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Android-based smartphone application simulation and systematic design to reduce medication administration error in prehospital emergency care.

Natalie Vazquez
Virginia Commonwealth University

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Biomedical Engineering at Virginia Commonwealth University.

By

Natalie Vazquez
Bachelor of Science
Virginia Commonwealth University
2011

Director: Ou Bai, Ph.D.
Assistant Professor
Department of Biomedical Engineering

Virginia Commonwealth University
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Abbreviations

ACLS	Advanced Cardiac Life Support
AHA	American Heart Association
ALS	Advanced Life Support
APK	Application Package File
App	Application
BLS	Basic Life Support
CPR	Cardiopulmonary Resuscitation
D50	Dextrose 50%
Dilt	Diltiazem
DPH HCl	Diphenhydramine Hydrochloride
ED	Emergency Department
EKG	Electrocardiogram
EMR	Electronic Medical Record
EMS	Emergency Medical Service
EMT	Emergency Medical Technician
ePCR	Electronic Patient Care Report
Epi	Epinephrine
FDA	Food and Drug Administration
GPS	Global Position System

IOM	Institute of Medicine
IV	Intravenous
MgSO4	Magnesium Sulfate
ODEMSA	Old Dominion EMS Alliance
QR	Quick Response
RAA	Richmond Ambulance Authority
VCU	Virginia Commonwealth University

Abstract

ANDROID-BASED SMARTPHONE APPLICATION SIMULATION AND SYSTEMATIC DESIGN TO REDUCE MEDICATION ADMINISTRATION ERROR IN PREHOSPITAL EMERGENCY CARE.

By Natalie Vazquez, Bachelor of Science

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Biomedical Engineering at Virginia Commonwealth University.

Virginia Commonwealth University, 2014

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Since 1999 when the report *To Err is Human: Building a Safer Health System* was released, medical errors have come into focus (Kohn, 2000). In an effort to reduce medication administration errors in prehospital emergency care, an android-based smartphone application simulation was created. The app has components including QR barcode scanning, text to speech for medication cross-checking, weight-based medication dose calculations, and time stamped medication data wirelessly transferring to a database in real-time. Color standard identification was implemented, aiding to a designed systematic process for patient treatment to reduce medication errors. Direct observation was performed of emergency patient calls with Richmond Ambulance Authority's providers for a preliminary assessment. Device testing was assessed with emergency medical interns and functionally tested in different light environments. Results

showed how similar different pharmaceutical vendors created medication labeling and that 58.3% of medical experts would say this device served to reduce medication administration errors.

Background and Introduction

United States citizens have high expectations when it comes to medical care; they expect to be well taken care of by all members of health care and they expect injuries and illnesses will be treated in a timely manner. Unfortunately, medical errors are more common than we think. They cause an uncountable number of injuries, disabilities, and deaths each year, and cost patients and hospitals billions of dollars every year. Finding ways to fix and reduce the number of medical errors is a big step in making health care safer.

In 1999, the United States Institute of Medicine (IOM) released their report *To Err is Human: Building a Safer Health System*, which was an effort to increase both the general public's and the health care provider's awareness of medical errors. The IOM report was based on two large studies where researchers examined medical records to see how often adverse events occurred. Adverse events were defined as injuries that were caused by medical management that prolonged admission in a hospital or left the patient with a disability at the time of discharge from the hospital (Kohn, 2000).

In a study of 15,000 medical records in Colorado and Utah, adverse events were found in 2.9% of hospitalizations, while a study of over 30,000 medical records in New York hospitals found adverse events in 3.7% of hospitalizations. In Colorado and Utah, 6.6% of these adverse events led to death, with the New York study reporting that 13.6% of adverse events resulted in death. When these numbers are extrapolated to represent the entire United States population, the results estimate that between 44,000 and 98,000 Americans die each year due to medical errors (Kohn, 2000).

Based on a more recent study by Dr. John James, it is estimated that more than 210,000 deaths a year can be attributed to preventable errors by medical personnel (James, 2013). Another report in July 2006 by the IOM found that medication administration errors harm an estimated 1.5 million people every year (National Research Council, 2007). These errors include administering the wrong drug, administering the correct drug but the wrong dosage, administering the drug in the wrong form (a pill instead of a liquid), or administering the drug at the wrong time. Administering the wrong medication or administering the wrong drug dosage are two of the main causes of medication administration error that cause permanent disability or death of a patient (Leape, 1993).

Although many medication administration errors occur at the hospital, many also occur during prehospital emergency care. Emergency medical technicians are often the first people to administer medication to a patient and they have to make quick diagnoses, deciding the best way to treat the patient. The stress that accompanies this responsibility, along with the limited resources available in an ambulance compared to the hospital, results in a number of medication administration errors.

According to the United States Food and Drug Administration (FDA), medication administration error can be caused by drug name confusion and confusing drug labels/labeling. A medication error is "any preventable event that may cause or lead to inappropriate medication use or patient harm while the medication is in the control of the health care professional, patient, or consumer," according to the National Coordinating Council for Medication Error Reporting and Prevention. In 2008, it was estimated that the cost of measureable medical errors exceeded $17 billion (Van Den Bos, 2011).

Richmond Ambulance Authority (RAA) is an emergency medical service (EMS) that has been providing emergency and non-emergency patient service to the City of Richmond, Virginia since 1991. RAA is an agency in The Old Dominion EMS Alliance (ODEMSA), which coordinates EMS systems in Virginia regions. RAA has a newly drafted protocol for medication administration cross-checking (Figure 1). This new verbal-based protocol will serve to assist the providers in double-checking the medications to be administered to patients.

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SECTION: Clinical Procedures

PROTOCOL: Medication Administration Cross-Check©

ORIGINAL: 06/2014 **REVISED:** 06/2014

MED ADMIN CROSS-CHECK

OVERVIEW:
In-line with Richmond Ambulance Authority's approach to develop a Culture Of Safety (i.e non-punitive error, near-miss, and safety reporting), the medication cross check procedure is a critical component of improving the care we deliver, and keeping our patients safe. As providers, we must appreciate that the measures developed to create barriers, redundancy, and recovery are not attempts to 'dumb down' the care we provide, but to address the ubiquitous vulnerabilities of human cognition so that our patients are more than one human error away from harm. The Medication Administration Cross-Check© is an attempt to do just that; to insert one more layer of protection for the patient from predictable patterns and frequency of human error.

INDICATIONS:

1. Any time a medication is to be administered.

CONTRAINDICATIONS:

1. None.

PROTOCOL FOR MANAGEMENT:

Two Providers:
1. The attendant in charge (AIC) obtains intended medication and confirms correct drug, concentration and expiration date.
2. The AIC initiates the procedure by stating one of the phrases: "**cross-check**," "**safety-check**," or "**med check**."
3. Provider two responds that he or she is "**Ready**." It is important to avoid using ambiguous responses such as "okay," since they may be interpreted many different ways.
4. The AIC states the phrase "**I am going to give**" and provides the following information:

    a. **Intended DRUG NAME**
    b. **Intended DOSE**
    c. **Intended RATE**
    d. **Intended ROUTE**
    e. **Intended REASON**

    Example, "I am going to give 75 micrograms of Fentanyl IV for pain."

    The AIC then gives the vial to provider two for confirmation of correct drug, concentration of medication in vial, and expiration of medication.
5. Upon provider two confirming correct drug and expiration of medication he/she responds with the question **"Are there contraindications?"** or simply **"Contraindications?"** This does not have to be robotic or verbatim, but the specific question must be asked.
6. The AIC must verify the patient's vital signs are appropriate and any drug allergies. The AIC should respond either by saying **"No contraindications"** or by stating any *relative* contraindications present.

Figure 1. RAA's Medication Administration Cross-Check protocol (part 1 of 2).

Section

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Continued

MED ADMIN CROSS-CHECK

7. If provider two concurs, he/she should respond with the question **"What's your volume?"** or simply, **"Volume?"**.
8. The AIC should then state the drug concentration and the volume he/she intends to deliver.

   Example, "50 micrograms per mL, I'm going to give 1.5 mL".

   Terms such as "amp" or "vial" should be avoided, as this may lead to an incorrect dose administration. By providing a specific amount, the false notion that the contents of a vial are a "dose" is avoided and directs the provider's attention to exactly how much liquid they intend to deliver.
9. Upon provider two confirming correct drug concentration in vial, he/she should respond with the phrase **"sounds good"** or **"I agree"**.
10. Upon the cross-check procedure being completed, the AIC should then administer the medication.

One Provider:

1. When an AIC must medicate a patient alone due to administering during transport to a hospital, the provider should follow and confirm the medication using a modified version of the established self-check procedure of the "Six Rights of Medication Administration."
2. The AIC must confirm by reading the label that it is the intended medication to administer.
3. The AIC must confirm by reading the label that the medication is not expired.
3. The AIC shall then confirm the proper route of administration; intravenous, intramuscular, sublingual, nasal atomization, or topical.
4. The AIC must then confirm the concentration of medication and volume within the vial.
5. Lastly, the AIC must verify the patient's vital signs are appropriate and any confirm any drug allergies.
6. Upon the self-check procedure being completed, the AIC should then administer the medication.

PEARLS:

1. It is essential that both providers participate in an engaged manner and not passively participate.
2. If a discrepancy, disagreement, or need for clarification is encountered at any step in the process, it must be resolved prior to continuing the cross-check procedure.
3. The cross-check confirmation has been created to be effective regardless of provider two's level of certification and/or knowledge of pharmacology. The drug name, concentration, and expiration date can all be verified by visual verification of the information printed on the drug label.

Figure 1. RAA's Medication Administration Cross-Check protocol (part 2 of 2).

Medications, such as dopamine, are being recalled due to shortages worldwide. The American Society of Health System Pharmacists and the FDA conducted a database search study of cardiovascular drugs. The factors contributing to drug shortages included increased demand, medication discontinuations, manufacturing delays, and lack of raw materials (Wiggins, 2014). With the rise in drug shortages, as displayed in Figure 2, these shortages continue to be common and can implicate negative interactions with provider medication administrations with the variability in different tier medications.

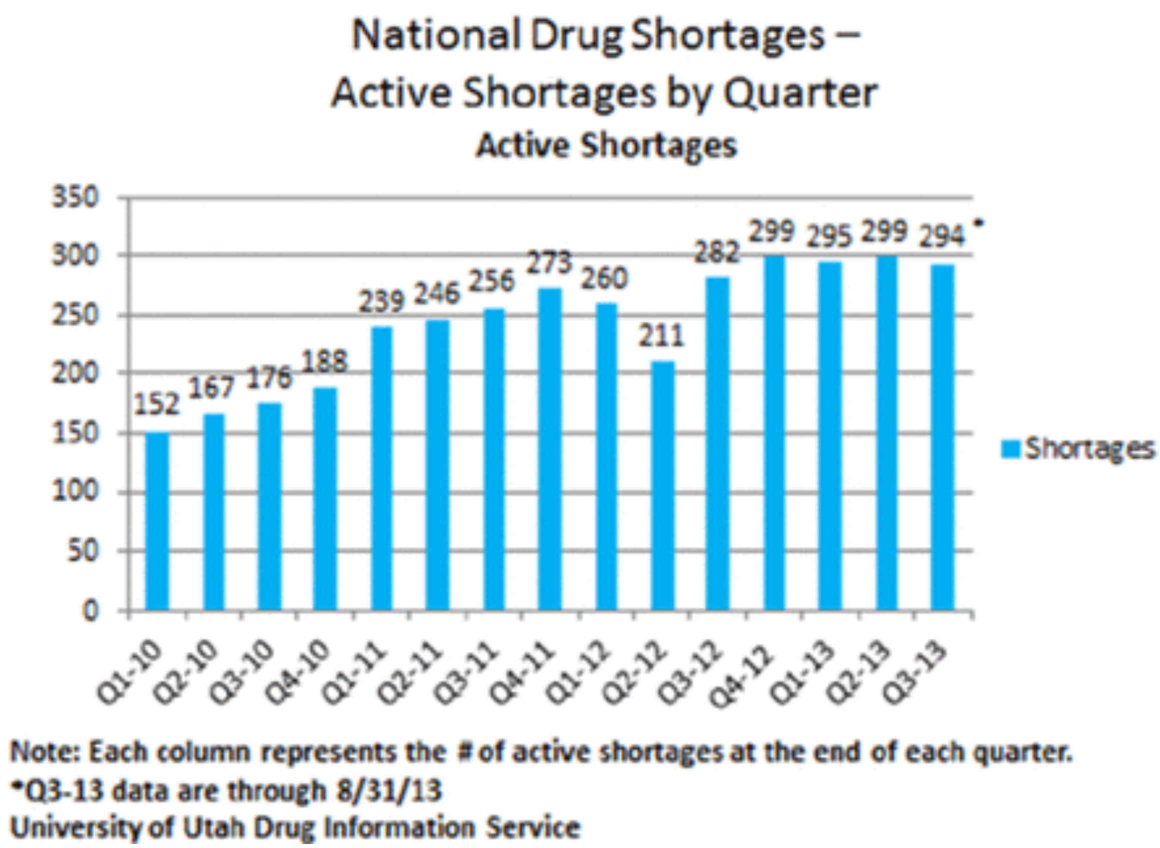


Figure 2. Drug shortages in the United States since 2010 from a cardiovascular study (Wiggins, 2014).

A systematic engineering principle of modeling and simulation was used in this experiment to explore a new idea and propose efficient and effective solutions. A study on a systems engineering perspective on homeostasis and human disease stated how the principles of analysis context, synthesis, design, control, and system operation hold a critical place in the physiologic medical world (Vodovotz, 2013).

Research aiming to mitigate medical errors includes mechanical chest compression devices, intravenous infusion pumps, and wireless technology.

A state-of-the-art technology that has innovated emergency medical care is a mechanical chest compression device, such as the LUCAS and AutoPulse. It is necessary for emergency medical technicians (EMTs) and paramedics in prehospital care to perform high-quality chest compressions on cardiac arrest patients. Human limitations for cardiopulmonary resuscitation (CPR) include shallow chest compressions, performance deterioration over time (longer compressions are needed during hypothermic cardiac arrest), ineffectiveness from ambulance movement and confined space, all of which decrease survival rates and neurological outcomes. LUCAS is an electrically powered piston device that delivers uninterrupted chest-compressions with the predefined depth of 4 to 5 cm, frequency of 100 min^{-1}, and duty cycle of 50%. In a 2013 study with advanced life support (ALS) paramedics, the quality between mechanical devices and manual chest compressions were tested on a Resusci Anne manikin. The quality outcome was measured on the percentage of correct chest-compressions relative to total chest-compressions according to American Heart Association (AHA) 2010 resuscitation guidelines, resulting in 99% for LUCAS versus 59% manually. CPR quality was improved with LUCAS compared to manual chest compressions (Putzer, 2013). Basic life support (BLS) chest compression quality is one of the most critical factors in CPR success (Fischer, 2014). Optimizing chest compressions to reduce medical error is important for prehospital care with 359,400 incidences of having cardiac arrest out of the hospital, with a 9.5% overall survival rate according to 2013 AHA heart disease and stroke statistics (Go, 2012).

A second technology that has innovated emergency medicine is the intravenous (IV) infusion pump, or "smart pump". Still currently in use, health providers can alternatively use the method of gravity-driven manual micro-drip IV infusions. Both pumps and micro-drips aid to infuse fluid medication intravenously to a patient at a calculated rate. Micro-drip infusions are designed with the number of drops per minute being equal to the number of milliliters per hour to determine the drip rate, which can be manually adjusted by a variable pinch or roller clamp. A laboratory simulation study on micro-drip infusion sets for clinical situations determined that micro-drip infusion rates could vary widely from extrinsic factors such as catheter size. The resistance inconsistency suggested there was nonlaminar flow with the infusions and that would not be easily mathematically predicted. To decrease medication infusion errors this study supported using mechanical IV infusion pumps instead of micro-drip infusions (Pierce, 2013). IV infusion pumps are equipped in EMS ambulances. However, to my knowledge there have been no previous studies analyzing IV infusion pumps with paramedic or EMT practice in the prehospital setting. In a relevant study at Carolinas HealthCare System, safety software was installed on IV infusion pumps to reduce medication errors. The safety software MedNet on the pumps examined critical catches from medication infusion data that estimated a $29,120,000 per year cost due to errors (Mansfield and Jarrett, 2013). In a study performed in a pediatric intensive care unit, IV infusion pump data was analyzed using CareFusion Alaris Guardrails and Hospira MedNet systems and an intervention method, showing that the smart pump proved to be successful in intercepting infusion errors from patients. The researchers also found that, when using the smart pumps, 48% of the intercepted errors were of high-risk medications (Manrique-Rodriguez, 2014). IV infusion pumps can also be integrated with wireless technology. A hospital system integrated Plum A+ infusion pump devices with MedNet software and wireless capabilities showing that the wireless infrastructure helped to support the avoidance of medication errors (Siv-Lee and Morgan, 2007).

Wireless technology in prehospital emergency care has been integrated into several devices to improve emergency care communication and data transfer. RAA ambulances are equipped with defibrillator devices that record electrocardiogram (EKG) signals, which is wirelessly transferred to Virginia Commonwealth University (VCU) Medical Center's electronic medical record, CERNER. In an emergency responder study on real-time biomedical sensors and software, an EKG senor was built to detect R-wave intervals with a noise resistant algorithm and then transmit the extracted data over a wireless network (Gao, 2006). RAA ambulances are additionally equipped with Toughbook laptops by ZOLL that allow paramedics to write electronic patient care reports (ePCRs), which are wirelessly transferred to a server. A prototype eMonitor system was created for EMS providers to record and wirelessly transmit ePCR data. eMonitor worked on an unreliable Cisco MobileIP secure wireless network allowing mobile data terminals to send and receive XML messages for patient documentation (Giovanni, 2008).

Lastly in an ambulance, global position system (GPS) is wirelessly integrated to see real-time ambulance location monitoring and assist EMTs with patient location directions. A study designed a real-time ambulance location monitoring system with Google Maps Open API for emergency situations where the ambulance would receive geographical information that was wirelessly transmitted to a maps server for location monitoring (Kim, 2008). Wireless technology in an ambulance is important for communication of the patient data, which can help to reduce medical errors.

A QR code (Quick Response code) is "a mobile phone readable barcode that can contain small sets of data", example shown in Figure 3. QR codes can encode alphanumeric data with a maximum of 4296 characters. The error correction capability for a QR code is up to 30%, including data restoration of partially dirty or damaged barcodes. QR codes are capable of stable high-speed readings even with background interference through position detection patterns encoded in their barcodes and by being omni-directional (360°) (Lorenzi, 2014).

Figure 3. Example of QR code used in the experiment. Alphanumeric data encoded is "Vasopressin 20 u".

