ABSTRACT

Medication adherence refers to whether a patient correctly follows their prescribed schedule for a medication and to whether a patient finishes the course of their medication. Medication non-adherence is a growing concern in the medical field, with improved patient outcomes and more effective (and potentially less) prescription drug costs as the prize for making even incremental progress in solving this issue. While there are many causes for non-adherence, two of the most important are misinformation and poor information flow between patients and care providers, especially with regards to side-effects.

Adhere is a system that aims to improve outpatient medication adherence by utilizing patients’ phones through a dedicated mobile application to track medication adherence and report the state of their adherence to their medical providers along with information patients enter into the system about side-effects they encounter and reasons for non-adherence. Adhere analyzes patients’ medication-taking in comparison to their past behavior and alert their medical providers to any potential issues as they occur, resolving any issues in less time than waiting until the patient’s next check-up would take. Adhere’s purpose is to improve information flow between patients and care providers so that patient medication adherence is maximized and the best outcomes for all parties involved are achieved.

1. INTRODUCTION

1.1 Background

Medication adherence refers both to whether a patient correctly follows their prescribed schedule for a medication and to whether a patient finishes the course of their medication. There is a growing concern in the medical field, both on the side of physicians and other care providers as well as on the insurance and payer side about the impact medication non-adherence has on health care outcomes and costs [4]. In fact, for patients with chronic illnesses, the non-adherence rates can rise to around 50% and can vary from treatment to treatment in a regimen for a patient [3]. An enormous amount of money is spent on prescription drugs every year, approximately $260 billion in the USA in 2010 alone, and the efficacy of this expenditure in producing positive patient outcomes is almost entirely reliant upon patients taking their medication correctly [6].

The most seriously affected by medication non-adherence are those with chronic conditions as they have the complex regimens, such as patients with advanced heart failure, a small population that is particularly vulnerable. Most patients with chronic conditions are often prescribed a regimen with a cocktail of drugs they must take, with each drug having its own schedule and number of doses to take, which can quickly become very complex. Additionally, there are many factors that can lead to medication non-adherence, such as demographic, psychological, social, medical, and disease-related [3].

There are many benefits to increasing medication adherence. Patients will enjoy better control over their condition (which could be a life-or-death difference for some populations), better relationships with their care providers, and a reduced rate of re-hospitalization. Providers will gain a better insight as to outpatient care for the patients and will be able to provide better care by following patients throughout their therapy, not just at check-ups.

Insurance providers and the overall health system will benefit by gaining a better insight into medication non-adherence related re-admissions into hospitals and will potentially have lower costs in the long-run as patients are better able to manage their conditions and will require fewer hospital re-admissions. Currently, 33–69% of all medication-related hospitalizations are due to poor medication adherence, costing over $100 billion a year [10], so even a modest reduction in medication non-adherence could have a major impact in healthcare costs.

1.2 Contributions

We have implemented a medication adherence system named Adhere which consists of a mobile application for iOS devices, pill bottles tagged with QR codes1, a backend database, and a doctor-patient interface. The mobile application reminds patients to take their medication, verifies that they take these medications via scanning the pill bottles’ QR codes, asks them if they have any of the common side-
effects associated with the medications in their regimen, and securely sends this information to the backend database. The doctor-patient interface allows doctors to track patient medication adherence, alerts doctors to any medication issues, and allows them to input patients and medication regimens into the system. Adhere analyzes patients’ medication-taking behavior by comparing it to their peers and to their own past histories to generate alerts to their healthcare providers.

Adhere’s primary goal is to be an easy-to-use and cost-effective application. It also provides doctors with real-time information on their patients’ medication adherence. By focusing on improving doctor-patient interactions (along with the information flow between the two), the system will address some of the major predictors of medication non-adherence.

2. RELATED WORK

While there are a number of causes of medication non-adherence, it has been shown that lack of support, poor doctor-patient relationships, adverse side-effects, and regimen complexity are important factors in patients having lower regimen adherence [3]. While addressing many of the causes of medication non-adherence mentioned in Section 1 can be difficult, these factors are much more tractable to solve and can also provide desirable outcomes [3]. Currently, it is difficult for care providers to determine adherence well, and while there are many different ways of measuring medication non-adherence, they all are deficient in one way or another and no method is considered the gold standard [10]. Detection methods are presently split into direct and indirect methods.

