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Design and Assessment of a Smart Inhaler with Bluetooth Connectivity for Real-Time Asthma Monitoring and Management

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Abstract:
This paper is a description of a Bluetooth-enabled smart inhaler which was designed, developed and clinically tested in an attempt to enhance the management of asthma. The device also captures usage patterns, inhalation technique, and environmental triggers provides real-time feedback and adherence reminders over a mobile app. Usability testing, over an 8-week period with 60 asthma patients (aged 1855), showed a notable 25-percent improvement in proper inhaler use ($p < 0.001$) and a 30-percent jump in medication compliance. There was a high patient satisfaction, 89% showed an interest to continue using it. The evidence indicates that the use of smart inhalers with Bluetooth technology has a significant effect as it improves inhaler technics, adherence, and patient engagement, which may lead to the diminution of asthma exacerbations and the overall healthcare costs.

Keywords: ***Bluetooth-based, smart-inhaler, asthma-control, medication-administration, usability-test, inhaler-technique, digital-medicine, pulmonary-medicine.***

1. Introduction

1.1 Background

Asthma is another most common chronic disease of respiratory system which involves inflammation and narrowing of the airways thus making it difficult to breathe. It is found in millions of individuals in the global population, and it has a huge burden to both patients and health care systems. Although pharmacological diseases have advanced, it has still failed to provide uniform better asthma control in patients, and non-adherence to prescribed medication and inappropriate inhaler technique represents the main aspects that lead to unsuccessful asthma management. The most often applied mechanisms of delivering the asthma medication are small inhalers that, once properly applied, supply the highly localized medication to the lungs. Nonetheless, research findings have revealed that a substantial number of asthma patients fail to use their inhalers occasionally, and this has caused poor drug delivery and worsening of symptoms.

Over the past years, digital health technologies used in chronic disease management have been on the rise. These technologies provide exciting avenues to keep track, monitor and cope with patient behaviors and may have a great potential in the management of asthma. According to these innovations, we should mention the application of so-called smart inhalers, which simply consist of regular inhalers along with digital technologies. The devices can monitor the use of an inhaler, offer feedback on the performance of an inhalation, and connect with mobile apps in order to provide reminders and record the usage information accessible to the patient and care providers.

The introduction of smart inhalers with Bluetooth access can be seen as a good decision towards the better care of people with asthma. These gadgets would be able to test the inhalation technique, the administration of the medication, and surrounding triggers like air pollution or pollen that could affect the asthma symptoms. Additionally, patients can be given timely feedback and reminders as they engage more in self-management, and timely data reported with the help of mobile applications can facilitate the process of such data transmission.(1)

1.2 Smart Inhaler Technology Need

The demand for the smart technology of an inhaler is connected to the identified discrepancy between the recommended treatment of asthma and its application in the real world. A significant number of patients do not follow the recommended inhaler regimes; this is either out of forgetfulness or lack of understanding on how to use the inhaler or the lack of the urge to keep checking their wounds. Moreover, once patients are compliant on prescribed treatment, the inappropriate use of an inhaler may cause a low response in drug deposition and function of the medication. Literature indicates that up to 80 percent of the asthma patients do not use their inhalers properly and as a result, may develop poorly controlled asthma and frequent exacerbations.

Inhalers allow minimal to no feedback regarding their use, and patients do not know whether they are using their inhalers or have wrong techniques. Although some inhalers are provided with small-scale trackers that count how many times you use a device, these do not show immediate feedback or advice and do not interface with other tools of health maintenance. Smart inhalers fill this gap because they provide dynamic feedback about inhaler technique which allows patients to alter their inhaler use to achieve optimal medications delivery. Moreover, this type of gadgets has the possibility to monitor the environmental elements that could increase the severity of asthma symptoms (this could be air pollution, humidity, or pollen count), and it offers a holistic management of the condition.(2)

The development of smart inhaler technology does not just lead to better compliance to medication and technique of inhaler use but provides a platform of better communication between health care providers and the patient. The information obtained through the device may be shared with healthcare providers, who will be able to track the patient progress, adjustment of the treatment plan, and give recommendations individually. The degree of interaction can be used to enhance long-term management of asthma and cut the cost of care through mitigation of asthma crises and hospital admissions.

