Temporal Rhythms and Patterns of Electronic Documentation in Time-Critical Medical Work

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ABSTRACT

We examine nursing documentation on a newly implemented electronic flowsheet in medical resuscitations to identify the temporal patterns of documentation and how the recorded information supported time-critical teamwork. To determine when the information was documented, we compared timestamps from 58 flowsheet logs to those of verbal communications derived from video review. We also drew on observations of 95 resuscitations to understand the behaviors of nurse documenters. We found that only 8% of the verbal reports were documented in near real-time (one minute within the verbal report), while 42% of reports were not documented in the electronic flowsheet. In addition, 38% were documented early (before the verbal report) and 12% were documented with a delay, ranging from one to 58 minutes after the report. Our study showed that the electronic flowsheet design posed many challenges for real-time documentation, leading to paper-based workarounds and the use of free-text fields on the flowsheet to visualize and keep track of time, and to communicate temporal information to the team. These findings suggest that documenters shape the temporal rhythms of not only their own work but also the rhythms of the electronic record and medical process. We discuss the implications of these rhythms for EHR redesign to support real-time documentation in high-risk, safety-critical settings.

CCS CONCEPTS

• Human-centered computing~Field studies • Human-centered computing~Empirical studies in HCI

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1 INTRODUCTION

Electronic Health Records (EHRs) are being increasingly adopted in medical settings as healthcare moves towards digitization. Most resuscitation settings in emergency departments (EDs), however, have not yet replaced paper forms due to the dynamic and team-based nature of the resuscitation process, which makes the electronic documentation challenging [14,21]. Nursing documentation has a critical role in supporting team communication and work coordination because it provides a historic and temporal record of team activities (e.g., treatments) and changes in patient status during care [32]. Although some prior work exists on documentation in the resuscitation settings [11,14,30], little is known about the temporality of documentation and how nurses document information during resuscitations. The efficiency of resuscitations depends on effective communication that not only serves to support information sharing but also a shared mental model among team members [15,20]. Insights gained through the study of documentation and communication behaviors can inform the design of documentation and decision-support systems that capture and display real-time process information, thereby improving situation awareness and communication during time- and safety-critical teamwork.

Our goal in this work is two-fold. First, we seek to understand when is the information documented during resuscitations. Our research site implemented an electronic

flowsheet associated with the EHR for documenting medical resuscitations in May 2017, providing an opportunity to study the temporality by using EHR logs as ground truth. Because verbal communication is the main source of information for nurse documenters [30], we examined the temporality of documentation in relation to team members' verbal reports about the patient and activity status. By doing so, we learned how nurses gathered information from verbal communication, how they recorded that information in the electronic flowsheet and at what times. Second, we examine the nurse documenters' information behaviors while they are producing the resuscitation record to understand how documenters supported both their own and other team members' information needs. These insights, in turn, have allowed us to understand the temporal rhythms of the EHR, the resuscitation process, and the nurse documenters [29].

To achieve this goal, we spent 14 months in the ED of a pediatric teaching hospital in the U.S. mid-Atlantic region, observing 95 medical resuscitations in situ and through video review. We time-stamped verbal reports about activity and patient status for 58 resuscitations using videos and compared those timestamps with the corresponding documentation times from the EHR logs. Our findings showed that 38% of the documented items were recorded before the verbal report, 8% within one minute of the verbal report (in near real-time), and 12% were documented with a delay, ranging from one to 58 minutes after the report. We also found that 42% of the verbally communicated information was not documented in the EHR. Early documentation was due to the nature of the activities such as multi-step or longer procedures, or information retrieval from visual sources (e.g., vital signs monitor). The causes for delayed documentation and missing information on the EHR included user interface issues and other barriers (e.g., overcrowded room, documenters' involvement with other tasks), leading to ineffective verbal communication and distractions. These findings suggested that processes and systems also have their own rhythms, in addition to those of people, and that these different rhythms interact with and affect each other. Our study also showed that nurse documenters relied on paper-based workarounds and free-text fields on the EHR to record temporal information during resuscitations. We contribute to HCI by (a) identifying new temporal rhythms in medical work—the rhythms of the process and electronic record, and discussing how nurse documenters shape these rhythms along with their own temporal rhythms, and (b) offering directions for redesigning EHRs to improve real-time documentation of temporal information during time-critical medical scenarios.

