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## Brief Communications

# The case for wearable proximity devices to inform physical distancing among healthcare workers

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### ABSTRACT

**Objective:** Despite the importance of physical distancing in reducing SARS-CoV-2 transmission, this practice is challenging in healthcare. We piloted use of wearable proximity beacons among healthcare workers (HCWs) in an inpatient unit to highlight considerations for future use of trackable technologies in healthcare settings.

**Materials and Methods:** We performed a feasibility pilot study in a non-COVID adult medical unit from September 28 to October 28, 2020. HCWs wore wearable proximity beacons, and interactions defined as <6 feet for  $\geq 5$  s were recorded. Validation was performed using direct observations.

**Results:** A total of 6172 close proximity interactions were recorded, and with the removal of 2033 false-positive interactions, 4139 remained. The highest proportion of interactions occurred between 7:00 AM–9:00 AM. Direct observations of HCWs substantiated these findings.

**Discussion:** This pilot study showed that wearable beacons can be used to monitor and quantify HCW interactions in inpatient settings.

**Conclusion:** Technology can be used to track HCW physical distancing.

**Key words:** physical distancing, COVID-19, wearable proximity beacon, wearable technology

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### Lay Summary

Physical distancing, or social distancing, is important in preventing COVID-19. It is hard for healthcare workers (HCWs) to physically distance at work. We tested a device (proximity beacon) that HCWs could wear to measure their distance from each other among HCWs on a medical unit. The device measured any time HCWs were within 6 feet of each other for at least 5 s. We watched HCWs who were close to each other. The devices and our observations showed that 7:00 AM–9:00 AM was the highest risk time for not physically distancing. This study shows that wearable devices can be a tool to monitor HCWs physical distancing on a hospital unit.

## INTRODUCTION

Physically distancing  $\geq 6$  feet from others is a key strategy in reducing the transmission of SARS-CoV-2.<sup>1</sup> However, the duties healthcare workers (HCWs) must perform often require them to be in close proximity not only to patients but also to each other, for example, to exchange confidential information or to perform patient care tasks.<sup>2</sup> Physical distancing lapses contribute to COVID-19 clusters and outbreaks among HCWs.<sup>3,4</sup> Monitoring the frequency that HCWs are in close proximity is essential to understand transmission risk and to inform approaches to improve physical distancing. However, little quantitative information is available to understand HCW physical distancing.

During the COVID-19 pandemic, location monitoring has provided insights into societal-level physical distancing.<sup>5,6</sup> For example, smartphone data have been used to show physical distancing across a region.<sup>5–7</sup> Digital proximity apps on smartphones have been used to enhance contact tracing<sup>8–10</sup> but are insufficiently precise.<sup>11</sup> Wearable proximity beacons (referred to as “beacons”) may hold promise, but studies examining these in healthcare have been limited to modeling contact tracing, and occurred prior to the COVID-19 pandemic.<sup>11–16</sup>

### Objectives

In this study, we piloted use of beacons among HCWs in an inpatient unit during the COVID-19 pandemic to highlight considerations for future use of trackable technologies in healthcare.

## MATERIALS AND METHODS

### Setting and participants

We deployed beacons on an inpatient, non-COVID, 24-bed medical unit in a tertiary care academic medical center from September 28, 2020 to October 28, 2020. The unit was staffed by internal medicine nurses, resident physicians, and attending physicians. Per hospital policy, HCWs were instructed to stay 6 feet apart from other HCWs and to wear surgical masks at all times, with face shields for patient interactions. Room occupancy signage and floor decals indicating where HCWs should stand to maintain distance were present.

Eligible HCWs included resident and attending physicians, nurses, unit managers, physical therapists, clinical services representatives, nutritionists, and unit associates based on the participating unit. HCWs were recruited through emails, flyers, and staff meeting presentations. Beacons were used from September 28, 2020 to October 28, 2020. The pilot occurred during day shifts (7:00 AM–7:00 PM). Data collection was anonymous. The study was considered non-human subjects research by the Johns Hopkins Institutional Review Board.

