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The impact of patient self-monitoring via electronic medication monitor and mobile app plus remote clinician feedback on adherence to inhaled corticosteroids: A randomized controlled trial

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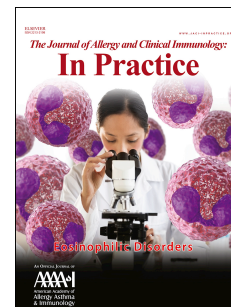
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Title: The impact of patient self-monitoring via electronic medication monitor and mobile app plus remote clinician feedback on adherence to inhaled corticosteroids: A randomized controlled trial

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Acquisition of data: CG, BA, NBO

Performed data analysis: RG

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Abstract

Background: Poor adherence to inhaled corticosteroids (ICS) and overuse of short-acting beta₂-agonists (SABA) are associated with increased asthma morbidity.

Objective: To assess whether patient self-monitoring via electronic medication monitoring (EMM) and smartphone application plus remote clinician feedback influences ICS and SABA use.

Methods: Adults with uncontrolled asthma and prescribed ICS and SABA were enrolled in this 14-week study. Inhalers were fitted with EMM to track real-time usage. After a 14-day baseline, participants were randomly assigned to the treatment group where they received reminders and feedback on ICS and SABA use via a smartphone application and clinician phone calls, or control group without feedback. Linear mixed models compared the baseline percent of SABA-free days and ICS adherence to the last 14 study days.

Results: Participants (n=100) had a mean age of 48.5 years, 80% were female, 68% Caucasian and 80% privately insured. The percent of SABA-free days increased significantly in the treatment group (19%, 95% CI: 12, 26; $P < 0.01$) and non-significantly in the control group (6%, 95% CI: -3, 16; $P = 0.18$), representing a 13% (95% CI: 1, 26; $P = 0.04$) difference. ICS adherence changed minimally in the treatment group (-2%, 95% CI: -7, 3; $P = 0.40$), but decreased significantly (-17%, 95% CI: -26, -8; $P < 0.01$) in the control group, representing a 15% (95% CI: 4, 25; $P < 0.01$) difference.

Conclusions: Patient self-monitoring via a digital platform plus remote clinician feedback, maintained high baseline ICS adherence and decreased SABA use. ClinicalTrials.gov (NCT03860519).

What is already known about this topic? Poor adherence to inhaled corticosteroids and overreliance on short-acting beta₂-agonists are risk factors for uncontrolled asthma.

What does this article add to our knowledge? Compared to a control group, patient self-monitoring via electronic medication monitors and a smartphone app plus remote clinician feedback helped maintain baseline adherence to inhaled corticosteroids and decrease short-acting beta₂-agonist use.

How does this study impact current management guidelines? While asthma guidelines endorse self-monitoring and feedback to increase or maintain adherence, most strategies are resource intensive. This intervention is delivered remotely via a digital platform and clinician phone calls thereby increasing flexibility and reducing costs.

Keywords: Asthma; mhealth; health outcomes; adherence; self-management; Apps; ICS; SABA

Abbreviations: Inhaled Corticosteroids (ICS); Short-Acting Beta₂-Agonists (SABA); Electronic Medication Monitors (EMMs); Expert Panel Report 3 (EPR-3); Minimal Clinically Important Difference (MID); Asthma Control Test (ACT); Emergency Department (ED); Electronic Medical Record (EMR); Odds Ratio (OR); Confidence Intervals (CI)

Introduction

Asthma affects more than 18 million adults in the US,^{1, 2} and accounts for nearly 500,000 hospitalizations and 1.8 million emergency department visits³ each year. The US spends approximately \$82 billion annually on asthma related costs,⁴ including medical expenditures and missed work and school days. The 20% of patients with asthma who have uncontrolled moderate-to-severe persistent asthma account for over 80% of asthma-related health care costs.⁵⁻¹⁰

Poor adherence to inhaled corticosteroids (ICS) containing medications and over-reliance on short-acting beta₂-agonists (SABA) are well-known risk factors for uncontrolled asthma.¹¹⁻²³

However, patient self-report and clinician assessment often over-estimate ICS adherence leading to costly treatment regimens that may not be appropriate.²⁴⁻³⁴ Rather than focusing on objectively assessing adherence and implementing strategies to promote medication taking behavior, clinicians will often prescribe additional controller medications, oral corticosteroids, or costly biologics (estimated cost of \$30,000/year).^{16, 34, 35}

Since 2012, the FDA has cleared platforms featuring electronic medication monitors (EMMs), patient-facing smartphone apps, and secure, HIPAA compliant clinician dashboards. These can be used to provide patients and clinicians with real time feedback on ICS adherence and SABA use, empowering patients with tools for asthma self-management and clinicians with accurate data to provide patients feedback on medication taking behavior and on which to make treatment decisions. The aim of this randomized behavioral controlled trial was to assess whether patient self-monitoring via a smartphone app plus remote clinician feedback on ICS and SABA use influences ICS adherence and SABA usage compared to a control group.

