Quartz App to Support Medication Adherence: Usability and Feasibility Assessment

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PURPOSE

The Clinical Decision Support Innovation Collaborative (CDSiC) aims to advance the design, development, dissemination, implementation, use, measurement, and evaluation of evidence-based, shareable, interoperable, and publicly available patient-centered clinical decision support (PC CDS) to improve health outcomes of all patients by creating a proving ground of innovation. The Innovation Center supports the measurement of PC CDS implementation and effectiveness to ensure that PC CDS works as intended. This report is intended for those interested in developing, implementing, and evaluating AI-based PC CDS technology. All qualitative research activities conducted by the CDSiC are reviewed by the NORC at the University of Chicago Institutional Review Board (FWA00000142).

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Executive Summary

Introduction

Few studies have explored the deployment and use of patient-centered clinical decision support (PC CDS) interventions in real-world practice settings. PC CDS tools are those that significantly incorporate patient-centered factors related to knowledge, data, delivery, and use. The Agency for Healthcare Research and Quality (AHRQ) Clinical Decision Support Innovation Collaborative (CDSiC) developed a PC CDS prototype, known as Quartz, that leverages text messaging and chatbot technology to gather information from patients with uncontrolled hypertension about their adherence to a prescribed blood pressure medication regimen. The prototype uses Substitutable Medical Applications, Reusable Technology (SMART) on Fast Healthcare Interoperability Resources® (FHIR) to integrate the externally hosted dashboard into an electronic health record (EHR) system. In this assessment report, we examined the design, development, deployment, and future use of Quartz in a primary care clinic to highlight challenges and advantages of leveraging PC CDS technology to support chronic disease management. Gathering these insights is the first step toward implementing in a real-world setting.

Purpose

The CDSiC team assessed the Quartz application (app) with the aim to 1) gather technical team perspectives on the technical feasibility of integrating the SMART on FHIR app in the EHR, and 2) collect clinician and patient perspectives on the usability and patient-centeredness of a text-messaging-based PC CDS. The formative assessment aims to generate a better understanding of factors supporting and impeding usability and integration of text-messaging-based PC CDS interventions in EHRs to advance design, development, and integration of similar technologies in health care settings.

Methods

We used a mixed methods approach for the formative assessment. To assess technical feasibility, we collected and reviewed meeting notes and conducted key informant interviews (KIIs) with three technical team members at Baystate Health System (app deployers) and Elimu Informatics (app developers). To assess perceptions on the usability and patient-centeredness of the Quartz app, we conducted KIIs with two primary care clinicians and think-aloud sessions with four patients who also responded to the System Usability Scale (SUS) survey. We then synthesized themes from all sources to generate findings.

Results

The following key findings are organized by the assessment goals.

Goal 1: Assess the Technical Feasibility of Integrating the SMART on FHIR Quartz App with the EHR: Overall, the team succeeded in integrating the SMART on FHIR app but encountered technical challenges due to limitations both with how Oracle Health implements FHIR application programming interfaces (APIs) and limitations in the FHIR standard. The technical team used a stepwise approach to develop, test, and integrate Quartz. First, they developed the app in an external SMART on FHIR launcher and HAPI FHIR server, then refined and tested the app in the Oracle Health sandbox. Once

all issues were resolved, they tested the app in the Baystate Health test environment. In Exhibit ES1, we highlight key challenges the team encountered during the EHR integration process. In the report, we describe solutions the team implemented at each step to overcome these challenges.

ES1. Challenges and Limitations Identified during Steps of App Deployment

#	Step Toward Deployment	Challenges and Limitations
1	App development	• Limitations in Oracle Health FHIR API that do not support robust write-back capabilities • Limitations in how the FHIR API handles data for groups of patients versus individual patients
2	App testing and refinement for vendor product compatibility	• Patient data in Oracle Health FHIR sandbox was inadequate for testing • Lack of access to the EHR user-interface for full user-experience testing
3	App integration testing and acceptance testing in client environment	• Working with a cross-functional team in health care organizations requires additional time • Lack of direct access to detailed error logs from Oracle's FHIR APIs • Creating realistic test data is time consuming • Lag times to load the SMART on FHIR app

Goal 2: Assess the Usability and Patient-Centeredness of Text-Messaging-Based PC CDS: Overall, clinicians and patients reported the Quartz app has the potential to support hypertension medication management. They shared suggestions to improve the app's usability and patient-centeredness (Exhibit ES2).

ES2. Suggestions to Improve App Usability and Patient-Centeredness

To improve primary care clinician workflows:
• **Improve integration into the clinician workflow:** Incorporate the hypertension dashboard into existing primary care worksheet currently used during patient encounters. • **Improve app response times:** Improve the app load time, so clinicians can quickly access during an encounter. • **Additional clinical information:** Include information on prescription fill data and features for sending orders (e.g., prescription changes) within the dashboard so that clinicians have everything they need to manage hypertension in one location.
To improve patients' satisfaction, trust, and engagement:
• Use 24-hour recalls instead of monthly recalls when asking patients about their adherence levels to improve the accuracy of responses. • Clearly explain the source of messages so patients know their clinician is involved in the process. • Personalize messages by making them "smart" or more responsive to the individual. • Build rapport with the patient by making the tone more empathetic or positive. • Acknowledge the clinician's receipt of information.

Overall, patients believed the text messages were clear and easy to understand and that the proposed monthly messaging cadence would not be too burdensome. The mean SUS score of the Quartz app was 77.0, which translates to an acceptable usability ranking.

Additional considerations for PC CDS interventions: In addition to the two main assessment goals, the assessment revealed important considerations for other PC CDS interventions implemented in health care settings. PC CDS interventions that involve patient-reported data will require **additional resources and workflow changes** in health care settings. There may be a need for patient education when using remote monitoring devices, summarization techniques to visualize large volumes of data, and systems to identify erroneous data. Further, managing a population of patients requires resources to monitor a panel of patient data at a regular cadence and alert clinicians when patients are experiencing barriers.

Conclusion

There is still much to learn about PC CDS interventions that incorporate patient-reported information in a health system EHR. This study identified sociotechnical obstacles to integrating a SMART on FHIR chatbot app in a clinical lab setting yet showed promise in supporting medication adherence for patients with uncontrolled hypertension. The next step is to deploy the Quartz app in a production setting and assess clinician and patient experiences using the app in the real world. Findings from the pilot will contribute to the evidence base on the technical and implementation considerations for successfully designing and deploying PC CDS tools like the Quartz medication adherence app.

1. Introduction

NORC at the University of Chicago (NORC) is pleased to submit this final Assessment Report for the Quartz Application (app) Implementation Pilot to the Agency for Healthcare Research and Quality (AHRQ). Since 2021, AHRQ has supported the Clinical Decision Support Innovation Collaborative (CDSiC) to advance evidence into practice for patient-centered clinical decision support (PC CDS) tools. PC CDS encompasses a spectrum of decision-making tools that significantly incorporate patient-centered factors related to knowledge, data, delivery, and use. Knowledge refers to the use of comparative effectiveness research (CER) or patient-centered outcomes research (PCOR) findings. Data focuses on the incorporation of patient-generated health data, patient preferences, social determinants of health, and other patient-specific information. Delivery refers to directly engaging patients and/or caregivers across different settings. Finally, use focuses on facilitating bi-directional information exchange in support of patient-centered care, including shared decision-making.

This report presents findings from the assessment of the design, development, and integration of a PC CDS tool, the Quartz app,[1] that leverages text messaging and chatbot technology to support medication adherence for hypertension. The technical team co-designed the app with patients and integrated the app into a health system electronic health record (EHR). The assessment team tested the app in a lab setting to gather patient and clinician perspectives on the app's usability and patient-centeredness. The findings from this report may be of interest to researchers, informaticians, developers, hospital administrators, clinicians, and policymakers seeking to develop and implement PC CDS.

1.1 Background and Significance

Poor adherence to medication regimens is an important reason for inadequate control of chronic diseases such as heart failure, diabetes, and hypertension. Medication non-adherence can lead to 2.5 times higher odds of hospital readmissions[1] and an estimated annual cost of $528.4 billion for the U.S. health care system.[2] Reasons for medication non-adherence are complex and patient specific but can include psychosocial (e.g., illness perceptions, health beliefs), practical (e.g., memory problems), and structural barriers (e.g., distance from pharmacy, cost of medication).[3,4]

Studies have shown that text messaging patients improves medication adherence. Two systematic reviews with meta-analyses[5,6] and a Cochrane review[7] analyzed randomized controlled trials on interventions with text messaging and found significant improvement in medication adherence in treating chronic diseases. A similar systematic review focused only on asthma[8] was inconclusive on the overall effect but noted that text messaging is an effective intervention if the reason is forgetfulness. Thakkur, et al.,[6] note that although the improvement across studies was significant, it was not an

[1] Note: The team developed this application for the purpose of this project. It is entirely distinct and independent form any other application that may share the same name.

effective intervention for all patients, and they call for further determination of features that would improve adherence in other patient populations.