For this experiment, direct observation of emergency medical providers will be investigated pertaining to medication administration errors. Medical errors are hypothesized to occur due to fatigue or lack of consistency between different pharmaceutical vendors. An Android-based smartphone application (app) will be created to assess the validity of this hypothesis and is estimated to significantly reduce medication administration errors in prehospital emergency care. To my knowledge, there is currently no created device that serves to reduce medication administration errors with EMS providers in reference to electronic medication cross-checking and real-time medication electronic records incorporating QR barcode scanning. This innovative device will serve to decrease the 9.1% of medication administration errors by paramedics. In a study of paramedics who self-reported medication errors over a 12-month period, 9.1% of medication errors were reported and classified as medication administration errors. Of these errors, included were dose-related, protocol, wrong route, and wrong medication. In contribution to the errors, factors included failure to triple check, dosage calculation error, infrequent use of the medication, and incorrect dosage given (Vilke, 2007). My device would serve to triple check medications, calculate correct dosages, and prevent the administration of incorrect doses given by an auditory cross-check speak out feature of the app. Medication calculation skills were tested in a group of practicing paramedics, with 33.9% of the paramedics calculating the correct dose for weight-based medication infusions. Paramedics reported that medication calculations were not commonly used in daily practice, with 33% not having drug calculation training since initial training (Hubble, 2000). My device would aid in correctly calculating weight-based medications with algorithms. Lastly in a study to establish if emergency physicians found prehospital PCRs to help in their patient medical decision-making, it was shown that 45.6% of emergency physicians said PCRs were "very important" and 43% "important" in their practicing. Yet it was said with 79.6% that ePCRs were available only less than 50% of the time for at time of medical decision-making. With most ePCRs being unavailable for medical decision-making and that handwritten PCRs had concerns of legibility (59.5%) and accuracy (15.4%), a more innovation solution would need to be implemented. The study suggested, "that strategies should be devised to improve the overall accuracy of PCRs and assure that electronic prehospital PCRs are delivered to the receiving emergency department (ED) in time for consideration in ED medical decision-making," (Bledsoe, 2013). With my app device, it would create an accurate barcode scanning time stamped record of the medication to be administered to a patient in prehospital care. This would provide a more accurate electronic record for the ePCR, which in the future would be able to in real-time, wirelessly transmit medication data to the hospital ED electronic medical record (EMR) for physician decision-making.

Materials and Methods

Direct Observation

To most efficiently become educated on advanced cardiac life support (ACLS) medications and comprehend the systematic dynamics of an EMS system, direct observation was performed. Direct observation was performed with RAA. The observation was conducted in 6 to 8 hour ride alongs both during day and night shifts, accumulating a total of 45 hours directly observed. Each ride along was facilitated with 1 EMT and 1 paramedic, or 1 supervisor, who was a paramedic. Observations took place riding along with the EMT and paramedic in an ambulance unit or with the supervisor in a supervisor truck, which was also equipped for emergency care, but no patient transport. RAA's ambulance units, once in operation, were stationed to different posts located around the city, in which a computerized system helped to predetermine call locations. Once a call was dispatched to the EMT/paramedic, the EMT drove to affirmed call location to assist a patient or more than one patient in emergency or non-emergency care. There were 28 different calls that were directly observed with patients ranging from 6 to 90 years old, with both emergency and non-emergency needs. On every call with patient observation, the following variables were recorded: call number, provider role (EMT/paramedic/supervisor), patient age, patient weight, general case scenario, and if medications were utilized – drug name, drug dose, route administered, vendor, expiration date, lot number (indicative of the batch manufactured in), calculated dose if the medication was a weight-based drug, time drug was utilized, how many times it took the provider to pull the correct drug, and if the provider spoke out the drug name and dose for cross-checking. These variables were recorded to analyze the systematic protocol of medication administration in an EMS system. Additionally, photographs were taken using an iPhone 4s camera of the medications. The photographs were acquired to evaluate similarities and differences in medication sizes, labeling, and color identifications because medications are manufactured and distributed by not one, but by several different pharmaceutical vendors.

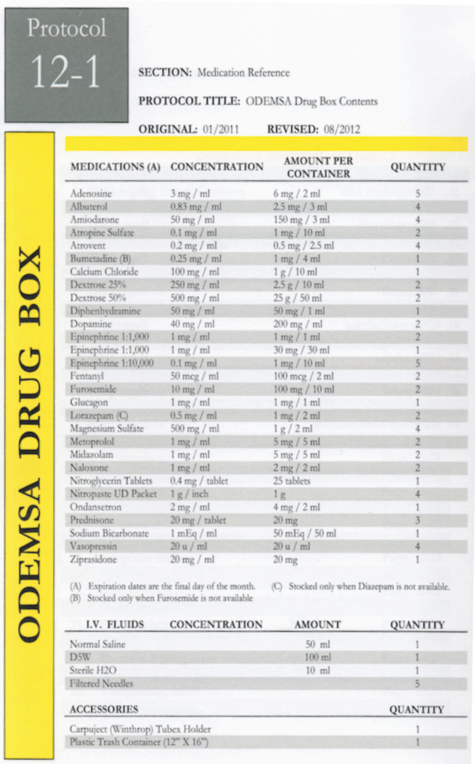
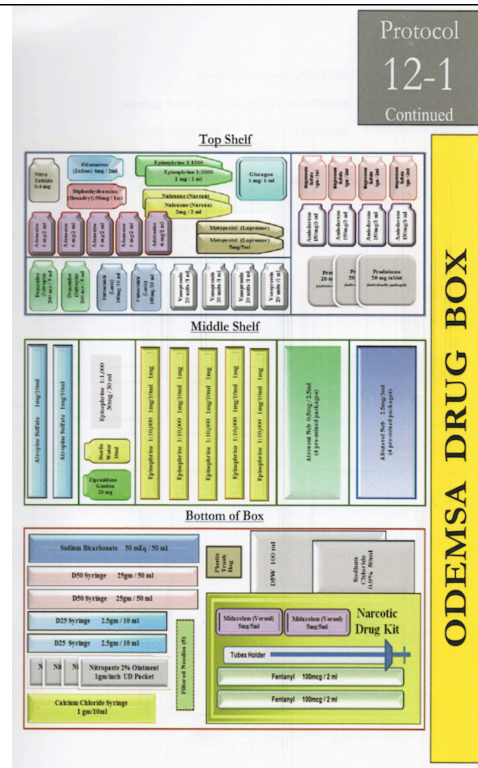
The medications were classified into the following container types: flexible container, glass ampul, glass fliptop vial, glass syringe, and plastic syringe (Table 1, Hospira). Glass fliptop vials were deemed the focused container type of study due to their abundance in the exposed medications during ride alongs and their predominant color identifications on top of the vials.

Table 1. Classification of medication container types.

Container Type	**Image**
Flexible Container	
Glass Ampul	
Glass Fliptop Vial	
Glass Syringe	
Plastic Syringe	

Medications onboard an ambulance or supervisor truck were located in either the ODEMSA drug box, narcotic drug kit included in the drug box, RAA drug pouch, RAA critical care drug box, red bag, or defibrillator bag (Table 2). Medications were designated specific places in their respective locations to safeguard the provider that a certain quantity of medications will be available for patient emergency care and are quickly accessible from knowledge of layouts.

Table 2. RAA medications onboard the ambulance/supervisor truck in respective locations, quantities, and layouts.

Medications Location	**Medications**	**Medications Layout**
ODEMSA Drug Box (EMS Box), including a Narcotic Drug Kit		
RAA Drug Pouch	Ondansetron Racemic Epinephrine Vasopressin	

Protocol 12-1

ODEMSA DRUG BOX

SECTION: Medication Reference

PROTOCOL TITLE: ODEMSA Drug Box Contents

ORIGINAL: 01/2011 REVISED: 08/2012

MEDICATIONS (A)	CONCENTRATION	AMOUNT PER CONTAINER	QUANTITY
Adenosine	3 mg / ml	6 mg / 2 ml	5
Albuterol	0.83 mg / ml	2.5 mg / 3 ml	4
Amiodarone	50 mg / ml	150 mg / 3 ml	4
Atropine Sulfate	0.1 mg / ml	1 mg / 10 ml	2
Atrovent	0.2 mg / ml	0.5 mg / 2.5 ml	4
Bumetadine (B)	0.25 mg / ml	1 mg / 4 ml	1
Calcium Chloride	100 mg / ml	1 g / 10 ml	1
Dextrose 25%	250 mg / ml	2.5 g / 10 ml	2
Dextrose 50%	500 mg / ml	25 g / 50 ml	2
Diphenhydramine	50 mg / ml	50 mg / 1 ml	1
Dopamine	40 mg / ml	200 mg / ml	2
Epinephrine 1:1,000	1 mg / ml	1 mg / 1 ml	2
Epinephrine 1:1,000	1 mg / ml	30 mg / 30 ml	1
Epinephrine 1:10,000	0.1 mg / ml	1 mg / 10 ml	5
Fentanyl	50 mcg / ml	100 mcg / 2 ml	2
Furosemide	10 mg / ml	100 mg / 10 ml	2
Glucagon	1 mg / ml	1 mg / 1 ml	1
Lorazepam (C)	0.5 mg / ml	1 mg / 2 ml	2
Magnesium Sulfate	500 mg / ml	1 g / 2 ml	4
Metoprolol	1 mg / ml	5 mg / 5 ml	2
Midazolam	1 mg / ml	5 mg / 5 ml	2
Naloxone	1 mg / ml	2 mg / 2 ml	2
Nitroglycerin Tablets	0.4 mg / tablet	25 tablets	1
Nitropaste UD Packet	1 g / inch	1 g	4
Ondansetron	2 mg / ml	4 mg / 2 ml	1
Prednisone	20 mg / tablet	20 mg	3
Sodium Bicarbonate	1 mEq / ml	50 mEq / 50 ml	1
Vasopressin	20 u / ml	20 u / ml	4
Ziprasidone	20 mg / ml	20 mg	1

(A) Expiration dates are the final day of the month. (C) Stocked only when Diazepam is not available.
(B) Stocked only when Furosemide is not available

I.V. FLUIDS	CONCENTRATION	AMOUNT	QUANTITY
Normal Saline		50 ml	1
D5W		100 ml	1
Sterile H2O		10 ml	1
Filtered Needles			5

ACCESSORIES	QUANTITY
Carpuject (Winthrop) Tubex Holder	1
Plastic Trash Container (12" X 16")	1

RAA Critical Care Drug Box	Midazolam Rocuronium Bromide	
Red Bag	Glucose Lidocaine Jelly Phenylephrine Hydrochloride	
Defibrillator Bag	Aspirin	

After calls involving medication use, providers restocked with new medications at hospital pharmacies. Drug boxes were tied off allowing paramedics to only have first access to medications at direct time of patient emergency care. If the medication had been recalled due to a drug shortage or changed for medical protocol, then the pharmacist labeled the change on top of the drug box (Figure 4).

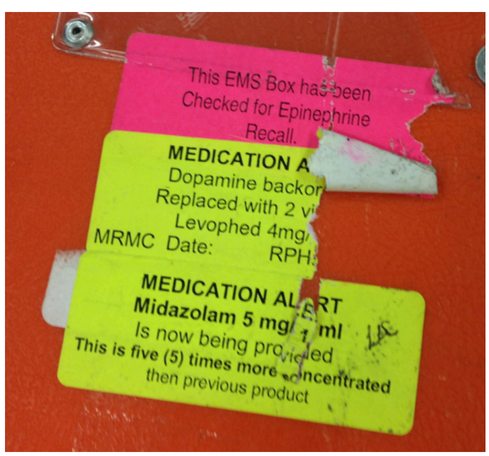


Figure 4. Example of the labeling noted by pharmacists on top of the drug box when medications are recalled or changed from the set drug list.

Smartphone Application Simulation Device Design: Software and Wireless Data Communication

Using the computer interface program, MIT App Inventor 2 Beta, an android-based smartphone application was created to simulate reducing medication administration errors with prehospital emergency care providers. MIT App Inventor 2 has cloud-based technology allowing the user to create applications in a web browser (Figure 5).

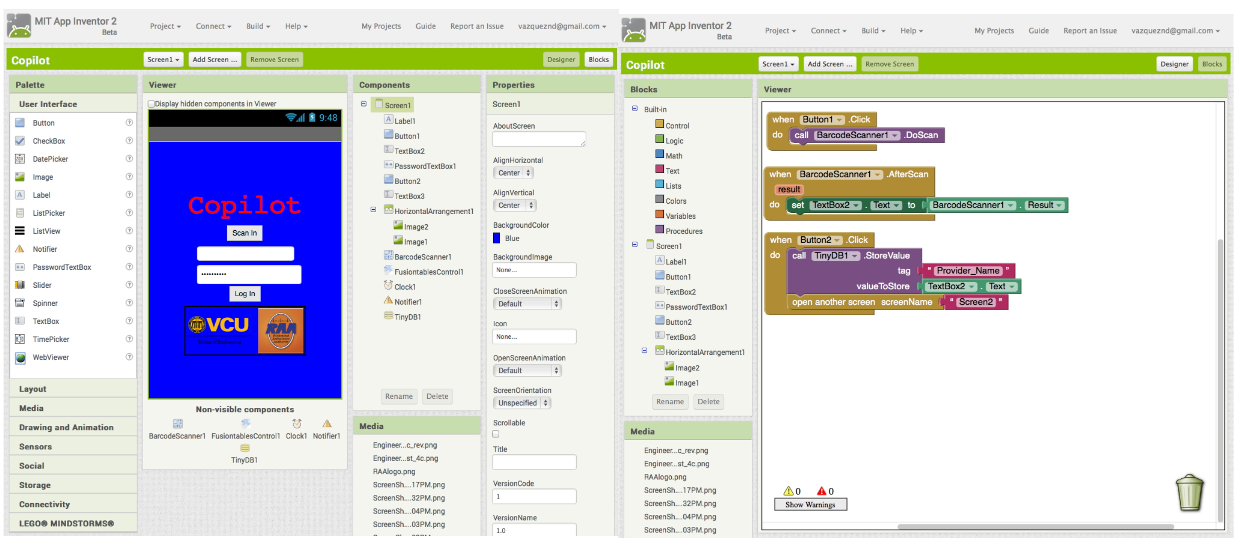


Figure 5. Diagram of MIT App Inventor 2 Beta's graphical user interface architecture. On the left shows the "Designer" view and the right shows the "Blocks" view.

The program incorporates block-based coding to create actions and commands for the app (Figure 6).

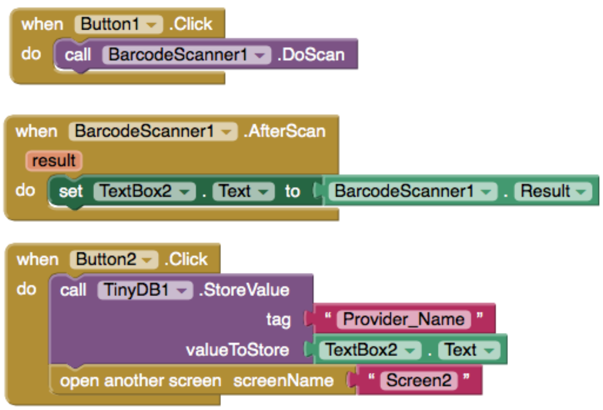
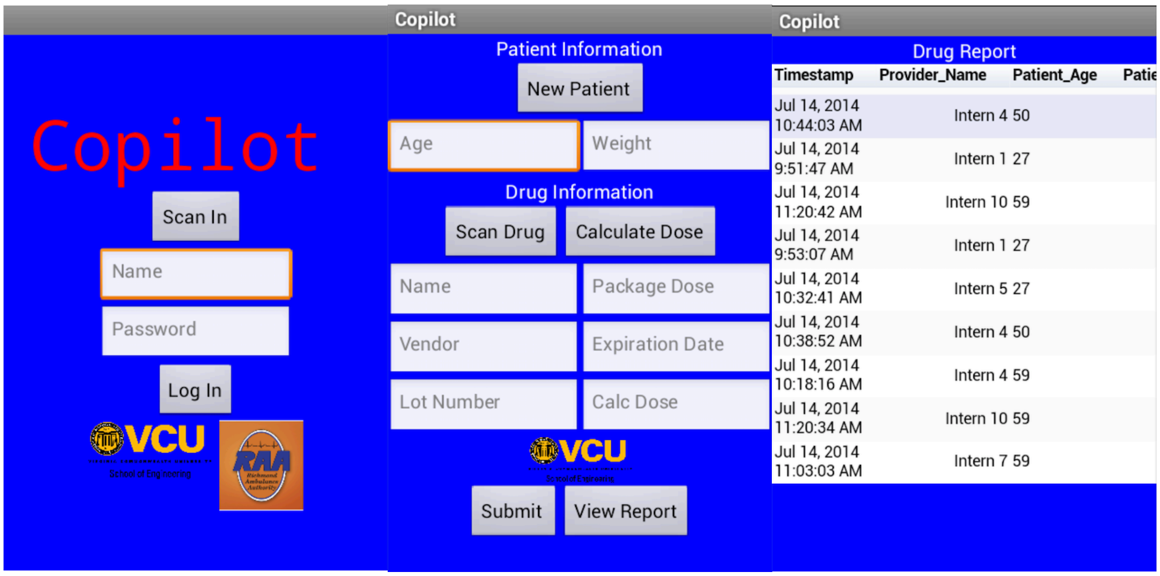


Figure 6. Example of MIT App Inventor 2's use of block-based coding for action command app building.

The web browser used to create the named "Copilot" app was Safari on a Mid 2011 iMac computer. After creation of the app in MIT App Inventor 2, the app was built yielding a QR code incorporating the Android application package file (APK) for download on an Android device for testing. Testing was performed using the Android operating system on a 4G capable network Verizon Ellipsis 7 tablet.

The app consisted of 3 screens: log in screen (screen 1), patient and drug information screen (screen 2), and drug report screen (screen 3) (Figure 7).



Screen 1 Screen 2 Screen 3

Figure 7. The 3 screens of the smartphone app; log in, patient and drug information, and drug report.

Non-visible components in the app included were a barcode scanner (screens 1/2), fusion table control (screen 2), clock (screen 2), notifier (screens 1/2), tinyDB (stores data, screens 1/2), and text to speech (screen 2). Screen 1 first permitted the user to press the button “Scan In”, which pulled the app “QR Droid” (previously downloaded on the tablet) for the provider to have their name quickly signed in, provided from barcodes on provider identification badges. QR Droid reads two-dimensional QR barcodes for fast data transfer to the app. There was a password textbox enabled for simulation effect, and was not functional to a user entry password protected system. When the user entered their name via barcode scanning, the name value was stored in TinyDB with a tag of “Provider_Name” to be able to transfer to the next screen for final reporting. The user then was permitted to press the button “Log In” to move to screen 2. Screen 2 allowed the user to enter patient and medication information including: patient age in years, patient weight in kg, drug name, drug packaged dose, drug vendor, drug expiration date, drug lot number, and drug calculated dose. The user is able to press the button “Scan Drug” to pull QR Droid and scan QR codes to quickly pull in the medication information into the textboxes. In device error avoidance, there is the ability to click into the textboxes and manually change the medication information by writing the drug information in. As the app reads the barcode, the device uses the text to speech component to speak out the drug name and drug dose for provider auditory cross-checking. Additionally, as the app reads the barcode, the VCU image changes to a colored block coordinated in a medication color identification standard that was created. The colored block images were all previously uploaded, stored in the app, and tagged to specific medications. If the medication was a weight-based drug or standard adult dose, then the user is able to press the button “Calculate Dose” and the weight textbox has a calculation embedded in it to yield a calculated dose that appeared in the calculated dose textbox or the appropriate dose-based on whether the patient was a pediatric (under 18 years old) or adult (18 years old and over). For example, the medication Aspirin is not recommended for pediatric use. Therefore if the user had a pediatric age in the age textbox, when the user would try to calculate the dose a notifier yielded a message error dialog saying, “Not recommended,” with the user able to dismiss the message. Additionally a text to speech “Error” message would yield for auditory notification. If the user had appropriate adult age in the age textbox, when the dose was calculated for Aspirin, the standard dose of 324 mg would yield in the calculated dose textbox.

