaler	Show and tell plus labels in active group vs control	Immediately after, and 3 mo after training	3 mo	3 mo (control)	Use of reminder labels reduced the extent of inhaler technique decay at 3 months
Press et al[38]	Adults hospitalized with asthma or COPD	MDI Accuhaler/Diskus	Teach-to-goal instruction vs brief verbal instruction	Immediately after, and 30 and 90 d after education	90 d	30 d (teach-to-goal)	Teach-to-goal instruction improved the inhaler technique, but the effect deteriorated over 30-90 d
Jolly et al[43]	Patients using MDI	MDI	Written vs. physical demonstration	After each of 3 training sessions, 1- and 2-month follow-up	1 mo	1 mo	Practical demonstration was superior to providing information alone in improving the inhaler technique; retraining helped to remedy decay in the inhaler technique after initial training
Carpenter et al[44]	Children with asthma	MDI ± valved holding chamber	Video intervention vs control	Immediately after, and 1 mo after training	1 mo	1 mo	Video training for the inhaler technique was effective in children, but not sustained after 1 mo

(continued)

TABLE I. *(Continued)*

Reference	Patients	Inhaler device type(s)	Training method	Re-evaluation dates	Study length	Decline date	Conclusion
Dominelli et al[42]	Medical students	MDI	One-to-one vs video	Immediately after and 3 mo after training	3 mo	3 mo (one to one)	Video education had a longer-lasting effect on inhaler technique improvement than one-to-one training at 3 mo
Ovchinikova et al[33]	Asthma	MDI Turbuhaler Accuhaler/Diskus	Pharmacist delivered training	Baseline and 1 mo after training	1 mo	1 mo	Past inhaler technique education factors did not affect inhaler technique maintenance, but patient psychosocial factors (motivation) did
Bosnic-Anticevich et al[29]	Asthma or COPD	MDI	Pharmacy written and verbal instruction with/without physical demonstration	Baseline, 4, 8, and 16 wk after training	16 wk	8 wk after the end of regular training	Physical demonstration improved the inhaler technique to a greater extent than verbal instruction alone during the training period, but the effect was lost over 8 wk after the end of the training period

COPD, Chronic obstructive pulmonary disease; *DPI*, dry powder inhaler; *INCA*, Inhaler Compliance Assessment; *MDI*, metered-dose inhaler.

Health literacy is an important consideration in this context. Targeted educational interventions for patients with low health literacy have been effective at improving rates of correct inhaler use in inner-city patients with asthma,[78] COPD patients with low health literacy,[79] rural communities with low literacy,[11] communities in the developing world,[80] and immigrant communities.[81] As standard educational materials may be adapted using language and illustrations appropriate for low literacy[11,53] and/or low health literacy,[79] and culturally relevant learning materials for specific populations may be produced by community members,[81] it should not be prohibitively complicated or expensive to provide relevant educational resources for specific patient groups.

CONCLUSIONS AND FORWARD-LOOKING DISCUSSION

Asthma and COPD are chronic diseases requiring continuous self-management, and a good inhaler technique is a vital component of effective treatment for these diseases. Neglecting to check and monitor patients' inhaler use has downstream negative impacts on treatment outcomes, clinical decision-making, and health care costs. Various factors may influence inhaler technique decay and/or patient confidence in the correct usage of their inhaler, including training method,[29,32,42] device type,[17,18] and individual patients' motivation, behaviors, and psychosocial factors.[33,37] However, a poor inhaler technique can be addressed in a variety of ways, with a real clinical impact. A good inhaler technique and its downstream effects on therapy efficacy may also help improve adherence, treatment satisfaction, and motivation for patients and quality of life.

