

Smartphone-Based Geofencing to Ascertain Hospitalizations

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Background—Ascertainment of hospitalizations is critical to assess quality of care and the effectiveness and adverse effects of various therapies. Smartphones, mobile geolocators that are ubiquitous, have not been leveraged to ascertain hospitalizations. Therefore, we evaluated the use of smartphone-based geofencing to track hospitalizations.

Methods and Results—Participants aged ≥ 18 years installed a mobile application programmed to geofence all hospitals using global positioning systems and cell phone tower triangulation and to trigger a smartphone-based questionnaire when located in a hospital for ≥ 4 hours. An in-person study included consecutive consenting patients scheduled for electrophysiology and cardiac catheterization procedures. A remote arm invited Health eHeart Study participants who consented and engaged with the study via the internet only. The accuracy of application-detected hospitalizations was confirmed by medical record review as the reference standard. Of 22 eligible in-person patients, 17 hospitalizations were detected (sensitivity 77%; 95% confidence interval, 55%–92%). The length of stay according to the application was positively correlated with the length of stay ascertained via the electronic medical record ($r=0.53$; $P=0.03$). In the remote arm, the application was downloaded by 3443 participants residing in all 50 US states; 243 hospital visits at 119 different hospitals were detected through the application. The positive predictive value for an application-reported hospitalization was 65% (95% confidence interval, 57%–72%).

Conclusions—Mobile application-based ascertainment of hospitalizations can be achieved with modest accuracy. This first proof of concept may ultimately be applicable to geofencing other types of prespecified locations to facilitate healthcare research and patient care. (*Circ Cardiovasc Qual Outcomes*. 2017;10:e003326. DOI: 10.1161/CIRCOUTCOMES.116.003326.)

Key Words: fast food ■ hospitalization ■ internet ■ pharmacies ■ smartphone

Ascertainment of hospitalizations and cardiovascular events is critical to assess disease occurrence, quality of care, and the effectiveness and adverse effects of various therapies.¹ Yet, there is currently no optimal method to ascertain these data.^{2,3} Self-reported data suffers from recall bias, and the use of medical records and administrative claims is resource intensive.⁴ In addition, because there is no universal electronic medical record and researchers from other institutions may have limited access to these records, relying on electronic medical records alone may miss hospital events at hospitals outside of a particular network.

See Editorial by Horvitz and White

Mobile devices are increasingly used for medical diagnostics,⁵ disease monitoring,⁶ and counseling.⁷ The use of smartphones is quickly becoming ubiquitous, and users are increasingly relying on smartphone applications (or apps) to monitor their

health.^{8,9} The emerging field of mobile health (mHealth) offers new opportunities for patients and providers to collect and share healthcare information and data. However, despite these advances, the location-sensing capabilities of smartphones have not yet been leveraged to ascertain healthcare data.

Smartphone-based geofencing, a location-based program that defines geographical boundaries, may allow real-time tracking of medical visits and reduce the measurement error of retrospective reporting. An important advantage of such a fence is that it does not require continuous tracking of location, which would impinge on privacy and therefore likely significantly limit applicability. Instead, a location is identified only when the fence is crossed. Additionally, once validated and optimized, this technology could be expanded into other arenas, such as grocery stores, fast food restaurants, gymnasiums, pharmacies, and liquor stores, allowing real-time collection of health-related behaviors and eventually real-time

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WHAT IS KNOWN

- Ascertainment of hospitalizations is critical in research studies, but an optimal method has not been identified.
- Smartphone users are increasingly relying on mobile applications to track and monitor their health.
- Smartphone-based geofencing theoretically allows for real-time tracking of hospital visits, yet its use for this purpose has not been validated.

WHAT THE STUDY ADDS

- This study found that smartphone-based geofencing of hospital visits can be achieved with modest accuracy.
- Users reported generally positive feedback and high interest in continued use of the application.

interventions. Therefore, as a proof of concept, we sought to evaluate the use of smartphone-based geofencing for tracking hospitalizations among (1) participants with a known hospital visit (the in-person arm) and (2) participants with an app-detected hospital visit (the remote arm).

Methods

Study Design

This was a 2-part study using data from the Health eHeart study (www.health-eheartstudy.org), a worldwide online cardiovascular cohort study coordinated at the University of California, San Francisco (UCSF). English-speaking adults (age ≥ 18 years) with an active e-mail address were eligible to participate in the Health eHeart study and were recruited through academic institutions, lay press, social media, and promotional events. On enrollment, participants were prompted to complete online questionnaires that included questions about demographics, personal and family medical history, physical activity, quality of life, and technology use. Individuals meeting inclusion criteria for the Health eHeart study and who reported having either an iOS or Android-based smartphone were offered participation in the current study.

Remote Arm

In a remote arm of the study, we evaluated whether, in participants with an app-detected medical visit, there was a true medical visit as determined from the medical record (the positive predictive value of the app). Health eHeart participants with smartphones received an e-mail invitation to download the smartphone app (developed by Ginger.io in collaboration with study investigators) in September 2013. Individuals who enrolled in the Health eHeart study after that date could also download the app as part of several optional study activities. Therefore, all Health eHeart participants with a smartphone were eligible to join the study between September 4, 2013, and September 9, 2015. Of note, download of the app required additional consent (obtained remotely and electronically) specific to the capabilities and monitoring of the app. Participation in the remote arm was not limited to individuals with a hospital visit scheduled, and participants were not provided specific instructions, outside of the consent process, regarding the use of the app to document medical visits.

