Quantifying and Visualizing Medication Adherence in Patients Following Acute Myocardial Infarction

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Abstract
Medication adherence is a critical component for recovery following acute myocardial infarction (AMI). Currently, numerous smartphone applications are capable of tracking medication adherence through patient-generated data (PGD), but few are integrated with the electronic health record (EHR). Integration of medication adherence PGD into the EHR can give both healthcare providers and patients increased insight into patterns of missed doses, effects on vital signs, and correlation with side effect symptomology to inform healthcare decisions. We propose the generation of a medication adherence “vital sign”, a score calculated based upon the patient’s reported doses taken collected through a smartphone application and streamed into the EHR on a daily basis. We also propose the creation of Patient Health Reports that incorporate relevant patient history, information from previous visits, and the medication adherence scores to give providers a comprehensive view of patients’ health prior to clinic visits. These features are intended to incorporate PGD into clinical care to inform decision making in a way that streamlines patient visits, reduces healthcare costs, and improves health outcomes.

Introduction
Medication non-adherence has been reported in over 60% of patients with cardiovascular disease (CVD), the leading cause of morbidity and mortality worldwide,¹,² and in approximately 50% of patients with chronic diseases.³ Typical medication regimens for CVD are complex and involve drugs from multiple classes that may require intake at numerous different time points⁴. Medication non-adherence contributes to poor achievement of treatment goals, increased patient morbidity and mortality, and an estimated $300 billion annually in U.S. healthcare expenditures.⁵

Verification of proper patient usage of prescribed medications is important for assessing treatment efficacy. In most outpatient settings, clinicians rely upon the patient’s self-report through recall.⁶ However, studies have shown that the patient’s recall for medical information may be poor, and patients generally over-report adherence.⁷ Suboptimal assessment of patient adherence leads to medication errors, such as over-prescription and dosing errors.

With the growth of health information technology, the Electronic Health Record (EHR) has become central to the practice of medicine. According to the Office of the National Coordinator for Health IT (ONC), approximately 74% of physicians have adopted certified EHR systems.⁸ However, approximately 51% of physicians are only using basic EHR functionalities, such as inputting patient demographic information.⁸ EHRs also introduce workflow disruptions for clinical staff that have been shown to lead to productivity losses of up to 20% in internal medicine clinics within the first month of implementation.⁹,¹⁰ These studies illustrate that EHRs are not yet being used to their greatest potential.

Recent developments in smartphone applications and wearable technologies have led to the concept of patient-generated data (PGD), which are health metrics captured by the patient outside of the context of formal clinical care.¹¹ The integration of PGD into the EHR has been suggested as a method of allowing providers to monitor patient health behaviors and key health metrics, enabling them to make more informed decisions on patient care.¹¹ However, incorporating PGD into the EHR is hindered by numerous challenges including the following: the capacity to handle large volumes of data in a manner that neither overwhelms the EHR¹¹,¹² nor the providers,¹²,¹³ and the presentation of PGD in a way that is easily interpretable and relevant to clinical decision making.

Proposed Solution

A. Medication Adherence “Vital Sign”
A group of clinicians, engineers, and hospital administrators have developed the first Apple CareKit smartphone-based cardiology application, Corrie, to reduce hospital readmission rates following acute myocardial infarction (AMI).¹⁴ Corrie aggregates all components of follow-up care surrounding AMI, including medication trackers, vital
sign intake, care team contacts, and educational modules into a single mobile application. Corrie’s current platform enables patients to log their adherence to each prescription on the basis of dose and time.