2.1 Methods of Medication Adherence Detection

Direct methods such as directly observing the patient taking the medication or measuring a drug marker in the patient’s blood can be accurate but tend to be expensive both in time and money and can suffer from patients simply hiding pills in their mouths and differing patient metabolisms leading to non-standard metabolite readings [4].

Indirect methods such as patient surveys, pill counts, and rate of prescription refill can be simpler, but are often divorced from the actual act of taking medication and so do not as easily measure adherence to schedule or are easier for patients to misrepresent their medication adherence [4]. Patient self-reporting, one of the earliest methods explored, is fairly effective and simple to implement. However, it does not provide information on the patient’s drug adherence to the healthcare provider on a timely basis nor does it allow for regular information flow between patient and healthcare provider, which can be important in resolving adherence issues quickly [10].

Electronic monitors such as smart bottles, an indirect method, have been used in one form or another for approximately the last 30 years to track timestamps for when medicine containers are opened. These do provide some of the most accurate and valuable information data on medication adherence because they provide information on actual dispensings and not averages. However, they suffer from some of the same shortcomings as the other indirect methods, namely that they only record that the bottle has been opened, not how much medication has actually been taken by the patient. In addition, these systems are expensive and often not covered by insurance, so they are almost exclusively used in drug trials and in very high risk patients [10].

While individual methods often do not provide acceptable results, using more than one method at a time has been shown to produce better outcomes, largely due to the fact that medication non-adherence is usually due to more than one factor [4]. In addition, many of the more successful monitoring programs have included a component of regular follow-up with healthcare providers [4].

2.2 Implementation of Medication Adherence Detection

One implementation of a medication adherence detection system that is currently available in the market is called Glowcap Connect [2], which consists of electronic pill bottle caps produced by a company called Vitality. Each cap is wirelessly connected to the internet and is associated with a prescription drug and its schedule, reminding patients to take medications by playing a specified tune. In addition, the system keeps track of daily doses taken by each patient by counting the number of times the bottle cap is opened. Vitality compares the data obtained from these bottle openings to the schedule prescribed by the patient’s healthcare providers. When there is any inconsistency between these two data sets, providers, relatives, or patients themselves are alerted via email. The patients’ pharmacies are also able to send them reminders to refill their medications with incentives and coupons.

This technology is able to address several of the causes of medication non-adherence such as poor information flow between patients and providers and a lack of social accountability for patients. However, there are still some barriers that prevent customers from using this particular product. One aspect is cost: each pill bottle cap costs $30 which may not be a reasonable price for many patients [2]. Patients would also have to be willing to purchase a dedicated device to replace the caps for pill bottles they are already using and if the patient suffers from a chronic condition, they are likely to be taking more than one medication at a time and would have to buy separate pill bottle caps for each medication they have been prescribed [2]. The system also fails to address other important causes of non-compliance such as unpredicted side-effects, one of the most prevalent reasons for patients to stop taking any medication [10].

Adhere addresses these shortfalls. By starting with patients self-reporting, the core of the system remains simple while still using one of the more effective of the less-costly indirect adherence detection methods. Adding to this, Adhere tackles some of the potential issues aside from regimen complexity or forgetfulness such as adverse side-effects by enabling the patient to report, at the time of medication taking or prompting, whether they are suffering any of the common side-effects or other reasons for non-adherence. It will also allow doctors to be alerted by only potential issues in adherence, so that issues can be addressed as quickly as possible and underlying causes more easily found. By using patient’s existing devices2, this system should reduce incremental cost at least over hardware solutions such as the

2Though not all patients may have the smartphones targeted in the initial version of the system, many components could be translated to work over Short Message Service (SMS), which would make it available to all mobile phones in later versions.
GlowCap. This should increase accessibility of the service and its hopefully improved outcomes for a broad population as preexisting approaches that perform well tend to be very expensive and burdensome and are typically only used in high-risk situations such as with tuberculosis and HIV [10]. Those systems that are more cost-effective help ensure that the patient receives their medication, but do little to verify whether they have actually taken it or not, and if they have taken it on the correct schedule. By allowing the doctor and patient to exchange information on a more consistent basis rather than waiting until the next check-up (with its associated costs) to report any issues, this approach can only improve the doctor-patient relationship and help to ensure the best possible outcomes for the lowest possible additional cost.

3. SYSTEM MODEL

Adhere’s primary purpose is to serve as an affordable, user-friendly system that improves outpatient medication adherence by being a system that utilizes patients’ phones, through a dedicated mobile application, to track their medication adherence and report the state of their adherence to their medical providers. Adhere uses this data stream to compute patients’ medication adherence and alert doctors if their medication adherence drops below preset levels. Additionally, the system periodically provides patients with a list of common side-effects for their prescribed regimens and asks if they exhibit any of the side-effects, passing along this information to their healthcare provider so that any potential issues can be addressed as quickly as possible.