Methods

Recruitment and eligibility

Patients with uncontrolled asthma, 25 to 65 years of age, were recruited between April 2018 and April 2019. Patients were required to be prescribed a daily inhaled corticosteroid (ICS) containing controller medication and a short-acting beta₂ agonist (SABA) inhaler. Patients were recruited from allergist/immunologist or pulmonologist practices at NorthShore University HealthSystem and needed to have an active patient portal account (NSConnect) and own a smartphone. Patients were excluded if their prescribed inhalers were not compatible with the study protocol at the time of the study (e.g. Symbicort, Xopenex and/or nebulizers) or if other co-morbidities (e.g., severe psychiatric disorder) could interfere with study participation.

Eligible participants were identified through electronic medical records (Epic, Verona, WI) review. Letters were mailed out to potentially eligible participants informing them about the study and inviting them to opt in or out. Those that were interested received a follow up phone call inviting them for an enrollment visit where they provided written informed consent. The protocol was approved by the NorthShore University HealthSystem IRB and was registered at ClinicalTrials.gov (NCT03860519).

Intervention description

Treatment and control group participants attached a small electronic medication monitor (EMM) (Propeller Health, USA) on their ICS and SABA asthma inhalers to passively track date and time of inhaler use. Propeller Health has a live support team that is available to help both patients and clinicians with technical issues as they arise. This can range from helping a patient to enroll, set up a new password, or trouble-shoot syncing issues. The battery life for Propeller Health sensors is 12-18 months.³⁶ The Propeller smartphone application ("app") was used to collect and share data with the participants and study staff. Participants could view their data in real time on their smartphones and study staff remotely through a secure, password protected dashboard. During the run-in period, the EMM and app were set to data collection mode so that no usage data or notifications were shared with the participants or staff.

Following the 14-day run-in period, participants were block randomized (3:1) to the treatment group or control group for the 12-week active treatment period. The block size in the randomization was 4. The randomization schedule was generated a priori by the study statistician using a random number generator and implemented by a study research assistant who was blinded to the full randomization list. The principal investigator was blinded to the participant study arm assignment. The study nurse conducting monthly phone calls only interacted with the treatment group participants to deliver the intervention, but was not involved in data collection.

Treatment group participants received audio-visual ICS medication reminders for missed or late doses and had access to their ICS and SABA inhaler usage data on the app. Additionally, patients were contacted through NSConnect if study staff review of the dashboard noted the patient had poor adherence (missed four consecutive days of ICS doses) or had worsening control (defined by EPR3 guideline criteria).³⁷ An asthma nurse practitioner (trained and supervised by an allergist/immunologist) called patients at months 1, 2 and 3 to review current asthma status and provide feedback on ICS adherence and SABA usage.

The control group also had EMM attached to their ICS and SABA inhalers, but did not receive audio-visual medication reminders, have access to ICS and SABA inhaler usage data, receive monthly nurse phone calls to provide adherence feedback nor additional study interventions beyond the standard of care. Of note, both the treatment and control participants were aware that their ICS and SABA inhalers were fitted with EMM and that the study team was monitoring their ICS adherence and SABA usage. The treatment group received feedback on their ICS and SABA use in real time on the Propeller Health Asthma app on their mobile phone. Immediately after randomization, the control group participants were notified that they would have access to view their ICS and SABA use data for the duration of the 3-month study on the Propeller Health Asthma app on their mobile phone after completion of the study. All patients received \$50 at the end of the enrollment and randomization visits, and \$50 if they completed the final study visit.

Population Characteristics

Self-reported demographics including age, gender, race and ethnicity, verified by EMR review, were collected at the enrollment visit.

Primary and Secondary Outcome Measures

The primary outcome was the difference in SABA-free days from run-in to the final 14 days of the study between groups. The percent of SABA-free days during run-in and final 14 days of study was calculated from remote EMM data.