### Description of wearable proximity beacons

Beacons (Estimote Technologies; Krakow, Poland; [Figure 1](#)) each weighed 2.5 oz., measured  $2.5 \times 2 \times 0.5$  inches, and were available on lanyards. Beacons contained multiple sensors: (1) an Inertial Measurement Unit (IMU) with a Machine Learning engine, (2) radio technologies including Bluetooth Low Energy (BLE) operating at 2.4 GHz, (3) an Ultra Wide Band (UWB) operating at 6 bands with center frequencies from 3.5 to 6.5 GHz, and (4) cellular connectivity over Long-Term Evolution for Machines (LTE-M) operating at multiple bands in MHz range.

The wearable proximity beacons exchanged preliminary data over BLE. When 2 beacons were in close proximity, UWB technology leveraging Time of Flight established interbeacon distance. These data were securely transferred over LTE-M and stored simultaneously in graph and relational databases leveraging AES-256 encryption algorithms. We adjusted the sensitivity and output of beacons during the study using a JavaScript program and real-time deployment of microapps to the beacons using an Integrated Development Environment (IDE). The microapp Application Programming Interface provided access to sensors, I/O elements, and radios.

We cleaned the data based on experiences trialing the beacons on the unit prior to implementation. Received Signal Strength Indicator (RSSI) signals were used to determine the presence of physical barriers in spaces, in order to reduce false positives resulting from individuals  $< 6$  feet apart, but not within shared air-space (eg, leaning against either side of a wall). RSSI signals between 2 beacons were measured in the presence and absence of barriers (eg, walls, doors) in the unit. RSSI signals below the average threshold of these measurements (ie, a barrier) were removed from the dataset. The human body also impeded some interaction signals (eg, beacon-wearers facing opposite directions) and was likely an occasional source of missed interactions. Finally, if devices were left unplugged at charging stations, sensors remained on and false interactions could have been recorded. Therefore, all interactions for which  $\geq 95\%$  of interaction time was spent at distances  $< 2$  feet were removed, as were interactions of  $> 2$  h.

### Implementation

We presented information about the pilot at unit huddles and resident physician meetings and via emails and flyers. As HCWs were concerned about the size and weight of the beacons, we encouraged HCWs to handle the beacons during these meetings. We worked with the unit manager and nurse and resident physician champions to encourage HCWs to wear beacons. Wearable proximity beacons were placed in common staff areas. HCWs selected a beacon at the start of their shift from a charging station. When operating at high accuracy, beacon batteries lasted  $< 24$  h, so HCWs plugged wearable proximity beacons into a charging station at the end of a shift. As HCWs sometimes did not charge beacons, visual (light) and audi-



**Figure 1.** Wearable proximity beacon worn by study participant HCWs. HCWs: healthcare workers.

tory (beep) device functionalities were implemented to indicate 15% and 10% battery life, respectively. Of note, similar functionalities could be used to provide feedback to users who were in close proximity; these functions were not activated.

### Analysis of interactions

Beacons were programmed to begin tracking an interaction when 2 beacons were <6 feet apart. Once an interaction had lasted  $\geq 5$  s, distance and duration began recording. Interactions ended when the 2 interacting beacons were  $\geq 6$  feet for  $\geq 15$  s. For example, if 2 individuals were interacting 4 feet apart for 1 min, and then separated to 7 feet for 10 s before returning to 5 feet, a single interaction would be logged (1 min at 4 feet and 5 feet for the remaining time).

### Validation of beacons

To validate distance between beacons, research team members and unit champions used visual feedback functionality when wearing beacons, validating visual feedback with a tape measurer. Beacons activated at 71 inches. To validate time data from the beacons, we performed direct observations.<sup>17</sup> An observation form was designed based on the unit map of common areas including nurses stations, breakrooms, and workrooms. Patient rooms were excluded because the focus of the work was not on HCW-patient distancing.