Our findings strongly suggest that while the inhaler technique may be addressed using a variety of educational methods, without ongoing monitoring and assessment, inhaler technique decay commonly occurs as soon as 2 to 3 months after training. Furthermore, device-related factors and patients' individual circumstances can impact the inhaler technique and adherence even with the availability of suitable educational resources. Gaining objective understanding of medication use and inhalation quality in real life, as opposed to occasional "unreal-life" clinical encounters, is paramount. Current and future digital health opportunities will play a key role in achieving this, but pharmacists and HCPs need greater support to realize the potential of digital technologies and the data they provide to support improved and personalized technique education. The advent of collaborative care, considering patients' values, motivations, learning styles, and health literacy levels, will hopefully help to bridge the knowledge gap between manufacturers, HCPs, and patients. This could be achieved through collaborations between device manufacturers and patient organizations, for example, to conduct evaluations on this topic and develop public awareness campaigns.

In the near term, a stepwise clinical framework to support improvement of the inhaler technique and integration of new technologies is needed. In recommending a similar approach to that outlined in the Global Initiative for Asthma, National Heart, Lung, and Blood Institute-National Asthma Education and Prevention Program, and Global Initiative for Chronic Obstructive Lung Disease guidance,[6,7,82] we support the provision of standardized guidance on best practice using available interventions. This will aid clinicians to effectively educate and

support their patients and promote proactive maintenance of the inhaler technique.

Acknowledgments

Medical writing support for the development of this article was provided by Ian C. Grieve, PhD, of Ashfield MedComms, an Inizio company.

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ONLINE REPOSITORY

METHODS

Literature search

A literature search was conducted to gather articles exploring the evidence regarding:

(1) Factors influencing the rate and degree of inhaler technique deterioration after instruction of patients with asthma and chronic obstructive pulmonary disease in correct usage.
(2) The relationship between initial inhaler technique instruction/training and inhaler technique maintenance.
(3) The role of inhaler technologies in addressing the issue of inhaler technique instruction/training and inhaler technique maintenance.

Literature searches were performed using PubMed, for articles published between 2010 and 2021, using search terms related to respiratory disease and inhaler use. The full lists of search terms are in Tables E2 and E3.

In the main search, 792 articles were screened and publications with no relevance removed. The remaining articles were categorized as having strong relevance to the research question (n = 14), some relevance to the research question (n = 133), and review/perspective articles (n = 111). Key details for the 14 articles considered to be highly relevant are in Table I.

TABLE E1. Critical errors in the inhaler technique associated with asthma symptom control or exacerbations[E1]

Error	MDI	DPI (Turbohaler)	DPI (Diskus)
Did not remove cap/slide cover open (includes "did not shake device before actuation" for MDIs)	S	S, E	
Insufficient inspiratory effort		S, E	S, E
Did not tilt head slightly upward	S, E	S	
Did not breathe out to empty lungs before inhalation	S, E	S, E	S
Did not hold breath for ≥3 s after inhalation	S, E	S, E	S, E
Did not seal lips around the mouthpiece	S	S, E	E
Incorrect second dose preparation, timing, or inhalation	S	S	S, E
Exhaled into device before inhalation (includes "did not hold device upright" for MDI)	S, E	E	E
Dose compromised after preparation by shaking or tipping (DPI only)		S, E	
Actuation before inhalation (MDI only)	S, E		
Twist errors (Turbohaler preparation only; includes "did not hold device upright" for Turbohaler)		E	
After inhalation did not replace cover	E	E	E
Did not inhale through mouth		E	E
Did not remove cap		E	
Empty inhaler			E
Expired inhaler			E

S, error significantly associated with uncontrolled asthma (univariable analysis). E, error significantly associated with exacerbations (univariable analysis).
DPI, Dry powder inhaler; *MDI*, metered-dose inhaler.