In the remote arm, an app-detected medical visit was defined as a hospital location detected by the app and confirmed by the participant as a medical visit through the app-based questionnaire. An app-based medical visit was considered a true positive if there was evidence from the medical record that participants visited the medical center

within 24 hours of the time reported by the app. In instances where the app detected multiple visits with the same dates, the visits were considered to represent a single encounter if the end of one detected visit and the beginning of another were within 4 hours (the set threshold for detection) of one another.

In-Person Arm

In an in-person arm of the study, we evaluated (1) whether the app detected known hospital visits (the sensitivity of the app), (2) the correlation between the length of the hospital visit detected by the app compared with the medical record, and (3) feedback from participants at 1 week and 1 month after enrollment in the study. We enrolled consecutive, consenting patients scheduled for electrophysiology and cardiac catheterization procedures at UCSF from July to August 2015. Individuals who had previously downloaded the mobile app as part of the Health eHeart study were excluded from this arm. Individuals were contacted by telephone and invited to enroll in the Health eHeart study and install the mobile app on their smartphone. Participants were asked to bring the smartphone with the app preinstalled to the hospital on the day of their scheduled procedure and to respond to any app-based notifications to confirm the hospital visit.

This study was approved by the UCSF Committee on Human Research, and all participants provided informed electronic consent. The consent was in a modular and hierarchical form, such that the basic Health eHeart consent was first required before participants were offered the specific Ginger.io app consent. The mobile app could be downloaded only after the specific app-related consent was obtained. Study data were collected and managed using Research Electronic Data Capture electronic data capture tools hosted at UCSF.¹⁰

Smartphone-Based Hospitalization Assessment

Once downloaded, the app operated in the background to collect behavioral data such as location data on Android- and iOS-based devices and self-reported data through application-based questionnaires. App-detected data were passive, not requiring that the app was opened or any active engagement by the user, and the regular function of the smartphone was not affected. Patients received notifications on their smartphone when a questionnaire was available, such as to confirm a medical visit.

The app was programmed to geofence all US hospitals using the global positioning systems and cell phone tower triangulation by defining a virtual perimeter around the geographical locations of hospitals. Using location services on the phone, if the phone was detected within the geofenced hospital location for ≥ 4 hours, a smartphone-based notification was sent to participants within 1 hour of leaving the hospital vicinity, asking them to respond to a smartphone-based questionnaire to confirm whether or not they visited the medical center for medical care. A 4-hour window was chosen to optimize the detection of as many true hospital visits as possible while attempting to minimize the potential for false positives for people within the geofence for a nonmedical reason, such as visiting a patient or briefly passing through the area.

Patients had ≤ 16 hours to confirm the visit through the app-based questionnaire. After this window, the questionnaire was no longer available to collect the data in real time and avoid confusion with hospitalizations on other dates. To enhance clarity, the smartphone-based questionnaire language was changed on May 2, 2014 (see Methods section in the [Data Supplement](#)). A sensitivity analysis done to assess the accuracy of the app before and after the language changed revealed no meaningful differences.

Technological eligibility was defined as having the smartphone present, turned on, and with location and notification services enabled.

Electronic Medical Record–Based Hospitalization Assessment

For participants who visited UCSF, actual hospitalization and duration of stay were determined from the electronic medical record. For participants in the remote arm who reported via the app that they

had received medical care at another institution, an e-mail questionnaire was sent in December 2015 requesting confirmation of the medical visit. To obtain permission to search medical record data, patients confirming that they had received medical care during the time indicated by the mobile app were asked to provide consent and Health Insurance Portability and Accountability Act authorization electronically via a workflow in the Health eHeart study. Among those who did not fill out the e-mail questionnaire, attempts were made to contact participants by telephone, text message, or mail based on their self-reported contact preferences. For consenting and Health Insurance Portability and Accountability Act–authorizing participants, we contacted the medical center where they had received care and requested the relevant medical records to confirm the visit(s).

Feedback and Usability Ascertainment

Participants in the in-person arm were contacted at 1 week and 1 month after hospital discharge, and a Feedback and Usability Survey (Methods section in the [Data Supplement](#)) was administered either via telephone or in person when they returned to UCSF for a post-procedure visit. Among participants who did not respond to the app-based survey to confirm the hospital visit, we attempted to elicit the reason(s). All participants were asked to rate the ease of use of the app, how bothersome the use of the app was, and their level of interest in continuing to use the app on a scale of 1 to 10.

Covariate Ascertainment

Demographics and medical information were self-reported by participants on the initial Health eHeart study entry questionnaire. Self-reported medical information has been found to have high accuracy within the Health eHeart study.¹¹ Self-identified race and ethnicity were combined, with Hispanic ethnicity taking precedence over race, and were categorized as white, black, Asian/Pacific Islander, Hispanic, or other. For the in-person study, race was determined from

the electronic medical record for participants who did not self-report race through the study questionnaire.