Observations were performed by 1 of 3 observers (PO, SCK, ACS-S) from July 29, 2020 to October 1, 2020. Each observation lasted 30–60 min. During each observation, every 5 min, observers recorded the numbers and types of HCWs in their visual field, even if the HCWs were only seen for a few seconds. To better model HCW experiences, the timing and location of observations were enriched for the likelihood of HCWs working in locations and times when HCW density was highest (eg, the nursing report room during shift change). We were therefore able to qualitatively compare beacon and observation data during times where more interactions were likely.

### Data analysis

Descriptive statistics were used to describe data from the beacons and observations. Validation occurred by comparing beacon data

{normalized to the number of potential interactions; ie  $(\#beacons \times [\#beacons - 1]) / 2$ } to observations. All data analyses were performed using R Project for Statistical Computing with standard and ggplot2 libraries.

## RESULTS

During the 31-day pilot study, 6172 interactions were recorded. We removed 2033 interactions where  $\geq 95\%$  of the interaction was at <2 feet, leaving 4139 interactions. The mean daily participation was 6.52 HCWs of a possible 14 nurses and resident physicians daily (standard deviation [SD]: 5.39; [Supplementary Appendix S1](#)). The mean interaction distance was 4.36 feet (SD 1.16), although most interactions (85.3%) were 3–6 feet ([Figure 2A](#)). Interactions were more frequent between 7:00 AM–9:00 AM, corresponding to shift change and morning rounds ([Figure 2B](#)). The majority of interactions were both of short duration and 3–6 feet ([Supplementary Appendix S2](#)).

We observed a mean interaction duration of 54.0 s (112.5 SD, [Figure 3A](#)). Most interactions (63.7%) lasted <30 s; these brief interactions were especially common 7:00 AM–9:00 AM, again during the unit's typical report, sign-out, and morning rounds ([Figure 3B](#)). However, fewer observations occurred in the afternoon.

### Observation data

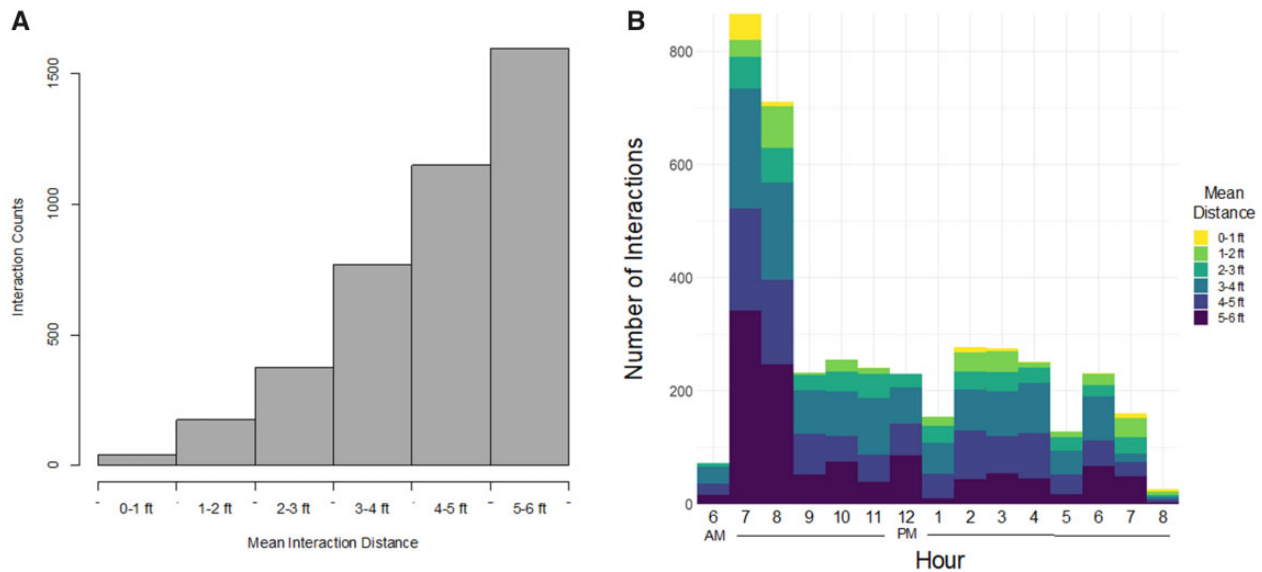
We observed the unit for 25 h on weekdays 7:00 AM–7:30 PM ([Supplementary Appendix S3](#)). Interactions were frequently observed 7:00 AM–9:00 AM, similar to data from the beacons.