1.3 Objectives of the study

The purpose of this study was to plan, create, and test the clinical feasibility of a Bluetooth intelligent inhaler that establishes an attached smart device utilized to observe asthma medicine intake and helps in supplying prompt practical insight. The main goals of the given study were following:

Clarify the Accuracy of Inhaler Technique: To answer the question whether Bluetooth-enabled smart inhaler is associated with increased accuracy of the inhaler technique among patients as compared with conventional use of the inhalers.

Measure Medication Adherence: To learn how the smart inhaler has led to improved Medication Adherence, especially the amount of doses taken and the frequency in using the medication as the treatment continues.

Patient Satisfaction and Usability: To determine how simple to use and easy patients find the smart inhaler, together with the ability to integrate with the mobile application and up-to-date feedback.

Monitor Clinical Outcomes: To explore whether the utilization of the Bluetooth-enabled smart inhaler will lead to better asthma control, fewer symptoms and the decline in the incidents of the escalation of the asthma during the period of the research.

This work was expected not only to examine the technical performance of the smart inhaler but also to present evidence of its possible effects on patient outcomes and treatment compliance with asthma treatment, which provides clues to its practicability in large-scale application in clinical practice.(3)

2. An Overview Of Digital Innovations and the Management of Asthma

2.1 Pharmaceutical Device Engineering Growth 2.1.1 Fixed-Dose Combination Drugs

Innovations in the pharmaceutical device design have witnessed tremendous growth in the past few years and recent technologies have made breakthroughs in inhaler device forms that are meant to enhance improved drug delivery and patient compliance. Even though traditional inhalers are empowered to deliver medicine to the lung, there is a high probability that a patient misuses the device, and this causes an ineffective treatment process. Innovations concerning inhaler design have been aimed at responding to these issues by enhancing the device performance and user-friendliness alongside the digitalization of these devices. These types of advancement include the development of smart inhalers, fitted with sensors to check usage, collect inhalation method, and upload to mobile phones or cloud facilities.

The smart inhalers were programmed to give real-time feedback concerning the technique the inhaler user is employing to ensure that the medication can reach the target via effective inhalation. Such devices can include sensors monitoring the amount of dosage per dose, the rate of inhalation and the duration of the inhalation process, which can be used by both patients and clinicians. Also, the treatment is also enhanced by integration with the smartphone app as most inhalers now run on them and provide a reminder on when to take medications, track compliance patterns, and remind patients when they fail to use medicines. Dose counters, electronic history of usage, and temperature sensors are also built in some intelligent inhalers to check on appropriate storing of medication. Such developments in the sphere of inhaler engineering have the possibility to make a huge impact on the way asthma is treated, making drug administration more accurate and patients more predisposed to follow the treatment.(4)

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2.2 How Mobile Health will contribute to Respiratory Care

mHealth technologies have changed the horizon of how chronic diseases such as asthma are managed. Smartphone and wearable technologies have permeated into popular culture and gapped the possibility of mobile applications that enable real-time feedback and monitoring as well as interaction between healthcare professionals and patients remotely. Mobile health applications are essential in the management of asthma since they increase the adherence to medications, symptom monitoring, and give users useful insights into their health like the ability to take actions relating to the inflammation.

The smart inhalers allow mobile health applications to perform a frequency of tasks. These apps will be able to offer in-time feedback of the inhaler technique, remind patients to use their medicine, and inform them of the available environmental conditions that could aggravate asthma effects. To give an example, in the case a patient uses incorrect inhalation technique, the app will be able to make them aware of this situation and also inform the patient about the proper way to use the gadget. The app will also be able to monitor whether the patient followed the prescribed treatment regiment and remind him or her about missed medication. In addition to managing drugs, mHealth apps are also able to track symptoms and patients can mention wheezing, coughing, or shortness of breath within an app. This immediate symptom monitoring has the potential of assisting medical professionals in making changes to treatment regimes in a timely manner so as to gain greater control over the condition.

The other significant feature of mobile health in the management of asthma is the capability of patients to monitor environmental triggers. External sources can be added to mobile apps that can connect to air quality monitoring such that real-time data about environmental factors that can affect asthma such as pollution levels, pollen counts, or even humidity can be displayed. This integration can also assist patients not to be exposed to such triggers and make a judgement in regard to their daily activities, thereby facilitating disease management.