Those error notification features are incorporated in the app to ensure the medication doses are administered in safe dosing ranges. When the provider had all necessary information in the textboxes (Figure 8), they then pressed the button "Submit" to record the data in a created database.

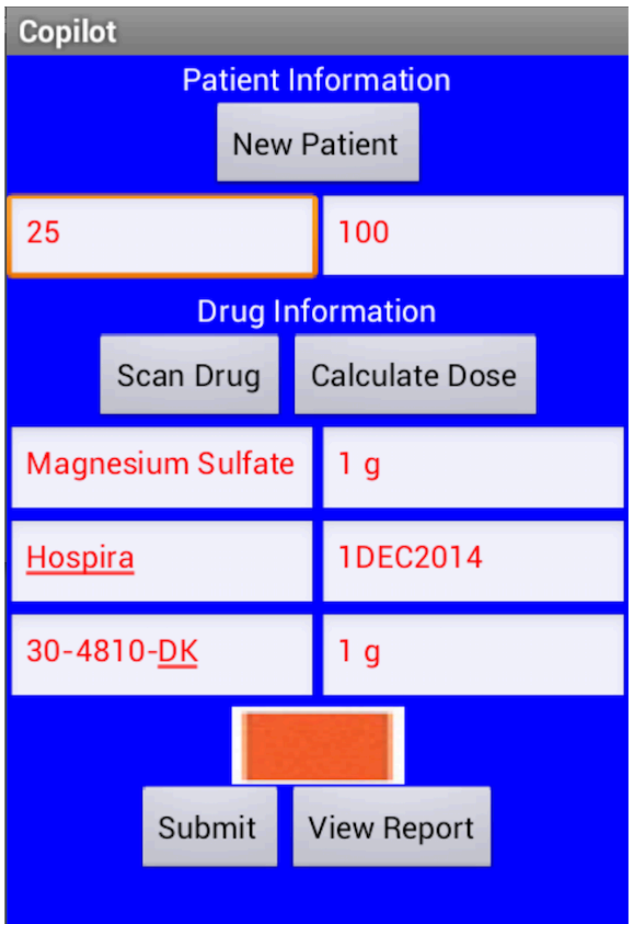


Figure 8. App screen 2 fully completed showing the patient and drug information, and medication color identification.

After the correct medication was submitted, the notifier yielded a message confirmation dialog saying, “Thank you. Your data has been recorded,” allowing the user to then dismiss the message. When the data was not submitted correctly, the notifier yielded an error dialog saying, “There’s been a transmission error. Please try again,” allowing the user to dismiss the message and try submission again. All of the textboxes had to be filled in in order to submit the medication data, or else a notifier yielded an incomplete entry dialog saying, “Please enter,” with the user then able to press try again. Medication submission was time stamped synchronized to the atomic clock using the clock component for a date and time record in the database. After medication submission, all of the textboxes except for the patient information are reset to blank. The colored block is reset to the VCU image. If the provider has a new patient, the provider was able to press the button “New Patient” resetting the patient information to blank for fast clearing. The user is able to press the button “View Report” to move to screen 3 to see the recorded medication data in real-time.

The database was on Google Drive in a created Google Fusion Table including the columns: Timestamp, Provider_Name, Patient_Age, Patient_Weight, Drug_Name, Drug_Package_Dose, Drug_Vendor, Drug_Expiration_Date, Drug_Lot_Number, and Drug_Calculated_Dose. The fusion table was able to sort information alphabetically. Screen 3 had a web viewer component that allows the user to view the recorded data on a scrollable screen, viewing the medication report in real-time. See Figure 9 for overall software flow and Appendix 1 for full app block coding.

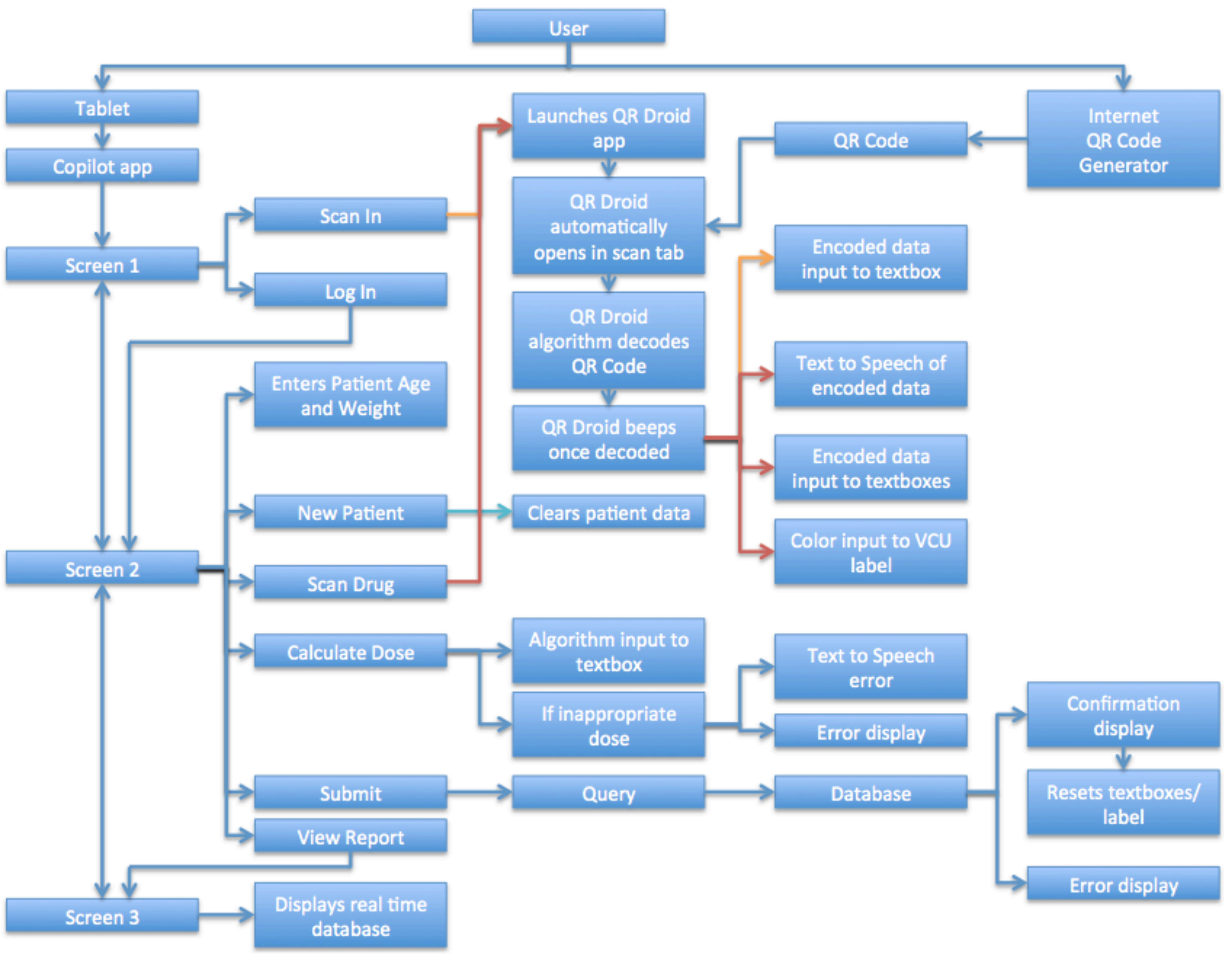


Figure 9. Flow diagram of software.

Device Testing: Color Standard Implementation and Functionality Analysis

In an effort to create a nationwide system of medication color standardization for all pharmaceutical vendors to use, a basic color chart including 34 different colors was selected (Figure 10).

Figure 10. Color chart for medication color standardization including 34 colors.

Device testing and systematic color standard implementation was performed at VCU Medical Center's Center for Human Simulation and Patient Safety for a simulated ACLS course based from the AHA. 12 emergency medical interns in their first year of residency in 4 groups of 3 underwent 7 case scenario simulations in a simulation exam room. They were each given a number for identification (i.e. Intern 1). A drug list from the department of pharmacy services was provided prior to simulation testing in order to prepare device-testing procedures (Figure 11). Packaged doses were calculated from concentration and amount per container to yield packaged dose values incorporated into the medication data. Packaged dose units were either in milligrams (mg), units (u), milliequivalents (mEq), grams (g), milliliters (mL), or liters (L).

VCU Medical Center
Every Day, A New Discovery.

DEPARTMENT OF PHARMACY SERVICES

ADULT EMERGENCY DRUG TRAY

Sodium Bicarbonate 8.4% (1 mEq/ml) 50 ml syringe, #2 ✓ 6/1/13	Lidocaine 2% (20 mg/ml) 5 ml syringe, #4 ✓ 6/1/13	Dopamine 400mg (1.6 mg/ml) in Dextrose 5% 250 ml IV bag , #1 ✓ 6/30/14	Lidocaine Infusion 0.4% (4 mg/ml) in Dextrose 5% 500 ml IV Bag, #1 ✓ 6/1/13
Calcium Chloride 10% (100 mg/ml), 10 ml syringe #1 ✓ 11/1/13	Atropine Sulfate 0.1 mg/ml, 10 ml syringe, #4 ✓ 6/1/13	Epinephrine 1 mg/ml, (1:1000), 30 ml vial, #1 ✓ 5/31/13	Bacteriostatic Sodium Chloride for Injection, 30 ml vial #1 ✓ 6/1/13
Epinephrine 1:10,000 (0.1 mg/ml), 10 ml syringe, #6 ✓ 6/1/13			Dexamethasone 4 mg/ml, 5 ml vial, #1 ✓ 12/31/13
	Adenosine 6 mg/2ml vial/syr, #5 ✓ 7/31/13		
	Potassium Chloride 10 mEq/50 ml sterile water, IV Bag, #1 ✓ 3/31/14	Amiodarone 50 mg/ml, 3 ml syringe, #4 ✓ 5/31/13	
	Vasopressin 20 units/ml, 1 ml vial, #4 ✓ 7/31/13	Filter needles, #2 ✓	Furosemide 10 mg/ml, 10 ml vial, #1 ✓ 9/1/14
		Dextrose 50% (500 mg/ml), 50 ml syringe, #1 ✓ 6/1/13	
			Norepinephrine 1 mg/ml, 4 ml amp, #1 ✓ 10/1/13
Medication Added Stickers (Orange Labels), #6 ✓	Magnesium Sulfate Injection 500 mg/ml, 2 ml vial, #5 ✓ 5/31/13		Naloxone 1 mg/ml, 2 ml syringe, #4 ✓ 8/31/13
Forms: Part II Medication Record, Cardio-Pulmonary Resuscitation Form (2 sheets) ✓	Hypothermia Protocol ✓		Nitroprusside 50 mg/vial, #1 ✓ 5/1/13

CODETRAY.XLS

Last Updated 03/15/12

Figure 11. VCU Medical Center adult emergency medication list including 21 different medications.

The VCU Medical Center drug list for adult emergency care included 21 different medications. The medications were located in the drug tray of a code cart stationed in the simulation rooms. QR barcodes were created using a QR code generator entering the medication name and dose from the drug list into the text information yielding a static QR code. Medications from the drug list were assigned a color standard from the color chart keeping in mind common color references already in place seen from the direct observation (Figure 12).

Drug Name	Dose	QR Code	Color Standard	Drug Name	Dose	QR Code	Color Standard
Sodium Bicarbonate	50 mEq		Gold	Nitroprusside	50 mg		White
Calcium Chloride	1 g		Yellow	Added Drug 1			Manilla Yellow
Epinephrine 1:10000	1 mg		Beige	Added Drug 2			Silver
Lidocaine	100 mg		Red	Added Drug 3			Lime Green
Atropine Sulfate	1 mg		Purple				
Adenosine	6 mg		Gray				
Potassium Chloride in Sterile Water	10 mEq		Chocolate Brown				
Vasopressin	20 u		Dark Blue				
Magnesium Sulfate	1 g		Rust Orange				
Sodium Chloride Cold (Hypothermia Protocol)	1 L		Cyan				
Dopamine in Dextrose 5%	400 mg		Pale Green				
Epinephrine 1:1000	30 mg		Magenta				
Amiodarone	150 mg		Burgundy				
Dextrose	25 g		Sky Blue				
Lidocaine in Dextrose 5%	2 g		Fuchsia				
Bacteriostatic Sodium Chloride	30 mL		Blue				
Dexamethasone	20 mg		Teal				
Furosemide	100 mg		Dark Yellow				
Norepinephrine	4 mg		Green				
Naloxone	2 mg		Salmon				

Figure 12. Color standard and QR barcode reference chart for simulated device testing of adult emergency medications.

With assistance, the interns tested and assessed the app device during simulated case scenarios on a simulation manikin. After completion of utilizing the device, the interns filled out a questionnaire to assess the tested device (Figure 13).

Copilot Questionnaire

Please answer the following questions after you have used the Copilot mobile application. Your responses will aid in an assessment of my device for my Master's thesis research.

Thank you!
Natalie Vazquez

1. What is your role? (Circle One) EM Intern Other, please list:_____________

2. Overall, would you say this device served to reduce medication administration error? (Circle One)

Yes No

3. How accurately in performance would you say this device worked today? (Circle One)

Excellent Very Good Good Average Poor

4. How did the color standard serve for color association recognition to the medications? (Circle One)

Extremely Helpful Very Helpful Helpful Somewhat Helpful Unhelpful

5. How satisfied were you using the device? (Circle One)

Extremely Satisfied Very Satisfied Satisfied Somewhat Satisfied Unsatisfied

6. Would you use this protocol to cross-check medication in the future? (Circle One)

Yes No

Comments & Suggestions ::

____

____

____

____

____

Thank you!

Figure 13. A questionnaire developed to have 12 emergency medical interns in their first year of residency at VCU Medical Center assess and review the created smartphone application.

In assessment of device functionality, the app device was tested in 6 different lighting types. This was necessary because during basic functionality testing and presentation of device demonstrations, the app at times presented barcode-reading delays. The light types were categorized into: outdoor direct natural light paper label, outdoor indirect natural light paper label, indoor direct natural light paper label, indoor indirect natural light paper label, indoor direct desk light paper label, and computer label. The desk light was a U shaped fluorescent 13-watt light bulb positioned 23 inches above a desk. The natural light conditions were cloudy with wind recorded between the hours of 3 and 4 pm. The recordings were timed with an iPhone 4S smartphone stopwatch in seconds (s) displayed as 0.00. Time recorded intervals were from when the user pressed the "Scan Drug" button on the app screen 2 to when the QR Droid app beeped once the QR code was decoded. The time recording process is shown in Figure 14. QR code labels were either printed or on a computer and read with the tablet 2 to 7 inches away. The 6 QR codes used in this study were the medication barcodes for magnesium sulfate 1 g, furosemide 100 mg, nitroprusside 50 mg, vasopressin 20 u, amiodarone 150 mg, and dextrose 25 g. Paper labels were 2.2-centimeter square QR codes. Data analysis consisted of sample sizes of 18 medication tests for each lighting group, with a total of 108 samples. The 6 medications selected were tested 3 times each in each lighting group for triple accuracy and to see variability. Low value, mean, and high value times were calculated for each lighting group with 5% error noted to show variability between lighting types. To assess if there was variability in QR code format specifically, the low and high value occurrences for each lighting group were calculated and recorded for respective medications. Additionally, the total mean times across all of the lighting groups were calculated for each medication to see variability between QR code formats.

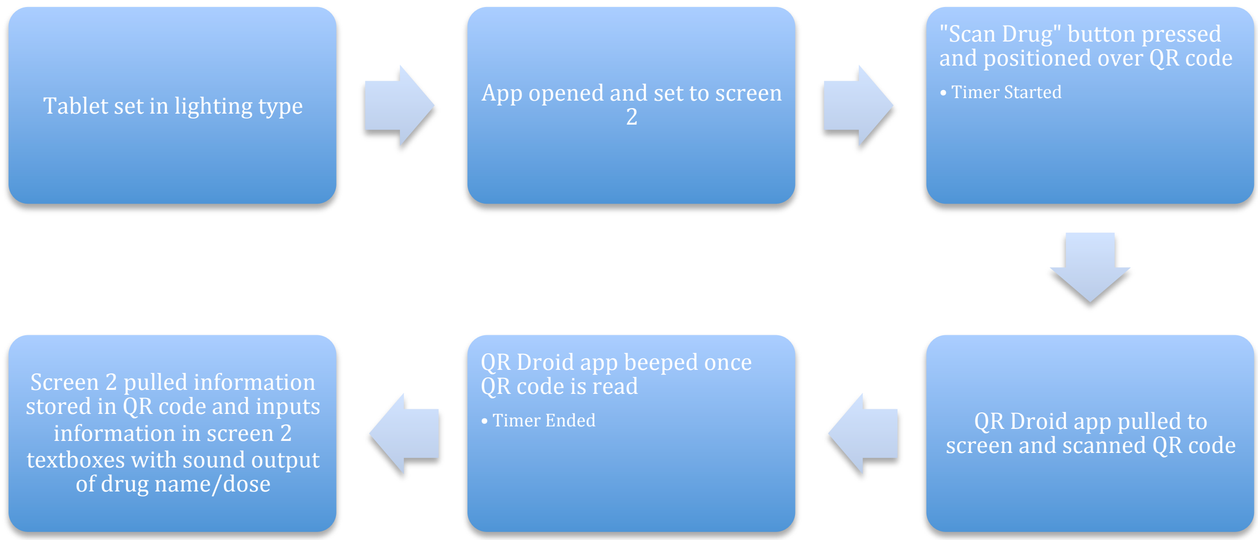


Figure 14. Process of recorded time (s) for QR codes tested in different lighting types.