We propose the creation of a medication adherence score and corresponding graph to be streamed into the EHR daily as a “vital sign”. The medication adherence score will be calculated for each medication as (#doses taken)/(#doses prescribed) *100. The visualization will be generated based upon the patient’s medication tracker that captures the patient’s adherence to each medication, temporal and prescription-specific patterns of adherence, and medication side effects (Figure 1). This feature will also have the capacity to generate visualizations that highlight time points throughout which the patient has not been adherent to specific medications (Supplemental Materials). Clinicians may hover over the plot in order to see precise data specific to time, day, and medication. The medication adherence “vital sign” will be incorporated into the EHR as a streaming data set that can be accessed for any day in the patient’s history, and as a cumulative report that summarizes the information into an adherence score for a specified window of time. Additionally, to evaluate whether the current medication regimen requires titration adjustments, adherence to medications targeted at outcomes such as blood pressure (BP) and heart rate (HR) can be viewed alongside the recordings of BP, HR, and other vital signs as well as reports of side effects or symptoms to determine trends between adherence and outcomes (Figure 2). Clinicians who are concerned about patient compliance to medications and the consequences on health outcomes may check on patient medication adherence and directly contact the patient through the mobile application’s secure platform. These visualizations will also be available to patients to increase patient engagement and empowerment, which has been shown to be linked to patient satisfaction and compliance, which in turn can lead to improved health outcomes.

![Figure 1: Medication adherence plot emphasizing completed doses](image)

![Figure 2: Medication adherence plot (bottom panel) with corresponding daily changes in vital signs, mood, and steps (top panel)](image)
B. Patient Health Reports

To streamline clinical workflow, we furthermore propose the creation of a Patient Health Report (Figure 3) that clinicians may generate and view before a clinical encounter. Clinicians may specify the timeframe of interest (e.g. since the last clinical encounter) for the Patient Health Report, which will include key components of every patient’s medical record such as past medical history, current medication regimen, concerns raised during the previous clinical encounter, a longitudinal graph of the patient’s medication adherence, and the overall medication adherence score for each medication. Since many clinicians prepare for patient visits by refreshing their knowledge of their patients’ medical history, needs, and active problems the night before or the morning of a clinical visit, we propose the health report to expedite pre-encounter preparation by providing clinicians with information that will inform the clinical encounter. In a process mapping study conducted by the Veteran’s Health Association, physicians agreed that reviewing recent patient information prior to a patient encounter helped to 1) build trust and rapport to establish a basis of familiarity and knowledgeability about the patient, 2) determine whether pre-visit tests or consultations are required, 3) remind clinicians about care plans from previous visits. By incorporating the Patient Health Report with the medication adherence information into the workflow that many clinicians already use, we hope to enhance the clinical workflow experience through the centralization of relevant information and the addition of the medication adherence vital sign. An example of the Patient Health Report can be accessed here: https://kathen.shinyapps.io/amia_visual3/. Further details may be found in the Supplemental Materials.

![Patient Health Report](https://kathen.shinyapps.io/amia_visual3/)

**Figure 3:** Sample Patient Health Report with pertinent patient demographics, history, and medication adherence.
Alternative Solutions Considered

A. Data collection methods for medication adherence: As an alternative to using the medication logging functionality of the Corrie app, we considered using data collected from smart pill bottles or smart pills with digestible circuits that can automatically keep a record of the patient’s medication adherence.

B. Medication adherence visualization: As an alternative to the heat map of medication adherence, we considered presenting the visualizations as longitudinal bar graphs or line graphs to display the trajectory of the adherence score over time.

C. Medication adherence “vital sign” and comprehensive summary: As an alternative to the medication adherence score and Patient Health Report summary, we considered presenting the adherence information in a separate tab in the EHR where the clinicians can navigate to view the adherence history.

Strengths and Weakness

A. Medication adherence data collection though Corrie mobile health app: Corrie already incorporates a comprehensive recovery plan for AMI patients, so logging their medication intake through this app will facilitate ease of use and centralize the patients’ self-care tasks to a single app. Using a smart pill bottle and smart pills with digestible circuits would add another level of unnecessary complexity to the data collection process. Additionally, using smart pills could limit which medications we could track. Nevertheless, smart pill bottle and smart pills could help address the issue of the validity of PGD from self-reported loggings of medication adherence through the Corrie mobile app. Yet, if patients intend to falsify their adherence, they could also manipulate the records from smart pill bottles (by simply opening the pill bottle but not taking the medication) and smart pills (by dissolving the pill rather than taking the medication).