The secondary outcome was the difference in mean ICS adherence from the run-in to the final 14 days of the study between groups. Daily adherence was calculated as the total number of ICS puffs recorded on the EMM divided by puffs prescribed, capped at 100%. Adherence was then averaged over the run-in and final 14 days of study.

Of note, the final 14 days was defined as either the last 14 days of the study or the last 14 days of inhaler use if the syncing ended prior to the final study visit.

Exploratory Outcomes

Two exploratory outcomes were evaluated. The first was improvement in asthma control, defined as a 10% (i.e. 10 point) increase in SABA free days, and/or minimal clinically important difference (MID = three points) improvement on the Asthma Control Test (ACT) and/or change from ACT score ≤ 19 to ≥ 20 from the run-in compared to the final 14-days of the study between groups.^{38, 39}

The second was the difference in the proportion of patients with at least one asthma exacerbation (self-reported by the participant and verified by EMR review) during the active treatment period between the two groups. Exacerbations were defined as having an asthma-related oral systemic corticosteroid prescription, emergency department visit and/or hospitalization.

Statistical Methods

The changes in outcomes from the run-in to the final 14 days of study were estimated using linear mixed effects models that included a random intercept for participant to account for within-participant variability (i.e., repeated measures). An interaction term between the study group and study period was included to estimate the differences in outcomes between groups. Effect estimates, 95% confidence intervals (CI) and *P* values were reported, with the threshold for statistical significance at $\alpha = 0.05$.

In the analyses of SABA-free days, three participants did not have inhaler data by the final study visit and in analyses of ICS adherence, two participants did not have inhaler data by the final study visit. As such, the last 14 days of sensor use were used in the analyses.

The difference in asthma control improvement from the run-in to the final 14 days by study group was estimated using linear regressions in participants with less than 90% of SABA-free days during run-in or an ACT less than 23. Specific analyses of SABA-free days included patients with less than 90% of SABA-free days during run in; of ACT improvement included patients with an ACT score less than 23; and of $ACT \leq 19$ to ≥ 20 included participants with an ACT less than 20. The occurrence of asthma exacerbations by study group during the active treatment period was estimated using a Fisher's exact test. All analyses were run in R version 3.6.1.

Results

Enrollment and Follow-up

Of 423 eligible participants identified by EMR review, 101 met inclusion/exclusion criteria and completed enrollment. (Figures 1 and 2). The participants were randomized (75 to the treatment group and 25 to the control group, and one patient was withdrawn for administrative reasons). There were 68 treatment and 23 control patients reporting SABA-free day data and 73 treatment

and 23 control participants with ICS data. Of the five participants that did not have ICS data, three were due to early withdrawals, one was due to loss to follow up, and one was due to multiple prescription changes during the study from supported to unsupported controller medications and resulting lack of ICS containing medication data capture.

Baseline Characteristics

Baseline characteristics are presented in Table I. The study population was on average 48.5 years of age, largely female (80%), Caucasian (68%) and without Hispanic ethnicity (95%). Most patients had private insurance (80%), a college, baccalaureate or post-graduate degree (60%), had never smoked (71%) and obtained asthma specialist care from an allergist/immunologist (81%). Baseline patient characteristics were balanced with the exception that asthma exacerbation requiring ≥ 2 oral systemic corticosteroids in the year prior was higher in the treatment group compared to control group (68% vs. 40%, $P = 0.03$).

Primary Outcome

The percentage of SABA-free days in the treatment and control group was 58% and 75% at baseline and 77% and 81% at study end, respectively (Figure 3; Table II). The absolute change in the percent of SABA-free days from run-in to study end in the treatment group was 19% (95% CI: 12%, 26%; $P < 0.01$) and in the control group was 6% (95% CI: -3%, 14%; $P = 0.18$). The increase in the percentage of SABA-free days in the TG was 13% (95% CI: 1%, 26%; $P = 0.04$) higher than in the control group.

Secondary Outcome

Adherence (%) to daily ICS for the treatment group and control group was 70% and 68% at baseline and 68% and 51% at study end, respectively (Figure 4; Table II). ICS adherence changed minimally from the run-in to study end in the treatment group (-2%, 95% CI: -7, 3; $P =$

0.40), but decreased significantly (-17%, 95% CI: -26, -8; $P < 0.01$) in the control group. The decrease in ICS adherence was 15% (95% CI: 4%, 25%, $P < 0.01$) greater in the control group vs. treatment group.