Results

In the 45 hours directly observing 28 different emergency and non-emergency related calls there were a total of 7 different medications from 7 of the calls that the providers administered to patients, including: normal saline, cold saline (hypothermia protocol), vasopressin, amiodarone, epinephrine, dextrose 50%, and sodium bicarbonate. Types of cases that were observed included: cardiac arrest, dehydration, breathing problems, fire, list assist, abdominal pain, assault, transport, car accident, unresponsive, stroke, and unconscious patients. Out of the providers from the ride alongs, 6 had iOS, 2 did not have a smartphone, and 1 had an Android device. That helped to see in small scale what type of operating system providers were using. Two examples of storage related errors not specific to medications during patient treatment included a missing tourniquet in an IV box and a lubricating jelly in the wrong pouch of the red bag. Those two situations were not critical cases, however both did add to delayed patient treatment. During a cardiac arrest call that was observed, there were several medications utilized in which from direct observation there had been recording of the medications and times. Once the last medication was administered, the provider in charge asked for a copy of the list of medications and times that had been recorded.

In analysis of the direct observation of ride alongs with RAA's providers in emergency cases, it was observed that there were 19 different pharmaceutical companies that provided medications (Figure 15).

Pharmaceutical Companies (19):

- Akorn
- Amphastar Pharmaceuticals
- APP Pharmaceuticals
- Baxter
- Bayer
- Bedford Laboratories
- Hospak
- Hospira
- IMS
- JHP Pharmaceuticals
- Level Life
- McKesson
- Nephron Pharmaceuticals
- Perrigo
- Pfizer
- Roxane Laboratories
- Sagent Pharmaceuticals
- Savage Laboratories
- West-Ward Pharmaceuticals

Figure 15. Nineteen different pharmaceutical companies from medications directly observed.

There were a total of 42 different medications from different vendors that were photographed on the ride alongs. Of those 42, 22 of the photographs were chosen for analysis based for their glass fliptop vial style of container type. The drug names, vendors, and pictures were compared (Figure 16). The drug names in Figure 16 represented the drug name, trade name, or an abbreviated version. The colors referred to HTML hex values to represent the most accurate selection of color identification, selected in a HTML color picker.

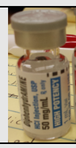
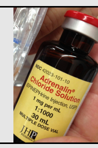
Drug Name	Adenosine	Adenosine	Amiodarone	D50	DPH HCl
Vendor	Sagent	Akorn	APP	Hospira	APP
Picture					
Color	B2B2B2	666666	A30000	0066FF	808080
Drug Name	DPH HCl	Epi 1:1000 1 mL	Epi 1:1000 30 mL	Epi 1:1000 30 mL	Furosemide
Vendor	West-Ward	JHP	IMS	JHP	Hospira
Picture					
Color	CCCCCC	47008F	FF33CC	FF0000	FF944D
Drug Name	Glucagon	MgSO4	Metoprolol	Midazolam	Midazolam
Vendor	Bedford	APP	West-Ward	Hospira	Sagent
Picture					
Color	FF6600	FF8533	FFFFFF	33B49A	A3C2FF
Drug Name	Levophed	Zofran	Zemuron	Sterile H2O	Vasopressin
Vendor	Hospira	Hospira	Sagent	Hospira	JHP
Picture					
Color	00B88A	008A2E	FFFF19	7A007A	FF5C33
Drug Name	Vasopressin	Geodon			
Vendor	APP	Pfizer			
Picture					
Color	0000A3	FFFFFF			

Figure 16. 22 ride along photographed glass fliptop vial medications.

The medications Adenosine, Diphenhydramine Hydrochloride (DPH HCl), Epinephrine (Epi) 1:1000 30 mL, and Midazolam displayed unsynchronized color top differences from at least two different vendors (Figure 16). Many colors were used to represent different medications. For example, the color orange was used to represent Furosemide, Glucagon, Magnesium Sulfate ($MgSO_4$), and Vasopressin. Those four medications were all from different vendors.

An example of two glass fliptop vials that were similar in size and top color were Adenosine 2 mL from the vendor Sagent (shown on the left in figure 17) and Diphenhydramine 1 mL from the vendor West-Ward (shown on the right in figure 17). These medications look similar in size even though they contain different volumes and are similar in their gray color tops even though are not the same medication.

Figure 17. Adenosine 2 mL (left) and Diphenhydramine 1 mL (right) displaying similarities in vial size and top color.

Medication packaging and labeling also presents clear systematic problems. As shown in figure 18, Albuterol Sulfate 3 mL (shown on the left) and Racepinephrine 0.5 mL (shown on the right) present the same packaging type and have the same blue labeling on top. These two different medications are both from the vendor Nephron Pharmaceuticals.

Figure 18. Albuterol Sulfate 3 mL (left) and Racepinephrine 0.5 mL (right) displaying similarities in packaging and color labeling from the same vendor.

While discussing the contents of the drug box with a paramedic, it was discussed how Dopamine had been recalled and was replaced with Levophed. However, the drug box was not labeled on top indicating the recall and replacement. The paramedic stated that in an emergency scenario requiring Dopamine that the provider would first look for the Dopamine and then the second tier drug to Dopamine, Levophed. That could delay medical treatment to the patient and arise further problems.

The created smartphone application to reduce medication administration error was assessed in a simulated emergency environment with 12 VCU emergency medical interns in their residency training at VCU Medical Center. In overall observance, the interns were all not familiar with the code cart drug tray medications. Some interns in simulation would specify a medication that was not readily available for emergency cases, such as asking for calcium glucagon when calcium chloride was an available calcium medication in the drug tray. The interns were divided into 4 groups of 3. The groups utilized the app device during simulated emergency codes with technical assistance. In a group of 3 interns, there was an intern in charge that would typically administer the medications, but some groups switched roles. The interns would use the device to scan the created medication QR barcodes and have viewing ability to the color standardization. Group one did not know dosing amounts of adenosine and calcium chloride. They also did not give an appropriate dosage of atropine, giving 0.5 mg instead of 1 mg in the simulated case to a hypothetical patient. Lastly, group one was unsure but correctly stated the dose ratio of epinephrine to use. The dosage of epinephrine was not even stated until I asked which one would be used since there are two different ratios of the medication available in the drug tray. Intern group two also gave the incorrect dosage of atropine of 0.5 mg. Even though some members of group two had on watches, they utilized the tablet to help time the drug length of epinephrine in order to administer an additional dose after the appropriate time of three minutes. Group two added two drugs that were not normally on the drug list to their simulation, ketamine and diltiazem (dilt). Ketamine is a patient weight-based medication at 1 mg/1 kg, with 100 mg utilized in the simulation for a hypothetical 100 kg patient. Group three did not know that calcium chloride could be substituted for calcium glucagon in the simulated emergency scenario. Group four during a simulated code asked to view the report on the app for quick case review and medication tracking. They also asked to view the report to see what time epinephrine was administered for tracking drug length and ability to give next dosing.

Table 3. VCU Medical Center emergency medical intern testing of created smartphone application simulation device data; variables held constant were timestamp date (July 14, 2014), patient weight (100 kg), drug vendor (Hospira), drug expiration date (1DEC2014), and drug lot number (30-4810-DK).

Timestamp					
Time	**Provider_Name**	**Patient_Age**	**Drug_Name**	**Drug_Package_Dose**	**Drug_Calculated_Dose**
9:28:15 AM	Intern 1	59	Atropine Sulfate	1 mg	0.5 mg
9:30:05 AM	Intern 1	59	Epinephrine 1:10000	1 mg	
9:33:23 AM	Intern 2	59	Vasopressin	20 u	
9:33:42 AM	Intern 2	59	Vasopressin	20 u	
9:35:09 AM	Intern 2	59	Calcium Chloride	1 g	
9:37:06 AM	Intern 2	59	Sodium Chloride Cold	1 L	
9:51:47 AM	Intern 1	27	Adenosine	6 mg	
9:53:07 AM	Intern 1	27	Adenosine	6 mg	12 mg
10:14:26 AM	Intern 4	59	Sodium Bicarbonate	50 mEq	
10:15:34 AM	Intern 4	59	Atropine Sulfate	1 mg	0.5 mg
10:15:56 AM	Intern 4	59	Epinephrine 1:10000	1 mg	
10:18:16 AM	Intern 4	59	Calcium Chloride	1 g	
10:32:41 AM	Intern 5	27	Adenosine	6 mg	
10:34:00 AM	Intern 5	27	Adenosine	6 mg	12 mg
10:34:25 AM	Intern 5	27	Adenosine	6 mg	12 mg
10:38:52 AM	Intern 4	50	dilt	20 mg	
10:39:47 AM	Intern 4	50	dilt	20 mg	
10:44:03 AM	Intern 4	50	ketamine	1 mg	100 mg
10:59:38 AM	Intern 7	59	Epinephrine 1:10000	1 mg	
11:00:55 AM	Intern 7	59	Epinephrine 1:10000	1 mg	
11:03:03 AM	Intern 7	59	Calcium Chloride	1 g	
11:03:14 AM	Intern 7	59	Sodium Bicarbonate	50 mEq	
11:18:31 AM	Intern 10	59	Epinephrine 1:10000	1 mg	
11:20:34 AM	Intern 10	59	Vasopressin	20 u	
11:20:42 AM	Intern 10	59	Vasopressin	20 u	
11:24:58 AM	Intern 11	59	Calcium Chloride	1 g	
11:25:11 AM	Intern 11	59	Sodium Bicarbonate	50 mEq	

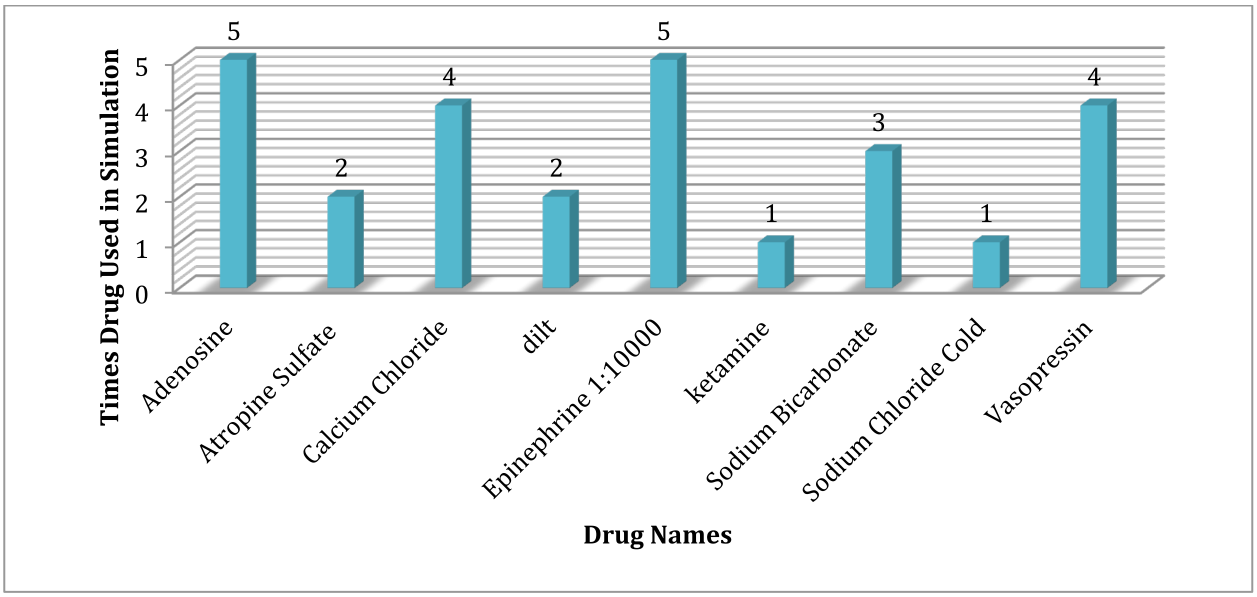


Figure 19. The medications that were utilized in simulation and how many times they were used.

The interns answered a series of questions using their medical expertise to assess the app device and the systematic color standardization implementation. The answered questionnaire results were collected and are shown in Table 4.

Table 4. App device testing intern questionnaire results.

Questions:

A: Overall, would you say this device served to reduce medication administration error?
B: How accurately in performance would you say this device worked today?
C: How did the color standard serve for color association recognition to the medications?
D: How satisfied were you using the device?
E: Would you use this protocol to cross-check medication in the future?

Results:

Questions	**Answer Choices**					
A (2)	Yes	No	Unclear Response			
Responses	7 (58.3%)	2 (16.7%)	3 (25%)			
B (3)	Excellent	Very Good	Good	Average	Poor	
Responses	4 (33.3%)	2 (16.7%)	6 (50%)	0 (0%)	0 (0%)	
C (4)	Extremely Helpful	Very Helpful	Helpful	Somewhat Helpful	Unhelpful	Unclear Response
Responses	0 (0%)	1 (8.3%)	3 (25%)	3 (25%)	4 (33.3%)	1 (8.3%)
D (5)	Extremely Satisfied	Very Satisfied	Satisfied	Somewhat Satisfied	Unsatisfied	Unclear Response
Responses	0 (0%)	2 (16.7%)	7 (58.3%)	2 (16.7%)	0 (0%)	1 (8.3%)
E (6)	Yes	No	Unclear Response			
Responses	7 (58.3%)	3 (25%)	2 (16.7%)			

In the questionnaire analysis, the medical expertise of the interns said (with 58.3%) this device served to reduce medication administration error. 16.7% of the interns did not agree and there were 25% unclear responses. In the device performance accuracy, 33.3% of the interns said it worked excellent, 16.7% said it worked very well ("very good"), and 50% said it worked well ("good"). There were no device performance assessments of it working average or poor. The interns said that the color standard served to be 8.3% very helpful, 25% helpful, and 25% somewhat helpful for color association recognition to the medications. There were no responses for it being extremely helpful, a negative response of it being 33.3% unhelpful, and 8.3% unclear responses. The interns reported to be 16.7% very satisfied, 58.3% satisfied, and 16.7% somewhat satisfied using the device during testing. There were no reports of being extremely satisfied or of being unsatisfied, and 8.3% unclear responses. For the future, 58.3% of the interns reported to say that they would use this protocol again to cross-check medications. 25% of the interns did not agree and 16.7% had unclear responses.

From the intern questionnaire results, an intern for question A commented that they were not sure what the current system is. An intern for question E commented that they would need more experience using the device. Additional comments and suggestions included:

- "Variability of doses according to clinical situation would need to be taken into consideration"
- "Add timer"
- "Seems like it would be helpful, but at our new stage of training it makes things a bit more complicated"
- "Good for pharmacist charting"
- "Try to link to cerner"

- “If I had more training and could quickly navigate it (or if the pharmacists used it) it would be great”

In analysis of the app device functionality in scanning QR codes in different lighting types, low value, mean, and high values times (seconds) were calculated for 6 lighting types, including outdoor direct natural light paper label, outdoor indirect natural light paper label, indoor direct natural light paper label, indoor indirect natural light paper label, indoor direct desk light paper label, and computer label (Figure 20). Limits recorded included 1.98 s (low value) and 16.03 s (high value). The lowest time recorded was for outdoor direct natural light paper label (1.98 s) and the highest time recorded was for indoor indirect natural light paper label (16.03 s). Faster scanning times were seen with indoor direct natural light paper labels, computer labels, and outdoor indirect natural light paper labels (in order from faster to slower mean times). Slower scanning times were seen with indoor indirect natural light paper labels, indoor direct natural light paper labels, and indoor direct desk light paper labels (in order from slower to faster mean times). Variability with direct light included shadow creations. Additional variability with all tests included scanning angles, scanning depth, user ability, and natural hand shaking. It was noticed in testing the computer labels that scanning was more efficient when the tablet was held at a 45-degree angle downward facing the computer screen.

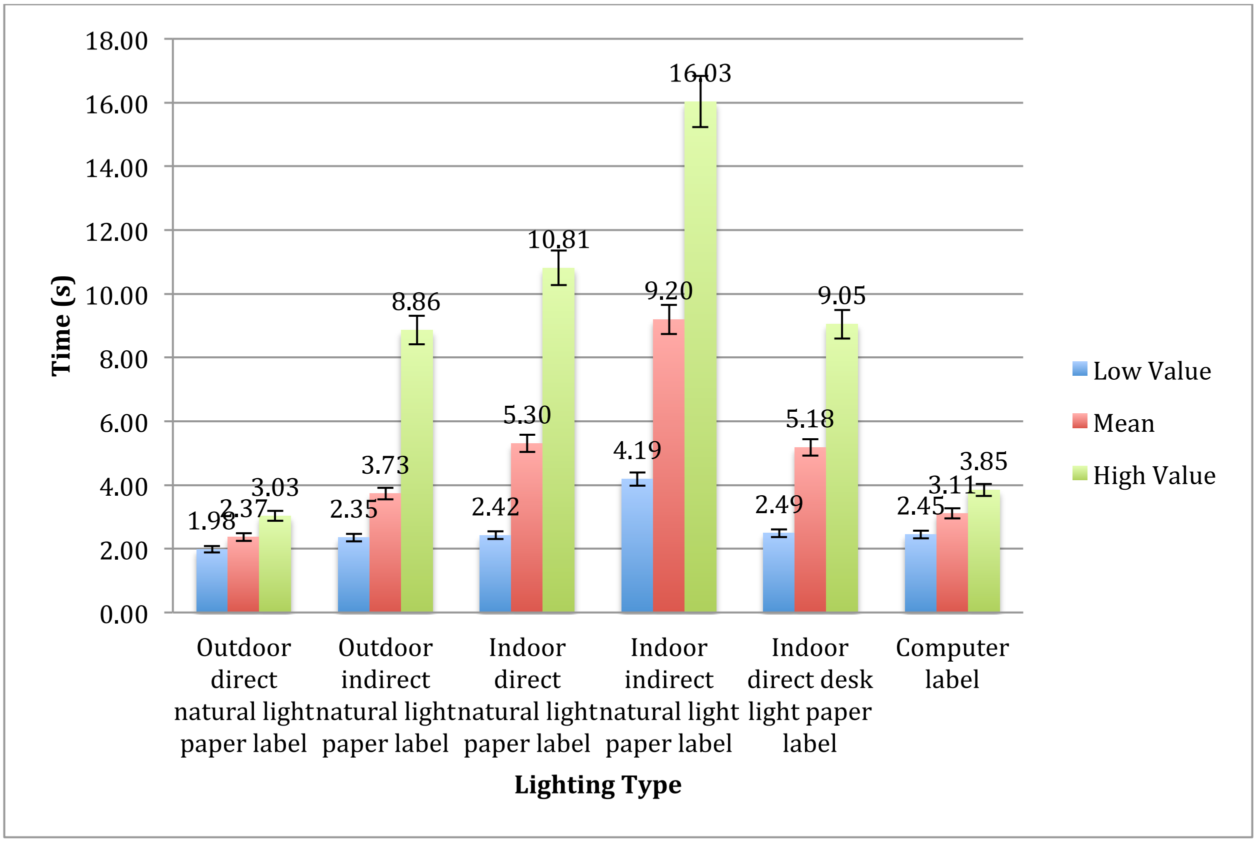


Figure 20. Low value, mean, and high value times (seconds) for 6 different tested lighting types.

It was postulated that the format of QR codes could have affected the app device readability. In was shown in Figure 21 that across all different lighting groups, that the total mean time for each medication was relatively similar with the fastest being magnesium sulfate (3.45 s) and the slowest being vasopressin (6.65 s). However, when the low and high value times were recorded for each lighting group, the total number of occurrences varied between the 6 medications with slower scanning times (high values) in vasopressin and faster scanning times (low values) more prevalent in nitroprusside (Figure 22).