Co-design, or the involvement of end-users as partners in developing, refining, and testing technologies, can improve developers' understanding of the features and functionalities that will be most effective for patients.[9] However, patients are rarely involved in design and development of digital health interventions such as text messages.[10]

A natural language chatbot app co-designed with patients can offer several improvements on prior efforts:

1) *Natural language*: A chatbot can allow more natural interaction with the patient, rather than automated text and prescribing numeric or simple text responses from the patient. Some users may prefer this feature.
2) *Patient-centric*: Involving patients in the design of the technology can strengthen understanding of patient preferences and needs related to text-messaging interventions for medication adherence, as well as the challenges patients face with medication adherence. The app could tailor features to patients' preferences without the need for a clinician or researcher to explicitly change a program's settings.
3) *Scalability and adaptability*. Chatbots can more easily adapt to various scenarios, such as scaling to multiple medications and conversing in other languages.
4) *EHR integration*: Prior text-messaging efforts were separate from EHRs, and any data collected were unavailable at the time of clinical decision-making. EHR integration enables the storage and subsequent accessibility of data from the patient to the responsible clinician both during and between patient encounters.

2. Overview of Quartz App

The technical team designed the Quartz app to be an additional component to an existing hypertension app that specializes in supporting patients with hypertension medication adherence. As a natural language chatbot, Quartz has the potential to advance the use of text messaging for medication adherence. In this section, we describe the technical components of the app, the co-design process, and the health system site where the technical team deployed the app and will integrate the app into clinician workflows.

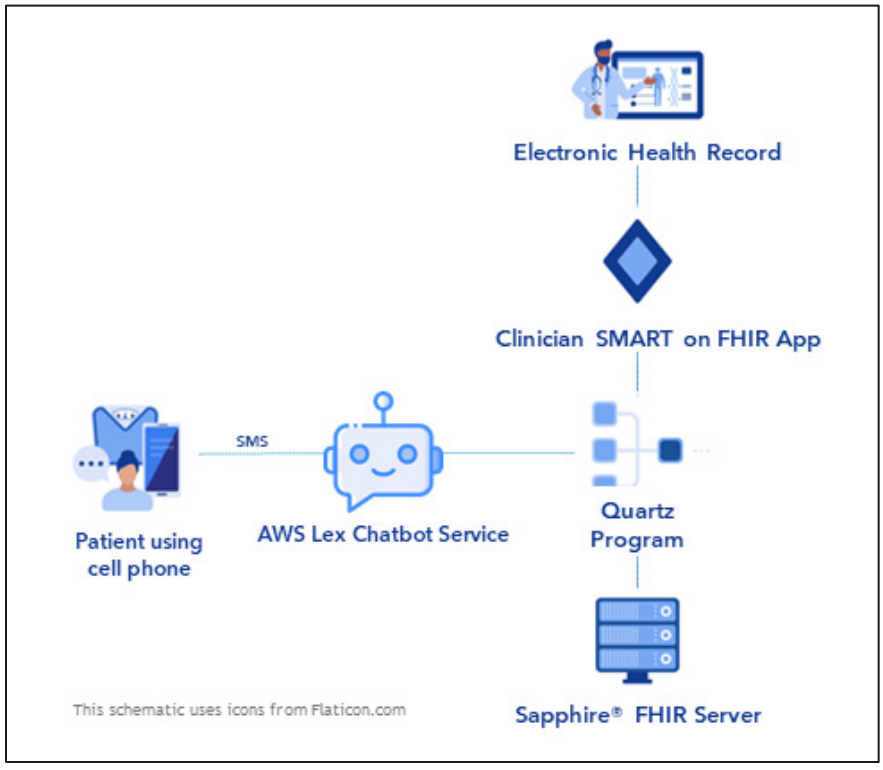
2.1 Technical Overview

The Quartz app has both a patient-facing and clinician-facing component. On the patient side, the app leverages an artificial intelligence (AI) chatbot tool to facilitate communication between the patient and clinician. The app texts enrolled patients who have uncontrolled blood pressure or have recently started a hypertension medication treatment to ask pre-programmed questions about their medication-usage

behavior and any barriers they are experiencing. The conversations are informed by a published patient-reported outcome instrument for assessing medication adherence and do not rely on AI for clinical knowledge[11, 12, 13] The AI chatbot functionality is only used to comprehend patients' natural language responses to the questions it is programmed to ask (i.e., it understands variations in responses for times of day and types of barriers). On the clinician side, the information on medication adherence obtained from the patient is integrated into a pre-existing hypertension app, which includes an individual patient hypertension dashboard as well as a roster view of all patients in the hypertension program. This enables clinicians to monitor the patient's medication use between visits alongside other relevant hypertension medical information (e.g., blood pressure readings) and intervene if necessary.

Quartz stores patient enrollment information and SMS conversation transcripts as Health Level Seven® (HL7) Fast Healthcare Interoperability Resources® (FHIR) on its server.[14] The clinician-facing app that clinicians use to enroll patients and monitor patient responses uses the Substitutable Medical Applications and Reusable Technologies (SMART) on FHIR standard to integrate with the EHR. Exhibit 1 provides an overview of the technical architecture.

Exhibit 1. Technical Architecture Diagram



- Clinician SMART on FHIR app inserts into clinical workflow and enables the clinician to enroll the patient in the Quartz program as well as monitor patient-reported responses to medication adherence queries.
- Quartz app is built on the Sapphire® Omnibus platform.[15] The platform defines the engagement protocol and provides integration and CDS features.

- Patient engagement for a conversation is via a chatbot built using Amazon Web Services (AWS) Lex, a fully managed chatbot service with natural language understanding capability.[16] The chatbot interacts with patients with two-way text messages using the Twilio, Inc., communication services.[17]
- Patient enrollment information and conversation transcripts are stored on the Sapphire FHIR server. The server complements EHR database services and supports efficient workflow performance.

2.2 Co-Design Process

The app has undergone an iterative co-design and development process with clinicians and patient representatives and advocates involved with the CDSiC Stakeholder Committee. The Elimu Informatics team designed the text-messaging flow. The team conducted a literature search for medication adherence instruments and applications. The search also reviewed text-messaging-based medication adherence tools. Based on this review, the team created a draft design for the text-messaging flow. This included the text-message content, the timing of the content, and specific instruments to assess medication adherence to use. Clinicians with various specialties (e.g., internal medicine, surgery, endocrinology, pharmacy) reviewed this design. The technical team used their feedback to refine the specification and then program the specification into AWS's Lex chatbot service. During testing by the technical team, they made additional refinements to the dialog flow in Lex. Once the prototype was functioning in Lex, the team conducted live app demonstrations for three patient representatives presenting various conversation scenarios programmed into the app (e.g., inquiring about the patient's ability to take their medications). The team also asked for feedback on the content and flow of the text messages. After each demonstration, the team refined the app based on feedback.