Statistical Analysis

Normally distributed continuous variables are presented as means±SD and were compared using *t*-tests, and continuous variables with skewed distributions are presented as medians and interquartile ranges and were compared using the Wilcoxon rank-sum test. Categorical variables were compared using the χ^2 test or Fisher exact test, as appropriate.

In the in-person study, we excluded participants who had a hospital stay <4 hours (*n*=3). Spearman rank correlation and a Bland–Altman plot were used to measure the correlation and agreement between smartphone-based and actual duration of hospital stay. Sensitivity was estimated using the in-person arm of the study, and positive predictive value was estimated in the remote arm of the study. Patient feedback was collected on a 10-point scale and presented as median (interquartile range). A 2-tailed *P* value <0.05 was considered statistically significant. Stata version 14 (College Station, TX) was used for statistical analyses.

Results

Among 68 individuals meeting inclusion criteria, 30 individuals were enrolled in the in-person arm of the study (Figure 1). Among those who did not consent to the study, concern for privacy was the cited reason in 4 individuals (6%). Among 24,212 participants in the Health eHeart study, the mobile application was downloaded by 3,443 remote participants residing in all 50 states with 676 potential hospital locations from 32 states detected (Figure 2). The median study duration was 260.5 days (interquartile range, 134–334), and the median duration that the application was connected was 252

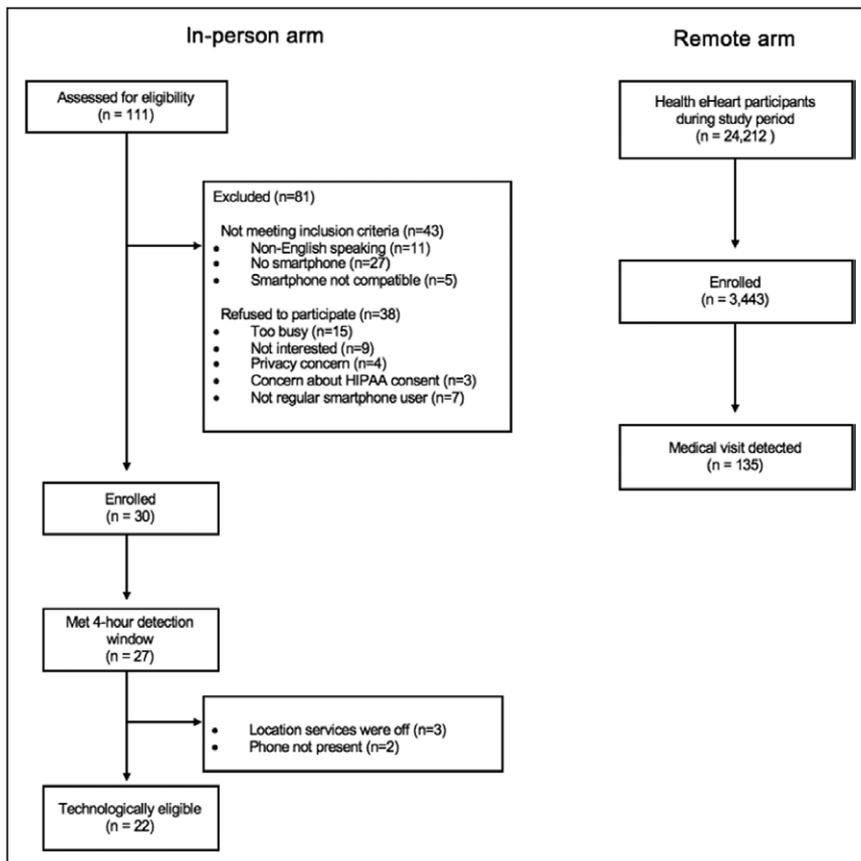


Figure 1. Enrollment and study process. HIPAA indicates Health Insurance Portability and Accountability Act.