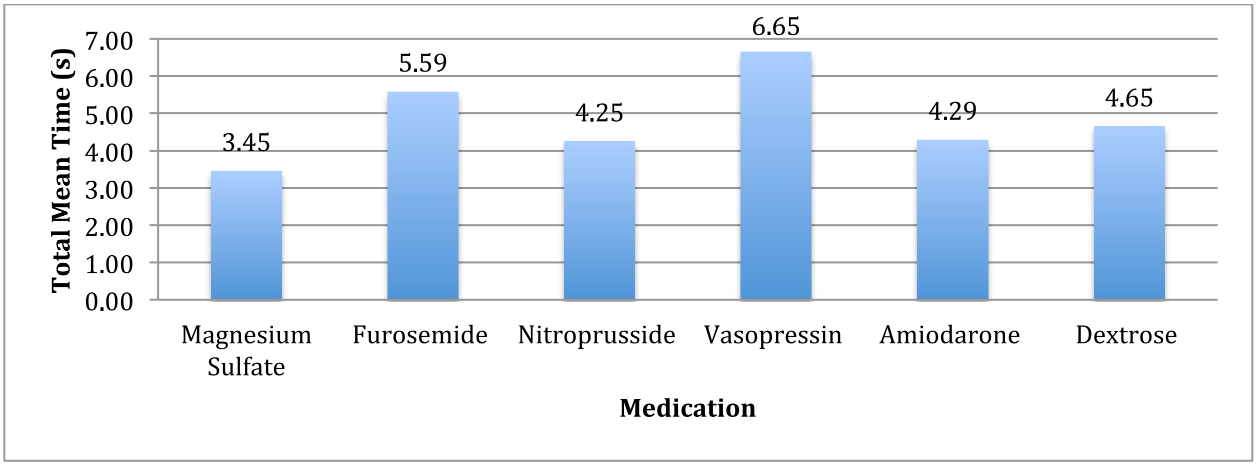


Figure 21. Total mean times (seconds) across all 6 lighting types for the 6 medications.

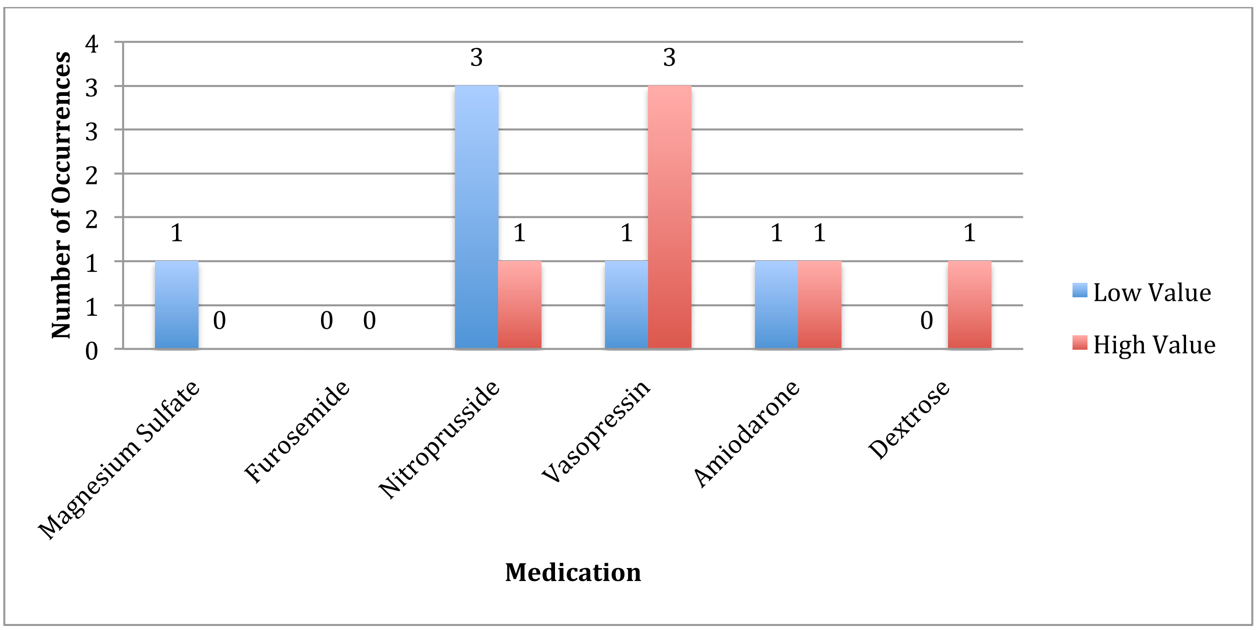


Figure 22. Low and high value time occurrences in all 6 lighting types for each medication.

Discussion

In a study to reduce medication administration errors and improve the systematic design in prehospital emergency care, an Android-based smartphone application simulation was created. The experiment was investigated through direct observation of RAA providers and concepts tested through emergency medical interns at VCU Medical Center. Education about the drugs used in prehospital care was important to evaluate and create the tested experiments. Overall, a systematic design was created (Figure 23) to reduce medication administration errors with prehospital providers and provide direct real-time communication with hospital emergency departments for the most accurate patient care.

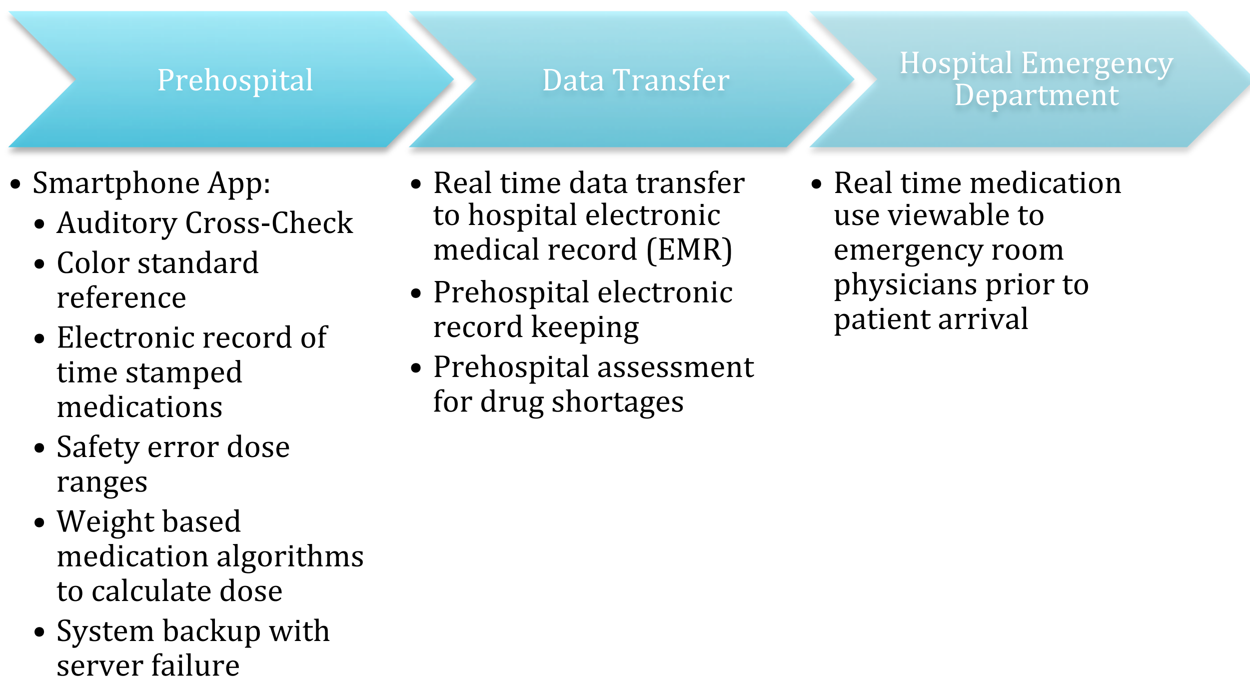


Figure 23. Systematic design from prehospital to the hospital emergency department, to reduce medication administration error and improve medication communication.

As this system would operate on a wireless cloud-based level for data transfer, a similar design was implemented in a Grassroot Healthcare Institution in China where a cloud-based virtual desktop infrastructure was created due to the country's fund shortage, inconsistent medical standards, and inefficient information sharing. This technology would serve to lower hospital costs and improve their medicine with the high-performance system (Yao, 2014). In a study that proposed a reliable architectural style for designing pervasive healthcare systems, an assessment that the design of a medical wireless communication system would need to be high quality, focusing on security, accessibility, reliability, and fault tolerance (Rafe and Hajvali, 2014). The performance and integration of a smartphone app like the one created from this experiment would be of high performance and be integrated well into RAA's already wireless equipped ambulances and high performance prehospital resources.

There is currently no FDA standard to regulate the several different pharmaceutical manufacturing and distributing vendor medication labels and color references. If a standard were implemented to add specific color identification there would be less medical administration errors from prehospital providers. From directly observing RAA, EMT and paramedics expressed how medications to them are identified by color (labeling and fliptop vial tops) and size. From the directly observed ride along results of 42 medications, the 19 seen pharmaceutical companies did not keep the glass fliptop vial colors specific to one medication. Ideally it would be efficient to see a color standardization where same medications that have multiple concentrations would have the same color, but in different shades with lower medication concentrations having a lighter shade and higher medication concentrations having a darker shade. That would be beneficial for medications such as dextrose that comes in dextrose 5%, 25%, and 50%, and for epinephrine that comes in ratios of 1:1000 for 1 mL, 1:1000 for 30 mL, 1:10000, and 2.25%. From testing the app device, the interns said the color standard served to be 8% very helpful, 25% helpful, and 25% somewhat helpful for color association recognition of the medications. That is a total of 58% assessing that having color identifications specific to medications and not just vendor labeling is helping with their emergency providing accuracy. The role of standards was supported in a study to emphasize the importance of user-oriented medical systems engineering methods, which would safeguard patient satisfaction, safety, and provider usability (Doerr, 2008).

From the intern questionnaire analysis, 58% of the interns overall said they felt this app device served to reduce medication administration error. 58% of the interns additionally said that they would be willing to use this protocol to cross-check medications in the future. In a control study, San Diego County paramedic self-reported medication errors totaled 9.1% over the duration of twelve months. The medication errors included dose, medication, route, concentration, and treatment. 42% of out 21.9% pediatric responses were self-reported errors being dose related. 4% out of the 9.1% errors were due to the wrong medication. The study recommends that in order to reduce medication errors, that prior to administration medications should be triple checked, drug boxes should be well labeled, and there should be pre-calculated dosing protocols (Vilke, 2007).

The medication data collected from app device testing with the VCU Medical Center emergency medical interns showed that the app correctly transmitted medication data to the Google database. The variations in calculated doses were from the interns manually inputting medication information after seeing the inputted packaged dose information. After hearing the cross-check of medication from the device, if the interns thought the medication dose should be given at a different amount there was no way to prevent that error in decision making because there is prior medication knowledge necessary to using the app. However, there are safety error ranges that will prevent harmful doses from being administered. There is currently no gold standard for electronic medication administration barcode scanned reporting or electronic error safety prevention for prehospital care. For EMTs and paramedics there is a verbal cross-check protocol draft to be implemented in their system for medication error safety prevention.

In the experiment that tested to see how the smartphone application would perform under different types of lighting, the results showed that outdoor direct natural light with a paper barcode label had the fastest mean times of barcode scanning indicating that full light is necessary for barcode scanning. However, more often a paramedic would be under indoor direct artificial light in an ambulance when administering medications to patients, thus needing to improve the scanning ability of this device to achieve the fastest scanning times to not slow down medical providers care. App testing with the group of interns was performed under indoor direct natural light with paper labels (having mean scanning times of 5.30 seconds) with a combination of overhead artificial light similar to indoor direct desk light paper labels tests with mean scanning times of 5.18 seconds. The second fastest mean scanning times performed with computer labels (3.11 seconds) indicates that having access to digital labels could improve scanning performance times. In assessing the number of occurrences for medications used, with vasopressin have 3 occurrences of high value scanning times may indicate that the QR code layout for vasopressin may have contributed to slower scanning times.

The created app device would serve to auditory cross-check the medication name and dose for administration, aiding to a triple checked standard. The app would greatly improve quality in medical dosing. Currently EMS systems use a Broselow tape that measures out pediatric height and has set doses dependent on height for medication administration. The app would serve to yield more accurately calculated pediatric doses for weight-based medications.

Most adult medications come in standard dosing, however pediatric dosing is highly variable and needs weight calculations.

Limitations of this study included the testing of the app device to only adult simulated emergency cases. Additionally, the app created was based off of action commands via blocks. A coding interface for app design and creation would have allowed ease of access for additional app modifications. The tablet used for experimentation did not have a flash incorporated with the camera. The QR Droid app allows a feature that if the device is in low light conditions, that you can click a light-bulb feature on the screen to activate the flash of the device. QR code scanning performed on a different device (iPhone 4S) with the barcode-scanning app "Red Laser" showed significantly quicker scanning and decoding rates of QR codes than the experimentally tested tablet.

The intellectual properties of this study encompass the design and invention of the Android-based smartphone application "Copilot". A design property features text to speech enabling after the medication to be administered is scanned via a QR barcode, that the device will speak out the medication name and dose in order to cross-check with the paramedic that the correct medication is about to be administered to the patient. This feature is especially useful when the paramedic is alone with the patient, for example while in transport where the other provider (the EMT) is driving the ambulance to the hospital destination. A second property is that after the medication barcode is scanned and inputs medication data into the app, the provider is able to submit the data and have the medication electronically time stamped to the atomic clock to provide an accurate record of medications used in prehospital care. During cases, the providers are also able to view the drug report, having the medication information available if needed and to see when last drugs were given for drugs that have to be given after a certain number of minutes. The last intellectual property of this app is the color standardization for medication reference synchronicity. An intellectual property for future studies would be to have the medication data communicate and transmit to the hospital EMR for emergency physician real-time use in patient treatment decision-making.

One impact that this smartphone application will have to the research community is more information pertaining to prehospital medication administration errors, as there are no studies related to biomedical devices to improve the errors. By showing a design that will enable a device used by prehospital providers to communicate medication information in real-time to emergency medical physicians, it will encourage the research community to test the design approach and implement into hospital systems. The results and observations from this study show the research community the need for innovation and technological needs in prehospital emergency care.

Future studies could expand testing on the systematic design to reduce medication administration error in developing the communication between the app report and the hospital EMR. The drug boxes are not accessible by the paramedic until they are with a patient in need of emergency care. A method to allow the paramedics to pre-check the drug boxes for correct medication layout and ensure all of the medications are there could be further investigated. That would serve to prevent provider error because of an incorrectly labeled drug box for a drug recall such as when Dopamine was recalled and Levophed was used in its place. All of the other supplies are pre-checked on an ambulance before the provider goes into operation. A future study would be to test the application on a smartphone instead of the testing performed on a tablet in this experiment. A benefit of using a smartphone would be the 1D barcode readability if the smartphone had an autofocus camera (almost all RAA medications observed had 1D barcode labels). There would be no need to add QR labels on the medications. However, this experimental testing was conducted with 2D QR barcodes that are flat and may provider quicker scanning times on rounded medication vial curves. Potentially a smartphone or tablet would both have the capability to read and decode 1D and 2D barcodes, depending if their cameras had autofocus to scan 1D barcodes. A 2D QR code would ideally be the fastest in reading times. Using a smartphone would be beneficial for app testing in real patient scenarios due to the smartphone's smaller screen and the compact size for the provider to store it on his/her belt or pocket when not directly in use during prehospital emergency care. Using a tablet would be beneficial for app demonstrations due to its large screen size and would be utilized in app device training.

Conclusion

The human will always be subjected to error. However, we can design and innovate new ways to reduce human error, training the human system to hopefully a one day error free state. Human error in the medical field is especially critical due to the life threatening implications it entails. Smartphone applications are widely used in today's society and therefore integrating this well-used technology to innovate a scientific field is key to achieving promising results. The app created in this experiment will serve to reduce medication administration with prehospital providers to possibly one day also with emergency room physicians and beyond. The technology for this simulated concept is about integrating pieces already in place to create a more communicated system in the emergency medical field.

