CLINICAL RESEARCH STUDY

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Estimating Time Physicians and Other Health Care Workers Spend with Patients in an Intensive Care Unit Using a Sensor Network

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ABSTRACT

BACKGROUND: Time and motion studies have been used to investigate how much time various health care professionals spend with patients as opposed to performing other tasks. However, the majority of such studies are done in outpatient settings, and rely on surveys (which are subject to recall bias) or human observers (which are subject to observation bias). Our goal was to accurately measure the time physicians, nurses, and critical support staff in a medical intensive care unit spend in direct patient contact, using a novel method that does not rely on self-report or human observers.

METHODS: We used a network of stationary and wearable mote-based sensors to electronically record location and contacts among health care workers and patients under their care in a 20-bed intensive care unit for a 10-day period covering both day and night shifts. Location and contact data were used to classify the type of task being performed by health care workers.

RESULTS: For physicians, 14.73% (17.96%) of their time in the unit during the day shift (night shift) was spent in patient rooms, compared with 40.63% (30.09%) spent in the physician work room; the remaining 44.64% (51.95%) of their time was spent elsewhere. For nurses, 32.97% (32.85%) of their time on unit was spent in patient rooms, with an additional 11.34% (11.79%) spent just outside patient rooms. They spent 11.58% (13.16%) of their time at the nurses' station and 23.89% (24.34%) elsewhere in the unit. From a patient's perspective, we found that care times, defined as time with at least one health care worker of a designated type in their intensive care unit room, were distributed as follows: 13.11% (9.90%) with physicians, 86.14% (88.15%) with nurses, and 8.14% (7.52%) with critical support staff (eg, respiratory therapists, pharmacists).

CONCLUSIONS: Physicians, nurses, and critical support staff spend very little of their time in direct patient contact in an intensive care unit setting, similar to reported observations in both outpatient and inpatient settings. Not surprisingly, nurses spend far more time with patients than physicians. Additionally, physicians spend more than twice as much time in the physician work room (where electronic medical record review and documentation occurs) than the time they spend with all of their patients combined.

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INTRODUCTION

Much attention has been paid to how many hours physicians work during a shift, with special attention to physicians in training.[1-3] In comparison, much less is known about how health care worker time is allocated to various tasks, including, more specifically, how much time physicians and other health care providers actually spend with the patients under their care. Furthermore, most existing studies measuring time spent with patients focus on ambulatory or emergency department settings,[4,5] or with physicians working in general hospital units,[6] as opposed to physicians caring for patients in intensive care settings. These settings are different, especially given the increased severity of illness of patients and the greater availability of more specialized nursing care for patients in intensive care settings.

CLINICAL SIGNIFICANCE

- Sensor networks can be used to measure contact time between health care professionals and patients under their care in the intensive care unit setting.
- Physicians and nurses spend a minority of their time on an intensive care unit in direct patient contact, but nurses spend far more time than physicians.
- Physicians spent more than twice as much time in a work room, where review of records and documentation occurs, than with all of their patients combined.

To date, studies exploring the allocation of physician time have used time-motion analysis or self-reported surveys. However, each of these approaches has limitations. Traditional time-motion analyses require a human observer recording and characterizing activities over a period of time. Such approaches are costly, time consuming,[7] capture only limited time frames, and are subject to both sampling bias and the Hawthorne effect. On the other hand, self-reported activity logs are subject to recall bias, as physicians tend to overestimate the amount of time they spend with patients.[4] Thus, there is a need for new approaches to more accurately and completely measure interactions between health care providers and patients, as well as, by extension, between different types of health care professionals. The goal of this study was to accurately and precisely measure the amount of time that physicians, nurses, and critical support personnel spend with patients (as well as with each other) using a fine-grained automated measurement approach.

To measure these contacts, we used an electronic system of our own design based on wearable sensor mote technology to accurately measure and record proximity among health care providers and the patients under their care. Temporally fine-grained (on the order of seconds) proximity data collected in a 20-bed intensive care unit over a 10-day period (both day and night shifts) were used to estimate the precise location of each badged health care provider within our medical intensive care unit (MICU).