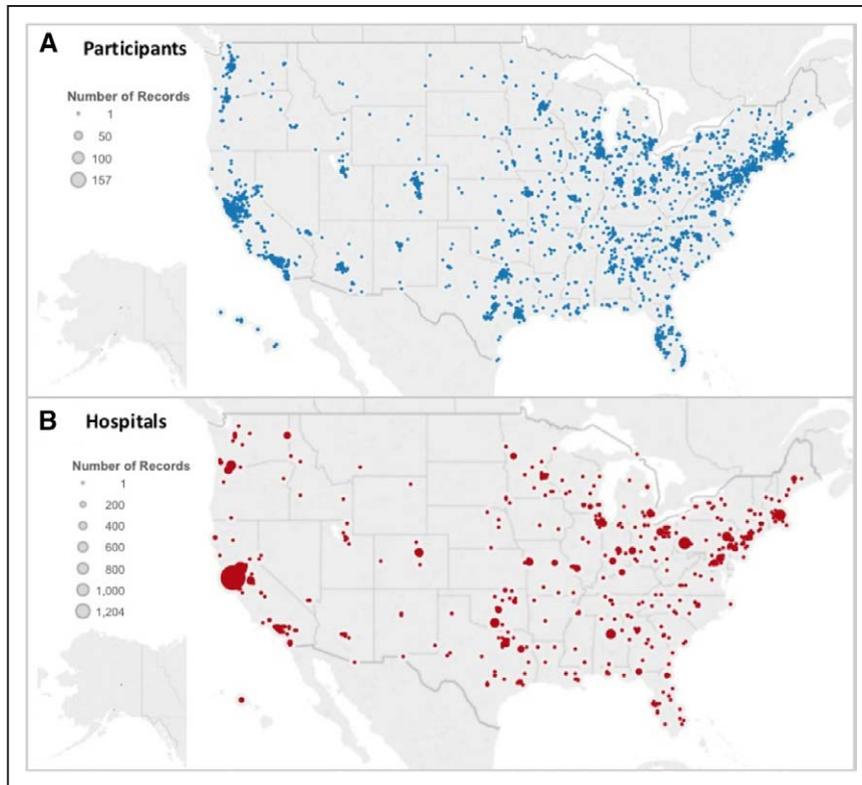


Figure 2. Geographical distribution of participants (A) and hospitals (B). Location based on zip code. The number of records represented by relative size. Created with Tableau Software (www.tableau.com) and US map provided under a CC BY-SA license from OpenStreetMap (www.openstreetmap.org/copyright). Copyright © OpenStreetMap contributors.

days (interquartile range, 134–330). Individuals in the in-person arm of the study were more likely to be male compared with those in the remote arm (Table 1). There was no evidence of differences in age, race, or smartphone type between the 2 arms of the study.

In-Person Arm—Smartphone-Based Ascertainment of Scheduled Procedures

Participants in the in-person study were predominantly male, white, and iOS users (Table 2). Of 30 participants, 27 participants had a hospitalization of at least 4 hours during the study period. Of these, a hospital visit was detected for 17 individuals. No difference was found in demographics, hospital duration, or types of procedure between participants who had a visit detected and those who did not.

Among the 22 participants who were technologically eligible to have the visit detected (Table 3), 17 visits were detected (sensitivity 77%; 95% confidence interval, 55% to 92%). Among technologically eligible participants, we did not find any differences between those whose hospitalization was detected compared with those who were not (Table I in the Data Supplement). None of these participants had another hospitalization detected by the app during the study period, yielding a positive predictive value of 100%. Of these, 15 visits (88%) were user confirmed through the smartphone app. In addition, during follow-up at 1 week, participants reported a high ease and low burden of use, and high interest in continued use of the application during both the 1-week and 1-month surveys (Table 4).

The geofencing app–reported length of stay had a moderate positive correlation with the actual hospital length (Figure 3). The mean difference in the visit duration ascertained through

the app and the actual duration was 2.6 hours (95% confidence interval, –38 to 43 hours).

Remote Arm—Remote Ascertainment of Visits for Medical Treatment

Among 3443 remote participants, >10 000 app-based questionnaires were sent to 800 unique participants asking them to confirm or deny the medical visit (Table II in the Data Supplement). Of these, 135 participants indicated through the app that they were at the hospital for medical care. These participants had 243 hospital visits at 119 different hospitals.

Table 1. Baseline Characteristics of Study Participants

Characteristic	Total n=3743	Study Arm		P Value
		In-Person Arm (n=30)	Remote Arm (n=3443)	
Mean age, y	49±14	53±16	49±14	0.10
Male sex, n (%)	1022 (30)	19 (63)	1003 (29)	<0.001
Race, n (%)				0.08
White	2726 (79)	19 (63)	2707 (80)	
Black	173 (5)	1 (3)	172 (5)	
Asian/Pacific Islander	157 (5)	2 (7)	155 (5)	
Hispanic	216 (6)	5 (17)	211 (6)	
Other	162 (5)	3 (10)	159 (5)	
Smartphone type, n (%)				0.72
iOS	2162 (65)	21 (70)	2141 (65)	
Android	1088 (33)	9 (30)	1079 (33)	

Table 2. Characteristics of In-Person Participants With and Without Hospitalization Detected

Characteristic	Total	Application-Detected Hospitalization		
		No (n=10)	Yes (n=17)	P Value
Age, median (IQR), y	51 (38–69)	42 (37–63)	58 (44–69)	0.15
Male sex, n (%)	17 (63)	5 (50)	12 (71)	0.29
Race, n (%)				0.15
White	17 (63)	4 (40)	13 (76)	
Black	1 (4)	0	1 (6)	
Asian/Pacific Islander	2 (2)	1 (10)	1 (6)	
Hispanic	4 (15)	3 (30)	1 (6)	
Other	3 (11)	2 (20)	1 (6)	
Procedure, n (%)				0.44
EP study and ablation	14 (52)	7 (70)	7 (42)	
Diagnostic EP	2 (7)	1 (10)	1 (6)	
Right heart catheterization	7 (26)	1 (10)	6 (35)	
Pacemaker or ICD	4 (15)	1 (10)	3 (18)	
Length of hospital stay, median (IQR), h	12 (6.5–27)	13 (7.9–26)	8 (6–27)	0.80
Smartphone type, n (%)				0.67
iOS	19 (70)	8 (80)	11 (65)	
Android	8 (30)	2 (20)	6 (35)	

EP indicates electrophysiology; ICD, implantable cardioverter-defibrillator; and IQR, interquartile range.