2 BACKGROUND AND RELATED WORK

2.1 Medical Resuscitation Domain Overview

Medical resuscitations are dynamic processes that take place in the resuscitation bay, a designated area in the ED filled with bed spaces, medical equipment, and information systems, such as vital signs monitor, X-ray machine, and wall displays for X-ray images. During resuscitations, a multidisciplinary team of specialists works to stabilize critically ill patients suffering from seizures, respiratory distress, cardiac arrest or altered mental status. Resuscitations follow a structured flow of activities, starting with the assessment of major physiological systems such as airway, breathing, circulation, and disability. Based on the assessment results, teams take rapid actions to stabilize the patient, like intubation or intravenous (IV) line placement to administer fluids and medications. These activities are followed by a detailed head-to-toe evaluation to identify other medical problems. Resuscitation teams normally consist of seven to 15 members, each having a specific role and pre-determined yet flexible responsibilities. A typical resuscitation team consists of an emergency medicine physician (team leader), a fellow or a senior ED resident, a physician surveyor, a medication nurse, two or three bedside nurses, a respiratory therapist, and a nurse documenter. Because team members' shifts and rotations vary based on their duties in the hospital, even two consecutive resuscitations may have different team members. All ED nurses rotate through the documenter role, depending on their schedules. While their patient care duties in the ED remain the same, patient care workload can be affected depending on the number of resuscitations during their shifts. The role of nurse documenter is to document all team activities, medical interventions and changes in patient conditions to produce a complete record of the event in the flowsheet (i.e., EHR). The documenter is also responsible for communicating changes in patient status, tracking medications, and alerting the team about missed or needed steps. Although they gather information by observing different information sources and team members' actions at the bedside, the documenters often verbally confirm the actions before documenting them in the flowsheet. Other team members are also formally trained to communicate the progress of their activities and

results upon completion, as well as changes in patient status. The process of nursing documentation therefore serves as an important mechanism for coordinating teamwork and real-time data sharing and archiving. The flowsheet itself has a key role in facilitating communication and coordination during resuscitations, while also contributing to the continuity of care and patient safety [32]. Even so, documenting a time-critical process in real time is challenging, giving rise to concerns about thoroughness, extensiveness and timeliness of data collection on electronic flowsheets [14,21].

2.2 Electronic Documentation in Healthcare

HCI and CSCW researchers have studied electronic documentation and patient records in a range of medical settings [4,6,23,26,28]. While some studies examined implementation challenges [5,23], others looked at the role of EHR in supporting information flow, decision-making, communication, negotiation, and awareness in teamwork [4,16]. These studies have shown that EHRs improve clinical workflow and recording of treatment trajectories because they are available across different locations and time zones [4,28]. In contrast, some studies have identified a mismatch between the EHR designs and clinicians' work practices, leading to negative effects on workflows [1,6,25,26]. For example, Park et al. [25] identified both direct and indirect effects of EHR on work practices in an ED, resulting in a workload shift between different clinicians and longer charting times. Prior studies also showed that EHRs do not always reflect an accurate account of clinicians' work [6,26] providing a factual representation of the gaps between the actual workflows and EHR design. We extend this work by showing that the dynamic nature of the setting and the requirement to produce a complete and accurate record of all resuscitation activities could lead to untimely documentation and inaccuracies in the EHR.

Another body of work studied the workarounds related to Electronic Health Record use in medical settings [7,12,34,35]. Electronic documentation is perceived cumbersome because it requires more cognitive energy to navigate and interact with information on the screen [11]. Structured data entry vs. free-text narratives have been a persistent challenge in electronic documentation systems [18,35]. We build on these findings by showing that paper-based workarounds and free-text fields in the EHR are used to overcome barriers such as challenging system navigation during more acute medical scenarios, overcrowded room and distractions.

In emergency medical settings, prior studies have focused on different aspects of documentation, including completeness of paper-based vs. electronic documentation [6,11], benefits of electronic recording [13], system design and implementation [32], and evaluation of electronic flowsheets [14,22]. These studies reported an increase in the completion rates on electronic flowsheets when compared to their paper-based predecessors, while also showing concerns with technology ability to fit the complex needs of documentation in resuscitation settings. Building on this literature, we seek to understand the temporality of documentation in relation to verbal communication by using EHR logs. We show that the design of the electronic flowsheet and the dynamics of resuscitations pose challenges for real-time documentation during time-critical medical scenarios.