2.3 Health System Overview

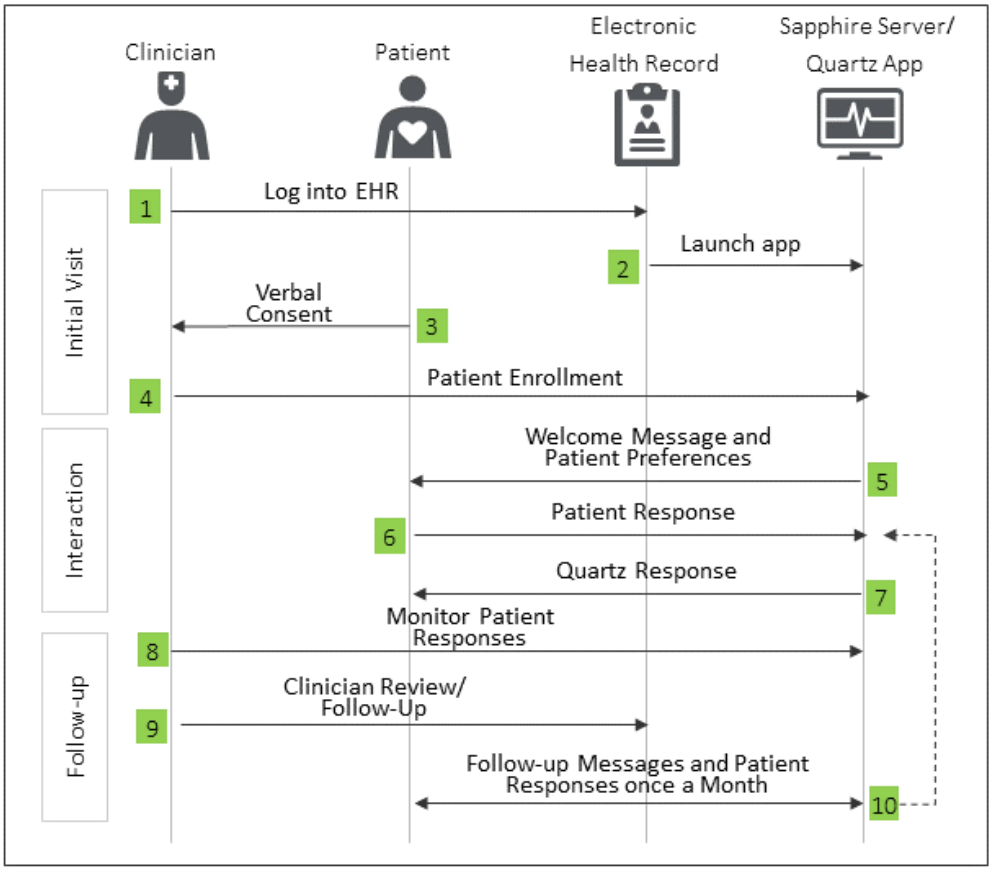
The Elimu Informatics team partnered with an application production team at Baystate Health System to integrate the Quartz app into the EHR environment.

Baystate Health System. Baystate Health is a not-for-profit integrated health system based in Springfield, Massachusetts. The system serves 800,000 people throughout western New England. As the largest health care organization in western Massachusetts, the system has 980 beds across five hospitals, over 80 medical practices, and 25 reference laboratories.[18] Baystate utilizes the Oracle Health Millenium EHR System (formerly Cerner Millenium). This EHR product provides support for SMART on FHIR. The capabilities of its FHIR application programming interfaces (APIs) are specified at its Developer Portal.[19] Baystate has implemented several SMART on FHIR applications integrated with its Oracle Health EHR. The earliest application for managing opioids went live in production in February 2020.

2.3.1 Quartz App Workflow at Baystate Health

We developed the proposed clinician workflow in consultation with the clinical lead at Baystate Health (Exhibit 2). Steps 1-4 occur during the patient-clinician encounter, which could be at an in-office visit or on a phone call. First, the clinician logs into the EHR to identify patients with uncontrolled blood pressure (>130/80 mm Hg). In step 2, the clinician launches the Quartz app from within the EHR to begin a new patient enrollment. In step 3, the clinician introduces patients to the program at the point of care (by phone or in person). Patients will provide verbal consent if they agree to be in the program, which clinicians will document in the EHR and the Sapphire server. Clinicians will also confirm the patient's phone number to receive text messages. In step 4, clinicians enroll the patient in the program and input the start date and time to begin the text messages. Steps 5-7 describe the patient-app interaction. In step 5, the Quartz app sends a welcome message to the patient and asks them for the time of day they would like to receive the messages. In step 6, the patient responds with their selection, and in step 7, Quartz confirms the selections.

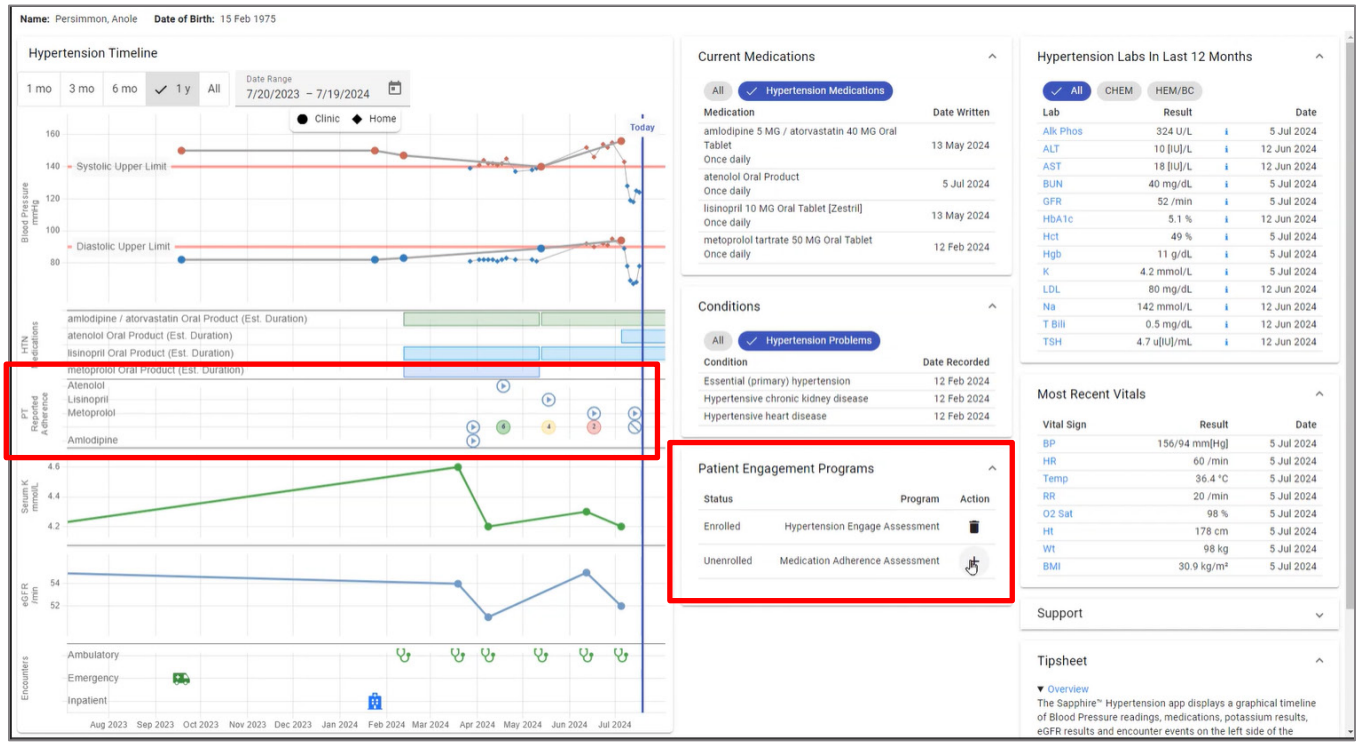
Exhibit 2. Clinical Workflow Diagram



Steps 8-10 describe the follow-up actions by the clinician and/or the Quartz app. In step 8, the data are stored in the Sapphire server for the clinician to view within the overarching hypertension app, which has two interfaces: 1) within the individual patient dashboard, there will be a widget with a line graph

showing the dates of text messages (color-coded by the reported adherence level) that clinicians can click on to view the full interaction (Exhibit 3); 2) within the patient roster view, there will be a tab for medication adherence that will show the list of all patients enrolled in the medication adherence program color-coded by the reported adherence level (Exhibit 4). In step 9, the clinician reviews the information either at the point of care or asynchronously and takes appropriate actions, such as adjusting the medication dosage or scheduling an appointment to verify blood pressure levels. In step 10, the Quartz app sends follow-up messages to the patient monthly to ask about their level of adherence and barriers to taking their medications, and the patient responds with the same interaction and clinician monitoring cycle (steps 6-9).

Exhibit 3. Clinician Hypertension Dashboard



Note: Components specific to Quartz are highlighted in red boxes.

Exhibit 4. Quartz Patient Roster View

Hypertension Patient Roster | Blood Pressure Monitoring | ✓ Medication Adherence

Name	DOB	Clinician	Status	Medication	Last Adherence Score	Reason
Honeydew, Kestral	15 Feb 1975	(unknown)	Unenrolled by patient	atenolol	2 (Poor)	"inconvenient"
Smitham825, Jessia669 Teri144	8 Jun 1984	(unknown)	Enrolled	Hydroclorthiaziade	(unknown)	""
Persimmon, Anole	15 Feb 1975	(unknown)	Unenrolled by patient	metoprolol tartrate 50 MG Oral Tablet	(unknown)	""
Dragonfruit, Komodo	15 Feb 1975	(unknown)	Enrolled	atenolol Oral Product	(unknown)	""
Apricot, Ocelot	15 Feb 1975	(unknown)	Enrolled	atenolol 25 MG Oral Tablet	(unknown)	""

2.3.2 Quartz App Deployment Process at Baystate Health

The technical team developed and deployed the Quartz app in a systematic process. They refined and tested the app in three environments with varying levels of support for standards and ability to create test cases specific to this app. Exhibit 5 describes the deployment steps. The process started with testing the prototype app in an environment with full support of interoperability standards. That is, the technical team used a HAPI FHIR server in lieu of the EHR's FHIR API (Step 1 in Exhibit 5). HAPI-FHIR is an almost complete implementation of the FHIR API specification, whereas EHRs implement a significantly smaller and more restrictive subset of FHIR API capabilities. Once the team tested the app in that environment, they then tested it in the EHR vendor's cloud-hosted sandbox (Step 2 in Exhibit 5). After successful testing in that environment, they tested the app in the client's pre-production environment (Step 3). While not done for this study, the next step of deployment and testing is to the client's production environment.