2.3 Incorporation of environmental data in the therapy

Making environmental information part of an asthma treatment plan is one of those developments that holds a lot of promise in terms of how the provision of asthma is customized and how it is handled. Allergens, air pollutants, weather conditions are all environmental factors that contribute significantly to asthma exacerbation and worse symptoms. The current thinking on asthma treatment has concentrated on suppressive medication to treat the disease, however the addition of environmental factors in the treatment regime gives a more comprehensive view of managing the disease.(5)

Patients may also access the information of real-time environmental conditions that can cause astha symptoms through mobile applications linked to smart inhalers or wearable devices. To illustrate this with an example, a patient with asthma might be notified of an increased high pollen level in the environment, forcing them to take precautions in terms of indoor staying, or an avoidance preventive inhaler. On the same note, apps can track air quality and alert patients when pollutant levels are elevated, thus enabling them to stay indoors or take their medicines depending on the condition.

Also, the inclusion of environmental information will enable healthcare professionals to make better choices regarding the management of asthma. To illustrate, examining the information on environmental exposures and unique patterns of the patient will allow a provider to individualize treatment advice, i.e. adjust medication dosages or recommend particular preventive measures. Not only does this data-driven asthma care strategy provide better patient outcomes, it also allows the patient to have more control towards their condition, making the overall care and management of the disease easier and may even minimize exacerbations.

Overall, introducing environmental data to asthma management in combination with smart inhaler technology and mobile applications can become a potent instrument that improves upon asthma management. It is enabling a more individualized, proactive course of treatment that increases medication compliance, decreases the severity of symptoms, and, ultimately results in overall patient outcomes. As sustainable technology advances, it is becoming ever-more likely that it will transform asthma treatment and allow more evidence-based and holistic care.

3. How Devices are Designed and Developed

3.1 Hardware Design of the Smart Inhaler

Hardware architecture of smart inhaler is a major component in the viability of a working and usable smart inhaler that blends well with the mobile apps. The core elements involved in designing the smart inhaler are selected in such a way that they enable it to record accurate data concerning the use of the inhaler. Such parts will normally

have sensors to track the inhalation procedure, a microcontroller to refine information and a battery to power the device, and Bluetooth modules to communicate with other gadgets.

The central sensor system is usually in the form of flow sensors that sense the speed and volume of inhalation and give information on how effective the medication is being administered. Such sensors will play a critical role in evaluation of the technique and guaranteeing the usage of the inhaler by the patient as per the instruction. Other sensors might be pressure sensors which measure the amount of force that is used during the inhaling process and temperature sensors to check the storage conditions of the drug.(6)

The microcontroller then acts as the central processor whereby it organizes the data being collected in its sensors and forces them ready so that they can be transmitted. The application of the microcontroller is also important in guiding the performance of the device such as energy consumption to prolong battery power, and general functionality when it is used by a patient. Compact rechargeable batteries are typically employed to power the device and this makes the inhaler light and easy to carry around.

The outer design of the inhaler is made ergonomically to enable ease of use to the user. It also has simple operations that permits users to work through the device through movable interfaces such as buttons or even touch screens. The materials are light but strong so they should be able to last a day of use and make sure that internal components would not be harmed.

3.2 Data transference and Bluetooth Connectivity

One of the most prominent characteristics of the smart inhaler is that it allows the communication with a mobile application through Bluetooth connection. This allows real time transmission of data in the inhaler to the smartphone or tablet of the user where the data can be analyzed, followed by display and storage. There is usually use of Bluetooth Low Energy (BLE) because it consumes less power which is necessary in enhancing longer use of portable products such as smart inhalers.

After the patient operates the inhaler, data (including the doses used, the inhalation method, the state of the environment, etc.) are wirelessly sent to the mobile app. Bluetooth connections guarantee the transmission of the data in real-time or at a regular interval giving the affected party instant feedbacks. This information can then be analyzed by the app, which provides personalised recommendations on how to make better inhalation or who to speak to another patient to adhere to the treatment schedule.