METHODS

Data

We deployed a wireless sensor network consisting of small radio sensors (or "motes") to measure interactions among health care workers and patients.[8] These data were collected as part of a process-improvement project that included monitoring hand-hygiene behavior. Because we did not collect any personal identifiers of patients or health care workers, this work was deemed non-human-subjects research by the institutional review board of the University of Iowa.

The sensor network monitored the location and activity of health care providers using 2 types of motes: badges and beacons. Wearable "badges" were distributed to health care providers at the beginning of each shift and were collected at the end of each shift. Stationary "beacons" were placed inside all 20 patient rooms in the MICU of the University of Iowa Hospital and Clinics, as well as outside rooms (eg, in hallways and at nurses' stations) throughout the unit.

Motes consist of a small processor with flash memory and an Institute of Electrical and Electronics Engineers 802.15.4-compliant wireless radio. We programmed the motes to broadcast every 7-12 seconds over an unused portion of the Wi-Fi spectrum that did not interfere with any medical equipment. Each mote receiving the broadcast recorded the identity of the originating mote, the received signal strength indicator associated with the broadcast message (a proxy for distance, because signal strength attenuates with distance), and the time that the message was received.[8]

We assigned badges to health care providers in accordance with their job types: 1) physicians, including staff physicians, fellows, and residents; 2) nurses, including MICU nurses, nurse assistants, and nurse managers; and 3) critical care support, including clerks, pharmacists, and respiratory therapists. Badges were assigned randomly to health care professionals within each job type, ensuring that individuals could not be identified. In practice, at the beginning of each shift, health care professionals picked a badge belonging to their job type from a basket. Thus, all badged health care professionals knew that their locations were being tracked. However, because of the anonymity protection constraint, specific health care providers could only be tracked within, and not across, different shifts.

Analysis

The data recorded by this network of motes allowed us to locate providers in the unit with a high degree of spatial and temporal resolution. We estimated location using the log-normal attenuation model of Patwari et al.[9,10] Using the data from 10 consecutive days and nights, we estimated and recorded the location of all health care providers wearing a badge. Note, in addition to recording data for tracking locations within our MICU, these badges recorded hand-hygiene

Figure 1 Floor plan of the medical intensive care unit displaying the placement of the stationary sensors and the worker and patient areas. Note that the work areas consist of nurse stations and physician workrooms. Any noninstrumented areas of the unit in this figure did not consist of areas where patients were cared for.

activity but did not record any other behaviors, and we did not attempt to gather any additional data from other methods (eg, surveys about health care provisional activity, actions, or behaviors).

Locations were then further classified by type, that is, "patient room," "patient ward" (area or hallway outside patient rooms: see **Figure 1**), "nurses' station," "physician workroom," and "other." For nurses, we further refined "patient ward" as either "area directly outside the patient room" or "pod hallway outside the patient room." The floor plan of our MICU, as well as the placement of the beacons and the classification of the spaces in the unit, is shown in **Figure 1**.

We calculated the percentage of time each health care worker spent in each location. In addition, we calculated what percentage of time each type of health care worker spent with every other type of health care worker (eg, physician with physician, physician with nurse). Also, to express the time spent with health care workers from a patient perspective, we calculated the percentage and duration of time that patients spent with different types of health care workers. Finally, we built a contact network of different types of health care workers. All analyses were performed for both day and night shifts.