These individuals were more likely to be older, iOS users, and have a history of hypertension, atrial fibrillation, and myocardial infarction compared with those who did not have an app-detected medical visit (Table III in the [Data Supplement](#)). Among 87 participants who responded to the follow-up e-mail survey to confirm hospitalization and using that e-mail response as the reference standard, 102 out of 157 medical visits were correctly reported through the app (positive predictive value 65%; 95% confidence interval, 57%–72%; Figure 4). Among 142 medical visits indicated as true positives by participants, there were 130 medical visits where sufficient permissions and hospital forms could be obtained to receive medical records. Of these, 102 were confirmed as true positives using the documented medical record as the reference standard (positive predictive value 78%; 95% confidence interval, 70%–85%). Among 27 instances of an incorrect app-detected medical visit, the most common reason was that the participant was employed by the medical center (n=15).

Discussion

Smartphone-based geofencing for the ascertainment of hospitalizations in electrophysiology and cardiac catheterization patients exhibited moderate sensitivity for hospitalization

detection and moderate correlation with hospital length of stay. In the in-person study, participants reported a high ease and low burden of use, and high interest in continued use of the application. Among remote Health eHeart users in the United States, the app had a positive predictive value of $\approx 70\%$. Given the importance of obtaining hospital utilization data and the growing ubiquity of smartphones, this sort of technology may provide an efficient and cost-effective method to collect, share, and react to such data in real time.

As the prevalence of chronic disease increases with the aging population, there is a need for improved healthcare monitoring and more timely treatment between encounters with healthcare providers.^{12,13} The majority of Americans now use smartphones, and patients are relying more on mobile apps to regularly monitor their health.^{14,15} Smartphone devices already have the capability to nearly continuously identify a user's location in real time, and publicly available data sets enable prespecification of a myriad of location types. Push notifications via mobile apps (as was used in the current study) or automated calls or texts triggered by some activity on an app allow for customized messaging or questions in response to an app-detected condition. Our proof-of-concept study suggests that a mobile app might be used to detect healthcare encounters, but the theoretical implications extend to any location (or location type) that can be predetermined (such as grocery stores, liquor stores, gymnasiums, pharmacies, or fast food restaurants).

As a proof of concept, we focused on the feasibility of hospital-based geofencing for the detection of hospital and medical center visits. Although ascertainment of this information is critical, there is currently no optimal method to do so. Although the medical record and administrative claims are generally considered to be the most reliable sources of this information, their use is time intensive and costly. In addition, medical records may have inaccuracies and administrative data may be incomplete or delayed.⁴ Self-reported data offer

Table 3. Summary of Patient Follow-Up

Visit was not detected (n=10)	
Reason hospital visit not detected (n=10)	
Technologically ineligible, n (%)	5 (50)
Patient did not have phone/phone off	3 (30)
Location services off	2 (20)
Unknown, n (%)	5 (50)
Visit was detected (n=17)	
Response to app-based question "Were you at Medical Center today?" (n=15), n (%)	
Yes, for medical treatment	15 (100)
Yes, another reason	0
No, I was not there	0
Reason patients did not respond to question (n=2), n (%)	
I thought I did respond	1 (50)
I meant to but forgot	1 (50)

Values are n (%) and based on the Feedback and Usability Survey, which can be found in the Methods section in the [Data Supplement](#).

Table 4. Participant Feedback During Follow-Up

1-wk survey (n=27)	
Ease of use (1=difficult, 10=easy; n=24)	8.5 (8–10)
Bothersome (1=least, 10=most; n=23)	1 (1–2)
Interest in continued use (1=low, 10=high; n=27)	7 (5–10)
1-mo survey	
Interest in continued use (n=25)	7 (5–8)

Values are median (interquartile range) and based on the Feedback and Usability Survey, which can be found in the Methods section in the [Data Supplement](#).

convenience and reduced costs but suffers from recall bias, and accuracy can vary based on diagnoses, recall timeframe, and type of utilization.^{16–18}

The ability to record medical visits in real time would substantially improve this limitation. In the in-person study, we found that when hospital locations were correctly detected, almost 90% of participants correctly used the app to confirm the visit. Although the app had only moderate sensitivity for the detection of medical visits, we think this could be improved with more clear instructions to participants, particularly regarding how to set up the app to allow notifications and access to location services. As participant feedback regarding the experience was generally positive, we think that further iteration informed by ongoing feedback is likely feasible.

The positive predictive value found in the remote arm was only modest and among those who provided a reason, the most common cause for an incorrectly reported medical visit was from participants actually in the hospital but not receiving care (such as there for work). Therefore, the rationale and language of the application needs to be clear and tested carefully to improve accuracy without being unnecessarily cumbersome. A next natural step would be to include a learning algorithm, such as adjusting the time window for those who indicate they work at a given hospital (perhaps a trigger extended for localization in that hospital for >12 or 14 hours, for example). For this initial study, we selected a 4-hour threshold in an attempt to optimize detection while reducing false positives. Although global positioning system is more accurate, a combination of cell phone triangulation and global positioning systems was used to minimize battery usage. We and others will continue to work on enhancing the accuracy of the app for the detection of a hospital location and the user-confirmation system to optimize true positives.