Exhibit 5. Quartz App Deployment within a Health System Environment

Step Toward Deployment	Integration environment	Integration activities
1. App development	Elimu's hosted tools, including SMART on FHIR launcher and HAPI FHIR server	• Create and configure various services in AWS • Specify and encode test patients in FHIR
2. App testing and refinement for vendor product compatibility	Oracle Health provided sandbox	• Register app in Oracle Code Console. • Test app in Oracle FHIR Sandbox • Address issues identified during testing
3. App integration testing, and acceptance testing in client environment	Baystate EHR test environment	• Request whitelisting (i.e., URL approval) of app by Oracle • Oracle whitelists the app for non-production use • Request Baystate Information Systems team to integrate app in development instance • Elimu and Baystate informatics test app together
Future Steps After Study Period		
4. App deployment to production, piloting with real patients	Baystate EHR production environment	• Request whitelisting of app for production by Oracle • Oracle whitelists the app in production • Request Baystate Information Systems team to integrate app in prod instance • Pilot Quartz app and provide feedback

3. Assessment Overview

NORC conducted a formative assessment of the Quartz app between May and August 2024. The assessment focused on the technical feasibility of integrating the app into a health system EHR and collecting clinician and patient perspectives of the usability and patient-centeredness of the app within a test lab setting. The overarching aim of the formative assessment was to generate a better understanding of the factors that support and impede usability and integration of text-messaging-based PC CDS interventions in EHRs to drive design, development, and integration of similar technologies.

Specifically, the goals of the formative assessment were to:

1) **Goal 1:** Assess the technical feasibility of integrating the SMART on FHIR app with the EHR
2) **Goal 2:** Assess the usability and patient-centeredness of text messaging-based PC CDS

In this section, we describe the research questions aligned with these goals as well as the data collection and analysis methods for the assessment.

3.1 Research Questions

To achieve the overarching goals of the assessment identified previously, we identified primary research questions that are specific to each goal (Exhibit 6). In seeking answers to these questions, we will: 1) describe the development and integration of Quartz, including the sociotechnical factors that affected the process; and 2) describe how the Quartz app's features and functionalities contribute to usability, satisfaction, and acceptability for patient and clinician users.

Exhibit 6. Key Research Questions for Quartz Assessment

Assessment Goal	Key Research Questions
Assess the technical feasibility of integrating the SMART on FHIR app with the EHR	• What changes were made to Quartz to support integration (e.g., how much EHR customization was required to integrate the PC CDS)? Why? • What resources were required to integrate the app? • What issues were encountered while integrating the app? How were they addressed? • What is the technical team's overall perspective on feasibility of integrating the app into the EHR? • What challenges were specific to the technical aspects of PC CDS technology versus traditional CDS technology?

Assessment Goal	Key Research Questions
Assess the patient-centeredness and usability of text-messaging-based PC CDS	• To what extent did patients and clinicians feel that the app was appropriate and acceptable for hypertension medications? • What overall did patients and clinicians like or dislike about the text messaging content and interactions? • What additional features and functionalities would patients and clinicians like to see in Quartz?

3.2 Data Collection Methods

This study uses qualitative and quantitative data collection methods. To assess technical feasibility, we collected meeting notes and conducted key informant interviews (KIIs) with the three members of the technical team. To assess perceptions on the usability and patient-centeredness of the Quartz app, we conducted KIIs with two clinicians and think-aloud sessions with four patients who were then asked to respond to the System Usability Scale (SUS).[20] Each KII included only one participant for a total of 9 interviews with 9 unique participants. The NORC Institutional Review Board reviewed and approved all methods and processes for this assessment and classified the assessment as exempt.

Exhibit 7 outlines the data collection methods used at each phase of the Quartz assessment, which we describe in detail below.

Exhibit 7. Assessment Methods Overview

EHR Integration

- Collected qualitative information during planning calls with Baystate Health and Elimu Informatics technical team.
- Conducted KIIs with the technical team (n=3)

Usability Assessments

- Conducted KIIs with clinicians (n=2)
- Conducted think-aloud sessions and the SUS survey with patients (n=4)

3.2.1 EHR Integration

The technical team, which included two members from Baystate Health and two members from Elimu Informatics, met weekly to discuss the integration of Quartz into the Oracle EHR system. To document the process and assess the integration experience, the NORC team participated in periodic virtual meetings and collected notes on any challenges encountered and solutions implemented by the

technical team, including any issues with the technical performance of Quartz. We also conducted 45-to-60-minute KIIs via Zoom web conferencing with one member from Baystate Health and two members from Elimu Informatics to gain a deeper understanding of their experience, including perspectives on salient challenges, overall feasibility, and lessons learned from the integration to guide future implementation. We used a semi-structured discussion guide for these discussions (Appendix A).

3.2.2 Usability Assessments

To assess usability, NORC engaged in two data collection efforts: 1) KIIs with clinicians to assess their anticipated experience with the Quartz workflow, and 2) think-aloud sessions and usability surveys with patients from the Baystate Health system to gather their perspectives on the Quartz app..

Clinician Assessments. The KIIs with clinicians provided insight into how Quartz will fit in clinician workflow and how they would use the app in a real-world setting with patients. We conducted 45-to-60-minute discussions via Zoom with two clinicians. We used semi-structured discussion guides (Appendix B) to examine their perceptions of the usability of Quartz (i.e., fit with workflow) and what refinements the technical team could implement to support future deployment.

Patient Assessments. The think-aloud sessions with patients gathered perceptions of the Quartz app's usability and patient-centeredness. We chose to use think-aloud assessments because they are a common approach in usability testing consisting of system users continuously verbalizing their thoughts while performing a series of set tasks.[20] To recruit patients to participate in the think-aloud sessions, two Baystate Health clinicians sent a patient portal message to 40 patients with the study information and recruited patients in person during a clinical encounter using a one-page handout with the study information. NORC conducted 30-to-45-minute virtual sessions with four patients within the Baystate Health system. During the sessions, we presented patients with a mock scenario about a patient with uncontrolled hypertension and asked patients to think aloud as they responded to the Quartz text messages from that mock patient's perspective. NORC moderators assisted users as necessary to respond to messages, documented which messages presented challenges, and prompted feedback on how to resolve identified challenges. See Appendix C for the think-aloud assessment guide.

After the scenario was complete, NORC moderators asked general questions about usability and administered a validated survey instrument, the SUS, to supplement findings (Appendix D). The SUS is an industry-standard 10-item questionnaire with a 5-response Likert scale that assesses perceptions of usefulness, satisfaction, and ease of use of a technology.[21] For this assessment, we removed one item ("I found the various functions in the product were well integrated") due to its irrelevance to the text messaging program. NORC offered a $50 honorarium to patient participants.

3.3 Data Analysis Methods

The NORC team conducted qualitative and quantitative data analysis. We synthesized and integrated themes from qualitative and quantitative findings to provide a better understanding of the Quartz app's integration and usability.

3.3.1 Qualitative Analysis

For the meetings with the technical team and the usability assessments with clinicians and patients, we conducted a rapid thematic analysis to identify factors that contributed to successes or challenges for the integration and usability of the app. A research team member reviewed the transcript-style notes after each session and produced key themes. The full research team reviewed each session's key themes to ensure they were comprehensive, useful, and accurate representations of the session. Once they reached consensus for each session, the research team conducted a collaborative mapping exercise to identify the overall key themes across the sessions.

3.3.2 Quantitative Analysis

The quantitative analysis consisted of univariate descriptive statistics of the SUS scores from the patient think-aloud sessions. Per the SUS scoring methodology, we took the average score for each item and subtracted 1 from the odd-numbered questions and subtracted the value from 5 for the even-numbered questions. Due to the deletion of one item from the 10-item SUS, we adjusted the calculations to take the sum of the adjusted scores and multiply them by 2.8 (instead of 2.5) to achieve a score out of 100. This enabled us to compare our score to the usual SUS benchmark score. We integrated these findings on usability with the qualitative findings.