## DISCUSSION

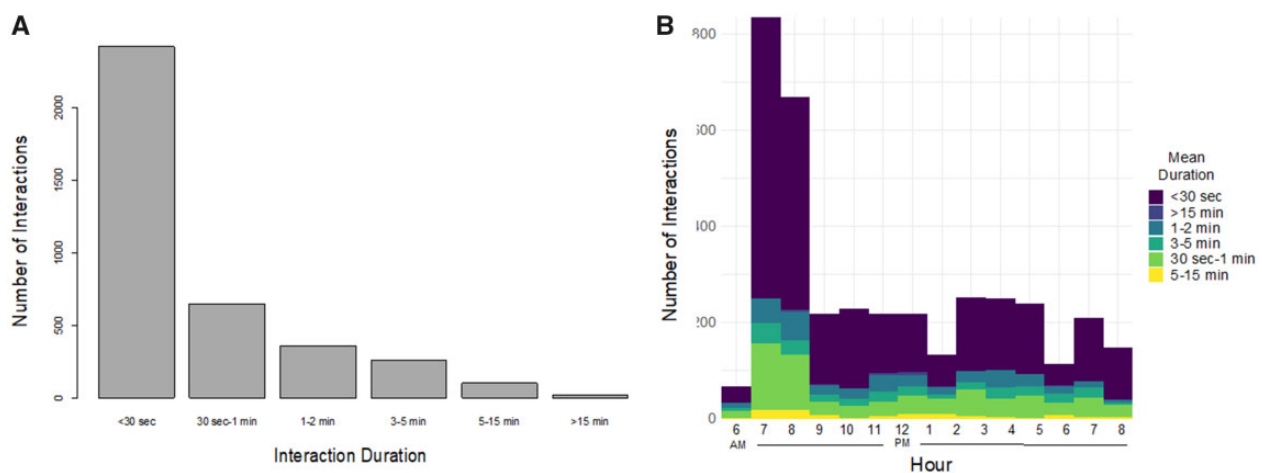
We found that beacon use was a feasible method to document physical distancing among HCWs in a hospital unit. Common times for HCWs to be closely gathered were during structured patient care communications (report and rounds); confidentially communicating patient information while physically distancing is difficult.<sup>17</sup> Strategies to improve physical distancing should focus on these activities. HCWs physically distanced during afternoons including common mealtimes. Staggered mealtimes implemented to promote physical distancing during meals may have impacted physical distancing, and HCWs could leave the unit during meals. When HCWs were <6 feet of each other, they were typically 3–6 feet from each other, which likely confers a lower risk of transmission.

Importantly, our observational data validated beacon interaction data. Times when frequent interactions were observed correlated with times when frequent interactions were noted with beacon data. Prior studies validated data from sensors primarily with participant-initiated surveys, social links, or diaries. However, compliance with participant-initiated validation activities in these prior studies was low.<sup>18,19</sup> Validation with direct observation is likely more accurate.