2.3 Temporality in Healthcare

The temporal sequence of events plays a critical role in understanding the patient's treatment trajectory and supporting situation awareness and team communication. Researchers have studied temporal coordination during medical work in surgery [2,3], hospital wards [9], intensive care units [27,29], and emergency departments [19,31]. For example, Sarcevic and Ferraro [31] studied data capture on the electronic flowsheet during trauma resuscitations, showing that little data were captured in real time. Their findings, however, were derived from observations and nurse shadowing, limiting the insights into the actual temporality of electronic documentation. Our study differs because it examines the temporal aspects of documentation during a less structured process by using timestamps from the actual EHR logs and video review of resuscitations as ground truth. To our knowledge, prior studies have not focused on timeliness of paper documentation given the challenges of timestamping pen- and paper-based data input. To bridge this gap, we studied temporal distribution of paper charting before the electronic flowsheet was implemented at our site [17]. While shadowing nurse documenters during 19 resuscitations, we used a paper copy of the flowsheet to mark the order of the entries as the documenters were entering values in the original paper flowsheet. We found that only 26% of documentation was completed in the first 15 minutes of the resuscitation (avg. event length 39 minutes).

Researchers have also looked into information-seeking behaviors and their relation to temporality in medical work, finding different "temporal rhythms" among clinicians [27,29]. These temporal rhythms serve as a resource for individuals in seeking, providing, and managing

information during the course of their daily work, allowing them to anticipate when information will be needed vs. available [29]. These researchers have also examined the temporal structure of activities and re-occurring patterns of work in medical settings, which are used by clinicians to orient their work practices. We use the concept of temporal rhythms and extend this body of work by investigating not only the rhythms of the nurse documenter, but also those of the resuscitation process and the EHR. Our results showed that nurse documenters continuously interacted with the electronic flowsheet while also using workarounds to document temporal information that was critical for team communication and coordination. In doing so, the documenters not only shaped their own temporal rhythms, but also the rhythms of the process and the record.

By taking a closer look into the temporality of medical documentation using timestamps from EHR logs, we identified three temporal patterns: early, near real-time and delayed documentation. We also explained the documentation and communication behaviors associated with the electronic flowsheet; the nurses faced challenges with the flowsheet navigation and complexities of the setting that led to issues in real-time charting. To overcome these challenges, the nurses relied on workarounds. These interactions with the flowsheet and the workarounds helped shape the rhythms of nurses' work, the electronic record, and the process. The identified rhythms will allow us to reconsider the EHR design to improve real-time documentation in high-risk medical settings.

3 METHODS

3.1 Research Setting

Our study took place in an ED of a pediatric teaching hospital serving over 90,000 patients a year. We obtained approvals from the hospital's Institutional Review Board (IRB) before the study. All data and records generated during the study were kept confidential and secure in accordance with IRB policies and Health Insurance Portability and Accountability Act (HIPAA). No personal identifiers were stored about study participants. The resuscitation bay at our research site has three bed spaces, each equipped with necessary instruments and technology. Three video cameras are set up at different angles to provide the views of the patient and team for quality improvement and research purposes. These videos are recorded using B-Line video recording software and are available to authorized staff within the hospital's network.

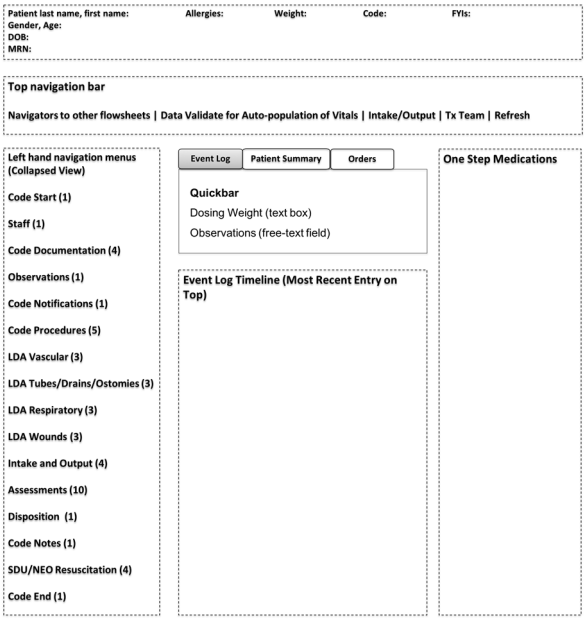

Figure 1: Graphical representation of the electronic flowsheet for medical resuscitations (actual screenshots are not available due to copyright protections). The size of each section is approximately proportional to the actual size of the corresponding sections on the flowsheet. The parentheses in the left navigation bar show the number of subsections in each section.