This pilot study provides some insights into the use of smartphone-based geofencing that may be improved in the future. Furthermore, we think that this feature has potential use in multiple arenas. Early on, smartphone-based geofencing could be used as a research tool to better understand health-related behaviors or patterns. In the future, this technology might be used to offer interventions to help change these behaviors as they occur. The validation of this methodology could lead to its use in a myriad of other facilities: the geofencing of fitness centers, fast food restaurants, and grocery and liquor stores could lead to insights into patient behaviors and heart health. This could be further developed to provide real-time guidance once a location is detected. For example,

once a grocery store location is detected, participants could be sent a notification reminding them to purchase healthy foods or vegetables.

Although privacy is a concern with any app that detects and shares behavioral information, the number of individuals in the in-person arm who did not enroll because of privacy concerns was low. Additionally, many individuals are motivated to monitor their health and share the information with others for both research and health management purposes. For example, Chen et al¹⁹ found that among 67 individuals surveyed in a university setting, 77% were willing to share health-tracking data for research purposes. Importantly, the majority of individuals required assurance of privacy and viewed anonymity as important. In studies evaluating the use of telemonitoring to monitor blood pressure, blood glucose, and weight, patients found telemonitoring to be useful and cited the potential of their health providers to view the information as a motivating factor for behavior change.^{20,21} In another study of the views of 17 seniors using a monitoring device to collect and transmit activity data to providers, 16 of

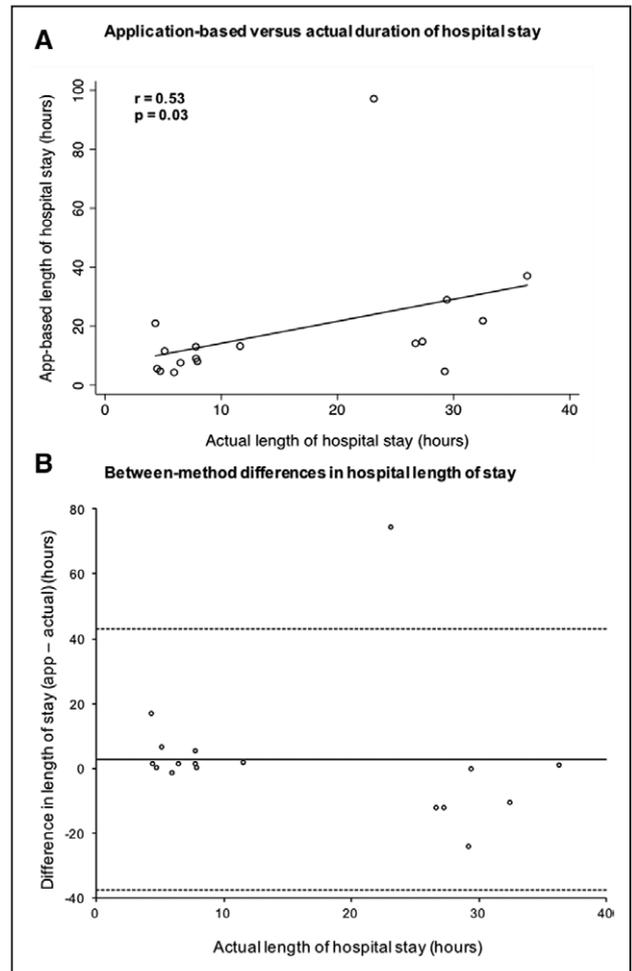


Figure 3. Comparison between application-based and actual duration of hospital stay. Actual length of hospital stay based on the electronic medical record. **A**, Correlation between 2 methods. **B**, Bland-Altman plot showing the difference between application (app)-based and actual duration of hospital stay. Solid line represents mean difference between the app-based and actual length of stay. Dashed line depicts the upper and lower bounds of the 95% confidence interval.