Exploratory Outcomes

Patients in the treatment group were more likely to have improved asthma control at the end of the study (OR: 2.3, 95% CI: 0.7, 7.7; $P = 0.20$), however these associations were not statistically significant (Table III). The proportion of patients with asthma exacerbations did not differ by study group ($P = 0.80$) (Table IV).

Discussion

This randomized behavioral controlled trial demonstrated that patient self-monitoring via an EMM and smartphone app plus remote clinician feedback on inhaler use helped maintain baseline adherence to ICS-containing controller medications and decrease the percent of days with SABA use compared to the control group. These results are encouraging given that *ICS adherence typically declines over time and this, in addition to overreliance on SABA, are consistently associated with increased asthma morbidity, mortality and costs.*^{11-23, 31, 32}

The decline in adherence noted in the control group might reflect either an initial increase at the time of enrollment and placement of the sensor on the controller or the effect of time on adherence.⁴⁰⁻⁴⁴ The decrease in SABA use is consistent with prior research by Merchant et al.⁴⁵

The positive outcomes may be due to the combination of patient self-monitoring and remote clinician feedback, or one of these intervention components. The EPR3 and GINA guidelines both endorse asthma self-management, and current interventions to improve asthma self-management demonstrate efficacy.^{37, 46, 47} Studies of clinician feedback on medication taking

behavior also show positive outcomes.^{44, 48} However, most of these interventions are resource intensive, requiring multiple in-person visits with physicians, nurses, social workers, asthma educators and/or community health workers.^{44, 47, 48} The current intervention is delivered remotely via a digital platform (passive EMM data collection plus smartphone app feedback) and clinician phone calls, increasing flexibility and reducing indirect costs to the patient (e.g. time away from work, travel costs) and health care system.

The COVID-19 Pandemic has accelerated the adoption of telemedicine.⁴⁹⁻⁵¹ As such, there is increased reliance on wearables and remote monitoring technologies to provide objective physiologic data despite previously slow adoption due to patient (privacy), clinician (liability, administrative burden, lack of reimbursement for remote monitoring) and payer (cost) obstacles to implementation.⁵² To address these implementation barriers, the Propeller Health platform is designed to minimize user burden. Clinicians are only alerted to those patients who have worsening asthma control or prolonged periods of controller non-adherence. Clinicians can then decide if the patient needs any follow-up. Clinicians are not required to monitor the system around-the-clock. Patients in this study were informed that the Propeller Health system should not be used for urgent care, and that they should follow standard protocol and follow their personalized asthma action plan should urgent care be required. In this study, remote capture of increased SABA use and poor ICS adherence triggered automated (algorithm based) patient portal messaging that may indicate asthma control worsening and directing participants to follow their asthma action plan. Clinician real time monitoring of the web dashboard also allowed the study team to reach out to patients with dramatic increases in SABA use to schedule a same-day urgent visit with their asthma specialist, thereby potentially avoiding an ED visit or hospitalization.

Furthermore, in the era of costly biologic therapies for the treatment of moderate to severe asthma, patient self-monitoring and clinician feedback on ICS and SABA use are key for optimal patient selection. The five biologic medications currently FDA-approved have demonstrated greatest efficacy in patients with T2 high asthma, a phenotype which has been found to be responsive to daily ICS therapy.⁵³⁻⁵⁵ Digital monitoring of medication use can serve as a diagnostic tool to understand which patients, despite being adherent to daily ICS, are still experiencing moderate-severe asthma and warrant a biologic medication. Patients non-adherent to daily ICS may need more intensive self-monitoring and clinician feedback on ICS and SABA use before considering the addition of a biologic.