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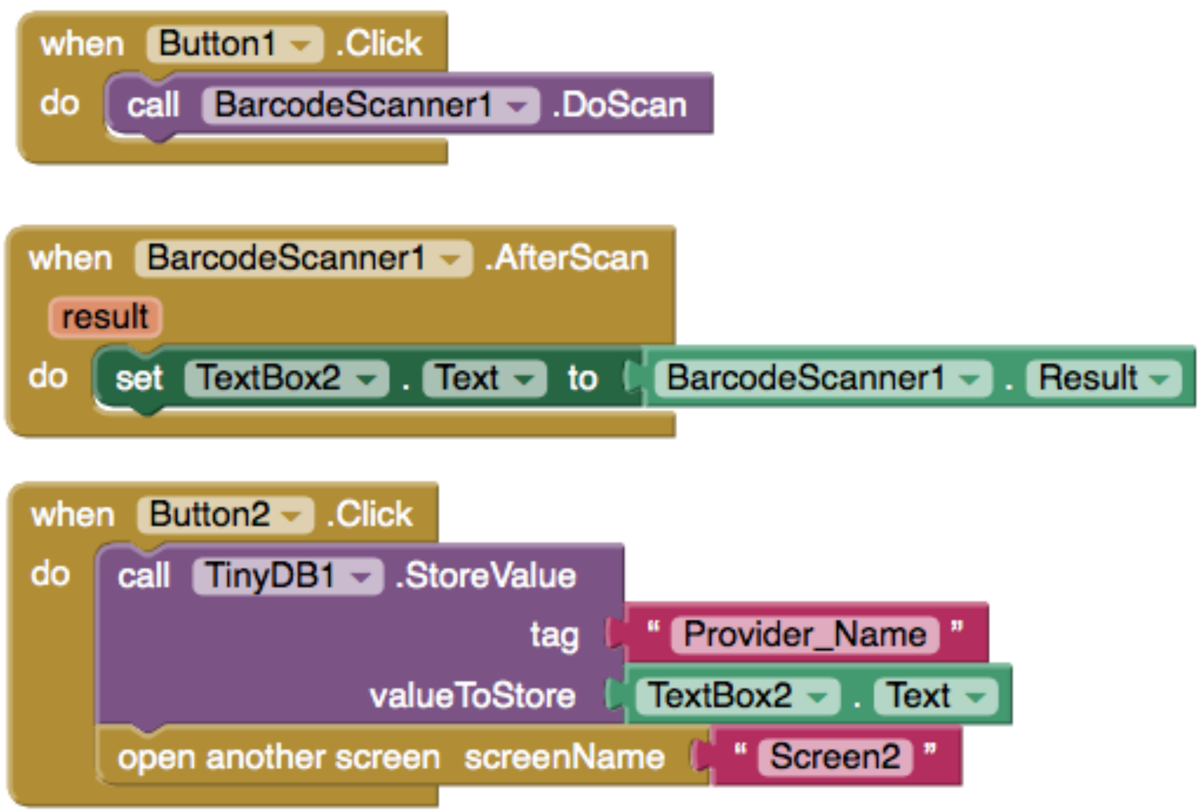
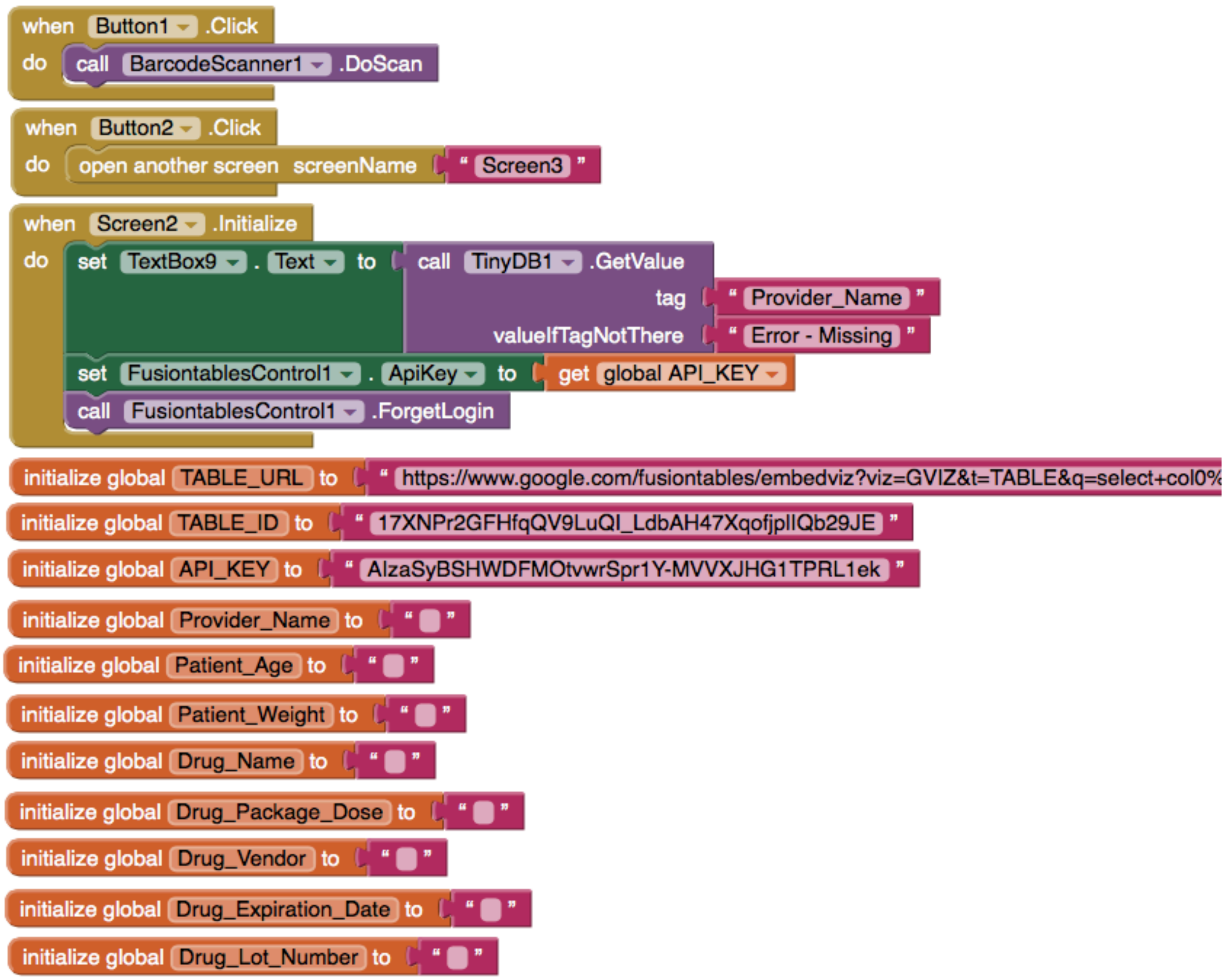
Appendix

Appendix 1. Block coding for screens 1, 2, and 3 of the created smartphone application.

Screen 1:

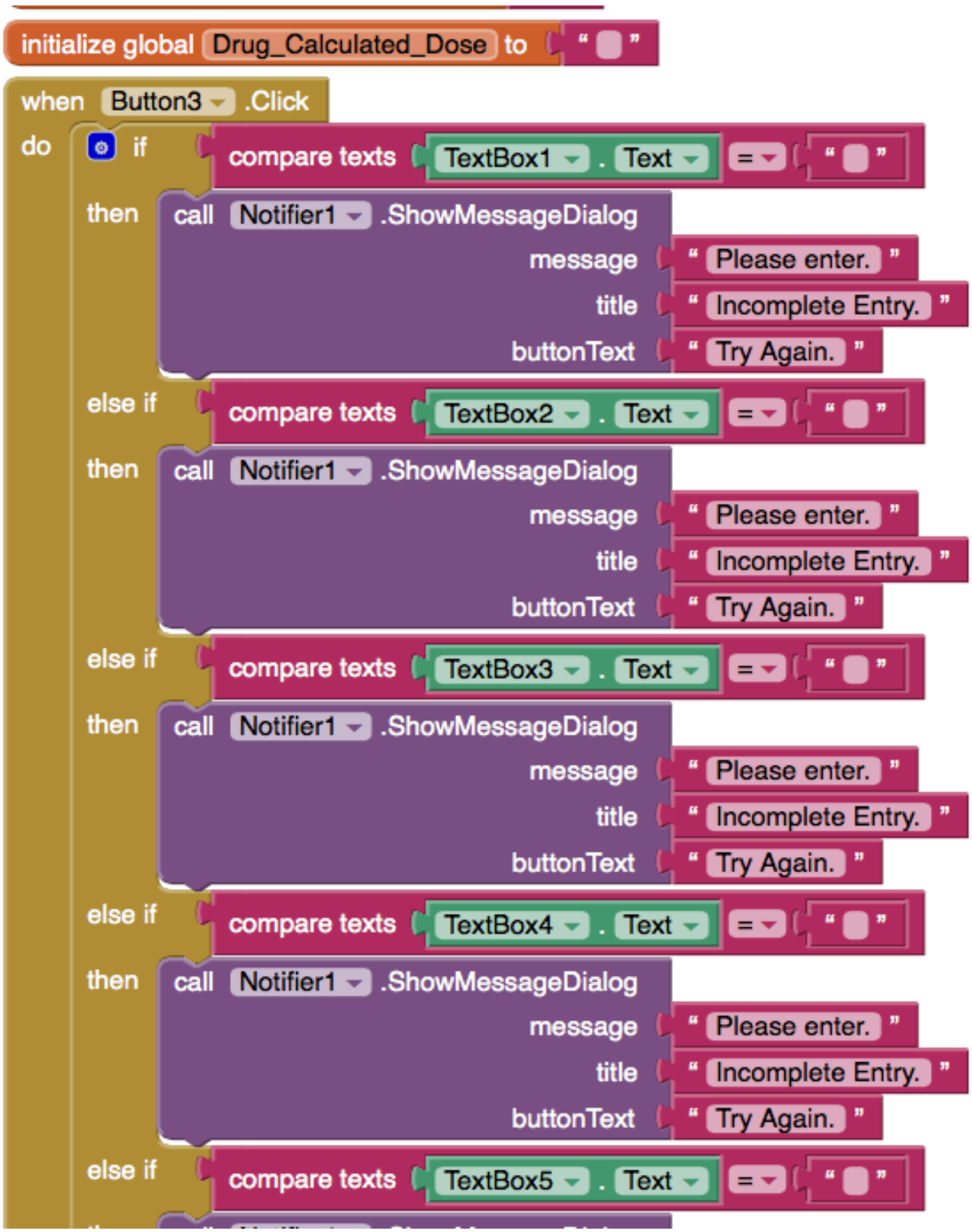


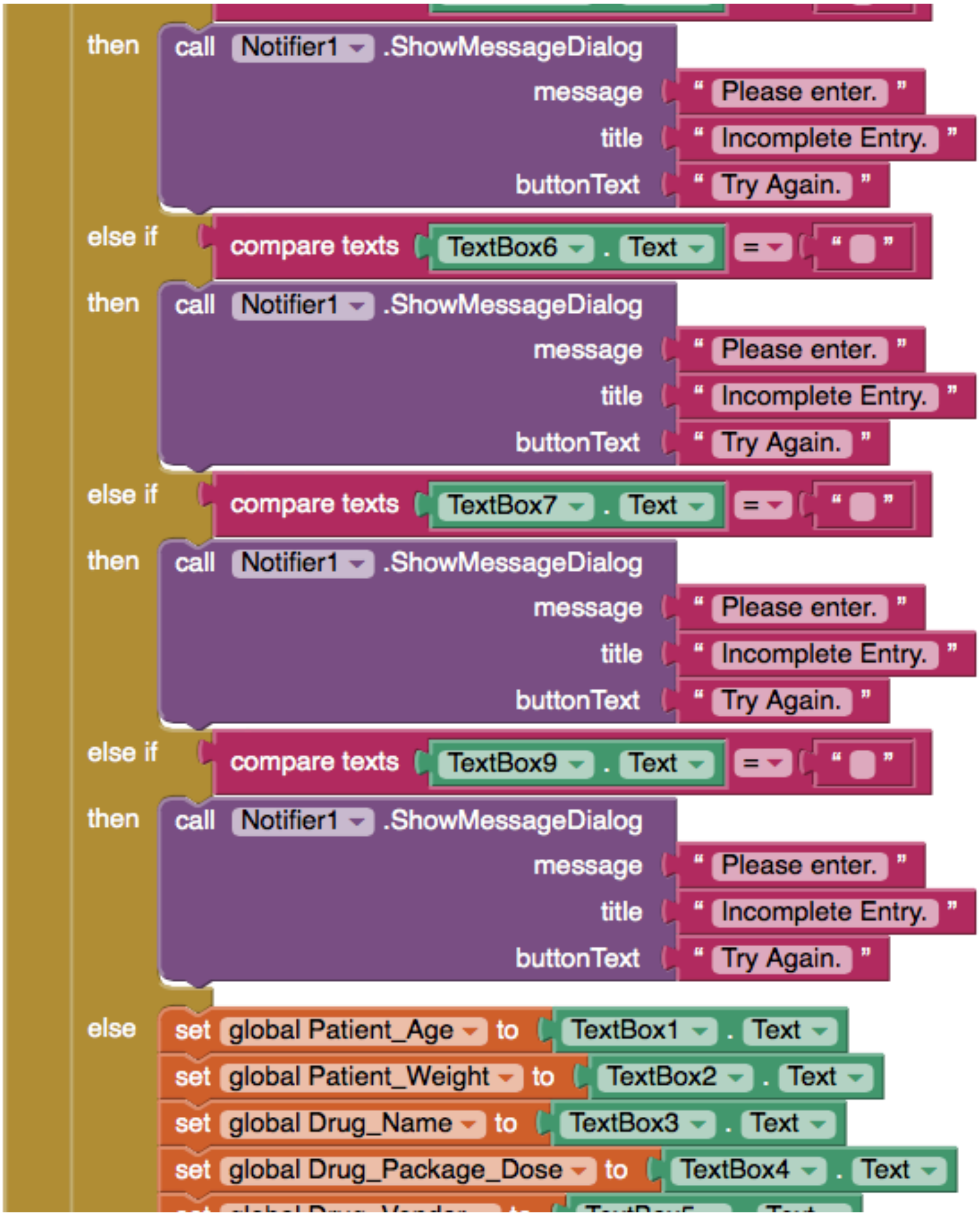
Screen 2:

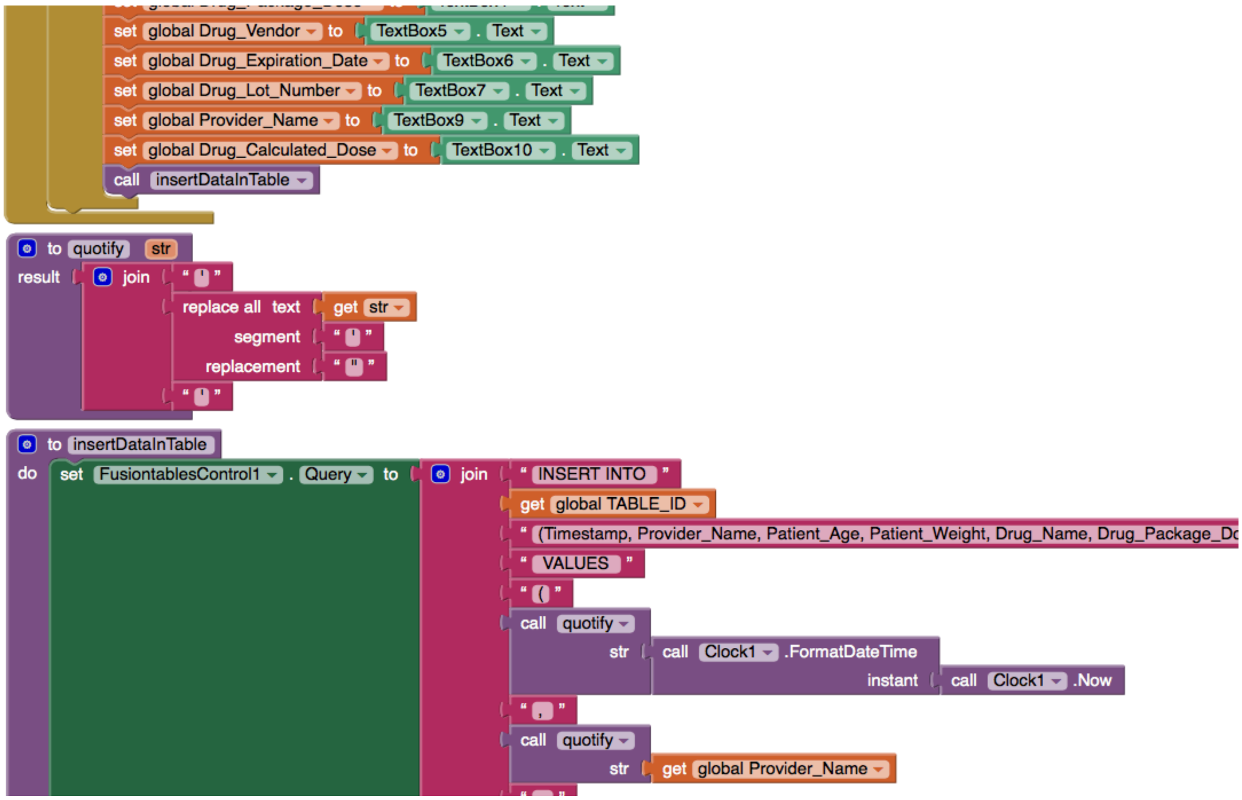


Missing information:

https://www.google.com/fusiontables/embedviz?viz=GVIZ&t=TABLE&q=select+col0%2C+col1%2C+col2%2C+col3%2C+col4%2C+col5%2C+col6%2C+col7%2C+col8%2C+col9+from+17XNPr2GFHfqQV9LuQI_LdbAH47XqofjplIQb29JE&containerId=googft-gviz-canvas

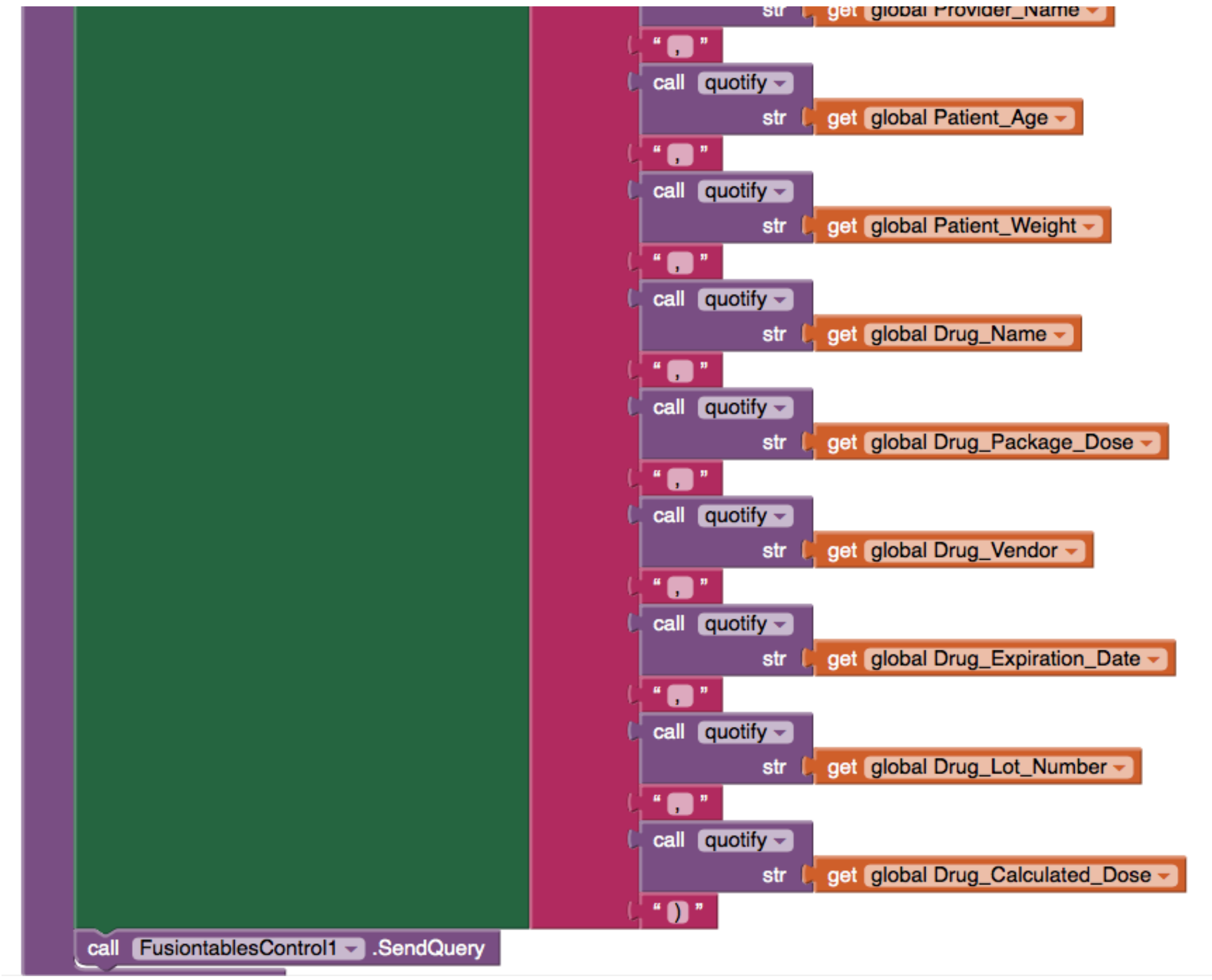

initialize global Drug_Calculated_Dose to
when Button3 .Click
do if compare texts TextBox1 . Text =
then call Notifier1 .ShowMessageDialog
message Please enter.
title Incomplete Entry.
buttonText Try Again.
else if compare texts TextBox2 . Text =
then call Notifier1 .ShowMessageDialog
message Please enter.
title Incomplete Entry.
buttonText Try Again.
else if compare texts TextBox3 . Text =
then call Notifier1 .ShowMessageDialog
message Please enter.
title Incomplete Entry.
buttonText Try Again.
else if compare texts TextBox4 . Text =
then call Notifier1 .ShowMessageDialog
message Please enter.
title Incomplete Entry.
buttonText Try Again.
else if compare texts TextBox5 . Text =