4. Assessment Results

This section describes the key findings related to the two assessment goals. We organized the findings by key themes in each of the following areas: 1) the technical feasibility of integrating the Quartz app into the EHR, 2) clinician and patient perspectives on the usability and patient-centeredness of the Quartz app, and 3) additional considerations for PC CDS interventions.

4.1 Goal 1: Assess Technical Feasibility of Integrating SMART on FHIR Quartz App with EHR

The Quartz app lifecycle (from design to pre-production) took about 7 months (Exhibit 8). Many of the informants noted that this is typical of most deployment processes, and perhaps quicker due to Baystate Health's experience working with SMART on FHIR visualization apps and their existing technical resources dedicated to app development. Further, their IT department designated this as a "standard request" meaning it was already an approved process that a triage committee could transfer to the appropriate team to operationalize, as opposed to a new "project" that would have to be reviewed

and approved through governance processes (i.e., for a new product or workflow). This accelerated the timeline by several months.

Exhibit 8. Timeline of Quartz App Development and Integration

During each stage of the process, the technical team experienced several challenges and limitations, many of which are common to SMART on FHIR apps and standards-based APIs in general (Exhibit 9).[22, 23] To overcome these challenges, the technical team tested the app in several different environments (e.g., HAPI FHIR server, Oracle Health's sandbox, Baystate's test server) to anticipate issues and strengthen the app's performance in the production setting at Baystate.

Exhibit 9. Challenges and Limitations of Testing the App Identified during Steps of App Deployment

#	Step Toward Deployment	Challenges and Limitations
1	App development	• Limitations in Oracle Health FHIR API that do not support robust write-back capabilities • Limitations in how the FHIR API handles data from groups of patients versus individual patientss
2	App testing and refinement for vendor product compatibility	• Patient data in the Oracle FHIR sandbox was inadequate for testing • Lack of access to the EHR user-interface for full user-experience testing
3	App integration testing and acceptance testing in client environment	• Working with a cross-functional technical team in health care organizations requires additional time • Lack of direct access to detailed error logs from Oracle's FHIR APIs • Creating realistic test data is time consuming • Lag times to load the SMART on FHIR app

Below, we describe each of the challenges in more detail and discuss how the team mitigated these challenges.

4.1.1 Challenges and Solutions During App Development

Two challenges arose when developing the Quartz app in Elimu's HAPI FHIR environment for future deployment in the Oracle Health EHR.

There were limitations in the EHR vendor write-back capabilities. Ideally, the technical team would like to write back patient-reported data to the EHR in a discrete format using FHIR resources. However, Oracle Health's FHIR APIs do not support the writing FHIR QuestionnaireResponse resource. Additionally, there are limitations with the use of FHIR Observation resource in Oracle Health's FHIR API. Consequently, when writing back patient-reported data such as blood pressure readings taken at home, the data are filed as physician entered. Clinician feedback indicated that they want a clear distinction between patient- and clinician-reported blood pressure readings as the accuracy and reliability of readings can vary when taken at home versus the clinic.

"We tried to write blood pressure data back [to the EHR] because they have a FHIR API to write blood pressure, but it shows up as clinician-entered blood pressure, not patient-entered blood pressure. That's Baystate's major hesitation on rolling out the app more widely, they'd like to have a copy of the blood pressure data in their EHR in a discrete format [showing the proper attribution for who entered the data]."

– Technical Informant

- **Proposed solution.** The technical team stored the patient-reported data, i.e., patient blood pressure readings, in the external Sapphire® FHIR server, which clinicians could view from the SMART on FHIR app launched from the EHR. The technical team is also exploring other avenues to write back data, such as using HL7 v2 messages or using Oracle Health's proprietary API (Millenium Objects). By using the proprietary API, they can make a distinction between patient- and clinician-reported blood pressure readings.

There were limitations in how the FHIR API handles data from groups of patients versus individual patients. FHIR APIs work well for accessing individual patient data, but working with groups of patients is more challenging. The technical team would like to create a feature in the Quartz app that enables clinicians to view their roster of patients and enroll multiple eligible patients at one time, but that is not currently possible using available FHIR APIs. Eligibility criteria for enrollment are complex and encompass multiple FHIR resources. Such querying capability is not feasible or practical with FHIR.

- **Proposed solution.** The technical team will explore the use of FHIR Bulk Data Access APIs to identify patients for enrollment, which only recently became available in Oracle Health's EHR. Currently, the enrollment workflow is still one patient at a time with the clinician opening the patient's chart, launching the hypertension app, and clicking "enroll" on the dashboard widget.

4.1.2 Challenges and Solutions during App Testing and Refinement

After developing the app, the technical team tested it in an Oracle Health sandbox environment for compatibility with Oracle Health's FHIR API. Two challenges arose when testing and refining the app in the sandbox environment.

The Oracle Health FHIR sandbox includes patient data that were inadequate for testing and does not allow creation of new test patients. When testing the Quartz app for compatibility with the Oracle

Health API, the patient data provided in the sandbox do not mimic the complexity of real patients and was not specific to the use case being tested. For instance, the team could not test changing prescriptions in the sandbox environment, and they did not anticipate missing codes for recent hypertension medications or diagnosis of hypertension in the Baystate outpatient records. Further, the technical team could not enhance the data by adding new variables due to limitations with Oracle Health's public sandbox. The latter capability to add data to a patient's record in the sandbox is only available to vendors participating in Oracle Health's paid developer program. This impacted the ability to test all FHIR queries before integration.

- **Proposed solution.** To comprehensively test the app, the technical team took a step-by-step approach to identify issues with the app in the HAPI FHIR test environment, then the Oracle Health sandbox, and then the Baystate test environment before moving forward to production.

The technical team originally did not have access to the EHR user-interface for full testing of the user-experience. The technical team wanted to ensure that clinicians could view the clinician flowsheet's features and functionalities as intended. However, due to proprietary features in Oracle Health, the sandbox environment does not have the same Quartz app launch points as in the EHR user-interface. This prevented the team from troubleshooting user issues before integrating the app at Baystate Health.

- **Proposed solution**. While the sandbox enabled limited testing of the integration, including the authorization flow and the FHIR APIs, the technical team deferred testing the full user experience to the next step.

4.1.3 Challenges and Solutions During App Integration

After testing the app in the sandbox environment, the technical team integrated the Quartz app into the Baystate Health test environment. Four challenges arose during app integration.

Working with a cross-functional technical team in health care organizations requires additional time. The technical team included both app developers at Elimu Informatics and analysts at Baystate Health. Integration of the app and refinement of the integration requires assistance from analysts at Baystate Health who have several other priorities related to support their production applications. The technical team noted the additional time it takes to identify the right point of contact on the other side and communicate with members across different teams as well as the EHR vendor.

- **Proposed solution**. The technical team included a member who was both a clinician and informatician who could make connections between the app developers and the Baystate Health analysts. The technical team also met weekly to discuss the deployment, and they set up channels on Slack and Microsoft Teams to facilitate quicker communication.

There was a lack of direct access to detailed error logs from Oracle Health's FHIR APIs. Because Oracle Health hosts the FHIR server, the integration team could not view the error logs when issues

arose. For example, the integration team needed detailed error logs for an issue related to opening links to hypertension guidelines within the app, which is done using browsers embedded in Oracle Health's server.

- **Proposed solution.** The technical team worked with the Baystate Health analysts to request the error logs from Oracle Health. Each request for error logs delayed integration testing by several days.

Creating realistic test data is time consuming. When testing the app in the Baystate Health test environment, a technical team member had to manually create realistic test patients one at a time. One of the challenges the team experienced is that testers needed specific EHR roles and permissions in the Baystate environment to add new patients. A member of the technical team had to email an administrator at Baystate to create the encounter, and then they were able to add new variables. Secondly, adding large volumes of data such as historical visits and vital signs through the EHR's user interface is tedious and time consuming but necessary to replicate the complexity and variability of real patient data. For example, blood pressure readings for outpatients will only occur once every 3-6 months, whereas inpatient blood pressure readings will occur hundreds of times over a 7-day period. Without manually creating those realistic bursts of data, the technical team cannot test to see if it causes issues with the app.

"Creating this test patient, you can't go out and find someone who has this data. You want it to tell a story, like one lab [result] increase that needs a change in medication, but you're not going to find that through mock data, you have to create that."

– Technical Informant

- **Proposed solution.** Baystate Health provided a technical team member with an enhanced EHR role that allowed him to create new patient variables. This team member also had a nursing background and could visualize realistic scenarios and test the app from the nurse, doctor, and patient perspective.

Delays in loading the SMART on FHIR app could inhibit clinical workflows. As with other FHIR APIs, because the overarching hypertension app was hosted on an external interface and was collecting data from various places in the EHR, there were delays when launching the app. Initially, it took 15-20 seconds for the app to load data when launched, when they would like to it to take less than 6 seconds.