This study has several limitations. First, with regard to the exploratory outcomes, while patients in the treatment group were more likely to demonstrate improved asthma control at the end of the study compared to the control group, these associations were not statistically significant. There was no difference across study groups regarding the proportion of patients with asthma exacerbations, however the 3-month study period may be too short to observe an adequate number of events. Second, date and time of ICS and SABA actuation were collected, but inhaler technique was not assessed. For inhaled medications to be effective, both adherence and proper technique for optimal lung delivery are required.⁵⁶⁻⁵⁹ Third, this study population was largely well-educated, privately insured, middle-aged, white, female, and received asthma specialist care from an allergist/immunologist or pulmonologist, thus limiting generalizability. Prior work by Mosnaim et. al. with low-income, urban, minority adolescents with uncontrolled asthma also demonstrated positive outcomes utilizing patient self-monitoring and clinician feedback, but this was an uncontrolled pilot study.⁶⁰ Future, large-scale multi-center randomized controlled trials testing this intervention with diverse groups of participants are needed. Fourth, in this study, the team viewed a separate dashboard to review participant data. However, this mobile platform can be integrated into the EMR to streamline clinician workflows.³⁶

362

363 In conclusion, patient self-monitoring via an EMM and smartphone app plus remote clinician
364 feedback on ICS and SABA use helped maintain baseline ICS adherence, and decreased
365 SABA usage in adult patients with uncontrolled asthma. As poor adherence to ICS and
366 overreliance on SABA demonstrate significant morbidity, mortality and cost, this is a novel
367 approach to these challenges. To date, the implementation of these technologies has been
368 fraught with obstacles. However, the accelerated uptake of telemedicine and demand for
369 associated remote technologies and wearables to measure physiologic parameters may
370 overcome these barriers. These technologies may also help clinicians to be more ethical
371 stewards of costly biologic therapies, focusing on measuring and improving adherence to ICS
372 before prescribing a biologic.

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Figure Legends

Figure 1. Consort Diagram The consort diagram illustrates the flow of participants from eligibility evaluation to treatment completion.

Figure 2. Study Timeline: The study timeline illustrates the run-in and active treatment phases. Data collection occurred in real time throughout the study using the Propeller Health medication sensor, mobile phone application and health care professional dashboard. In-person data collection occurred at the 0-week and 3-month study visits.

Figure 3. Change in SABA-free days. Control vs. treatment group difference $P = 0.04$: This figure illustrates the change in SABA-free days from run-in to study end in the treatment and control groups.

Figure 4. Change in ICS adherence. Control vs. treatment group difference $P < 0.01$: This figure illustrates the change in ICS adherence from run-in to study end in the treatment and control groups.

Table I. Baseline characteristics of 100 randomized participants

	Overall n = 100	Attention Control n = 25	Treatment n = 75	<i>P</i> value
Age, mean years (SD)	48.5 (12.3)	46.06 (14.29)	49.30 (11.63)	0.26
Male gender, n (%)	20 (20)	5 (20.0)	15 (20.0)	1.00
Ethnicity, n (%)				1.00
Hispanic	5 (5)	1 (4)	4 (5)	
Non-Hispanic	95 (95)	24 (96.0)	71 (94.7)	
Race, n (%)				0.31
Black or African American	26 (26)	7 (28.0)	19 (25.3)	
Asian	6 (6)	3 (12.0)	3 (4.0)	
White or Caucasian	68 (68)	15 (60.0)	53 (70.7)	
BMI, mean (SD) / median (IQR) kg/m2*	33.6 (10.0)	32.20 (6.77)	34.11(10.97)	0.45
Health insurance type, n (%)				0.71
Medicaid	9 (9)	3 (12.0)	6 (8.0)	
Medicare	9 (9)	3 (12.0)	6 (8.0)	
Medicaid & Medicare	2 (2)	0 (0.0)	2 (2.7)	
Private	80 (80)	19 (76.0)	61 (81.3)	
Highest degree, n (%)				0.16
High school or GED	13 (13)	2 (8.0)	11 (14.7)	
Some college or associates degree	27 (27)	6 (24.0)	21 (28.0)	
College graduate or baccalaureate	27 (27)	11 (44.0)	16 (21.3)	
Post-graduate degree	33 (33)	6 (24.0)	27 (36.0)	
ICS containing medications, n (%)				
ICS monotherapy	18 (18)†	7 (28.0)	11 (14.7)	0.23
ICS and LABA combination therapy	81 (81)	18 (72.0)	63 (84.0)	0.30
ICS and LABA and LAMA combination therapy	1 (1)	1 (4.0)	0 (0.0)	0.56
Other asthma controller medications, n (%)				
LAMA	23 (23)	5 (20.0)	18 (24.0)	0.89
LTRA	47 (47)	13 (52.0)	34 (45.3)	0.73
Biologic	2 (2)	1 (4.0)	1 (1.3)	1.00
Baseline ACT categories, n (%)				
< 15	47 (47)	12 (48.0)	35 (46.7)	0.99
15-19	20 (20)	5 (20.0)	15 (20.0)	
≥ 20	33 (33)	8 (32.0)	25 (33.3)	
Asthma healthcare utilization in the prior 12 months, n (%)				
Unscheduled or same-day doctor visit				
1	21 (21)‡	5 (20.0)	16 (21.3)	1.00
≥ 2	4 (4)§	0 (0.0)	4 (5.3)	0.56
Immediate care center visit				
1	10 (10)	1 (4.0)	7 (9.3)	0.67
≥ 2	2 (2)	0 (0.0)	2 (2.7)	1.00
Requiring oral systemic corticosteroids for asthma exacerbation				
1	27 (27)	5 (20.0)	22 (29.3)	0.52