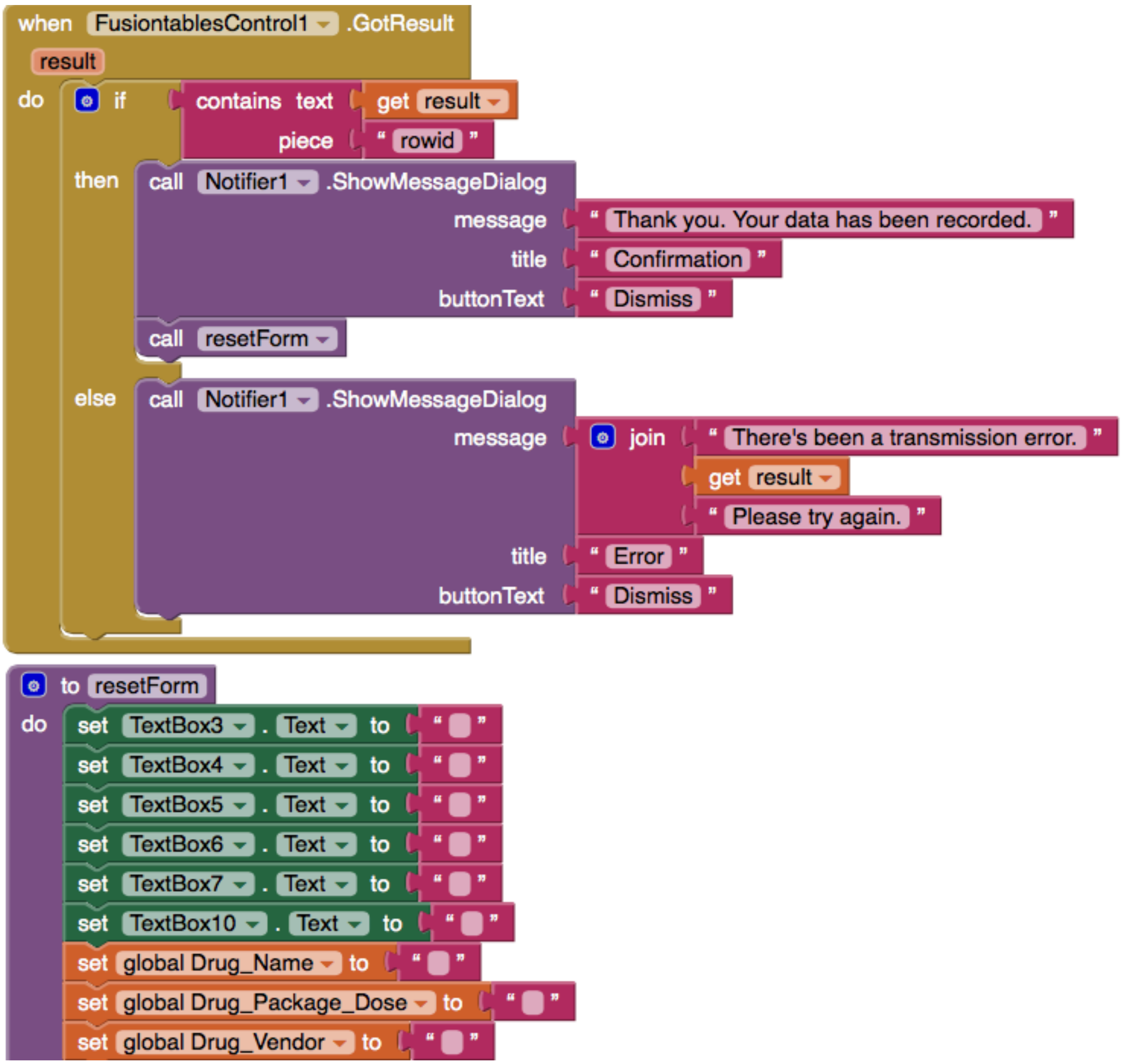

then
call Notifier1 .ShowMessageDialog
message "Please enter."
title "Incomplete Entry."
buttonText "Try Again."
else if
compare texts TextBox6 . Text = " "
then
call Notifier1 .ShowMessageDialog
message "Please enter."
title "Incomplete Entry."
buttonText "Try Again."
else if
compare texts TextBox7 . Text = " "
then
call Notifier1 .ShowMessageDialog
message "Please enter."
title "Incomplete Entry."
buttonText "Try Again."
else if
compare texts TextBox9 . Text = " "
then
call Notifier1 .ShowMessageDialog
message "Please enter."
title "Incomplete Entry."
buttonText "Try Again."
else
set global Patient_Age to TextBox1 . Text
set global Patient_Weight to TextBox2 . Text
set global Drug_Name to TextBox3 . Text
set global Drug_Package_Dose to TextBox4 . Text

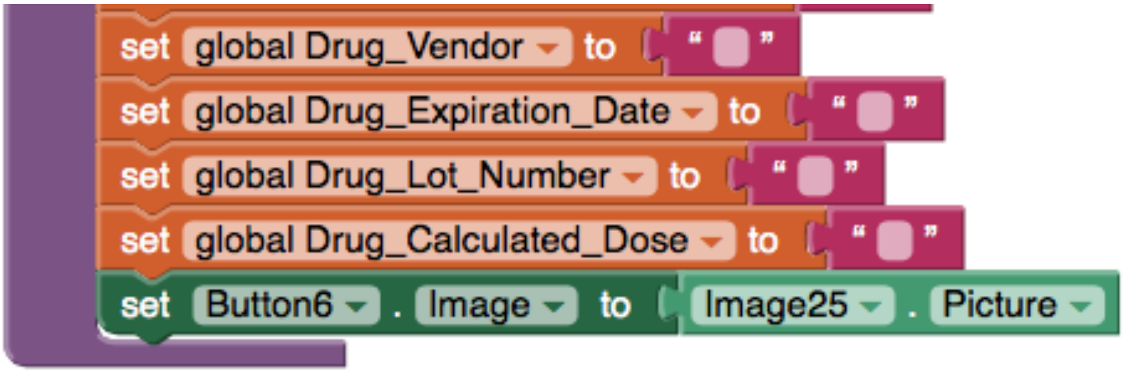


Missing information:

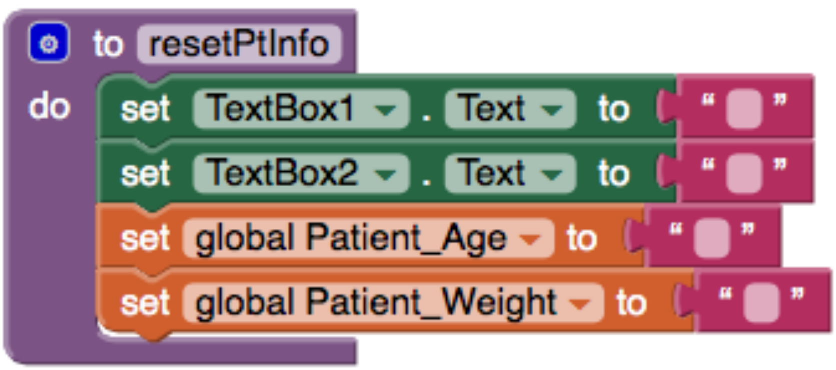
(Timestamp, Provider_Name, Patient_Age, Patient_Weight, Drug_Name, Drug_Package_Dose, Drug_Vendor, Drug_Expiration_Date, Drug_Lot_Number, Drug_Calculated_Dose)

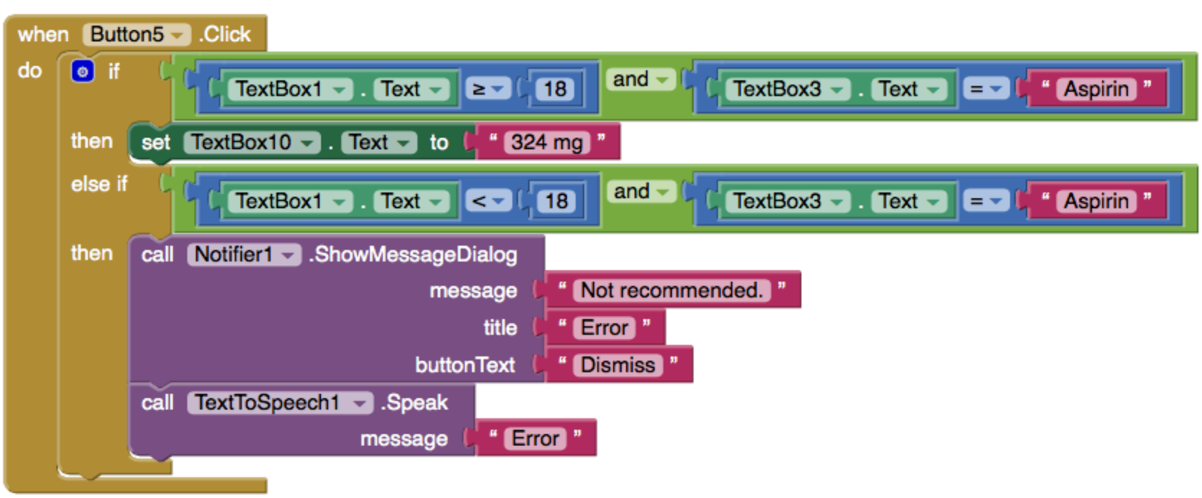

str get global Provider_Name
" , "
call quotify
str get global Patient_Age
" , "
call quotify
str get global Patient_Weight
" , "
call quotify
str get global Drug_Name
" , "
call quotify
str get global Drug_Package_Dose
" , "
call quotify
str get global Drug_Vendor
" , "
call quotify
str get global Drug_Expiration_Date
" , "
call quotify
str get global Drug_Lot_Number
" , "
call quotify
str get global Drug_Calculated_Dose
") "
call FusiontablesControl1 .SendQuery

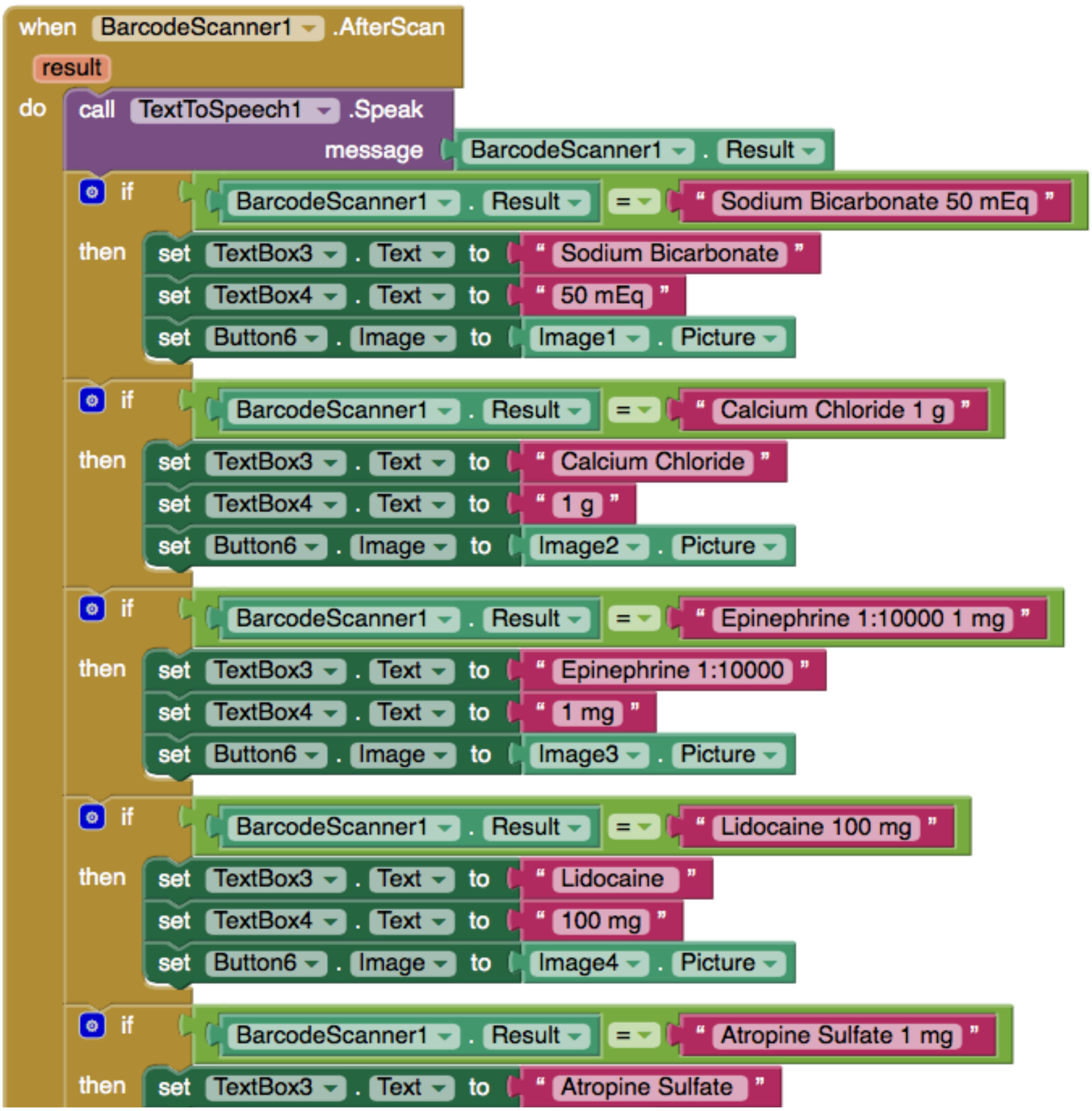

when FusiontablesControl1 .GotResult
result
do if contains text get result
piece "rowid"
then call Notifier1 .ShowMessageDialog
message "Thank you. Your data has been recorded."
title "Confirmation"
buttonText "Dismiss"
call resetForm
else call Notifier1 .ShowMessageDialog
message join "There's been a transmission error."
get result
"Please try again."
title "Error"
buttonText "Dismiss"
to resetForm
do set TextBox3 . Text to ""
set TextBox4 . Text to ""
set TextBox5 . Text to ""
set TextBox6 . Text to ""
set TextBox7 . Text to ""
set TextBox10 . Text to ""
set global Drug_Name to ""
set global Drug_Package_Dose to ""
set global Drug_Vendor to ""

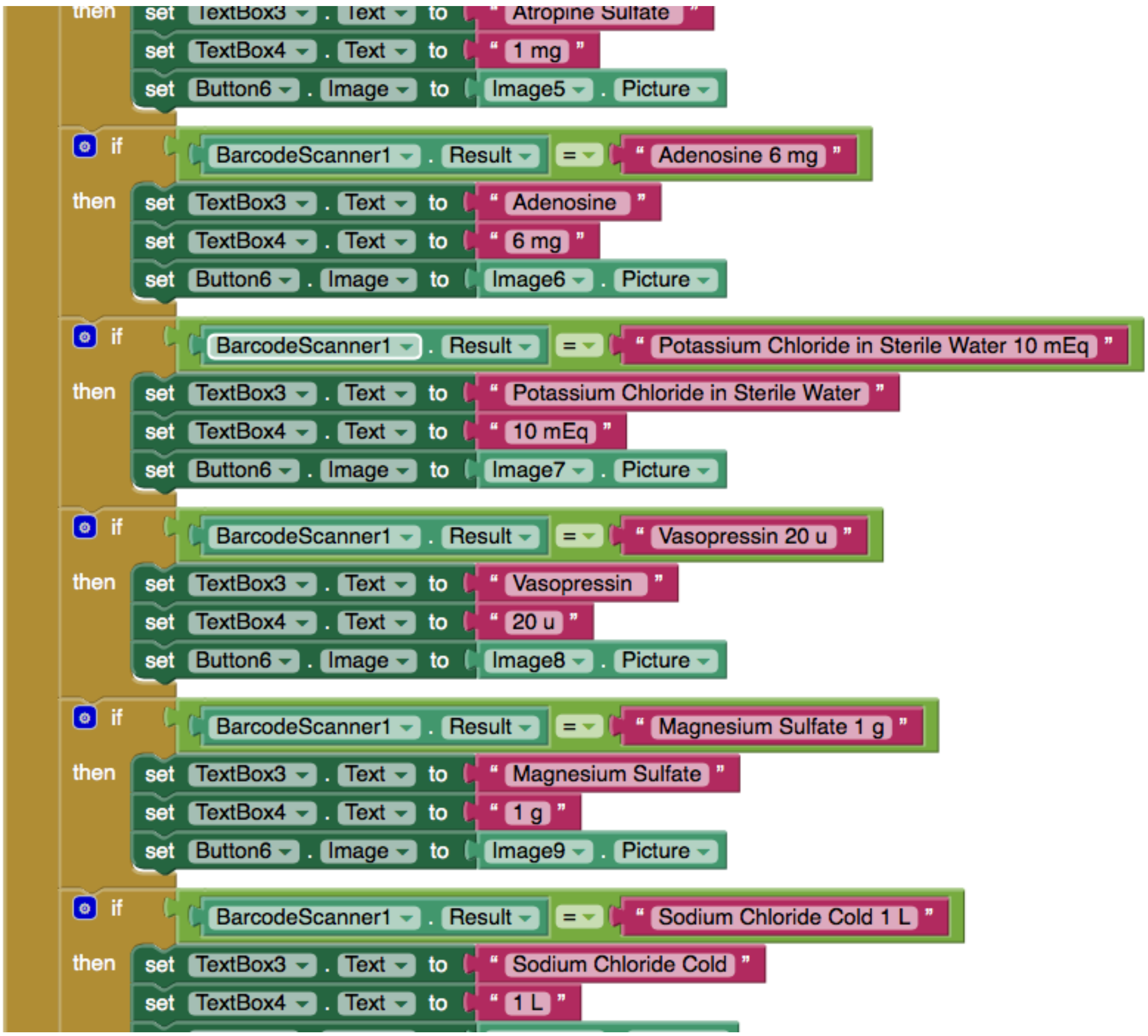

set global Drug_Vendor to " "
set global Drug_Expiration_Date to " "
set global Drug_Lot_Number to " "
set global Drug_Calculated_Dose to " "
set Button6 . Image to Image25 . Picture