- **Proposed solution**. The technical team found ways to reduce the load time by relocating it to a tab so that it downloads as the clinician is viewing their other patient flowsheets. In addition, when the team used the Microsoft Edge browser to launch the app, this improved the app's performance. The team is continuing to explore ways to improve app speed and performance.

4.2 Goal 2: Assess Usability and Patient-Centeredness of Text-Messaging-Based PC CDS

Using an inductive approach, we identified key themes that emerged from clinician and patient KIIs.

4.2.1 Clinician Perspectives on Usability and Patient-Centeredness

Both clinicians reported that the Quartz app has potential to provide useful information on barriers to medications and adherence levels between appointments. They said they would use the information for more context to what the patient shares at the time of the appointment. At the same time, clinicians said that as it currently stands, the Quartz app might inhibit standard workflows in primary care. They provided the following feedback to improve app usability:

For clinicians:

- **Integrate the hypertension dashboard into the existing primary care worksheet.** Primary care physicians at Baystate Health currently use a patient primary care worksheet that includes all medical information and history (e.g., all medications, lab results, vital signs, and problem lists). One informant noted that the hypertension dashboard repeats some of this information, while some information clinicians would need to adjust prescriptions (like the full medication list and prescription fill history) is missing. Additionally, because the hypertension dashboard sits as an extension on a separate tab, the clinician would have to toggle back and forth to view all the information they need to make decisions. Technical team informants explained that this integration is technically possible, but they will not attempt it at this time because it would slow down EHR response times.

"If it loads faster or if that information came into the primary care workflow page that we use with patients, as opposed to a different page [that would be better]. There's a lot of information that is doubled on this page that is on my other page, but all the meds aren't on there, all the labs, all the problems aren't on there [and I need them to inform my next action]."

– Clinician Informant

- **Improve the app load time.** As noted previously (Section 4.1.3), clinicians believed that the time it takes to load apps in their EHR would discourage them from using the app. Primary care physicians have many competing priorities and needs during patient visits, particularly for patients in a community health setting, so choosing to focus exclusively on hypertension would pose a problem for some. Clinician informants believed this would be less of an issue for specialists (i.e., nephrologists) who would only be focusing on hypertension and would not have as many time constraints.
- **Include information on prescription fill data and ability to send orders within the dashboard.** Clinicians requested more features and functionality to facilitate decision-making. Prescription fill data would let them know when a patient is due for a refill and whether they should adjust their supply to accommodate cost barriers (many insurance companies are shifting to covering 90-day supplies instead of 30-day supplies). Additionally, having the ability to send an order for a

medication change within the dashboard would be helpful so that it is all in one place; however, the technical team reported that this is a limitation of the SMART on FHIR standard.

For patients:

- **Use 24-hour recalls instead of monthly recalls to ask patients about their adherence levels.** One clinician informant stated that they ask their patients about their ability to take their medications as prescribed during in-office visits, so knowing how their responses appear at other points of the month would be helpful. In addition, they believed that asking patients to recall their adherence for one day would lead to more accurate responses than recalling adherence over the past month.
- **Clearly explain the source of the messages.** Although not tested yet, clinicians believed that there may be challenges with patient trust when enrolling them in the program. They emphasized the importance of explaining where the messages are coming from and how their clinician will use the information to improve their care.

"I'm at a community health clinic with people who have many barriers to care, limited health literacy and general distrust of medical system and technology, so I worry that people will have concerns about who is texting them and all the information is HIPAA compliant."

- Clinician Informant

4.2.2 Patient Perspectives on Usability and Patient-Centeredness

Overall, patients reported that the Quartz app might be helpful for patients with uncontrolled hypertension and that monthly check-ins seems appropriate, but they also provided several suggestions to improve the text-messaging program.

Patient Feedback on Usability

For the two message scenarios, patients thought that most of the messages were clear and understandable, but there were a few that could be shortened and simplified to improve readability (Exhibit 10). The patients were in favor of direct, simple, and straightforward language. One patient said this straightforward communication would be especially important for people experiencing socioeconomic barriers.

"If someone is experiencing economic difficulties or transportation difficulties or other problems other than just oh the routine this morning changed so I forgot, there may be socioeconomic factors involved, and I think simple, direct language would be most effective."

– Patient Informant

Exhibit 10. Patient Feedback on Text Message Content

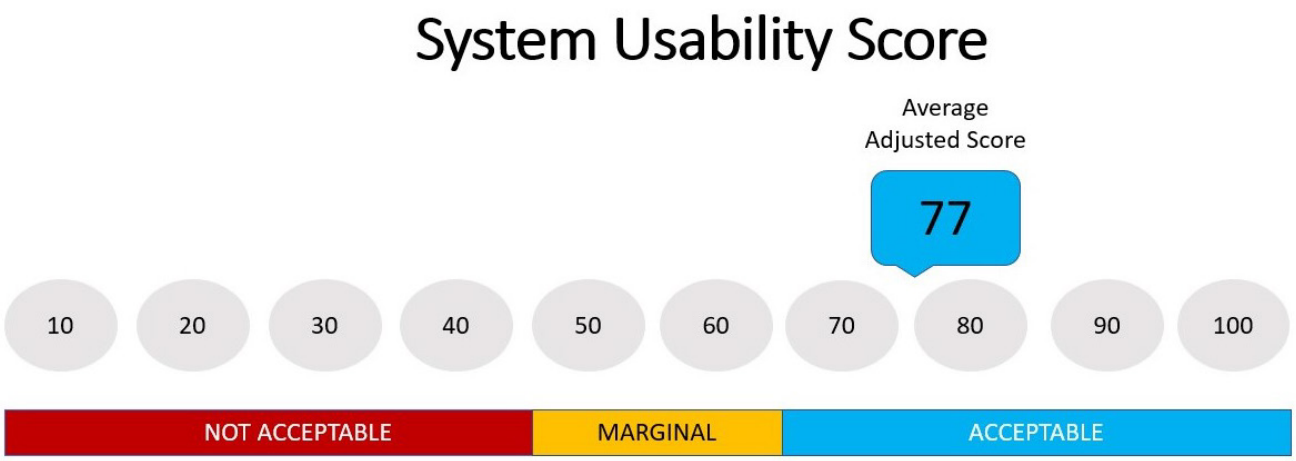
Text Message Content	Patient Feedback
Welcome/Enrollment Scenario	

Welcome. Your doctor has enrolled you in this txt program to help you take Atenolol. Click http;//short.url to learn more. Msg and Data Rates May Apply. Reply STOP to unsubscribe.
IMPORTANT: Your replies may not be checked immediately by your care team. They cannot send msgs to you via this app. For urgent concerns, contact your doctor's office directly.
 	
Reply 'agree' to proceed.
	• One patient said to clarify that, "click this link to learn more" is to learn more about the text messaging program, not about Atenolol.
	• Two patients recommended spelling out "txt" because they thought it was a typo.
	• Three patients thought the message was easy to understand, while one thought it would be clearer to use complete sentences and consistently use acronyms.

We will send you messages at 08:00. *Would you like to change the time (reply y/n)?*	• When one patient responded, "I would like to change the time," Quartz responded with the same message. They thought it should be able to understand their response better. • One patient did not like the use of military time.
Medication Adherence Check-In Scenario	
Hello. We would like to check-in with you about your medications. Please reply "ready" to proceed.	• One patient did not know how long the check-in would take when he responds "ready." • Two patients suggested adding which medication it is checking in about.
Rate your ability to take Atenolol as prescribed (reply 1 for very poor, 2 for poor, 3 for fair, 4 for good, 5 for very good, and 6 for excellent).	• One patient suggested writing the scale as a column rather than a list to improve readability. • Two patients were initially confused by the word "ability" until they saw the response message. They suggested alternatives such as "likelihood" or "how easy is it."
What makes it difficult for you to take your medications as prescribed? Reply "ran out," "forgot," "inconvenient," or type a side-effect or other reason.	• One patient suggested saying "another reason" instead of "other." • One patient did not feel that this captured their issue that they are taking their medications, but the medications are not working as intended.
Got it. *Thx. A summary of this information you've provided will be available for your care team to review. There may be delays in their access; if you have urgent concerns or questions, please contact your doctor's office directly.*	• Three patients thought message could be shortened and simplified. – One suggested, "Thanks. This information will be shared with your care team. You may not hear from them immediately, but if you have urgent concerns or questions, contact your doctor's office directly." – One suggested, "We will give this information to your care team. If you have any questions, please contact your doctor."