RESULTS

Health care provider shifts are 12 hours long in the MICU. Data were collected for the full 12-hour shift for each health care provider. During our period of study, the bed occupancy was 78.6%. In total, 64 patients stayed in the MICU during this period. No patient stayed in the unit for the entire 10 days of the study period. Note, there were 13 patients in the MICU when the period began and 18 when it ended (they were excluded from the length-of-stay calculation). Every bed became occupied or was released at least once during the 10 days. For the 33 patients who arrived and left during the period, the average length of stay was 4.03 "shifts." However, the median length of stay was 3 shifts. **Table 1** shows the distribution of time spent in various areas during the day shift (night shift) for the different types of health care professionals. During the day shift (night shift), physicians spent 13.73%

Table 1 Distribution of Time Spent by Health Care Professionals during Day and Night Shifts

		Percent of Time	
JobType	Activity	Day	Night
Physician	Patient room (not rounding)	9.26%	12.67%
	Patient room (rounding)	4.47%	5.29%
	Patient ward	19.91%	12.84%
	Nurses' station	12.53%	10.76%
	Physicians' workroom	40.63%	30.09%
	Other	13.19%	28.36%
Nurse	Patient room	32.97%	32.85%
	Directly outside patient rooms	11.34%	11.79%
	Outside patient room in a pod hallway	23.89%	24.34%
	Nurses' station	11.58%	13.16%
	Physicians' workroom	2.06%	0.86%
	Other	18.16%	17.00%
Critical support	Patient room	20.48%	21.89%
	Patient ward	17.51%	11.58%
	Nurses' station	11.44%	7.54%
	Physicians' workroom	13.36%	2.62%
	Other	37.21%	56.37%

(17.96%) of their time in patient rooms and 40.63% (30.09%) of their time in the physician work room. The remaining 45.63% (51.95%) of their time was spent elsewhere on the unit (eg, nurses' station, hallway). In contrast, nurses spent 32.97% (32.85%) of their time in patient rooms and an additional 11.34% (11.79%) of their time directly outside the patient rooms. They spent 11.58% (13.16%) of their time at the nurses' station, 23.89% (24.34%) of their time near but not directly outside the patient's room, and the remaining 20.22% (17.86%) elsewhere on the unit.

Most health care workers' visits to patient rooms were brief. On average, visits lasted 72 seconds, with a median duration of 32 seconds; only 10% were longer than 88 seconds. Visit times were skewed; only 32% of the visits lasted 1 minute or more, with only 0.2% lasting more than 15 minutes. These statistics remain similar when differentiating by job type; the average duration of a visit is 73.5 seconds for doctors, 71.2 seconds for nurses, and 72 seconds for critical care personnel. Similarly, the proportion of the visits lasting for more than 1 minute is 31.3% for doctors, 32.2% for nurses, and 33.5% for critical care personnel.

In **Table 2**, we show the proportion of time spent by each type of health care professional with both health care professionals of the same type (ie, physicians with other physicians) as well as with health care professionals of other types (eg, physicians with nurses). Note that during the day shift, physicians spent the majority of their time with other physicians; the same is true for nurses. The same is generally true for the night shift, except that the reduced number of physicians present tend to spend slightly more time alone. Note also that, during the night shift, all health care professionals spend the majority of their time alone.

Table 3 shows these data from the patient's perspective. We define "care time" to be the percentage of time a patient has at least one health care provider of a given type in their ICU room. Care time during the day shift (night shift) was distributed as follows: 13.11% (9.90%) with physicians, 86.14% (88.15%) with nurses, and 8.14% (7.52%) with critical support personnel. Note that the vast majority of care time (93.11% day, 94.61% night) is attributable to a single health care provider in the room. In addition, **Table 3** shows the mean number of minutes spent by the health care professionals considered both during day and night.

Table 2 Proportion of Time Spent by Health Care Professional with Other Health Care Professionals

Job Type	Activity	Day	Night
Nurse	With nurses	40.39%	41.56%
	With physicians	11.95%	5.43%
	With critical support	5.67%	3.48%
	With any of the above*	49.16%	45.92%
Physician	With nurses	33.44%	21.57%
	With physicians	63.27%	26.43%
	With critical support	16.13%	3.37%
	With any of the above*	78.63%	42.79%
Critical support	With nurses	31.62%	24.54%
	With physicians	25.92%	5.81%
	With critical support	11.15%	4.78%
	With any of the above *	51.43%	32.73%

*Refers to the proportion of time spent with any of the classes of health care professionals.