≥ 2	47 (47)	17 (68.0)	30 (40.0)	0.03
Uncontrolled asthma defined by ≥ 1 criteria below	100 (100)			
EPR3 asthma guidelines, n (%)	81 (81)	19 (76)	62 (82)	0.66
ACT score ≤ 19	67 (67)	17 (68.0)	49 (65.3)	1.00
≥ 2 oral systemic corticosteroids for asthma exacerbation	47 (47)	17 (68.0)	30 (40.0)	0.03
≥ 1 ED visit or hospitalization for asthma exacerbation	28 (28)	10 (40.0)	18 (24.0)	0.20
Asthma specialist, n (%)				
Allergist/immunologist	81 (81)	21 (84)	60 (80)	0.88
Pulmonologist	19 (19)	4 (16.0)	15 (20.0)	0.88
Smoking behavior reported by participant, n (%) [*]				0.73
Current smoker	5 (6)	1 (4.5)	4 (6.7)	
Former	19 (23)	4 (18.2)	15 (25.0)	
Never	58 (71)	17 (77.3)	41 (68.3)	
Enrollment in EMR Patient Portal, n (%)	99 (99) [¶]	25 (100)	74 (99)	1.00
iPhone iOS (vs. Android), n (%)	74 (74)	18 (72.0)	56 (74.7)	1.00

Body Mass Index (BMI); Interquartile Range (IQR); Inhaled corticosteroids (ICS); Long-acting beta-adrenoceptor agonist (LABA); Long-acting muscarinic antagonist (LAMA); Leukotriene receptor antagonist (LTRA); Expert Panel Report 3 (EPR3); Asthma control test (ACT); Emergency Department (ED); Electronic Medical Record (EMR)

^{*}1 participant missing BMI data and 18 participants did not consent to share BMI or smoking status

[†]10 participants were also on ICS but were not sensed as they were also using ICS/LABA inhalers that were sensed, 1 participant had two ICS sensors, but only their primary ICS use was measured

[‡]7 to a primary care provider, 12 to an allergist/immunologist, and 2 to a pulmonologist

[§]All visits were to allergists/immunologists

^{||}Uncontrolled asthma criteria verified by view of EMR

[¶]1 participant did not activate NorthShore Connect

Table II. Change in SABA-free days and ICS-containing controller medication adherence from baseline to study end (last 14 days of the study or sync^a if last sync occurs before the final visit).

	Baseline (pre- randomization)	Study end (last 14 days of study or sync)	Δ (95% CI)*	P value*	Treatment vs. Control Δ (95% CI)*†	Treatment vs. Control Δ P value*†	N
SABA-free days, mean (SD) %							
Control group	75 (32)	81(34)	6 (-3, 14)	0.18	13 (1, 26)	0.04	23§
Treatment group	58 (37)	77 (30)	19 (12, 26)	< 0.01			68§
Daily ICS adherence, mean (SD) %							
Control group	68 (30)	51 (37)	-17 (-26, -8)	0.01	15 (4, 25)	< 0.01	23¶
Treatment group	70 (27)	68 (32)	-2 (-7, 3)	0.40			73¶

Short-Acting Beta₂-Agonists (SABA); Standard deviation (SD); Inhaled corticosteroids (ICS); Confidence Interval (CI); Δ , change

^aSync is defined as the successful communication between the Propeller electronic medication monitor and the paired smartphone app

*Estimated using linear mixed models that accounted for repeated measures

† Δ (95% CI) and P value is for the interaction term between the intervention group and study period

§Sum of N does not equal 100 due to early withdrawal (n=1), lacked a final study visit (n=2), or first synced their inhaler sensor after baseline (n=2) or did not have a sensor for their SABA inhaler (n=4)

¶Sum of N does not equal 100 due to early withdrawal (n=1), lacked a final study visit (n=2), or first synced their inhaler sensor after baseline (n=1)

Table III. Improvement in asthma from baseline to study end, as defined as a 10% increase in SABA-free days and/or ACT improvement by three points and/or change from ACT score <20 to ≥20.