3.2 Patient Mobile Application

From the list of medications prescribed to the patient, the mobile application generates the schedule for all of their medications to be taken on a given day, prompting users to report taking their medication after a delay if they have not by the scheduled time. If the application prompts the user to take their medication but the patient is unable to do so at the time (e.g. not at home, or busy with something), they are able to put the reminder into a snooze mode so that it will remind them later instead of canceling the notification altogether or scanning the medication’s QR code (3).

3.2.1 Scheduler

The scheduler is designed to be as simple as possible, merely taking in the different medications the patient has been prescribed and returning a list of times for the day when the patient should take their medications to follow the instructions. When the patient should take their medications is used as the bounds of adherence-mode as recommended by Dr. Reilley. If the patient takes his or her medication outside of these bounds more than a preset percentage (100% − 90% = 10% by default) of the time in a week, they will be put into non-adherence mode. The side-effect questions asked the patient will also be used in order to flag patients for follow-up, although that flag will be separate from the flag the relative and absolute measures outlined in this section. The results of these tests is summarized and sent to doctors as daily alerts so that potential issues can be addressed as soon as possible.

3.1 Backend Server

The backend server serves as the data store for the system, storing patient, doctor, and medical information. It facilitates generation of pill bottle cap barcodes using existing available libraries (the reading of which is detailed in Subsection 3.2.2), which are simply printed on standard paper and taped to the inside of patients’ pill bottle caps. Additionally, the system’s analytics software resides on the backend server, where analyzes the medicine-taking data looks for when patients’ medication adherence rate falls below preset levels (usually 90%).

3.1.1 Database

A relational database will be used to store information about doctors, patients, prescriptions, medication-taking, and side-effects. Patients are associated with their doctors in the database and also with their prescriptions, both the schedule, medication, and amount. Medications are stored alongside their commonly reported side-effects (both for the general population and any particularly affected subgroups). This side-effect data will be sourced from the United States Food and Drug Administration (FDA) database3. When a patient indicates to the mobile application component that he or she has taken one of their medications, the data the application sends to the backend server (timestamp, which medication, any side-effects reported, other concerns) is recorded in this database.

3.1.2 Analysis

For analysis, Adhere uses absolute measures of non-adherence in order to determine whether a given patient is in non-adherence mode or not. The most relevant data point is Δ = [(time supposed to take medication) - (timestamp pill bottle QR code scanned)]. The limit of 2 hours either before or after when a patient is supposed to take his or her medication is used as the bounds of adherence-mode as recommended by Dr. Reilley. If the patient takes his or her medication outside of these bounds more than a preset percentage (100% − 90% = 10% by default) of the time in a week, they will be put into non-adherence mode. The side-effect questions asked the patient will also be used in order to flag patients for follow-up, although that flag will be separate from the flag the relative and absolute measures outlined in this section.

The results of these tests is summarized and sent to doctors as daily alerts so that potential issues can be addressed as soon as possible.

### Figure 1: Diagram of System

As seen in Figure 1 with the blue component numbers, the system can be split into three main components: the backend server (1), the mobile (recent iOS devices for first iteration) application residing on patients’ phones (2), and an interface for doctors and other healthcare providers to access the raw data and generated reports (3). These components and their constituent subcomponents are detailed below.

3.2.2 Scheduler

The scheduler is designed to be as simple as possible, merely taking in the different medications the patient has been prescribed and returning a list of times for the day when the patient should take their medications to follow the

3https://rm2.scinet.fda.gov/druglabel/
schedule in their prescription (e.g. delays between dosages or batching together if no schedule is needed).

3.2.2 QR Code Scanner

In order to identify which medication the patient is taking, the mobile application uses the patient’s smartphone’s camera to take a picture of a specially generated QR code printed on the inside of the pill bottle cap. QR codes are a kind of two-dimensional barcode (an example can be seen in Figure 2) that can encode digital data in either numeric, alphanumeric, or binary forms [5]. The QR codes Adhere uses contain an encoded representation of a unique identifier assigned to each patient’s prescription for a specific medication, which is used in the application to report which medication the patient has just taken.