TABLE E2. Main literature search terms and results

Query	Subject	Results
"Pulmonary Disease, Chronic Obstructive"[MeSH] OR "COPD"[ALL] OR "Pulmonary Disease, Chronic Obstructive"[ALL] OR "Chronic Obstructive Airway Disease"[ALL] OR "COAD"[ALL] OR "Chronic Obstructive Lung Disease"[ALL] OR "Chronic Airflow Obstruction"[ALL] OR "Chronic Airflow Obstructions"[ALL] OR "Asthma"[MeSH] OR "Asthma"[ALL] OR "Asthmas"[ALL]	COPD/asthma terms	261,657
"Inhaler"[ALL] OR "Inhalers"[ALL] OR "pMDIs"[ALL] OR "pMDI"[ALL] OR "MDI"[ALL] OR "Metered-dose inhaler"[ALL] OR "Metered dose inhaler"[ALL] OR "Metered-dose inhalers"[ALL] OR "Metered dose inhalers"[MeSH] OR "Soft Mist"[ALL] OR "SMI"[ALL] OR "Respimat"[ALL] OR "Hydrofluoroalkane"[ALL] OR "Nebulizers"[ALL] OR "Nebulizer"[ALL] OR "Vaporizers"[ALL] OR "Vaporizer"[ALL] OR "Vaporizers and Nebulizers"[MeSH] OR "Dry Powder Inhalers"[MeSH] OR "Inhalators"[ALL] OR "Inhalator"[ALL] OR "Atomizers"[ALL] OR "Atomizer"[ALL] OR "Inhalation Devices"[ALL] OR "Device, Inhalation"[ALL] OR "Devices, Inhalation"[ALL] OR "Inhalation Device"[ALL] OR "Inhaler, Metered Dose"[ALL] OR "Inhalers, Metered Dose"[ALL] OR "Spacer Inhalers"[ALL] OR "Spacer Inhaler"[ALL] OR "Spacer-Inhalers"[ALL] OR "Spacer-Inhaler"[ALL] OR "Spinhalers"[ALL] OR "Spinhaler"[ALL] OR "Dry powder inhaler"[ALL] OR "Dry powder inhalers"[ALL] OR "Inhaler, Dry Powder"[ALL] OR "Inhalers, Dry Powder"[ALL] OR "Powder Inhaler, Dry"[ALL] OR "Powder Inhalers, Dry"[ALL]	Inhaler terms	30,408
"Inhaler Misuse "[ALL] OR "incorrect Inhaler technique"[ALL] OR "inhaler use"[ALL] OR "pMDI technique"[ALL] OR "MDI technique"[ALL] OR "pMDI Misuse"[ALL] OR "MDI Misuse"[ALL] OR "Incorrect use"[ALL] OR "Shaking the inhaler"[ALL] OR "Shaking of the inhaler"[ALL] OR "Shaking inhaler"[ALL] OR "Inhaler skill"[ALL] OR "Inhaler skills"[ALL] OR "Unintentional nonadherence"[ALL] OR "Inhaler error"[ALL] OR "Inhaler training"[ALL] OR "Inappropriate Inhaler use"[ALL] OR "Inappropriate ICS"[ALL] OR "Equipment Failure"[Mesh] OR "inhaler adherence"[ALL] OR "treatment adherence"[ALL] OR "inhaler technique"[ALL] OR "inhaler guidance"[ALL] OR "treatment guidance"[ALL] OR (("technique" OR "handling" OR "techniques" OR "Training" OR "train"[ALL] OR "educat*[ALL] OR "operating"[ALL]) AND ("Error" OR "errors" OR "misuse" OR "wrong use" OR "incorrect" OR "problem" OR "problems" OR "decline" OR "Decay"[ALL] OR "deterioration"[ALL] OR "deteriorate"[ALL] OR "poor"[ALL] OR "wrong"[ALL] OR "bad"[ALL] OR "ineffective"[ALL] OR "noneffective"[ALL]))	Inhaler decay and misuse terms	108,466
#1 AND #2 AND #3	COPD/asthma and inhaler and decay and misuse terms	1197
#4 Filters: from 2010 − 2021	COPD/asthma and inhaler and decay only terms (from 2010 to 2021)	792
"Review"[publication type] OR "This review"[TIAB] OR "We review"[TIAB] OR "A review of"[TIAB] OR "Opinion"[TIAB] OR "Perspective"[TIAB] OR "Letter"[publication type] OR "Editorial"[publication type] OR "Comment"[publication type] OR "Personal narrative"[publication type]	Review/perspective terms	4,947,960
#5 AND #6 Filters: from 2010 − 2021	COPD/asthma and inhaler and decay only terms (from 2010 to 2021)	166

COPD, Chronic obstructive pulmonary disease.