Metric	Control total n	Treatment total n	Control n outcome (%)	Treatment n outcome (%)	Odds ratio (95% CI)*	P value	Adjusted† odds ratio (95% CI)*	P value
Asthma control improvement	21	64	13 (62)	48 (75)	1.8 (0.6, 5.3)	0.25	2.3 (0.7, 7.7)	0.20
10% increase in SABA-free days	10	50	5 (50)	32 (64)	1.8 (0.5, 7.0)	0.41	1.8 (0.5, 7.2)	0.39
ACT improvement by ≥3 points	20	62	11 (55)	41 (66)	1.6 (0.6, 4.5)	0.37	1.9 (0.6, 6.1)	0.30
ACT score from <20 to ≥20	17	49	8 (47)	26 (53)	1.3 (0.4, 3.8)	0.67	1.3 (0.4, 4.0)	0.64

Short-Acting Beta₂-Agonists (SABA); Asthma Control Test (ACT); Confidence interval (CI); Δ, change; N, sample size

*Estimated using logistic regression models

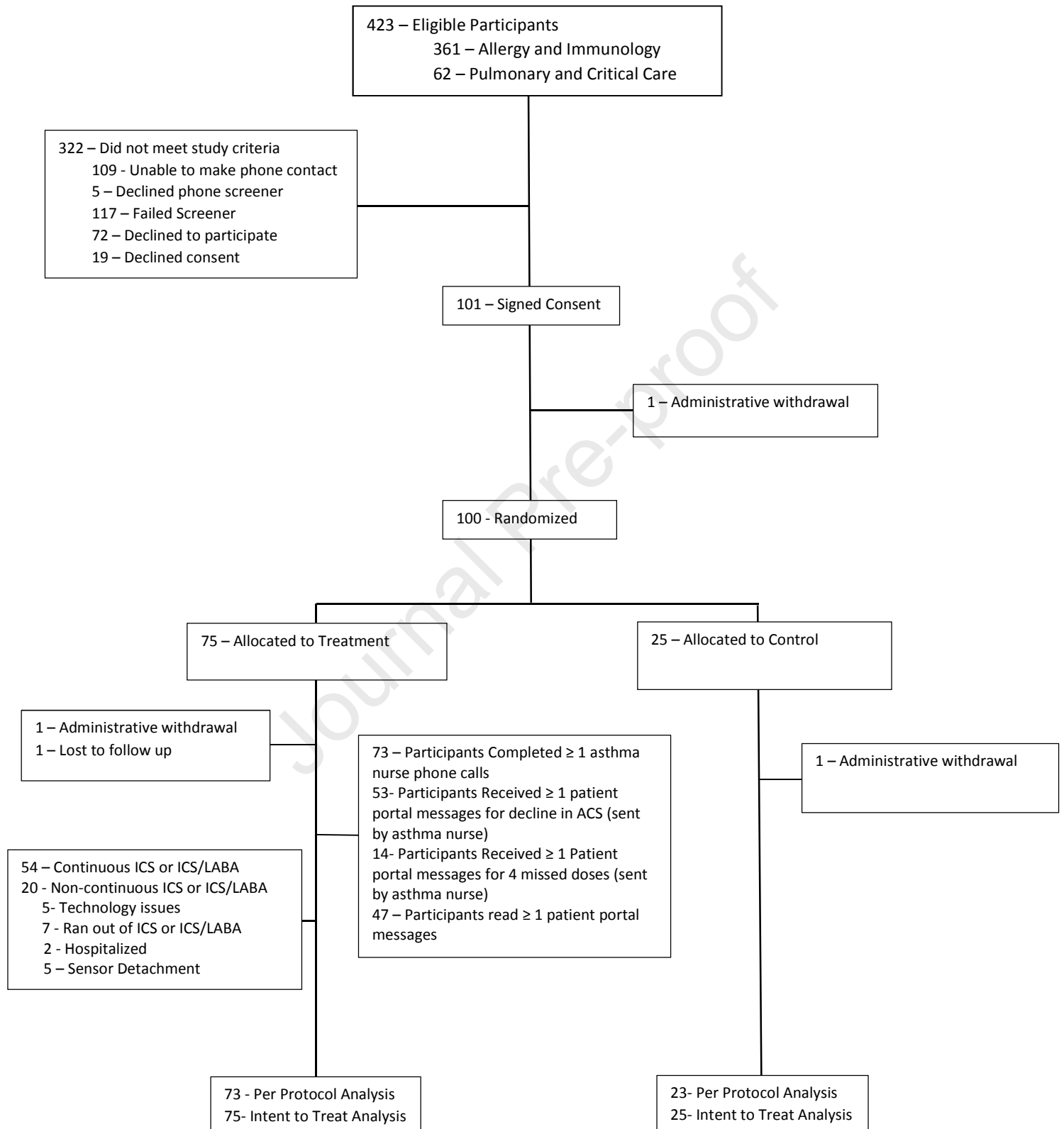
†Adjusted for baseline value of each metric