Each participant (n=4) also completed the SUS questionnaire immediately following the think-aloud session. The mean SUS score of the Quartz app was 77.0, which translates to an acceptable ranking (Exhibit 11).

Exhibit 11. Results from the System Usability Scale Questionnaire



Patients generally agreed that the text messaging program was easy to use and that most people would learn to use the program very quickly. They also agreed that they felt confident using the text messaging program. Patients disagreed that the program was complex, that they would need support to use the program, that it was cumbersome to use, and that they needed to learn a lot before getting started with the program. The patients participating in this assessment reported good adherence to their medications, which was reflected in their disagreement that they would use this program frequently. They gave a neutral score to the statement that there was too much inconsistency in the program, which reflects the feedback on text message language and content.

Patient Feedback on Patient-Centeredness

Notably, all patients who participated said they did not personally have trouble taking their medications as prescribed, so this program would be not appropriate for them. However, they discussed several ways to improve patient engagement, trust, and satisfaction with the program for people with uncontrolled hypertension.

- **Personalize the messages by making them "smart" or more responsive to the individual.** Patients suggested finding ways to incorporate patient-specific information in the messages to increase the likelihood of engagement. For example, in the initial outreach, it could state their name and pull information from the EHR and state the medication and dosage that the patient is on and ask them to confirm. One suggestion was to have Quartz acknowledge the barrier previously reported in subsequent check-ins and ask them if they are still experiencing that barrier (e.g., "The last time we talked, you said you weren't able to get a refill of your prescription. Were you able to

get the refill?"). Another suggestion was to give patients the option to change the frequency of the messages they would like to receive. They thought a person who forgets to take their medication might want more messages compared to someone experiencing transportation barriers.

- **Build rapport with the patient by making the tone more empathetic or positive.** Patients generally thought that the messages were clear and understandable, but they lacked warmth in the responses. They suggested adding more questions in the initial contact to establish a relationship and a level of comfort with the patient. One patient also thought that patients might need more supportive messaging after reporting the barriers they are experiencing as some might find it sensitive information and might be embarrassed to share.
- **Acknowledge the clinician's receipt of the information.** While the patients interviewed did not have privacy concerns with sharing information via text message, they were skeptical that their clinician was going to use the information they provided. Patients thought it would be more reassuring to some if there were a direct link to their provider, such as a response directly from the provider every few months. Otherwise, patients will feel that their responses are going to a "black hole" and will be less likely to engage month after month, especially if they are reporting barriers and do not receive a response. One patient who had experience with inconsistent blood pressure readings said it would have been important for her clinician to know this before the next appointment.

"I think people are often suspicious of who's at the other end of the text message. You know, how many messages do you get that you just ignore, even if you are expecting this and you know it's coming?"
– Patient Informant

4.3 Additional Considerations for PC CDS Interventions

In addition to the findings on technical feasibility, usability, and patient-centeredness, informants described several other considerations for PC CDS interventions that work with patient-reported data in health systems.

As an overarching consideration, clinician informants believed that there would need to be a mindset shift in clinical care when engaging in this type of PC CDS. First, patient care would encompass both in-clinic and at-home settings, which might be difficult for some clinicians to engage with when they are already overwhelmed. There will be large volumes of data to process monthly adherence level for a chronic condition, which often requires medication for a patient's lifetime. The hypertension visualization dashboard currently signals good or poor adherence at certain time points, but there may be additional summarization needed for longer periods of time. Further, at-home patient-reported data has its own limitations and biases that the care team should consider, such as incorrectly using a blood pressure cuff or contextual factors (e.g., recent physical activity, diet) that might influence blood pressure readings. The Quartz app seeks to minimize these factors by using simple SMS technology for medication adherence, but apps with more complex capabilities may require additional education for patients, e.g., when using remote monitoring devices or procedures.[24]

Second, patient care should be at the population level as well as individual level. The Quartz app patient roster view enables clinicians to monitor a panel of patients and identify those who might need medication management. This puts the onus on the clinician to proactively reach out to patients who are experiencing barriers, and it means clinicians will need to devote more asynchronous time to routinely monitoring patients. Clinicians believed that there would need to be systems and resources in place to support this type of patient care, such as having a nurse monitor the patient roster daily or weekly and message clinicians when there are issues with a patient. There is also potential for AI to play a role in this information processing and triaging as the standard of care moves more toward PC CDS.

"That is a departure from the standard of care, but standard of care is that I might not see the patient for 2 months and then they tell me they aren't taking their medications. So, part of the new workflow is to quickly view the roster and see if they are having adherence issues to be more proactive. That's where I'd love to see this get to for a number of issues."

– Clinician Informant

5. Conclusion

PC CDS has the potential to facilitate patient care by collecting valuable information about patients between visits, and SMART on FHIR apps can graphically display this information in a meaningful way for clinical decision-making. In this report, we evaluated a clinician- and patient-facing SMART on FHIR app to assess the technical feasibility of EHR integration as well as the usability and patient-centeredness of text-messaging-based PC CDS. Overall, the integration process faced similar challenges to other SMART on FHIR apps, such as limited write-back capabilities, difficulties testing patient data, and slower speed times loading the data. The clinician dashboard and roster view provided helpful contextual information for clinicians, but there is a possibility that it could impede clinician workflows. The patient-facing text-messaging program was understandable and easy to use, yet there could be ways to improve patients' trust and satisfaction with the program with a few modifications. While this prototype is a minimum viable product, it shows the potential of leveraging text messaging and chatbot technology to advance patient-centered care. Future steps to deploy the app in a production environment will shed more light on its usability in a real-world setting.

Appendix A. Technical Team Discussion Guide

Introductions

We'd like to start with having you introduce yourself.

1. Could you briefly describe your position at [Baystate/Elimu] as well as your specific role for the development and integration of the medication adherence app project?
    a. What aspects of the development process were you involved in?
2. To make sure we're on the same page, could you describe in your words what the points of integration for Quartz are in the EHR at Baystate, i.e., when you say integration, what do you mean?

Technical Development

3. Can you describe who all has been involved in the [technical development and] integration process at [organization]? By development we mean the part of the process where the app was built and tested in Elimu's hosted environment (e.g., SMART on FHIR launcher and HAPI FHIR server) and by integration we mean what was done so that the app could work with Oracle Health in Baystate's test environment.
    a. *Probe*: informaticians/technical experts at Baystate and Elimu, EHR vendor, end users
    b. Were there any skillsets or expertise that were not included on the technical team but were needed?
4. [*If end users were involved above*] Other than the patient co-design process that we're familiar with, what type of feedback did you receive from end users during the development of the app?
    a. What changes were made to the design of the app in response?
    b. What changes, if any, were requested that were not made, and why?
5. We understand there is an existing, clinician-facing SMART on FHIR app for hypertension monitoring that Signet was built into. What standards or data infrastructure were necessary to integrate Signet in that app?
    a. What, if any, functionality could not be integrated, and why?
    b. What kind of technical standards and resources are needed to make this kind of development work easier to do in the future?
6. What challenges were encountered during the development of Signet? For example, we heard that there were difficulties with the EHR write-back capabilities that led to the need for a FHIR data store. Were there other challenges that influenced the app's design or architecture?
7. We know one of the challenges was inability to write medication adherence info from Quartz to the EHR and that you ended up using an external FHIR data store. What resources were required to develop the external store?
    a. Is this a challenge you foresee with other EHRs?

8. Another challenge you mentioned is that the data in test environments is not comparable to real-world EHR environments. What data elements do you think will be in the production environment that you weren't able to test in the development phase? How do you prepare for this?
9. You noted some other issues with the test environment such as not having access to the user interface of the EHR. How did you address this?

Technical Integration

We'd like to ask some questions about the process for integrating the Medication Adherence App with the Oracle Health EHR system at Baystate Health. We'd like to focus here on the steps where you conducted testing in the Oracle Health provided sandbox and then conducted integration, testing, and acceptance testing in Baystate's EHR test environment.

10. Has the integration into the EHR thus far gone as you expected? Why or why not?
    a. How easy or difficult was it to integrate the app in Baystate's test environment?
    b. What facilitators were there to the process?
11. What integration issues did you encounter, and how were they resolved?
    a. For the challenge with needing to request additional detailed error logs from Oracle Health, what are some examples of logs that the team needed to review?
    b. For the challenge about realistic test data, what environment is that in? What do you have to do to make a realistic test data set?
    c. *Probes:* Challenges during app testing and refinement in the sandbox environment? Challenges with creating or storing test data?
12. What changes were made to Quartz to support integration?
    a. *Probe*: How much EHR customization has been required to integrate the app in the test environment, if any?
13. What processes were (or will be) in place to monitor the ongoing functionality and to identify possible issues with the app?
14. Overall, how successful would you say the integration of Quartz has been thus far?
    a. Were there any challenges that were specific to the fact that it is using patient-reported data, versus other types of traditional clinical decision support?