During resuscitations, the leader stands at the foot of the bed overseeing the team. The nurse documenter is positioned next to team leader and behind a mobile workstation called Workstation on Wheels (WOW), where the electronic flowsheet is accessed.

3.2 Electronic Flowsheet

The electronic flowsheet for medical resuscitations is divided into six sections (Figure 1). The horizontal section at the top provides patient information, such as patient name, gender, age, date of birth, and medical record number. Below this section is a navigation bar that allows for a quick access to other flowsheets and validation for auto-populated data from different sources. The other four sections are placed vertically on the flowsheet. The left navigation bar provides access to major sections, such as staff information, notifications, procedures, assessments and disposition. The contents of the left navigation bar can be collapsed and expanded, depending on the information needs of each resuscitation. The navigation bar contains 16 sections in the collapsed view, each with three subsections, on average (not shown in Figure 1). For example, the assessments section consists of major physiological

assessments, including airway, breathing, circulation, and disability. The central part of the screen is divided into two sections, one for accessing dosing weight and the other for entering free-text "Observations." Nurse documenters use the "Observations" field to type unstructured notes. Using the tabbed view, the documenter can navigate to patient summary and orders. Below this view is a timeline of events with the most recent flowsheet entry at the top. The right navigation bar contains medications and fluids. When a nurse clicks the section on either the left or right navigation bars, a small window opens up in the middle of the screen, allowing the nurse to enter and save data, which is then added to the event log in the center of the screen.

3.3 Data Collection

The study spanned 14 months (April 2017 – June 2018) and involved 766 hours of data collection. We used in-situ observations and video review of actual resuscitations, interviews with nurses, and review of EHR logs. A total of 222 medical resuscitations occurred over the course of the study, 95 of which were observed (17 in situ and 78 using video). The observed resuscitations were on average 35 minutes long, ranging from seven to 153 minutes. The first author, trained in ethnographic fieldwork and basics of emergency medical resuscitations, shadowed nurse documenters during resuscitations and recorded notes on nurses' behaviors and attitudes towards the electronic flowsheet. Video review was used for observing events that occurred outside of our work shifts. Following the IRB protocol, the videos are deleted after one month, limiting the time available for review. The first author also interviewed 26 documenters after resuscitations. The interviews focused on the advantages and barriers of electronic documentation.

To examine the temporality of documentation in relation to activity completion, we worked with medical experts on our team to create a list of activities that nurses solely document based on team members' verbal reports. This list included 23 commonly performed and verbalized activities, such as Assessments of physiological systems (Airway, Breathing, Circulation), Administered Medications, Pelvis Exam, and Temperature Check. The first author timestamped all verbal reports for the identified activities for all 58 resuscitation that were available for video review between November 2017 and May 2018. We then collected EHR logs for these 58 resuscitations and compared the timestamps between the two sources. Based on the EHR logs, these resuscitations were on average 49 minutes long.

Manual timestamping of videos can be up to five times longer than the actual resuscitation (i.e., up to five hours of annotation per 45-minute resuscitation). Timestamping activities based on team performance requires even more time, as well as medical expertise to determine start and end times based on team actions rather than just verbal reports. We therefore only relied on verbal reports because they provided explicit clues about activity progress and completions that could be identified by a non-expert. Our findings provide valuable insights and have validity because verbal communication serves as the main source of information acquisition for nurse documenters [30].

3.4 Data Analysis

We analyzed the data in three phases. During the initial phase, we first aligned the data from resuscitation videos and EHR logs. The timestamps on the videos were in elapsed time since the recording start time. To derive the actual time of the verbal report, we added this elapsed time to the recording start time. For example, a timestamp for airway assessment at 00:02:00 meant that a report about airway assessment was verbalized two minutes into the recording. If the recording started at 5:00:00PM, then the verbal report occurred at 5:02:00PM. The accuracy of timestamps alignment between the video recording software and the EHR logs was verified by randomly starting video recording in the bay on three different days during the study and comparing that time with the actual time of the day shown on the EHR. On all days we found a seven-minute lag in the video recording software compared to the actual time of the day and the EHR. We therefore aligned the timestamps on the video recordings and EHR logs by adding seven minutes to the video timestamps. Next, we determined whether the verbal reports about each activity were documented in the flowsheet by correlating the video timestamps to the closest data entry of that activity in the EHR. We looked for entries in both the designated flowsheet sections for the activity, as well as in free-text fields. Finally, we created a histogram of timestamps for all documented information by plotting the timestamps into 30-second intervals to identify temporal patterns of documentation and define the thresholds.