B. Medication adherence visualization: Presenting the adherence score as a heat map allows clinicians to easily visualize the general patterns of medication adherence. Visualizations as longitudinal bar graphs or line graphs would allow for exact values to be plotted and displayed over time. However, with patients commonly on dozens of medications, presenting the scores as bar or line graphs in different colors for different medications can become complex and challenging to interpret. In our proposed solution, clinicians may hover over each box in the heat map to see the actual value of the adherence score and how it was calculated.

C. Medication adherence “vital sign” and comprehensive summary: Incorporating the adherence score as a vital sign stresses that medication adherence is an essential component of medical care that must be considered frequently. One weakness of including the medication adherence as a vital sign is that this requires the adherence of all the medications to be summarized into a single value. To overcome this limitation, we have also included the options for clinicians to view the adherence score for each medication separately under the medications list section of the EHR. Our proposed solution would be more helpful clinically than presenting the adherence information in a separate tab in the EHR since our method integrates the medication adherence information into a clinical workflow that clinicians are already accustomed to.

Implementation and Dissemination Plan

Implementation: Our implementation plan includes feasibility and usability studies as the initial step. We propose to pilot our proposed solution in the cardiology clinic, specifically with Corrie patients and providers. The feasibility and usability studies will begin with clinician training of the new EHR features and patient education on medication adherence and the medication logging function on Corrie. Then, the patients and clinicians will be surveyed (additional details are provided in the Evaluation Plan section below).

Dissemination: To disseminate our proposed solution, we will develop open-source software that is modular, scalable, and easily adapted to a variety of EHR systems. Additionally, we propose to publish the results of our small-scale implementation and feasibility-usability studies to inform future large-scale implementations across various institutions and EHR systems. The Shiny app demonstration of the implementation as well as videos with step-by-step user instructions for patients and providers will help facilitate the dissemination and adoption of this proposed solution at a large scale. The code will also be published on GitHub, so individuals interested in adapting it to their systems can easily access and modify the code for implementation at their institutions.

Evaluation Plan

The efficacy of our proposed solution may be evaluated through the following methods:

1. User satisfaction and feasibility-usability surveys: These surveys will be incorporated into the Corrie application and administered at 1 month intervals to patients; providers will receive monthly surveys via email; they will evaluate the frequency of Corrie use, ease of use, medication compliance following Corrie use, and efficiency of use during clinical encounters.
2. Comparison of medication adherence rates of CVD drugs (e.g. aspirin, clopidogrel, simvastatin, etc.), hospital readmission rates, and blood pressure and heart rate control within a target range between Corrie users and the national average at the time points of 1 month, 3 months, and 6 months.

3. Comparison of medication adherence rates of CVD drugs, hospital readmission rates, and blood pressure and heart rate control within a target range between high-frequency Corrie users (log at least 5 medications/week) and low-frequency Corrie users (log 4 or fewer medications/week) at the time points of 1 month, 3 months, and 6 months.

Conclusion
Medication adherence is one of the most frequently cited causes of hospital re-readmissions following AMI. We propose streaming recorded medication compliance PGD from the Corrie application directly into the EHR that can be visualized and assessed in the same capacity as a vital sign. Providers and patients may monitor and conduct early modifications to the medication regimen. We furthermore propose the creation of a Patient Health Report that streamlines clinical encounters by incorporating all relevant information (including the medication adherence score) that providers may need to prepare for patient visits. The integration of medication adherence PGD has widespread implications in CVD management and can be easily translated to other disease entities. We hope that our proposed solution will improve medication adherence rates and ultimately, long-term patient health outcomes at reduced healthcare costs.

References
8. Monegain B. More than 80 percent of docs use EHRs [Internet]. Healthcare IT News. 2015 [cited 2017 June 30].