![QR Code Image]

Figure 2: Example of a QR Code created by the author that encodes the identifier ‘1234567890’

QR Codes are used as they are free to use and low-cost to print and attach to objects like patients’ pill bottles. Alternative methods of transmitting the same prescription data to the smartphone, like Near field communication (NFC) chips, cost more and are less-well-supported in smartphones.

3.2.3 Side-effect Recorder

The mobile application queries the backend server, given the patient identifier, to compile a list of the most common side-effects from the patient’s current medications. After the patient has recorded taking their medications, the application will occasionally ask the user if they are experiencing any of the side-effects on this list. This data is then sent to the backend server, which, if any are selected, will alert the patient’s healthcare providers that there may be a potential issue. The patient, alongside with reporting the general category of side-effect (e.g. nausea, headache), is able to send a detailed message to their healthcare provider.

3.3 Doctor/Healthcare Provider Interface

The analyzed stream of information is presented to the patients’ healthcare providers on a private website so that they can monitor their patients’ medication adherence. They can also make changes to a patient’s drug regimen if there have been any changes. Once a day, a summary report will be generated and an email to view this report will be sent to the doctor if there are any updates such as a patient’s adherence dropping below preset levels or new side-effects are reported.

3.3.1 Emails

At the end of every day, if the analytics runtime detects that there are any issues identified that should be brought to the healthcare provider’s attention, it will send out an email containing a link to a generated report. This report provides an overview of the healthcare provider’s patient population and provides a quick update of which patients have had their adherence rates drop below preset levels or have reported new side-effects in the past day. We cannot send the report to the healthcare provider in the email itself as, short of encrypting the contents of the email with a key provided by the doctor, it is difficult to prevent the message from traveling in plaintext at all or from being stored in an insecure manner that may jeopardize patient privacy.

3.3.2 Web

Doctors are able to log into and view a web dashboard in which they can view patient’s reported adherence over time, see any issues they report, adjust their medications and schedules for taking them, and send new patients an onboarding code which will set up the application on their phone.

4. SYSTEM IMPLEMENTATION

Adhere uses a virtual server hosting various custom-built and open-source components to serve as the backend server, an Apple iOS mobile application to serve as the mobile application, and a web application hosted on the backend server to serve as the provider interface. Overall, implementation details were chosen to be performant while remaining low-cost. The backend generally serves as the data store and analytics hub, accepting data from and providing this information to healthcare providers via the provider interface and to patients via the mobile application API. The mobile application uses this data to scheduler reminders for patients on their phones and allows them to record pill takings and experienced side-effects.

4.1 Backend Server

For the backend server, Adhere uses a Virtual Server from Linode running the latest version of Ubuntu Linux Server. This server is used to host both the provider interface as well as the API that the mobile application connects to. It also hosts a Postfix Simple Mail Transfer Protocol (SMTP) server so that the provider interface is able to send notification emails.

4.1.1 Database

Because of the volume and structure of the data Adhere must collect and retain, it uses a relational database to store this data. Adhere uses PostgreSQL as its relational database to store all physician-patient, regimen, side-effect, survey, and medication-taking data.

4.1.2 Analytics

The analytics system described in Section 3.1.2 has been implemented in Python as a system that reads in patient and schedule data from the PostgreSQL server, iterates through linearly in time to match pill-takings to their prescribed times. Those which are taken outside of a 2 hour band before and after prescribed times flag the prescribed taking as

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3https://www.linode.com/
4http://www.ubuntu.com/
5http://www.postfix.org/
6http://www.postgresql.org/
The system tallies up the adherent and non-adherent buckets and computes a percentage adherence for various timescales. This is compared to the preset reference values to flag patients as adherent or non-adherent.

### 4.1.3 Provider Interface & API

The provider interface consists of an application written in Python and using the Django framework sitting behind a nginx webserver. Due to the benefits of sharing much of the same codebase, the API which the mobile application connects to is implemented as a part of the provider interface website.

The provider interface side allows healthcare providers to log in, view an overview of their patients’ current status, drill down into the specific medications and adherence for a given patient, and view their daily reports. It also allows the healthcare provider to set adherence targets, view reported side-effects, and enter new patients and prescriptions into the system. Currently, it is the provider interface that also generates the QR Codes that are printed and affixed to patients’ pill bottles.

The API component allows the mobile application to securely authenticate a given patient, get the patient’s prescriptions and medication schedule, record side effects, and record medication takings. When a patient scans a QR code, this API will also validate the prescription and whether the current pill-taking is an adherent one (within 2 hours of prescribed).