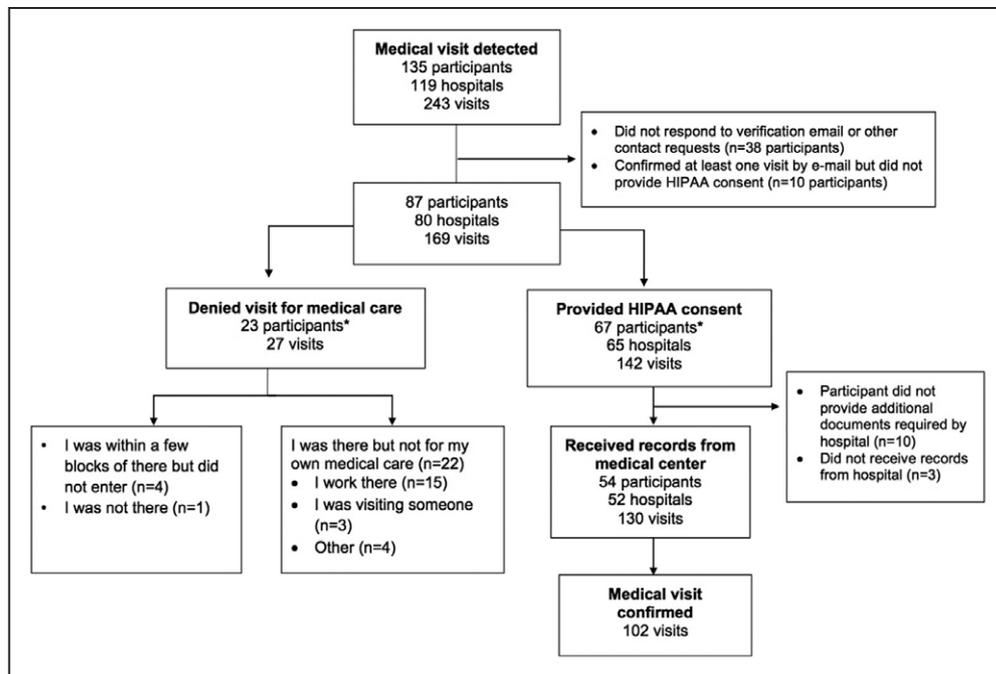


Figure 4. Accuracy of medical visits confirmed through the application in remote arm. *Three participants were included in both groups (multiple visits detected with participants verifying via e-mail at least one visit for medical care and denied at least one visit for medical care). HIPAA indicates Health Insurance Portability and Accountability Act.

the 17 participants had positive views and did not feel that it invaded their privacy.²²

However, research has also found that some individuals who consent to health monitoring may not understand how their data are being tracked or may refuse to use or continue such technology because of privacy concerns.²³ Therefore, taken together, we think that many individuals are willing to share health-related information for research purposes as long as their information is kept private and secure. For clinical purposes, although there is increasing interest in telemonitoring, it is important to ensure that patients understand what data are being tracked and how the data will be used. An important advantage of our study is that geofencing allows individuals to only transmit information about specific types of locations. Therefore, an individual may opt to record and share information on hospital visits but not on fast food restaurants, if preferred. However, in some individuals, privacy concerns may outweigh the potential benefits of the use of geofencing, which would limit the applicability of its use in these individuals.

Our study had several limitations that are important to address. Technological eligibility was based on self-report; however, when possible, this information was confirmed at the clinic visit. Hospital visit duration ascertained from the electronic medical record may not reflect total time within the geofence (such as time spent in the hospital before check-in and after discharge). Participants in the in-person arm were scheduled for elective procedures and thus may not be generalizable to other hospitalization types. Although all individuals not previously enrolled in Health eHeart who were scheduled for eligible procedures were invited to enroll in the in-person study and all Health eHeart study participants were eligible to enroll in the remote study during the study periods, those who chose to enroll may be different from those

who did not, which may affect the generalizability of our results. However, this would not affect our internal validity, specifically the accuracy of the app to detect a hospital visit within the study populations. Reasons for declining to participate were not collected from remote arm participants, and privacy concerns may hinder similar efforts using geolocation in the future. Although the medical record is commonly used as the reference standard, it may not have captured all medical visits, particularly those in which a clinician was not seen such as laboratory testing or radiology imaging. Similarly, we considered true positives in the remote arm to be a medical record-confirmed visit within 24-hour of the app-detected visit. However, it is possible that such a reference standard is not sufficiently sensitive to detect all visits. Finally, the study was not designed to determine specificities or negative predictive values (where, as an extreme example that would not be feasible, all hospitals in the United States would need to be queried daily for all participants to assure true negatives).

Conclusions

Smartphone-based geofencing may enable real-time tracking of hospitalizations. Use of the tool yielded a moderate sensitivity and a positive predictive value of 65%. Future work should focus on optimizing the accuracy of geofencing applications both in detecting hospital locations and in collecting accurate user feedback. This concept may be used to leverage the ubiquitous use of smartphones to facilitate clinical research and ultimately to help optimize patient care.

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Disclosures

Drs Moturu and Kaye are employees of Ginger.io. None of the other authors report any potential conflict of interest.

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Smartphone-Based Geofencing to Ascertain Hospitalizations

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SUPPLEMENTAL MATERIAL

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Supplemental Methods. Questionnaire language before and after change

The smartphone-based application questionnaire prior to the language change on May 2, 2014 was:

“Were you at _____ Medical Center on _____ for a medical reason?

Based on your location activity, we think you may have gone to a hospital on _____.

Have you been visiting the hospital or the emergency room for a health problem or medical procedure that you are having?

- Yes, I was
- No, I was not”

After the language change, the questionnaire was:

“Were you at X medical Center on _____?

- Yes, for medical treatment
- Yes, another reason
- No, I was not there

By understanding when you’ve been hospitalized or received care, Ginger.io can provide better insights about your health. This information may be shared with UCSF Health eHeart.”