TABLE E3. Social determinants of health search terms and results

Search	Query	Subject	Results
1	"Pulmonary Disease, Chronic Obstructive"[Majr] OR "COPD"[title] OR "Pulmonary Disease, Chronic Obstructive"[title] OR "Chronic Obstructive Airway Disease"[title] OR "COAD"[title] "chronic respiratory disease"[title] OR "Chronic Obstructive Lung Disease"[title] OR "Chronic Airflow Obstruction disease"[title] OR "Asthma"[Majr] OR "Asthma"[title]	COPD/asthma terms	119,621
2	"social determinants of health"[tiab] OR "SDOH"[tiab] OR "social determinant"[tiab] OR "social determinants"[tiab] OR "structural determinant"[tiab] OR "structural determinants"[tiab] OR "social and environmental factors"[tiab] OR "social factors"[tiab] OR "psychosocial"[tiab] OR "sociocultural"[tiab] OR "stigma"[tiab] OR "socioeconomic"[tiab] OR "health status disparities"[tiab] OR "health status disparity"[tiab] OR "vulnerable populations"[tiab] OR "underserved populations"[tiab] OR "Social Determinants of Health"[Majr] OR "Health Status Disparities"[Majr]	Social determinants of health terms TIAB/MAJR	309,310
3	#1 AND #2	COPD/asthma and social determinants of health terms	2209
4	#3 Filters: from 2010 − 2021	COPD/asthma and social determinants of health terms (from 2010 to 2021)	1220
5	"Inhaler"[ALL] OR "Inhalers"[ALL] OR "pMDIs"[ALL] OR "pMDI"[ALL] OR "MDI"[ALL] OR "Metered-dose inhaler"[ALL] OR "Metered dose inhaler"[ALL] OR "Metered-dose inhalers"[ALL] OR "Metered dose inhalers"[MeSH] OR "Soft Mist"[ALL] OR "SMI"[ALL] OR "Respimat"[ALL] OR "Hydrofluoroalkane"[ALL] OR "Nebulizers"[ALL] OR "Nebulizer"[ALL] OR "Vaporizers"[ALL] OR "Vaporizer"[ALL] OR "Vaporizers and Nebulizers"[MeSH] OR "Dry Powder Inhalers"[MeSH] OR "Inhalators"[ALL] OR "Inhalator"[ALL] OR "Atomizers"[ALL] OR "Atomizer"[ALL] OR "Inhalation Devices"[ALL] OR "Device, Inhalation"[ALL] OR "Devices, Inhalation"[ALL] OR "Inhalation Device"[ALL] OR "Inhaler, Metered Dose"[ALL] OR "Inhalers, Metered Dose"[ALL] OR "Spacer Inhalers"[ALL] OR "Spacer Inhaler"[ALL] OR "Spacer-Inhalers"[ALL] OR "Spacer-Inhaler"[ALL] OR "Spinhalers"[ALL] OR "Spinhaler"[ALL] OR "Dry powder inhaler"[ALL] OR "Dry powder inhalers"[ALL] OR "Inhaler, Dry Powder"[ALL] OR "Inhalers, Dry Powder"[ALL] OR "Powder Inhaler, Dry"[ALL] OR "Powder Inhalers, Dry"[ALL]	Inhaler terms	31,102
6	#4 AND #5 Filters: from 2010 − 2021	COPD/asthma and social determinants of health terms (from 2010 to 2021) and inhaler decay terms	51

COPD, *C*hronic obstructive pulmonary disease; *MAJR*, MeSH major topic; *TIAB*, title/abstract.

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