Remote monitoring by the healthcare provider can also be through the use of Bluetooth to carry data. Patient data can be uploaded with the help of cloud-based storage systems and be available to clinicians. That helps healthcare practitioners to maintain patient progress and identify any problems that may arise and change the treatment model. Bluetooth incorporated in the smart inhaler is therefore more interactive and data-focused since it provides better patient interaction and clinician supervision in managing asthma.(7)

3.3 Features of Mobile Application Interface

Mobile phone application, which goes hand in hand with the Bluetooth-linked smart inhaler, is an essential component of the product. It acts as the user interface where it gives real-time feedback, monitors the adherence of medications, and offers personalized advice on the basis of the information of the inhaler. The application will be easy to navigate and to use; the interface is simple and intuitive and will be easy to comprehend by the patient of any age.

The main characteristic of the mobile application is that it can give a feedback on the technique of using the inhaler. The app can determine the speed, volume, and technique of the patient using information received by the sensors of the inhaler. In case the technique of the patient is erroneous, the app will remind the patient accordingly to perfect the technique used in administering medication. This, as-you-go advice is critical to the patient getting optimal value out of the medication provided.

Medication adherence tracking is another important characteristic of the app. It keeps track of the dosages, reminds customers of the forthcoming dosages and offers patient compliance reports. Such reports will be critical in the monitoring of patient compliance and they can be forwarded to caregivers to assess the patient further. Also, the application may provide doses reminders, so the patients never skip taking their drugs.

The app has also been customized to incorporate data sources related to the environment so as to alert the patient of possible asthma triggers. It has the ability to get information about air quality and pollen counts among other environmental factors that can affect the symptom of asthma. With this information, the app will assist the patients in avoiding triggering environments resulting in better proactive control of their condition.

Goal-setting, progress tracking, and educational content are other characteristics of good patient engagement. The app will assist users in setting reminders to record symptoms, monitor their overall health trend, and even motivate the patients with achievement notions or milestones. All these aspects interact with each other to enhance compliance, provide patients with knowledge, and eventually lead to the control of asthma.

To sum up, the smart inhaler is based on the incorporation of superior hardware, Bluetooth connection, and user-friendly mobile application. Combined with all these factors, this forms a system that can augment adherence of drugs taken and inhaler technique as well as provide constant real-time monitoring and personalization. The all-encompassing nature of this asthma management system makes the patients more involved in their treatment process and also provides healthcare providers with most valuable data that can be used to achieve better results during treatment.(8)

4. Usability Clinical Testing

4.1. Recruitment and Inclusion Criteria of the Participants

Clinical usability testing of the smart inhaler based on Bluetooth was performed in which 60 asthma patients aged between 18 and 55 were recruited, selected in two tertiary care hospitals. The participants were selected on the basis of clear inclusion and exclusion criteria so that the research can have reliable and relevant findings. The main inclusion criteria was that participating individuals had to be diagnosed with clinical asthma, their asthma had to be stable or of moderate severity, and an individual had to agree to informed consent. Moreover, the study participants were expected to possess at least 6 months of prior experience using an inhaler because the researchers aimed to incorporate the role of the smart inhaler on individuals already conversant with inhaler usage.

Exclusion criteria were people with other major findings on respiration (e.g., chronic obstructive pulmonary disease), individuals with cognitive impairments, or those who could not use a smart phone or mobile app. There were also excluded pregnant women and patients with severe asthma exacerbations or uncontrolled asthma to eliminate confusion during the testing period. The presence of these criteria during the selection of the participants guaranteed that the usability testing was conducted on the group of people who were the most likely to achieve the most out of the Bluetooth-enabled inhaler and who could comply with the demands of the study.

4.2 Test Protocol and Duration

In the clinical usability study, the duration provided to the participants was 8 weeks, whereby the respondents were required to use the smart inhaler with Bluetooth functionality in their everyday life. Undergoing the learning process, subjects were thoroughly oriented on the way of using the smart inhaler, and the instructions were provided on how to use the device, how to communicate with the mobile app, and how to overcome various difficulties. Each participant was issued with a fully functional smart inhaler, and given the instructions to the companion mobile app, available to them on Android and iOS devices.