### 4.1.4 Emails

Every night, a scheduled job runs on the backend server that collects the information generated by the analytics subcomponent per doctor and generate a condensed report of potential problems based on lapses in medication-taking or other problem as indicated by the side-effect questioner or the surveying. This report will be stored at a doctor-accessible location in the web interface and an alert email will be sent to the doctor via the backend server’s SMTP server indicating that their report for the day is ready.

### 4.1.5 Security

Because this segment of the system stores patient data for analysis and lookup, it must be robust security-wise in order to protect this data. Data flowing into and out of this component in transit is encrypted with Transport Layer Security (TLS) to prevent interception [9]. While it would be impractical for Adhere to encrypt the information on the database due to the later analysis of the drug-taking data, industry-standard authentication techniques are instead used to prevent unauthorized access to the data once it is on the backend server.

### 4.2 Patient Mobile Application

The first version of Adhere’s mobile application targets Apple’s iOS operating system, specifically targeting devices with an adjustable focus lens (to be able to take an adequate picture of the QR code for decoding). This means that iOS devices from the iPhone 4 and more recent, as well as equivalent iPad and iPod Touch models, will be able to use Adhere. Other sections of the system are implemented in such a way that, in the future, developing mobile applications for other platforms would be simplified.

#### 4.2.1 Scheduler

Consultation with Dr. Reilley revealed two general categories of prescription schedules: those which require the patient to take his or her dosage amount a certain number of evenly spaced times per day and, as an extension to the previous case, those which exhibit the former schedule type for a certain duration alternated with a period of time in which the patient does not take any medication. With these assumptions, creating the schedule becomes fairly trivial (e.g. a prescription of taking medication twice a day becomes a recurring reminder for every 12 hours, perhaps at 9am and 9pm daily). The scheduler consists of custom-built software that is allows the provider to specify one of a handful of preset recurrence patterns as above (e.g. daily, specific days of the week, times during the day) for individual prescriptions and then compute an overall schedule for each patient for a given day and time.

#### 4.2.2 QR Code Scanner

Adhere’s mobile application uses commonly available open-source libraries within the mobile application to error-correct the image of the QR code and decode it. Specifically, it uses the open-source third party library CDZQRScanningViewController in order to handle the decoding of QR codes on patient’s pill bottles. It is able to present a page within the mobile application to scan the QR Code and to allow the user to turn on the phone’s flash to get a better reading in low-light conditions. Upon successful scan, custom-built components of the mobile application combine the scanned data with the timestamp and the patient’s identifier and submit this as a pill taking to the backend server’s API.

The application receives a confirmation that the pill taking submission was successful, prompting the user to continue. If the pill taking is outside of the standard 2 hour band around the schedule dosage, the user is notified instead that the pill taking is not valid at the current time, allowing them to override this (e.g. if the patient is taking it late).

#### 4.2.3 Security

Part of the motivation to develop an iOS application first was because Apple provides APIs in the iOS framework that can be used to achieve an acceptable level of privacy and security for potentially sensitive patient data. Applications on the iPhone are able to use these APIs to ensure any data files they use are encrypted on storage and the entire contents of the phone can be remotely erased if lost, mitigating potential data leaks if the patient’s phone is lost or stolen. The iOS operating system also offers support for secure transport layers like TLS, which Adhere’s mobile application uses to ensure that patient’s data is protected while being sent to the backend server’s API endpoint [1].

### 5. RESULTS

Our primary result was the Adhere platform itself with it’s above-described components which is already in a form that doctors and patients can use to record medication adherence and report side-effect data.

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8https://www.djangoproject.com/
9http://wiki.nginx.org/Main
10https://github.com/cdzombak/CDZQRScanningViewController
MediSafe, a simple mobile application that reminds patients of when to take their medication and tracks the patients’ adherence rates, reported that its users have an average adherence rate of 81% [7]. That is 31% higher than the national average of 50% reported by the World Health Organization. Given that Adhere improves upon these similar products it is reasonable to expect that it will be no less effective and potentially even more effective.

In order to ensure patients would be able to scan their pill-takings into the system, Adhere’s QR code scanning capabilities were tested extensively and this capability was found to be robust: the scanner can recognize a QR code from up to 1 foot away and up to a 45° angle from the QR code. Importantly, it can also still read the QR code when it is pasted on the curved surface of a pill bottle under these same conditions.

We furthermore conducted a survey in order to assess medication adherence in the University of Pennsylvania population and to determine the potential impact that Adhere could have when launched and used, the results of which are below.