Table 3 Percentage of Patient Time Spent with Health Care Professionals (Patient Perspective)

At Any Moment of Time a Patient is Receiving Care. . .

During the day time	Percent of Time	Time in Minutes (Mean)
Spent with physicians	13.11%	28.9
Spent with nurses	86.14%	189.8
Spent with critical support personnel	8.14%	17.9
Spent with exactly one health care professional	93.11%	205.1
During the night		
Spent with physicians	9.90%	20.5
Spent with nurses	88.15%	182.8
Spent with critical support personnel	7.52%	15.6
Spent with exactly one health care professional	94.61%	196.2

From a patient perspective, visit times were longer, because of overlapping visits from different health care professionals or rotating visits (when one health care professional leaves and another enters shortly after). Patients received uninterrupted visits lasting an average of 105.4 seconds, with a median of 32 seconds, with only 10% of these times lasting more than 3 minutes. Most of the visits included only one health care professional, because patients were seen continuously by only one health care professional for the most part (86.3%). Patients were seen by 2 health care professionals 10.5% of the time and 2.2% by 3. However, outlier visits did exist. For example, we observed a patient who was seen continuously for about 10 hours, involving 28 different health care professionals.

Figure 2 shows the social network of the MICU for a representative day and night shift, respectively (recall that, due to privacy concerns, we can track individual health care workers only within, and not across, shifts). Nurses are represented by green dots, physicians are blue dots, and gold dots are critical care staff. The strength of the connection (the number of times that a given pair of health care workers were co-located) is represented by the width of the line. During the day shift (**Figure 2**), there appear to be strong connections between critical care support personnel and physicians. The connections between critical care staff and nurses as well as physicians and nurses were noted to be less strong. There were less strong connections at night (**Figure 2**), but they were more equally distributed among critical care staff, nurses, and physicians.

DISCUSSION

Our results demonstrate that physicians, nurses, and critical care support personnel working in a MICU spend only a mi-