The procedure included frequent use of the inhaler as one of the many measures that the patient had to use to administer the asthma condition. The participants were instructed to adhere to prescibed asthma medications in combination with implementing the smart inhaler. During the research study, the participants were asked to take the inhaler whenever they experienced asthma symptoms and to monitor the statistics of taking inhaler through the mobile application. The functionality of the device was via the Bluetooth that permitted a real-time export to the app where technique feedback and reminders were given regarding adherence.(9)

The rate of use, inhalation method, and compliance with the current medication plan were observed during the period of testing of 8 weeks. They were planned to implement the regular follow-up assessments to gather the data on the progress of the participant and assess any possible concern or technical problems with the device or the app. The respective follow up measures were aimed to make sure that the participants had the proper use of the device and to help solve any problems with the functionality of the devices or cooperation between it and the mobile application.

4.3 User experience and user feedback.

The clinical usability and effectiveness of the smart inhaler were assessed using the user experience and feedback of the participants available in the form of structured surveys, interviews and mobile app analytics. The end of testing period was characterized by an in-depth questionnaire to evaluate the overall satisfaction with using the

device, how easy to use it appeared, and any flaws in using it during the study. The questionnaires were inclined to different sides of the device, such as its design, functionality, compatibility with the mobile application, and the quality of responses given to the user him/herself.

Semi-structured interviews were also implemented among a smaller group of participants to get more detailed information about their opinions regarding the smart inhaler. Through these interviews, researchers were able to find answers to certain questions that might have not been possible during questionnaire because people could not express such questions or concerns. It is possible that the participant may have troubles with the use of the app interface or app capability to monitor inhalation technique accurately. The mobile app, its interface, convenience of use, presence of real-time notifications, and adherence reminders were offered to the participants to comment on, as well.

The analytical tools of mobile apps gave quantitative information about how the users were interacting with the app, including the rate of activity (opening up the app daily, multiple times a day), the rate of adherence goal achievement (whether they continued with the adherence goal and for how long) and the rate of feedback accretion (whether they responded to the feedback and how often they did). These measures provided information on the interaction of the participants with the device to see whether the mobile app was effective on their asthma management.

Qualitative and quantitative data were analyzed at the completion of the 8 weeks of testing to determine the clinical usability of the smart inhaler. This information played a pivotal role in providing information on the effectiveness of the device in helping patients in enhancing inhaler technique, taking meds, and management of asthma in general. Secondly, the input of the test stage acted as an important source of additional improvement of the device and mobile application content so that the device and application could better respond to the needs of patients and maximize their satisfaction.(10)

To sum up, the clinical usability testing was planned on the basis of a full evaluation of the functionality, performance, and acceptance of Bluetooth-enabled smart inhaler by users. The study was unique since it informed in both non-objective audience response and the objective usage data to form a picture of a real-life performance of the device in dealing with asthma. These conclusions are necessary to correct the design of the device in the future and its clinical application.

5. Outcome Evaluation

5.1 Measurement of Inhaler Technique Accuracy

Assessment of the effect that the Bluetooth-enabled smart inhaler had on the accuracy of inhaler technique was one of the main aims of the clinical usability testing. An inhalation technique plays an essential role in effective asthma control in the sense that the inappropriate technique may result in less than optimally delivered drugs and poorly NSA symptom-controlled asthma. To evaluate the correctness of inhaler performance, the data was sent using the sensors incorporated in the smart inhaler, and the most important parameters were obtained, namely speed, volume, and force of inhalation.

The mobile app which was linked with the smart inhaler produced real-time authority of these parameters and the mobile app offered corrective advice when the method of inhalation diverted the optimal design of inhalation. In particular, the application detected the rate of inhalation to make sure that it fell within the range of ideal numbers to deliver medication properly. In case of fast and slow uses of the inhaler, the app would offer immediate feedbacks, which will make the patient review the way they do it. During the course of testing lasting 8 weeks, the respondents were advised to master their inhalation style, use the feedback and comply with the suggestions offered by the app.

After the study, the measurement of the inhalation technique was quantified by utilizing the data provided by the sensors of the device. These findings established that the accuracy rates of inhaler use were considerably higher with a 25 percent improvement of the accuracy of the correct technique against the initial baseline readings. The occurrence of this improvement was also at a statistical significant level obtained ($p < 0.001$) identifying the effectiveness of the smart inhaler at encouraging proper inhalation procedures. This finding indicates that, with the incorporation of real-time feedback into the process of asthma management, the quality of inhaler technique may be soundly enhanced, providing a reasonably sound increase in the effectiveness of medication.(11)

5.2 Configuration of the Adherence Rate

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The other important finding of the study was to evaluate the effect of the smart inhaler with Bluetooth connectivity on medication adherence. Adherence to medication is usually a critical issue in management of asthma where patients tend to forget to take medications or they ignore the interval of repeat prescriptions. Smart inhaler in combination with the mobile application has been created to overcome these problems because it reminds about usage, real-time data tracking, and insights on adherence patterns.