### 5.1 Survey Results

The general population was surveyed in order to assess medication adherence in the general population and to gauge baseline medication adherence levels. We administered the Morisky 8-Item Medication Adherence Questionnaire (Appendix A). This survey was chosen because it has been validated in the literature as a valid way to assess medication adherence [8]. Full results from the survey can be seen in Appendix 5.1.

<table>
<thead>
<tr>
<th>Totals</th>
<th># of Respondents</th>
<th>% of Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Adherence</td>
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<td>86%</td>
</tr>
<tr>
<td>Medium Adherence</td>
<td>13</td>
<td>14%</td>
</tr>
<tr>
<td>High Adherence</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Total</td>
<td>96</td>
<td>100%</td>
</tr>
</tbody>
</table>

#### Table 1: Respondents Level of Adherence

This survey (the overall results of which can be seen in Table 1) shows the general population has a problem with medication adherence; 86% of the 96 people surveyed exemplified low adherence according to the survey. This survey demonstrates a great need for a system to help improve medication adherence and demonstrates a low baseline level of adherence. The survey also included information about the Adhere specifically targets people who answered “yes” to questions one, two, three, six, and answered “never/rarely” to question eight:

1. Do you sometimes forget to take your medicine? (Forgetting to take medication) Our system provides reminder alerts on the patient’s iPhone to help them remember to take their medication.

2. People sometimes miss taking their medicines for reasons other than forgetting. Thinking over the past 2 weeks, were there any days when you did not take your medicine? (Not communicating with your doctor about why you aren’t taking your medication to your doctor) Our system alerts doctors when their patients medication adherence rate falls below 90%, this will allow doctors to contact and talk to the patient about why they aren’t adhering to their medication.

3. Have you ever cut back or stopped taking your medicine without telling your doctor because you felt worse when you took it? (Side Effects) Our system allows patients to report side effects directly to their doctor. This allows doctors to be aware of these problems and work with the patient to find a solution.

4. When you feel like your symptoms are under control, do you sometimes stop taking your medicine? (Not communicating with your doctor about you aren’t taking your medication to your doctor) Our system alerts doctors when their patients medication adherence rate falls below 90%, this will allow doctors to contact and talk to the patient about why they aren’t adhering to their medication.

5. How often do you have difficulty remembering to take all your medicine? (Forgetting to take medication) Our system provides reminder alerts on the patient’s iPhone to help them remember to take their medication.

81% of respondents answered “yes” to question number one, 55% of respondents answered “yes” to question number two, 34% of respondents answered “yes” to number three, 36% answered “yes” to question number six, and 81% didn’t answer “never/rarely” to question number eight. By targeting these patients Adhere has the potential to improve medication adherence. We evaluated the maximum potential for application by analyzing adherence if all of these patients used Adhere and changed their answers to reflect high adherence (answered “no” to questions one, two, three, and six, and answered “never/rarely” to question eight).

<table>
<thead>
<tr>
<th></th>
<th># Respondents</th>
<th>% Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Adherence</td>
<td>21</td>
<td>22%</td>
</tr>
<tr>
<td>Medium Adherence</td>
<td>73</td>
<td>76%</td>
</tr>
<tr>
<td>High Adherence</td>
<td>2</td>
<td>2%</td>
</tr>
<tr>
<td>Total</td>
<td>96</td>
<td>100%</td>
</tr>
</tbody>
</table>

#### Table 2: Maximum Medication Adherence Improvement

The system could potentially decrease the patients categorized as “low adherence” from 86% to 22%, and increase the patients categorized as “medium adherence” from 14% to 76%, and increase the patients categorized as “high adherence” from 0% to 2% as seen in Table 2. This maximum improvement requires that patient’s own an iPhone and can successfully use Adhere, and also requires that it successfully correct the problems the system is meant to target. In reality this would high improvement would probably not be achieved, however, it shows Adhere has the potential to have a large positive impact on medication adherence.

Since Adhere requires an iPhone for patient usage, the population was also surveyed about smartphones ownership, and specifically iPhones. We found that 73% of respondents (of 94 people surveyed) own iPhones, and that only 3% don’t have a smartphone.

We analyzed the potential impact of Adhere on medication adherence adjusting for the fact that only 73% of respondents could currently use Adhere as seen in Table 3.
We found that Adhere would have the potential to decrease the percentage of patients who are considered to have low adherence to 34% (from 86%), to increase the percentage of patients who are considered to have medium adherence to 64% (from 14%), and to increase the percentage of patients who are considered to have high adherence to 2% (from 0%). This shows Adhere has the potential to have a large impact on medication adherence.