Front-line HCW involvement was essential in beacon implementation. HCW concerns about the size of the beacons were mitigated by having HCWs handle the beacons during unit huddles. We provided lanyards for beacon wearing, but as HCWs were concerned that the beacons could interfere with patient care, some HCWs instead wore them on their backs, used badge clips, or placed them in pockets. HCWs have expressed concerns about their privacy,<sup>20,21</sup> thus, we did not link beacons to individual HCWs, although these data could facilitate outbreak investigations. Beacons may be partic-



**Figure 2.** Interaction frequency at different distances <6 feet. (A) Frequency of interactions between 2 HCWs using wearable proximity beacons at different distances <6 feet. (B) Interactions logged per hour of a shift. Colors indicate mean distance of the interactions logged. HCWs: healthcare workers.



**Figure 3.** Interaction duration at distances <6 feet. (A) Distribution of mean interaction durations logged between 2 HCWs using wearable proximity devices. (B) Interactions logged per hour of a shift. Colors indicate mean duration of the interactions logged. HCWs: healthcare workers.

ularly useful for contact tracing as the data provided preserve temporal and structural information.<sup>12-15</sup>

Our study was innovative in its use of wearable proximity devices during a time when physical distancing among HCWs was emphasized. We remotely monitored and augmented the onboard software to smoothly roll out the technology. We worked closely with the unit to implement the study. We validated our findings with direct observations and found it was accurate at distinguishing distance between beacons, as well as identifying when interactions were likely to occur (eg, times of day).

There were several limitations to the study. The validation process was imperfect as the study focused on day-shift and did not capture night-shift experiences. Implementation of the beacons requires HCW involvement and can be costly. Therefore, HCWs not primarily assigned to the unit were not asked to wear beacons, but would have been observed in the direct observations. In addition, beacon uptake by HCWs was incomplete, which impacted the number of interactions captured. We reached out through unit meetings to increase participation, and

unit leadership including HCW champions further encouraged participation,<sup>22-25</sup> but over time fewer HCWs wore beacons, possibly due to fatigue with COVID-related restrictions. Those seeking to implement the beacons should encourage sustainability, perhaps through staff engagement through contests or recognition. In addition, some close proximity events were likely missed if >1 HCW was not wearing a beacon. It is unclear what proportion of HCWs must be wearing beacons for an acceptable level of reliability, and this could be an area of future research. As more specific, dense data were needed to preserve temporal and structural information,<sup>13</sup> battery life lasted <24 h, and HCWs needed to charge the beacons after shifts. Others using this technology may consider optimization of settings to achieve longer battery life.

## CONCLUSIONS

Deployment of beacons on an adult inpatient non-COVID medical unit is feasible and valid. This technology could be applied within healthcare settings to monitor physical distancing to reduce the like-

likelihood of pathogen transmission, or to monitor the effectiveness of physical distancing mitigations. Managers could use beacon data to target interventions to times or locations where physical distancing is challenging. Feedback from beacons could be used to remind HCWs when they are standing in close proximity. Further research should be performed to measure methods of ensuring beacon use sustainability. Those considering deployment of beacons should consider specific HCW task requirements, potential false-positive interactions, the balance between data depth and battery life, participant privacy, and participant engagement.

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## AUTHOR CONTRIBUTIONS

SCK, ABS, OO-S, SEC, RL-C, PO, APG, RJ, KKZ, KMB, KVB, CR, and ACS-S designed the work. SCK, ABS, OO-S, RL-C, PO, and ACS-S acquired data for the work. SCK, PO, RJ, KKZ, KMB, KVB, and BV-P analyzed data for the work. SCK, ABS, OO-S, SEC, PO, APG, CR, ACS-S, and BV-P interpreted data for the work. SCK and BVP wrote the manuscript. All authors revised the manuscript critically for important intellectual content, approve of the final version to be published, and agree to be accountable for all aspects of the work.

## SUPPLEMENTARY MATERIAL

[Supplementary material](#) is available at *JAMIA Open* online.

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## CONFLICT OF INTEREST STATEMENT

None declared.

## DATA AVAILABILITY

The data underlying this article will be shared on reasonable request to the corresponding author.

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