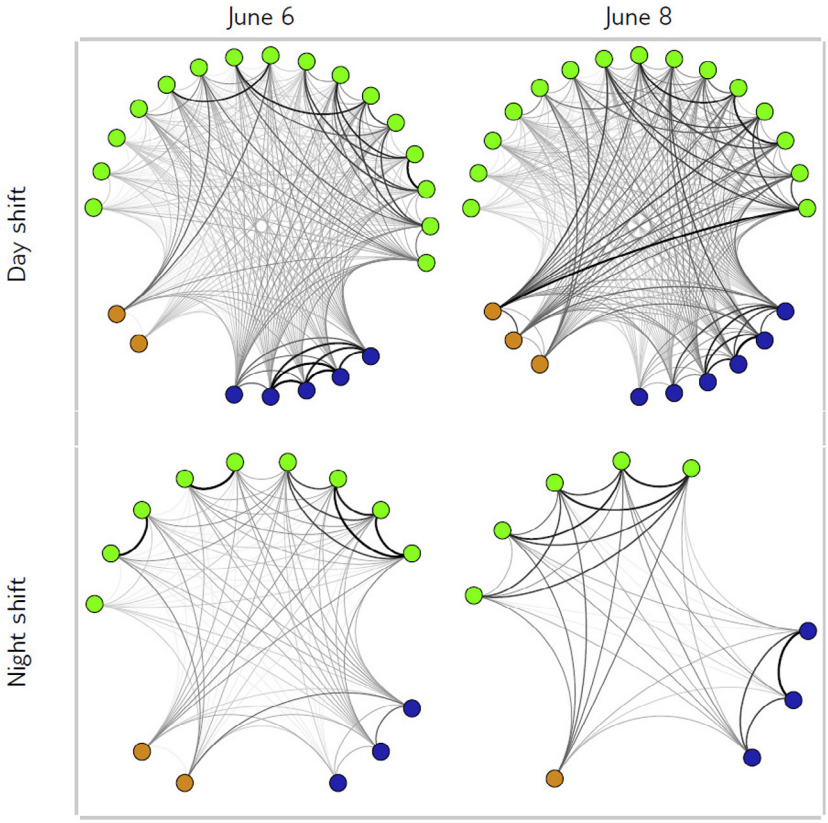

Figure 2 Visualization of the contact networks among health care workers. Health care worker job type is represented by node color, namely: nurses are green, physicians are blue, and critical care personnel are brown. Darker and thicker links indicate greater interaction among workers. This figure makes it clear that physicians primarily are co-located with other physicians and that nurses are co-located with other nurses. This contact network highlights the limited opportunities that nurses and physicians are in close proximity across the course of a day.

nority of their time in direct contact with patients. On average, of time spent on the unit, physicians spend only 13% of their time with patients; in contrast, they spend nearly 3 times as much time in the physician work room. Not surprisingly, nurses spent far more time with patients than physicians. Overall, we found that nurses spend almost half of their time in close proximity to patients, either in their rooms or at a nursing desk immediately outside a patient room. Interestingly, physicians and nurses rarely spend time together in the patient room.

While previous studies in outpatient and inpatient settings have shown that physicians spend only a minority of their time in direct contact with patients, little is known about the time spent by physicians in direct contact with patients in a critical care setting. In outpatient settings, estimates of direct patient care range from 31% in emergency departments to 55% in outpatient clinics.[4,5] For physicians working as hospitalists on general wards, time spent with patients also varies greatly, ranging from 18% to 34%.[11] However, patients hospitalized in intensive care settings are considerably different from patients in other health care settings and thus, the care they require is fundamentally different. In the ICU, critically ill patients are cared for by a team of health professionals. Physicians must quickly aggregate and communicate a large amount of clinical information obtained from a wide range of sources, including electronic medical records (EMRs). This information is often then integrated into team-based decision-making.[12] Team-based approaches to care may lead to decreased time spent in direct contact with patients, especially if data gathering is done by a smaller group of health care professionals. Yet, our study showed that physicians, at least during the day, spend the majority of their time with other physicians.

The hospital EMR might also help explain why physicians spend so little time with patients relative to time spent in the physician work room. Currently, the full impact of EMRs on patient care has yet to be fully understood. For example, a recent review of the impact of EMRs on time spent charting highlighted different findings across several different studies, with some studies showing more time spent on documentation and others showing no difference, and some showing a decrease in time spent with documentation.[7] However, if time dedicated to documentation increases, time spent with patients and other activities must necessarily

decrease. And while our study was not originally designed to investigate the impact of EMR system use, we were able to document that physicians spent a large proportion of their time in the work room where they go to access our hospital's EMR.

The amount of time that intensive care physicians spend with patients is important for a number of reasons. First, time spent with patients has implications for physician and patient satisfaction. In general, physicians are happier when they spend more time with their patients,[13] and allowing adequate time for physician–patient interaction is associated with higher physician job satisfaction.[14] In contrast, more time spent on administrative tasks has been independently associated with lower job satisfaction.[15] Moreover, patients and their families value time with their physicians, and this time is likely related to patient satisfaction.[16]

Of course, the ICU is a unique environment where patients experience significant illness, and mortality rates are significantly higher than in other patient care settings. In these settings, the relationship between physicians and patients under their care is more transient and often involves surrogate decision-makers when patients are unable to communicate. Critical decisions must often be made prior to developing a relationship with the patient.[17] Thus, it is important to identify factors that may interfere with the amount of time that physicians can spend with patients and their families. In addition, given the limited time that physicians spend with patients, it is important to ensure that barriers to communication between nurses and physicians are minimized. From a patient perspective, 86% of the time spent with any health care professional in their room was with a nurse. Yet we documented only relatively sparse interactions between physicians and nurses; indeed, we found that nurses spend just 2% of their time in the physician's work room, thus limiting opportunities for interaction between physicians and nurses.