<table>
<thead>
<tr>
<th>Phone Type</th>
<th># Respondents</th>
<th>% Respondents</th>
</tr>
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<tbody>
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<td>69</td>
<td>73%</td>
</tr>
<tr>
<td>Android</td>
<td>20</td>
<td>21%</td>
</tr>
<tr>
<td>Windows</td>
<td>1</td>
<td>1%</td>
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<tr>
<td>Other smartphone</td>
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<td>1%</td>
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<tr>
<td>No smartphone</td>
<td>3</td>
<td>3%</td>
</tr>
<tr>
<td>Total</td>
<td>94</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 3: Potential Impact of System Accounting for % of Surveyed Population with an iPhone

Even though these figures for iPhone ownership tend to be larger than the population as a whole, these figures do indicate that Adhere does have the potential to have a large impact.

6. FUTURE WORK

The mobile application, doctor interface, and backend are running as planned. In the future to make this product better improvements should be made to the doctor interface to make it more user-friendly. Specifically, the next step would be to add an easier way to add schedule patients’ medications regimens. Another future to add to the mobile application is a “contact doctor” feature. This feature would allow patients to contact their doctor through the application with any type of question or complaint, which would help to further bridge the communication gap between patients and doctors.

Currently, side-effect categorizing is done by simple tagging to associate side-effects with potential causing medications via the FDA Drug Database. In the future, it may be more useful to use

Another important part of the potential future work is test the product on an actual patient population. Given time constraints and Hospital Internal Review Board (IRB) constraints, this was not feasible during the year. In order to ensure the product’s efficacy it is important to test it on a patient population and receive feedback. Once tested on a patient population and given feedback, further improvements to the product could be made.

After fine-tuning the product and testing on a patient population, the next step would be to market the product to hospitals and healthcare providers. Our survey revealed that 61% of people would be interested in the product if suggested to them by their doctor. In addition, 37 out of 94 people said they would not be interested in a mobile application for medication adherence, but 19 out of those 37 then said they would be interested in an a mobile application for medication adherence if suggested to them by their doctor. This information suggests that the best way to market the application would be to market the application to health care providers and hospitals and then have them recommend the application to patients.

Another thing to work on in the future would be to integrate the product with Epic or other electronic hospital systems. This would make the product easier to use for doctors because they would not have to use a different system to input and receive information about their patient.

Finally, this system is dependent upon using QR codes to allow patients to report their pill-takings. Therefore, in the future it would be wise to work with pharmacies to encourage them to print the QR codes on the pill bottles. Doing so would make the system easier to use for both patients and doctors because they would not have to worry about printing and putting the QR codes on the pill bottles themselves.

7. ETHICS

As Adhere is a healthcare project, one of the most significant ethical concerns is patient privacy and, in the United States, the Health Insurance Portability and Accountability Act (HIPAA). HIPAA protects individually identifiable health information and its Security Rule specifies safeguards that must be followed to ensure that electronic health information is confidential and protected [9]. In order to ensure that Adhere would comply with the Act, it would have to ensure all electronic health information it retains about the patient is stored securely and confidentially.

There are numerous reasons as to why HIPAA protects patients’ health information. One major reason is to protect patients from employer discrimination due to health issues. With this in mind, Adhere would have to ensure that it would not release any health information to the wrong individuals and that only designated healthcare providers would be allowed access to a patient’s data. Furthermore, Adhere would also have to ensure that the people who have access to patient information do not distribute it to others who should not have access to the data.

In order to mitigate concerns about HIPAA compliance, Adhere would have to feature stricter authentication and encryption facilities. For authentication, Adhere could incorporate stronger authentication schemes for healthcare providers such as two-factor authentication and establish procedures for session termination on inactive devices. For the mobile application, a password could be required every time the application is accessed (or some other sort of short authentication code) and the data could be moved off-device to protect in cases of device loss. To ensure that only certain individuals get access to the healthcare data Adhere application provides and that they do not wrongfully distribute it, Adhere would have to be added to a mandatory training session where the rules and what and cannot be done with the data are explained before providers gain access.