Supplemental Methods. Ginger.io Feedback and Usability Survey

Participants who did not respond to the triggered Ginger.io hospitalization surveys:

1. Did you bring your smartphone with you during your HOSPITAL visit on DATE?
 - A. Yes
 - B. No
 - C. I don't remember
2. If "YES" or "I don't remember" in #1 → Do you remember receiving a notification on your smartphone that said "Were you at HOSPITAL for medical treatment recently?"
 - A. Yes
 - B. No
 - C. I'm not sure
3. If "YES" in #2 → The interviewer will let the participant know that no response was received by Ginger.io and will ask the participant to indicate possible reasons. A list of potential choices for the participant:
 - A. I thought I did respond
 - B. Too busy
 - C. I didn't know what it was about
 - D. I meant to, but forgot
 - E. I saw the message, but could not find it when I was ready to respond
 - F. I was unable to figure out how to respond on the smartphone
 - G. I don't carry my phone very often
 - H. Other

For ALL participants, whether a Ginger.io hospitalization survey response was received or not:

4. Is Ginger.io still downloaded and present on your smartphone now? A. Yes B. No
5. What alerts have you received? To record and confirm all instances:

6. Did you visit any other hospitals between the time you first downloaded the Ginger.io app and now? A. Yes B. No If "YES" → Places and dates:

7. How easy was it to use the mobile application to track your hospitalization? On a scale of 1- 10 (1=very difficult, 10=very easy)
8. How bothersome was using the mobile application to track your hospitalizations? On a scale of 1- 10 (1=not bothersome at all, 10=extremely annoying)
9. What is your level of interest in continuing to have this application run on your phone? On a scale of 1-10 (1=strongly prefer to turn off/delete the app, 10=extremely fascinating and awesome)

Table S1. Characteristics of “technologically eligible” participants with and without hospitalization detected in in-person arm

Characteristic	Total n=22	Application-detected hospitalization		P value
		No n=5	Yes n=17	
Age, median (IQR), y	58 (38-69)	41 (31-63)	58 (44-69)	0.26
Male sex, n (%)	13 (59%)	1 (20%)	12 (71%)	0.12
Race, n (%)				
White	16 (73%)	3 (60%)	13 (76%)	0.56
Black	1 (5%)	0	1 (6%)	
Asian/Pacific Islander	1 (5%)	0	1 (6%)	
Hispanic	2 (9%)	1 (20%)	1 (6%)	
Other	2 (9%)	1 (20%)	1 (6%)	
Procedure, n (%)				
EP study & ablation	9 (41%)	2 (40%)	7 (42%)	0.80
Diagnostic EP	2 (9%)	1 (20%)	1 (6%)	
Right heart catheterization	7 (32%)	1 (20%)	6 (35%)	
Pacemaker or ICD	4 (18%)	1 (20%)	3 (18%)	
Length of hospital stay, median (IQR), h	9 (6-27)	9 (8-13)	8 (6-27)	0.84
Smartphone type, n (%)				
iOS	15 (68%)	4 (80%)	11 (65%)	1.0
Android	7 (32%)	1 (20%)	6 (35%)	

Abbreviation: IQR, interquartile range; EP, electrophysiology; ICD, implantable cardioverter-defibrillator

Table S2. Summary of participants, hospitals, and app-based questionnaires sent with a hospital location detection

	n (%)
Total participants*	800
Total participants with response†	597 (75%)
• Medical treatment	135 (23%)
Total hospitals	676
Total hospitals with response	514 (76%)
• Medical treatment	119 (23%)
App-based questionnaires	
Total questionnaires sent	10,761
Total questionnaires with response	5,515 (51%)
• Medical treatment	243 (4.4%)
After language change	
Total questionnaires sent	9,504 (88%)
Total questionnaires with response	4,735 (50%)
• Medical treatment	202 (4%)
• Visited for another reason	3,560 (75%)
• Did not visit	973 (21%)
Before language change	
Total questionnaires sent	1,257 (12%)
Total questionnaires with response	780 (62%)
• Medical treatment	41 (5%)
• Did not visit OR visited for another reason	739 (95%)

*Unique participants with at least one hospital location detected

†Unique participants who responded to at least one app-based questionnaire to confirm or deny the medical visit

Table S3. Characteristics of “remote” arm participants with and without medical center visit detected

Characteristic	Hospitalization detected*			P value
	Total n=3,443	No n=3,308	Yes n=135	
Mean age, y	49 ± 14			
Male sex, n (%)	1,003 (29%)	953 (29%)	50 (37%)	0.001
Race, n (%)				
White	2,707 (80%)	2,595 (79%)	112 (83%)	0.82
Black	172 (5%)	166 (5%)	6 (4%)	
Asian/Pacific Islander	155 (5%)	151 (5%)	4 (3%)	
Hispanic	211 (6%)	202 (6%)	9 (7%)	
Other	159 (5%)	155 (5%)	4 (3%)	
Medical conditions				
Hypertension	1,195 (36%)	1,133 (35%)	62 (47%)	0.005
Diabetes	283 (9%)	268 (8%)	15 (11%)	0.23
High cholesterol	1,409 (42%)	1,342 (42%)	67 (51%)	0.048
Coronary artery disease	403 (12%)	368 (12%)	35 (26%)	<0.001
Atrial fibrillation	270 (8%)	250 (8%)	20 (15%)	0.002
Congestive heart failure	146 (4%)	136 (4%)	10 (8%)	0.065
Myocardial infarction	202 (6%)	185 (6%)	17 (13%)	0.001
Stroke	122 (4%)	118 (4%)	4 (3%)	0.71
Smartphone type, n (%)				
iPhone	2,141 (65%)	2,041 (65%)	100 (76%)	0.03
Android	1,079 (33%)	1,049 (33%)	30 (23%)	

*For the comparison of the indicated characteristic in participants with vs. those without a hospital location detected.