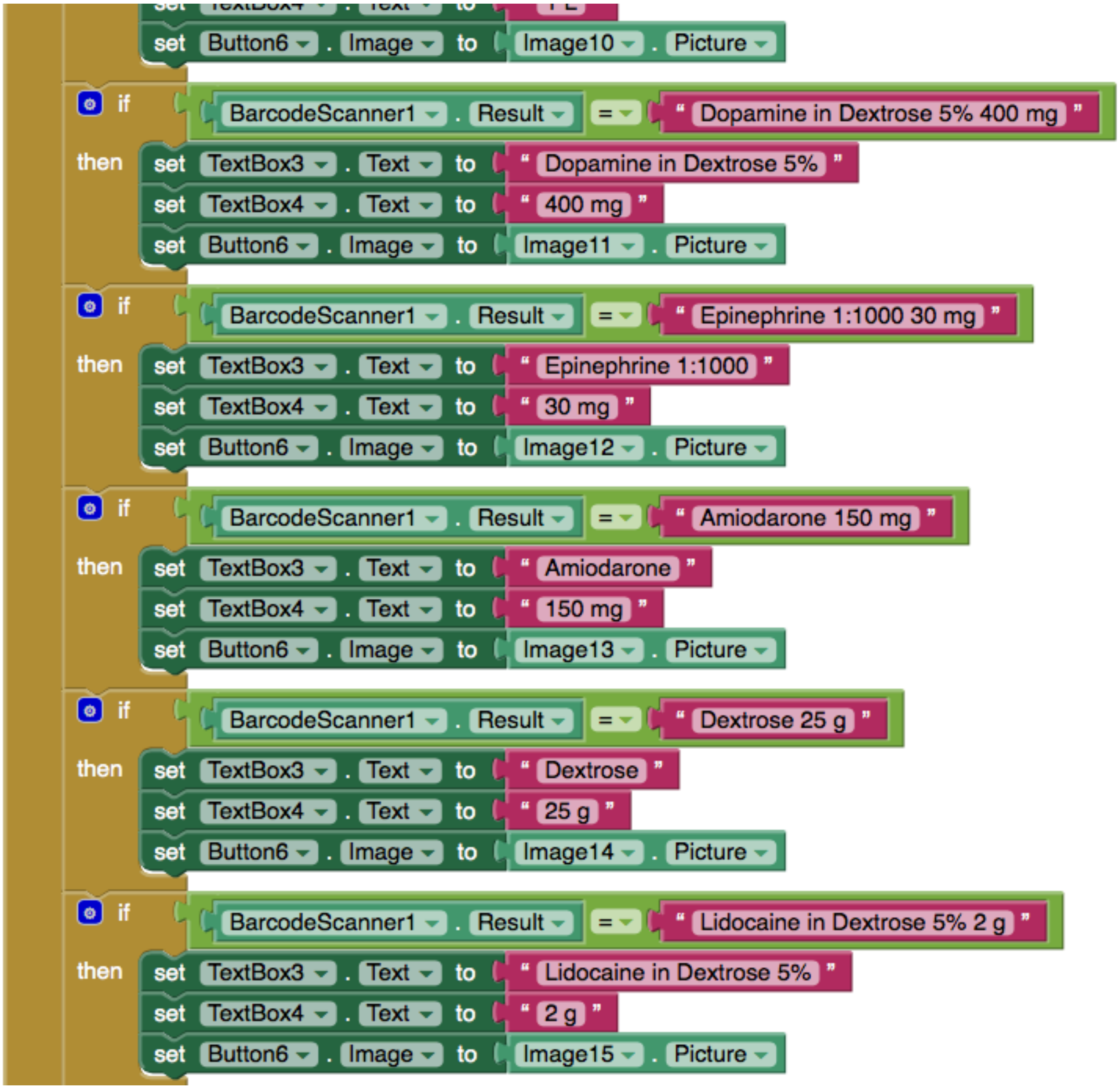

when Button4 .Click
do call resetPtInfo

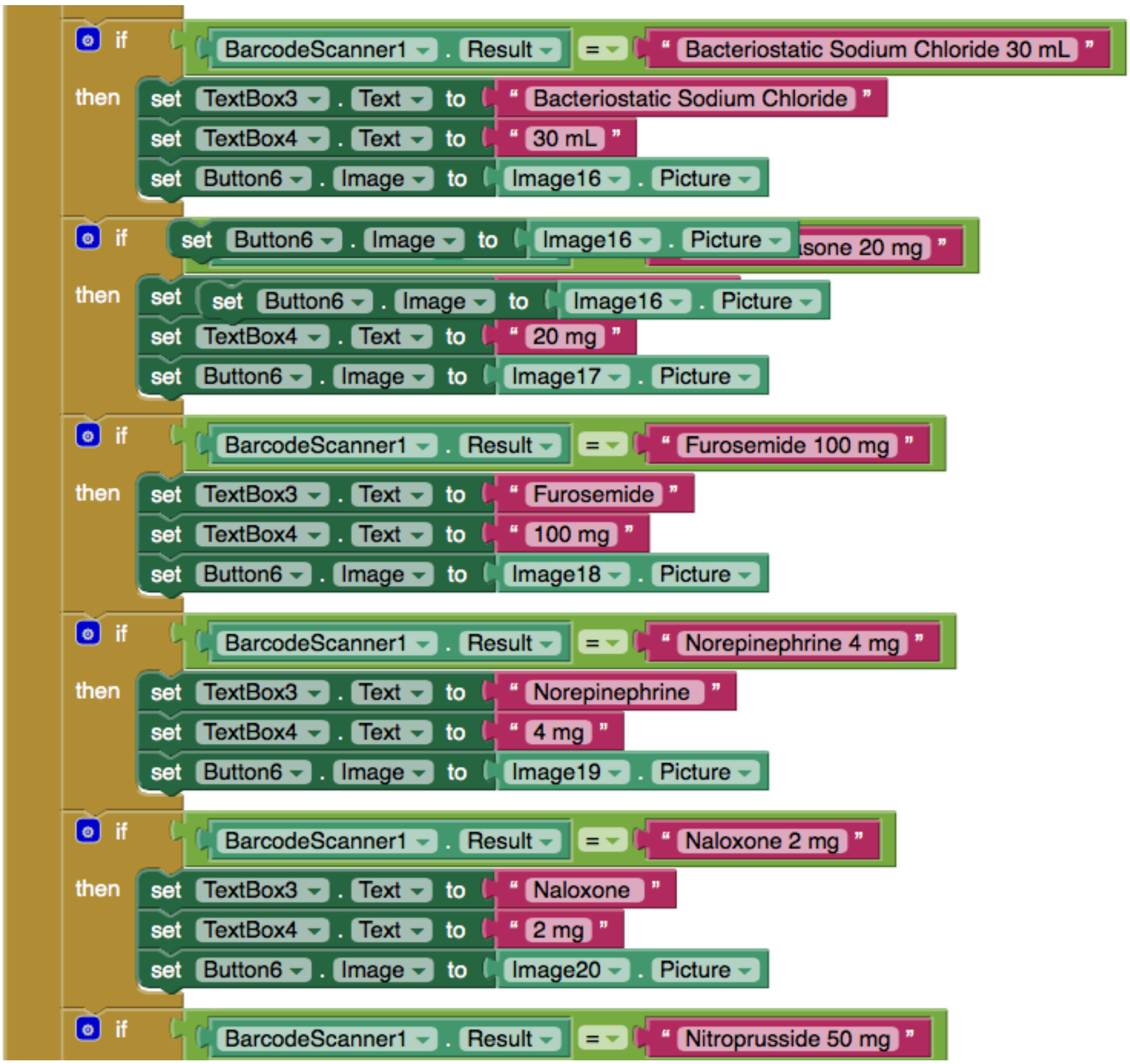

to resetPtInfo
do set TextBox1 . Text to " "
set TextBox2 . Text to " "
set global Patient_Age to " "
set global Patient_Weight to " "

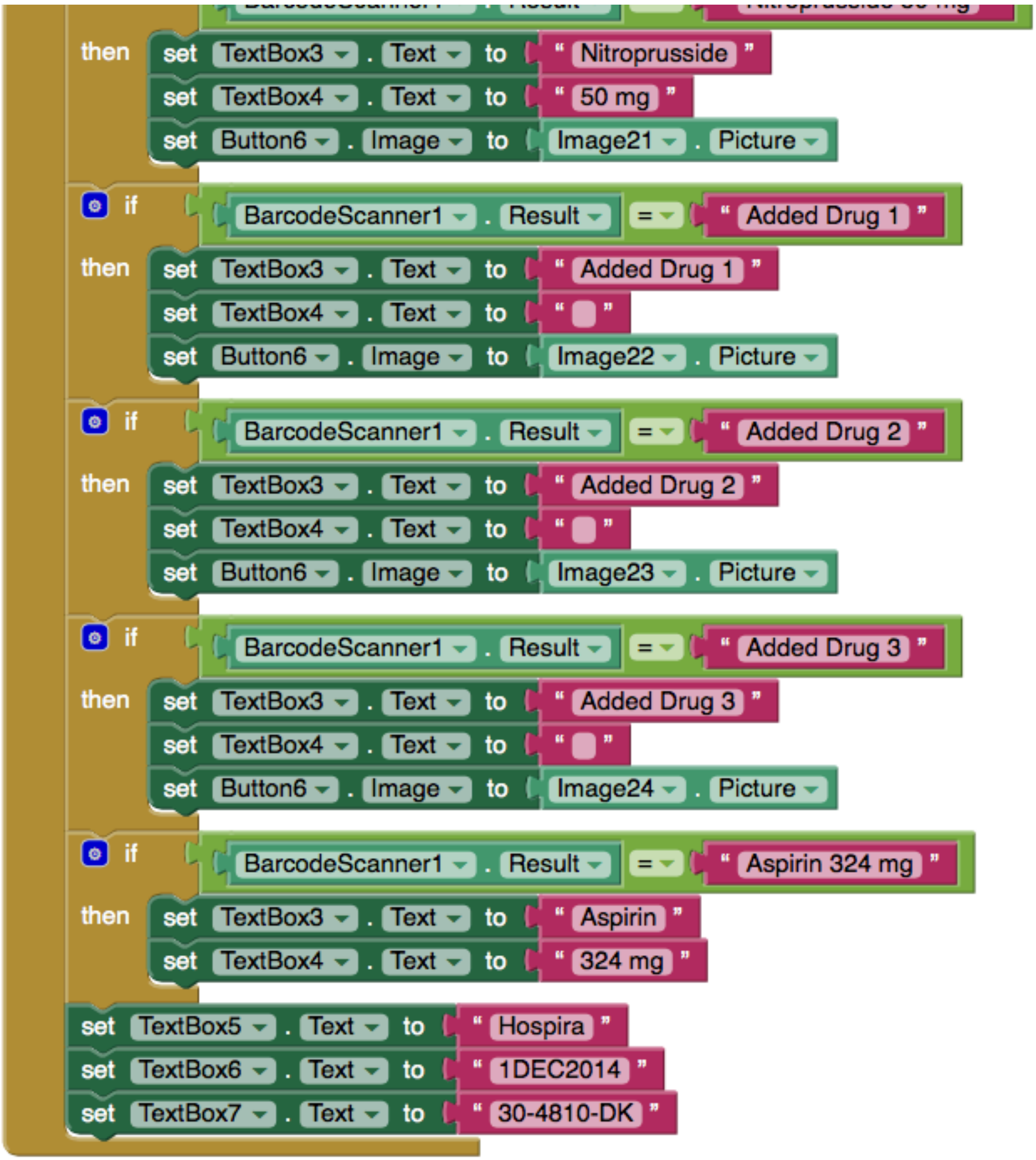

when Button5 .Click
do if TextBox1 . Text ≥ 18 and TextBox3 . Text = " Aspirin "
then set TextBox10 . Text to " 324 mg "
else if TextBox1 . Text < 18 and TextBox3 . Text = " Aspirin "
then call Notifier1 .ShowMessageDialog
message " Not recommended. "
title " Error "
buttonText " Dismiss "
call TextToSpeech1 .Speak
message " Error "


when BarcodeScanner1 .AfterScan
result
do call TextToSpeech1 .Speak
message BarcodeScanner1 . Result
if BarcodeScanner1 . Result = " Sodium Bicarbonate 50 mEq "
then set TextBox3 . Text to " Sodium Bicarbonate "
set TextBox4 . Text to " 50 mEq "
set Button6 . Image to Image1 . Picture
if BarcodeScanner1 . Result = " Calcium Chloride 1 g "
then set TextBox3 . Text to " Calcium Chloride "
set TextBox4 . Text to " 1 g "
set Button6 . Image to Image2 . Picture
if BarcodeScanner1 . Result = " Epinephrine 1:10000 1 mg "
then set TextBox3 . Text to " Epinephrine 1:10000 "
set TextBox4 . Text to " 1 mg "
set Button6 . Image to Image3 . Picture
if BarcodeScanner1 . Result = " Lidocaine 100 mg "
then set TextBox3 . Text to " Lidocaine "
set TextBox4 . Text to " 100 mg "
set Button6 . Image to Image4 . Picture
if BarcodeScanner1 . Result = " Atropine Sulfate 1 mg "
then set TextBox3 . Text to " Atropine Sulfate "

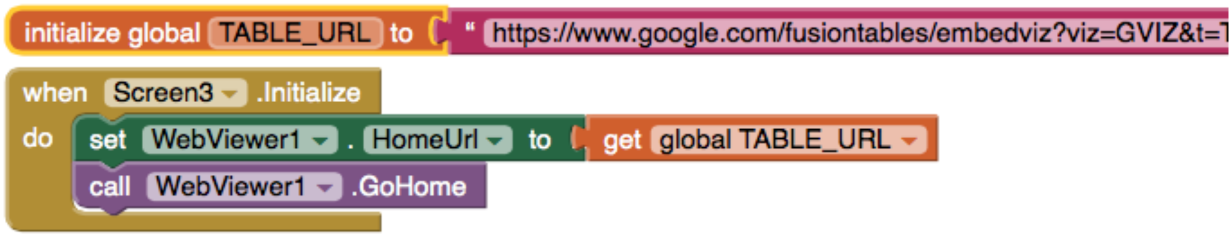

then set TextBox3 . Text to " Atropine Sulfate "
set TextBox4 . Text to " 1 mg "
set Button6 . Image to Image5 . Picture
if BarcodeScanner1 . Result = " Adenosine 6 mg "
then set TextBox3 . Text to " Adenosine "
set TextBox4 . Text to " 6 mg "
set Button6 . Image to Image6 . Picture
if BarcodeScanner1 . Result = " Potassium Chloride in Sterile Water 10 mEq "
then set TextBox3 . Text to " Potassium Chloride in Sterile Water "
set TextBox4 . Text to " 10 mEq "
set Button6 . Image to Image7 . Picture
if BarcodeScanner1 . Result = " Vasopressin 20 u "
then set TextBox3 . Text to " Vasopressin "
set TextBox4 . Text to " 20 u "
set Button6 . Image to Image8 . Picture
if BarcodeScanner1 . Result = " Magnesium Sulfate 1 g "
then set TextBox3 . Text to " Magnesium Sulfate "
set TextBox4 . Text to " 1 g "
set Button6 . Image to Image9 . Picture
if BarcodeScanner1 . Result = " Sodium Chloride Cold 1 L "
then set TextBox3 . Text to " Sodium Chloride Cold "
set TextBox4 . Text to " 1 L "


set Button6 . Image to Image10 . Picture
if BarcodeScanner1 . Result = "Dopamine in Dextrose 5% 400 mg"
then set TextBox3 . Text to "Dopamine in Dextrose 5%"
set TextBox4 . Text to "400 mg"
set Button6 . Image to Image11 . Picture
if BarcodeScanner1 . Result = "Epinephrine 1:1000 30 mg"
then set TextBox3 . Text to "Epinephrine 1:1000"
set TextBox4 . Text to "30 mg"
set Button6 . Image to Image12 . Picture
if BarcodeScanner1 . Result = "Amiodarone 150 mg"
then set TextBox3 . Text to "Amiodarone"
set TextBox4 . Text to "150 mg"
set Button6 . Image to Image13 . Picture
if BarcodeScanner1 . Result = "Dextrose 25 g"
then set TextBox3 . Text to "Dextrose"
set TextBox4 . Text to "25 g"
set Button6 . Image to Image14 . Picture
if BarcodeScanner1 . Result = "Lidocaine in Dextrose 5% 2 g"
then set TextBox3 . Text to "Lidocaine in Dextrose 5%"
set TextBox4 . Text to "2 g"
set Button6 . Image to Image15 . Picture


if BarcodeScanner1 . Result = " Bacteriostatic Sodium Chloride 30 mL "
then set TextBox3 . Text to " Bacteriostatic Sodium Chloride "
set TextBox4 . Text to " 30 mL "
set Button6 . Image to Image16 . Picture
if set Button6 . Image to Image16 . Picture sone 20 mg "
then set set Button6 . Image to Image16 . Picture
set TextBox4 . Text to " 20 mg "
set Button6 . Image to Image17 . Picture
if BarcodeScanner1 . Result = " Furosemide 100 mg "
then set TextBox3 . Text to " Furosemide "
set TextBox4 . Text to " 100 mg "
set Button6 . Image to Image18 . Picture
if BarcodeScanner1 . Result = " Norepinephrine 4 mg "
then set TextBox3 . Text to " Norepinephrine "
set TextBox4 . Text to " 4 mg "
set Button6 . Image to Image19 . Picture
if BarcodeScanner1 . Result = " Naloxone 2 mg "
then set TextBox3 . Text to " Naloxone "
set TextBox4 . Text to " 2 mg "
set Button6 . Image to Image20 . Picture
if BarcodeScanner1 . Result = " Nitroprusside 50 mg "


then set TextBox3 . Text to "Nitroprusside"
set TextBox4 . Text to "50 mg"
set Button6 . Image to Image21 . Picture
if BarcodeScanner1 . Result = "Added Drug 1"
then set TextBox3 . Text to "Added Drug 1"
set TextBox4 . Text to ""
set Button6 . Image to Image22 . Picture
if BarcodeScanner1 . Result = "Added Drug 2"
then set TextBox3 . Text to "Added Drug 2"
set TextBox4 . Text to ""
set Button6 . Image to Image23 . Picture
if BarcodeScanner1 . Result = "Added Drug 3"
then set TextBox3 . Text to "Added Drug 3"
set TextBox4 . Text to ""
set Button6 . Image to Image24 . Picture
if BarcodeScanner1 . Result = "Aspirin 324 mg"
then set TextBox3 . Text to "Aspirin"
set TextBox4 . Text to "324 mg"
set TextBox5 . Text to "Hospira"
set TextBox6 . Text to "1DEC2014"
set TextBox7 . Text to "30-4810-DK"

Screen 3:



Missing information:

https://www.google.com/fusiontables/embedviz?viz=GVIZ&t=TABLE&q=select+col0%2C+col1%2C+col2%2C+col3%2C+col4%2C+col5%2C+col6%2C+col7%2C+col8%2C+col9+from+17XNPr2GFHfqQV9LuQI_LdbAH47XqofjplIQb29JE&containerId=googft-gviz-canvas