Table IV. Number (%) of patients with at least one asthma exacerbation during the active treatment period by intervention group.

	Control n = 25	Treatment n = 74	<i>P</i> value*
Any asthma exacerbation	6 (24)	14 (19)	0.80
≥ 1 course of oral systemic corticosteroids, n (%)	6 (24)	13 (18)	0.68
≥ 1 ED visit or hospitalization, n (%)	1 (4)	5 (7)	0.99

Emergency Department (ED)

*Fisher's exact test



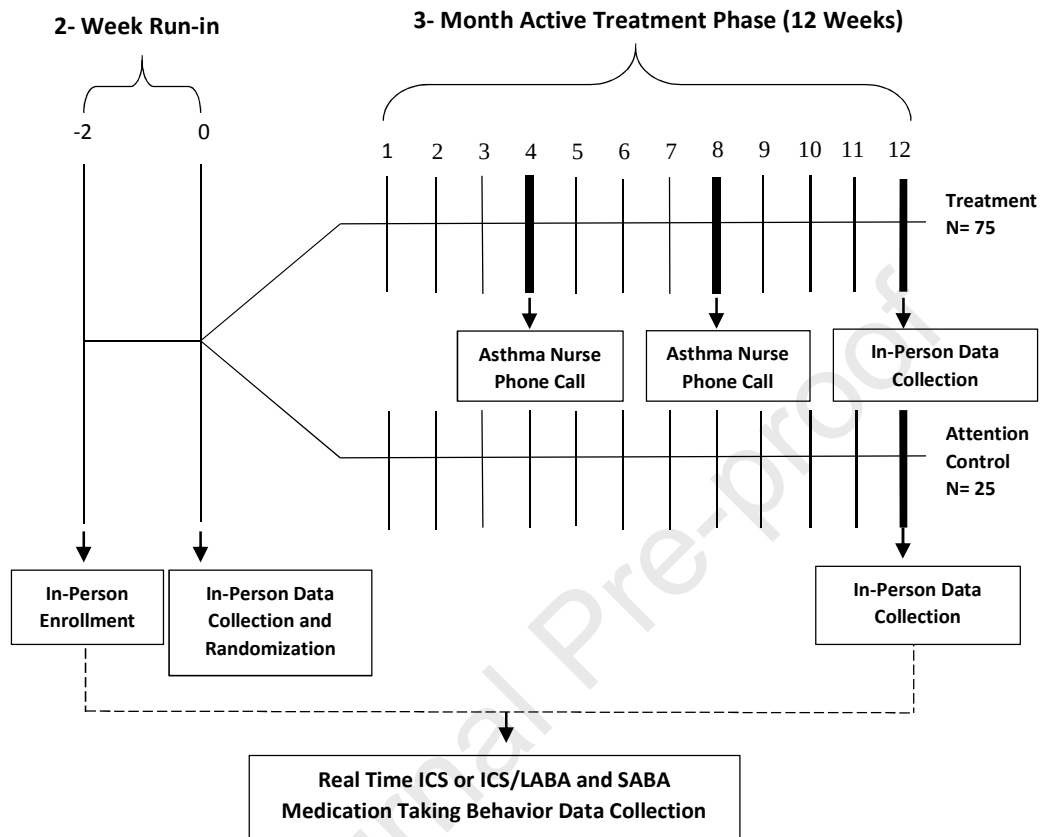


Figure 2.