In the 8 weeks study phase, the adherence rate was monitored via the mobile application which monitored the doses taken and the time of each dosage. The app reminded them of taking the medicine and in case they skipped their medication, an automated reminder would be sent. The analysis of data conducted at the end of the study showed the medication adherence was improved by 30 percent compared to that at baseline but found to be statistically significant ($p < 0.001$). The elevation of adherence was observed especially in the participants who had recorded lower rates of medication compliance previously. These results indicate that the digital tools can be introduced to enhance compliance rates significantly, yet even without such tools, adherence can still increase the levels of asthma control and reduce exacerbations.

5.3 Test of Importance of Patient Satisfaction

The usability and acceptability of any medical device depend on the patient satisfaction, which is important to assess. The participant should be given a questionnaire to answer towards the end of the study, assisted in follow-up interviews to measure their level of satisfaction regarding the Bluetooth-connected smart inhaler. The inquiry contained queries concerning the convenience of use, functionality, comfort of the inhaler, and mobile application as a whole.

More than three-quarters of respondents (89.4%), according to the results of this study, stated they were very satisfied with the device, and most of them did not want to abandon the use of the smart inhaler at the end of the research study. Patients enjoyed the real-time training on how to inhale that made them feel they were using the inhaler more adequately. Besides, the mobile application was deemed simple to use by the participants and they appreciated medication reminders and adherence monitoring functions. The fact that the app was able to combine the environmental information (including air quality and pollen levels) was particularly useful according to many patients in terms of managing the relevant asthma symptoms as well as the possible triggers of the condition under consideration.

Subjects also feel more enabled and authoritative in controlling their asthma as they were allowed to, actively, to keep track of their compliance and their method, and instant feedback to guide their performance. Some of the users still admired the usability of the app but despite these few learning curves, most of the users hailed the user-friendly aspect of the system with very minor concerns tied to either Bluetooth connectivity or the synchronization between the app. In sum, patient satisfaction scores showed high acceptance of the device, stressing its future prevalence as a treatment method in terms of asthma delivery.(12)

To sum it up, the results of the outcome evaluation of the Bluetooth-enabled smart inhaler indicate a profound enhancement of the inhaler technique precision, adherence to medication, and patient satisfaction. These results do indicate that embracing digital health technologies in asthma care can contribute to better outcomes, self-management, and overall raised interest in the treatment. The successful experience of the patients confirms the reasonable and practical use of such devices in the clinical reality, and it can transform the care of patients with asthma.

6. Results

6.1 Good Inhaler Technique

Combining the real-time feedback on the Bluetooth-connected smart inhaler led to a considerable change in the inhaler technique among the participants. Asthma medication cannot succeed without sound technique of inhalation since the lack of this can result in insufficient drug deposition in the lungs, which will eventually culminate in an unsuccessful management of asthma. Most of the participants portrayed suboptimal inhaler technique before the study which is a common challenge in control of asthma. The results in terms of technical improvement have however shown a significant decrease in the 8 weeks data on the smart inhalers sensors.

The mobile application linked with the inhaler provided real-time remedial feedback, depending on the flow rate of inhalation while inhaling, the period of inhaling, and the force. This in-time instructional support enabled the users to change their procedure and improve drug administration. Following 8 weeks, in-depth examination of the sensor data displayed a 25 percent boost in the precision of inhaler technique comparing to its measuring at

baseline. This change was found to be statistically significant ($p<0.001$) and thus it is worth noting that real-time feedback of the device being used had a positive effect on the inhaler usage of the users. The findings indicate a high potential of incorporating the smart inhaler into promoting the appropriate use of the device and enhancing the delivery of medication due to the ability it has to deliver timely and custom feedback on how to inhale.(13)