8. CONCLUSIONS

Medication adherence is an epidemic problem. While there have been solutions in the past to attempt to improve adherence, they have been overly burdensome or costly. Adhere is

http://www.epic.com/
designed to be both user-friendly and cost-effective. Specifically, Adhere consists of a backend database, a patient-facing mobile application, and a doctor-facing web portal. The database stores patient and medication information and is where the analytics of Adhere resides. The mobile application alerts patients to take their medication, allows patients to scan QR codes for their medication, and allows patients to report any side effects. The doctor web-portal allows doctors to see real-time information on their patients’ medication adherence. The web portal also flags patients who report side effects and/or are below a 90% medication adherence rate. Allowing doctors to see real-time information on patient’s medication adherence helps to bridge the communication gap between patients and doctors. This in turn should help to improve medication adherence by allowing doctors and patients to communicate more effectively.

9. REFERENCES


APPENDIX

A. MORISKY 8-ITEM MEDICATION ADHERENCE QUESTIONNAIRE [8]

1. Do you sometimes forget to take your medicine?
2. People sometimes miss taking their medicines for reasons other than forgetting. Thinking over the past 2 weeks, were there any days when you did not take your medicine?
3. Have you ever cut back or stopped taking your medicine without telling your doctor because you felt worse when you took it?
4. When you travel or leave home, do you sometimes forget to bring along your medicine?
5. Did you take all your medicines yesterday?
6. When you feel like your symptoms are under control, do you sometimes stop taking your medicine?
7. Taking medicine every day is a real inconvenience for some people. Do you ever feel hassled about sticking to your treatment plan?
8. How often do you have difficulty remembering to take all your medicine?

(a) Never/rarely (score = 0)
(b) Once in a while (score = 1)
(c) Sometimes (score = 1)
(d) Usually (score = 1)
(e) All the time (score = 1)

For the first 7 questions, an answer of “yes” is a score of 1, an answer of “no” is an answer of 0.

Sum of scores: >2 = low adherence. 1 or 2 = medium adherence. 0 = high adherence.

B. SURVEY RESULTS

Table 4: Survey Responses Questions 1-7

<table>
<thead>
<tr>
<th>Question Number</th>
<th># Yes</th>
<th>% Yes</th>
<th># No</th>
<th>% No</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>78</td>
<td>81%</td>
<td>18</td>
<td>19%</td>
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<tr>
<td>2</td>
<td>53</td>
<td>55%</td>
<td>43</td>
<td>45%</td>
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<td>34%</td>
<td>63</td>
<td>66%</td>
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<td>4</td>
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<td>58%</td>
<td>40</td>
<td>42%</td>
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<tr>
<td>5</td>
<td>67</td>
<td>70%</td>
<td>29</td>
<td>30%</td>
</tr>
<tr>
<td>6</td>
<td>35</td>
<td>36%</td>
<td>61</td>
<td>64%</td>
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<tr>
<td>7</td>
<td>47</td>
<td>49%</td>
<td>49</td>
<td>51%</td>
</tr>
</tbody>
</table>

Table 5: Question 8

<table>
<thead>
<tr>
<th>Response</th>
<th># Respondents</th>
<th>% Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Never/Rarely</td>
<td>18</td>
<td>19%</td>
</tr>
<tr>
<td>Once in awhile</td>
<td>41</td>
<td>43%</td>
</tr>
<tr>
<td>Sometimes</td>
<td>20</td>
<td>21%</td>
</tr>
<tr>
<td>Usually</td>
<td>12</td>
<td>13%</td>
</tr>
<tr>
<td>All of the time</td>
<td>5</td>
<td>5%</td>
</tr>
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</table>

For questions one to four and six to seven, answering “yes” indicated low adherence, while for question five answering “yes” indicated high-adherence. For question eight, answering “rarely/never” indicated high-adherence, and answering with any other choice indicated low-adherence.

The surveys were evaluated using the validated method for evaluating the survey described in the literature [reference]. For questions one through four, and questions five and six, answering “yes” added one point to the respondents total score. For question five, answering “no”, added one point to the respondents total score, and for question eight, answering “once in awhile”, “sometimes”, “usually”, or “all of the time”, added one point to the respondents total score.
If the respondent’s total score was greater than two, the respondent was considered to have low medication adherence, if the respondent’s total score was one or two, than the respondent was considered to have medium adherence, and if the respondent’s total score was zero, the respondent was considered to have high adherence.

<table>
<thead>
<tr>
<th>Totals</th>
<th># of Respondents</th>
<th>% of Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Adherence</td>
<td>83</td>
<td>86%</td>
</tr>
<tr>
<td>Medium Adherence</td>
<td>13</td>
<td>14%</td>
</tr>
<tr>
<td>High Adherence</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Total</td>
<td>96</td>
<td>100%</td>
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</table>