Scalability

Looking beyond this pilot, we'd like to ask a few questions that may help others develop and integrate a similar application.

15. In terms of integrating this app in other EHRs, what are the minimum requirements needed to integrate it?
16. Is there anything in particular about the Baystate setting that you think made its integration particularly successful? Or particularly difficult?

17. What are potential barriers to deployment of Signet into a production environment?
18. Do you have any recommendations for others seeking to integrate applications for remote patient monitoring that could be applied to other conditions?

Wrap Up

Thanks so much for your time. To wrap up:

19. Are there any other final thoughts on the development and integration of this app that you would like to share?

Thank you for your time!

Appendix B. Clinical Team Discussion Guide

Introductions

We'd like to start with some brief introductory questions.

1. Could you briefly describe your role at Baystate Health and your experience with the current hypertension monitoring program?

2. Are you familiar with the text messaging program that will ask patients about their level of adherence and barriers to taking hypertension medications? If so, what was your initial impression of the text messaging service?
    a. In what ways does this meet a need in your practice?

Workflow

We'd like to turn to your perspectives on how the Signet app would fit into your workflow if you were to use it in the future. We are going to provide a quick overview of the clinician-facing components of the hypertension monitoring app. For this assessment, we are specifically focusing on the medication adherence data that will show the history of the app's text messaging interactions with patients. [SHARE SCREENSHOTS of workflow diagram, patient log report, and clinician dashboard].
+++++++
Workflow diagram:

- During a visit with a patient, the clinician logs into EHR and launches the app. The clinician then gets verbal consent from the patient and enrolls them in the Signet program. The patient gets a welcome message and a question about their preference for timing of the text messages. They respond and Signet responds. Signet checks in monthly with the patient about their ability to take their medications and you as the clinician would monitor their responses via the dashboard and follow up as needed.

Video:

- This is the clinician dashboard with not just the information from Signet but other information about patients with hypertension like blood pressure, current medications.
- The arrow is moving down to the section that shows the Signet medication adherence info. Each icon is an interaction. The ones that look like play buttons are enrollment interactions, and the color-coded ones are check-ins. Green indicates the patient reported an excellent ability to take their meds, yellow is good, and red is anything that is not excellent or good.
- Now he's moving to the enrollment widget. If you click the plus button this comes up where you can input when you want to start messaging the patient, the time of day, and select the medication you want to check in on, and the patient's preferred language.

Screenshot:

- There's also in development a roster view where you can see the medication adherence rating information from all of your patients enrolled in the program. That workflow is still TBD but the idea is that you could use the roster view asynchronously to check in on your patients versus waiting until the next visit.

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3. To begin, how does the process for enrolling patients in the program (i.e., launching the app through the patient's clinical chart) fit with your current workflow?
    a. Do you foresee any challenges with enrolling patients in this way?

4. How does this workflow compare to your existing methods for monitoring medication adherence at Baystate Health?
    a. Do you think the dashboard graph for medication adherence will be more or less useful than the workflow you used prior to implementation of the App? Why, or why not?

5. Will the patient-reported information provided by Signet be helpful to support decision-making about patients' hypertension medications? How?
    a. In what part of your workflow do you envision using the information (e.g., with the patient during a visit, asynchronously, both)?
    b. What features would you like added to the report/dashboard to support decision-making?
    c. What, if any, escalation pathways/triage rules would be helpful for this use case? For which patient populations?

6. What are your general thoughts on how the information is displayed? Do you have any recommendations for changes/improvements that would better align with your workflow and/or decision-making process?

7. Do you foresee the Signet App being disruptive to your workflow in any way? If so, how?
    a. What kind of processes should be in place to monitor ongoing functionality and to identify possible issues with the app?

8. Do you think the Signet App will allow you to engage with patients more effectively about their medication behaviors?
    a. Do you feel the frequency with which the app will interact with patients will be sufficient?
    b. What do you think will be the biggest barriers to engaging patients in the program?
    c. The facilitators?

9. What recommendations do you have that would improve the workflow for future implementation with clinicians? Patients?

Clinical Care Team Perspectives on the use of AI

Diving a little deeper, we'd like to hear more about your impressions of the Signet App technology, which leverages chatbot and natural language processing techniques to interact with patients. The chatbot is programmed to not provide medical advice or answer patients' questions. It will only ask pre-programmed questions and provide the patients' responses to the clinicians.

10. Do you have any concerns about using a chatbot to collect information on patient-reported medication adherence?
    a. Do you think it is appropriate for the use case of hypertension medications?
    b. Would you have any concerns about the validity of the data patients submit?

11. What are the potential benefits of using AI for this use case?
    a. *Probes:* Will it improve the timeliness of collecting patient-reported data? Your ability to review that data in a meaningful way?

Scalability

Looking beyond this study, we'd like to ask a few questions that may help others implement PC CDS interventions in other practices.

12. What are other potential clinical use cases for this medication adherence app?
    a. Which patient populations might be best suited for this monitoring app?

13. Is there anything in particular about your setting that you think will make its implementation particularly successful? Or particularly difficult?

Wrap Up

Thanks so much for your time. To wrap up:

14. Any final thoughts on the future implementation of this PC CDS?

Thank you for your time!

Appendix C. Patient Think-Aloud Assessment Protocol

Introductions

1. Can you start by telling us about how often you use your phone to text message (e.g., every day, every week)?
    a. What barriers if any, do you encounter with text messaging?

Think-Aloud Tasks

Thank you. We'll start by sharing our screen and giving you remote access to the Google Voice chat to respond to the text messages. [**share screen**]

This was also in the background document but as a refresher, the scenario to keep in mind as you complete these tasks are:

"Imagine that you were diagnosed with hypertension or high blood pressure two years ago. Your doctors started you on some medication, but it took a little while to get your blood pressure under control. Because of a new job, you moved across the country and the move was stressful. You also had to find a new doctor to help you manage your blood pressure. Your new doctor told you about a new text messaging program that helps monitor hypertension medications. After talking with your doctor, you agreed to join the program and are now receiving text messages."

Do you have any questions?

Great. Please respond to the text messages as they appear on the screen. Remember to talk through your thoughts as you are responding.

- Scenario 1: Enrollment and Patient Preferences
    - We will send this message right after your doctor enrolls you in the text messaging program.
- Scenario 2: Medication Adherence
    - We plan to send this message 3 days after a patient is enrolled, and then every 30 days or so.
- Scenario 3: Disenrollment
    - This message is how someone would remove themselves from the program if they would like to.

Acceptability Questions

1. **Affective Attitude:** Would this type of program be helpful to manage your medications? If so or if not, why?
    a. Probe: How often would you prefer to receive check-in messages on how well you are able to take your medications?

2. **Burden:** To what extent do you feel, if at all, that participating in a text messaging program like this would be burdensome to you? Why?
3. **Ethicality:** To what extent do check-ins on your ability to take your medications align with your values and beliefs?
    a. Probe: Is this an appropriate intervention, in your opinion?
    b. Probe: Would you have any concerns about sharing any of this information with your doctor over text message?
4. **Intervention Coherence:** To what extent do you feel that text message check-ins can be used to support peoples' ability to take medications?
    a. Probe worded another way: As an intervention, does it make sense to you?
5. **Perceived Effectiveness:** To what extent do you feel that text message check ins would support ***your*** ability to take your medications?
6. **Opportunity Costs:** To what extent do you feel that you would give up some of your time to use this program?
7. **Self-Efficacy:** To what extent do you feel that you can confidently use this program as a tool to support your ability to take your medications?

<u>High-Level Usability Questions</u>

8. What do you think about the messages overall?
    a. Probe: Were the messages clear and understandable?
    b. Probe: Is there anything you would change about the messages?

9. What additional questions/information would you want to be asked to tell your doctor about your hypertension medications?

10. Is there anything else that you'd like to mention about the text messaging program?

Appendix D. Patient System Usability Scale Survey

Each item is scored on a scale of 1-5, with 1 being strongly disagree and 5 beign strongly agree.

1. I think that I would use this text messaging program frequently.
2. I found the text messaging program unnecessarily complex.
3. I thought the text messaging program was easy to use.
4. I think that I would need the support of a technical person to be able to use the text messaging program.
5. I thought there was too much inconsistency in this text messaging program.
6. I imagine that most people would learn to use this text messaging program very quickly.
7. I found the text messaging program cumbersome to use.
8. I felt very confident using the text messaging program.
9. I needed to learn a lot of things before I could get going with this text messaging program.

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