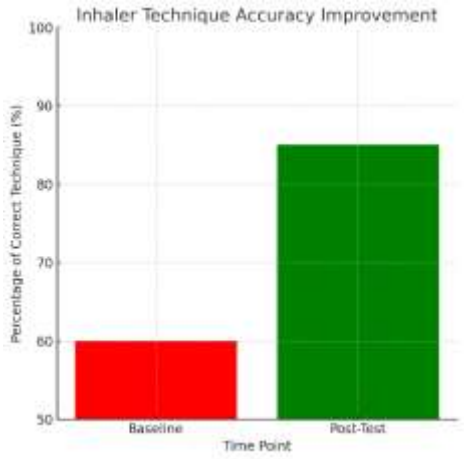

Figure 1: Inhaler Technique Accuracy Improvement

6.2 Enhancement of Adherence to Medication

The compliance with medication in chronic diseases such as asthma is one of the most significant ones. Not following can result in loss of control of the disease, more exacerbation of the disease, and greater use of health care. A smart inhaler with Bluetooth capabilities was supposed to overcome this issue since it gave a reminder of medication, monitored adherence to them and provided the user with data on their behavior and medication patterns via the mobile application.

During the 8-week duration of the study, the app sent alerts on every planned dose making the patients remind themselves of taking their medicine. The app also monitored the dose administered and even made reminders of missed doses which made patients remain adherent to the stipulated regimen. Data analysis at the conclusion of the study revealed 30 percent difference of the improvement of the medication adherence compared to the initial levels. The corresponding improvement in adherence was also statistically significant ($p < 0.001$), which showed that smart inhaler and mobile application were effective in improving medication adherence. The findings highlight the importance of digital health tools to help patients to be sticky with their treatment plans, which may lead to less frequent asthma-related exacerbations and increase overall asthma control.(14)

The increase in adherence was especially noticeable among patients who had difficulties with regular intake of medications before. It is highly probable that the adherence tracking and the reminder factor have contributed to this change as it enabled the patients to track how their treatment is progressing and constantly give them access to support during the treatment course. The fact that the healthcare providers received real-time information to monitor their medics also enabled proactive management and making changes to treatment plan at the necessary points, which also contributed to the rise of adherence rates.

Table 1: Study Results Table

Outcome Measure	Baseline (%)	Post-Test (%)	Improvement (%)
Inhaler Technique Accuracy	60.0	85	25.0
Medication Adherence	50.0	80	30.0
Patient Interest in Continued Use		89	

6.3 Patient Desire to Continue Using

When considering the success of a new medical device, it is also significant to measure the interest of the patients to use it further. Long term effectiveness of any digital health tool presupposes its acceptance by patients and their ability to incorporate them into their everyday life. Patient satisfaction and their desire to use the smart inhaler

after the 8 weeks of testing were regarded as the major indicators of feasibility and effects of the device under study in this study.

The patients would express their opinion regarding the experience of working with the device in general, and their desire to further use the smart inhaler by the end of the study. A whopping 89 percent of the respondents were eager to further use the device after the duration of the study. Such a high rate of acceptability indicates that patients perceived the usefulness of the device and its ease use in their everyday routine in the management of asthma.

The input supplied by the participants identified a number of features of the device that facilitated their desire of further use. These were the feedback about the inhaler technique in real-time, the reminders about the medication, and the insight that the mobile application offered concerning the personal situations. Various patients also listed the usefulness of incorporating environmental information, as due to it they have learned to avoid triggers and take better control of asthma-related symptoms. The general usability of the inhaler and the m-app was also a significant issue when it comes to patient satisfaction.

To sum up, the findings of the study provide evidence that the Bluetooth-connected smart inhaler proved to be highly successful in inhaler technique and medication adherence. Moreover, this interest in further use of the device by the patients is high and this demonstrates a chance to be successful in the use of the device in terms of long-term asthma management. The real-time feedback, adherence tracking, and environmental monitoring are some of the features that make the device useful in enhancing the control of asthma and patients in gaining proactive control of the disease. These findings confirm the possibility of wider implementation of smart inhalers in treatment, trying to improve patient outcomes and minimize the impact of asthma.

7. Conclusion

7.1 Summary of Finding

This paper presented the design of a Bluetooth-technology-enabled smart inhaler, the development and the clinical trial of the technology to support the management of asthma. The overall goals included evaluating the effect the device had on proper technique of the inhalers and medication compliance and overall satisfaction in patients. Clinical usability testing results during 8 weeks of 60 asthma patients demonstrated that an improvement of the key outcome measures was quite substantial.