The complex nature of the care team was also captured by our sensor network. Our sensors allowed us to not only measure the time that different types of health care professionals spent with their patients, but also the proportion of time spent with other clinical team members. We believe that some of the interaction patterns observed among health care professionals may be constrained by the layout and design of the unit. For example, the greater number of contacts among health care professionals of the same type (eg, within groups of physicians) may be influenced by the segregated work and documentation areas. Similarly, the relatively high proportion of time that nurses spend near their patients may well be due, in part, to the presence of charting areas located just outside the patient rooms. In fact, we measured that nurses spend an average of 33% of time directly in patient rooms and 11% in the observation desks immediately outside the patient rooms where nursing documentation can be performed. We posit that time nurses spend near their patients would substantially decrease if our unit had documentation stations farther from the patients under their care. The data we collect could also be used to help make ICUs more efficient by moving equipment or engineering the environment to help reduce the amount of time that health care professionals need to retrace their steps or travel between different places to gather supplies or information.

Our process of measurement may have affected health care professional behavior. For example, all health care professionals wearing the badges knew that they were being observed, and this might have changed their behavior (eg, the Hawthorne effect). However, we do not think that our monitoring caused health care professionals to change their behavior and spend less time with patients under their care. For example, the health care professionals were aware that, in addition to tracking their location, we were also tracking their adherence to hand-hygiene recommendations on entering and leaving patient rooms. Nevertheless, the effect of our monitoring on hand-hygiene behavior seemed to be modest. In contrast to the effect of the monitoring technology, the presence of other health care professionals did affect hand-hygiene behavior.[10]

There are several limitations to our study. First, we report the results of experiences at a single academic center and our findings might not be generalizable to other settings. However, the approach we used is not subject to recall or sampling bias: our sensor motes operated day and night as well as on weekends. Second, we used time spent in patient rooms to estimate time spent on direct patient care. Indeed, the sensors we deployed did not allow us to determine precisely what health care workers were actually doing while in a patient room or at any other location. Third, the quantity of time spent in direct patient care may not necessarily correlate with quality of care or satisfaction in the unit. For example, a patient that is sedated may not benefit from a physician's extended physical presence as much as, say, a patient in a clinic setting. Indeed, it may be impossible to communicate effectively with many patients in the ICU, furthermore, because of the patient's condition, physicians may need to spend much more time reviewing images, outpatient records, and laboratory values than physicians working in other care settings. Intensive care physicians may also need to spend more time communicating with other health care professionals because of the complexity of the patients and the number of consultants involved in the MICU. In short, we do not really know the ideal amount of direct patient contact time needed to maximize any clinically relevant outcomes. Fourth, we only instrumented health care workers assigned to this closed ICU. For example, consultation teams, whose presence in the unit were quite transient, were not instrumented. Nevertheless, from a patient perspective, our estimates of the time that patients spent with health care professionals does underestimate actual physician care time, as we could not include time spent by the patients in direct contact with physicians working on different consulting services. Finally, our sensor network data tracked only the location of health care workers and hand hygiene, and did not track or record any other activity or behaviors. We did not attempt to correlate our findings with any clinical outcomes (eg, mortality, severity of illness) because our project was designated as non-human-subjects research and accordingly, no specific patient data could be collected concerning

medical conditions. In addition, we did not gather any subjective or qualitative data from patients or from health care professionals (eg, patient satisfaction or physician job satisfaction). Future studies should attempt to link such outcomes with the data collected by the approach we used. Capturing time spent with family members (with family members wearing badges), and also time spent communicating with family members or other health care professionals by phone, will provide additional insights.

In conclusion, while previous investigations have estimated the time health care providers spend with patients and at other tasks, most of these estimates are based on human observations. Given the limitations associated with traditional time and motion studies, new approaches providing fine-grained measurements, like the ones used here, could help provide insights to improve team-based approaches to care delivery in intensive care settings.

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