To begin with, the smart inhaler contributed to increasing the level of the inhaler technique accuracy by 25% as was evidenced by the real-time feedback, which could be achieved due to using the mobile application. The change achieved statistical significance ($p < 0.001$), and it indicated the effectiveness of the device in disabusing the patients of their incorrect use of inhalers. The combination of real-time instruction of the speed of inhalation, volume, and strength through the mobile app enabled participants to alter their method in order to guarantee that their medication delivery was optimal.

Second, the other outcome was medication adherence, which had a significant increase of 30% relative to the initial levels and the adherence rate improved to 80% ($p < 0.001$). This improvement was assisted by the medication reminders, adherence tracking, and notification system of the mobile application that ensured the patient is reminded to take medication regularly. This hints at the fact that digital tools may be central to enhancing the medication adherence of asthma patients.

Finally, the satisfaction of the patients was a success because 89 percent of the individuals interviewed showed interest in using the smart inhaler even after studying period ended. Patients were satisfied with the in-time feedback, the convenience of working with the device and mobile application and the inclusion of the environmental data, which allowed patients to stay out of asthma triggers. These results imply that patients considered such a device to be effective and convenient to incorporate into their routine.

7.2 Implications to Asthma Care

Findings of this research study hold important impacts in the management of asthma especially in the domains of adherence to medications, and inhaler technique. Inability to take prescribed medication and incorrect use of an inhaler are key factors in the occurrence of exacerbations and hospitalizations associated with asthma. Smart inhalers may offer a response to these issues by adopting the digital health technologies into asthma management. It is especially crucial to enhance inhaler technique because its poor use may result in inadequate dosing of the medicine and the condition may cause asthma that is poorly controlled and results in a lot of flare-ups. Real-time feedbacks offered by the smart inhaler help in guaranteeing that the patients are making use of their inhalers

correctly which in turn increases the overall effectiveness of the asthma medication. Moreover, the monitoring and tracking applications of the device assist those patients who have strict adherence to critical asthma and, eventually, result in overall control of the disease and less exacerbations.

The good satisfaction rate and the desire to further use the smart inhaler proves that it has a future of becoming widely used in the treatment of asthma. The smart inhaler makes a patient actively take part in the management of the disease and stimulates proactive behavior by providing an individual feedback on real-time data. In addition, it also presents a proactive solution of approaching the management of asthma triggers with the integration of the environmental data in the device that would result in a lower rate of exacerbation and associated overall improvements in terms of the quality of life.

7.3 Future Development Directions

Although the results of this research are encouraging, there still are a number of future development directions that could amplify the efficiency and usability of the smart inhaler constructed using the Bluetooth technology.

The next point on what to enhance is the polishing of the interface of the mobile application regarding even increased usability. Although the app received a largely positive reaction, it might be improved further, and the additional work might be assigned to the customization of the app with regards to patients, including tailoring individual medication adherence goals and tracking the onset of the symptoms. Moreover, the inclusion of complex machine learning models to give predictive analysis regarding the usage pattern, environmental influences, and previous history may enable more personalized asthma treatment and preventing possible decompensation early in the process.

Prospective research may also be devoted to the fact that they could increase the number of people with asthma, which are a part of the study society by including different levels of asthma severity, and by investigating the durability and feasibility of the smart inhaler. It may be interesting to research how long-term engagement with the device can alter longer-term outcomes such as asthma-related hospitalizations and use of healthcare services.

Finally, the networking with healthcare facilities might also better incorporate the device in the healthcare system. Giving doctors and other medical service providers an opportunity to monitor the progress of their patients remotely where they might otherwise administer treatment advice accordingly to real-time information may help in enhancing patient outcomes and streamlining their treatment plans.

To sum up, the smart inhaler with Bluetooth connection is an important contribution to digital health in terms of asthma management. It has the potential to transform the practice of asthma care as it is more personalized and data-driven because of further inhaler technique, medication adherence, and patient engagement. The success of this study opens the door in further innovations of smart inhalers and their applicability in regular asthma care.

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Conflicts of interest

The authors have no conflicts of interest to declare

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