In the second phase, we performed open coding on the free-text entries to identify emergent themes. We analyzed the temporal distribution of these entries to determine the periods when documenters typed into the free-text fields vs. in the designated flowsheet sections. In the final phase, we analyzed our notes from observations and interviews using thematic analysis [10] to identify factors that contributed to (1) temporal patterns of documentation and (2) nurses' workarounds used for recording temporal information. We performed member-checking with two medical experts (one

ED physician and one nursing manager) at our research site to validate the results.

4 FINDINGS

We present our findings in three parts. First, we describe the temporal patterns of documentation. We then discuss the causes of these patterns and missed information on the flowsheets. Finally, we describe the use of workarounds to overcome the challenges in electronic documentation.

4.1 Temporal Patterns of Documentation

The histogram of timestamps for all documented information across 58 resuscitations showed a sharp decline after the first minute of resuscitations. Based on these data, we identified and defined three temporal patterns of documentation relative to verbal reports about activities: (1) *early documentation*—information is recorded before the activity completion or before the results are verbally communicated or reported; (2) *near real-time documentation*—information is recorded within one minute of the verbal report about the activity; and, (3) *delayed documentation*—information is recorded one or more minutes after the report. These patterns could simultaneously occur during the same resuscitation event. We next describe each temporal pattern, as well as types of information that were not documented in EHR.

4.1.1 Early Documentation. Our findings showed that 38% of verbal reports were documented early. Flowsheet sections that were most commonly documented early included Medications Administered, Circulation Assessment, IV/IO Placement (Intravenous or Intraosseous line placement to administer medications and fluids), Temperature Check, Fluids Administered, Pupil Exam, Intubation Attempts, Dosing Weight, Shock Treatment, and GCS (Glasgow Coma Score or Neurological Score) Calculation (Figure 2(a)). Higher percentages of early documented verbal reports were particularly observed for multi-step activities such as Shock Treatment (100%), Medications Administered (58%), Circulation Assessment (46%), Fluids Administered (39%), Pupil Exam (34%), and IV/IO placement (33%). These are longer activities consisting of several steps (e.g., checking the left pupil first, followed by checking the right pupil), each of which can span longer periods or take more time to manifest. For example, we observed the documenters recording the information about IV placement as soon as they observed the nurse starting to disinfect the arm in preparation for needle insertion.

4.1.2 Near Real-Time Documentation. Although timely documentation is difficult due to process complexity, we found that 8% of the information were recorded in near real-time, i.e., within one minute of the verbal report. This information included Circulation Assessment, Medications Administered, Temperature Check, IV/IO Placement, Pupil Exam, Dosing Weight, Fluids Administered, Intubation Attempts, Back Exam, and Eye Exam (Figure 2(b)). Activities that normally occur in the beginning of the resuscitation had higher percentages of verbal reports documented in near real-time, such as Circulation Assessment (20%), Temperature Check (17%), Pupil Exam (14%), IV/IO Placement (11%), and Dosing Weight (10%).

4.1.3 Delayed Documentation. Twelve percent of all documented information was recorded with a delay ranging from one to 58 minutes. Flowsheet sections that were most frequently documented with a delay included Chest X-ray, Circulation Assessment, IV/IO Placement, Pupil Exam, Breathing Assessment, Fluids Administered, Temperature Check, Dosing Weight, ECMO (ExtraCorporeal Membrane Oxygenation) Start (artificial cardiac and respiratory support), and GCS Calculation (Figure 2(c)). Activities that occurred towards the end of the resuscitation, such as ECMO Start (100%) and Chest X-ray (35%), had the highest number of verbal reports documented with a delay.

4.1.4 Not Documented Information. We found that 42% of the verbal reports were never documented in the EHR. Information that was most commonly found missing from EHR included results from the head-to-toe evaluation that usually occurs in the second half of the resuscitation, once the patient has been stabilized (Figure 2(d)). For example, none of the verbal reports about Abdomen, Chest, Extremities, Genitalia, and Pelvis Exams were documented in the EHR, while 83% reports of Back Exam and 82% of Ear-Nose-Throat and Eye Exams were missing as well.

4.2 Causes of Temporal Documentation Patterns

We identified several causes and factors contributing to the three temporal patterns of documentation, as well as to missing information from EHR: (1) technological factors related to the interface design of electronic flowsheet, (2) environmental factors related to the resuscitation setting and distractions, and (3) procedural factors related to the nature of resuscitation process and activities.

4.2.1 Technological Factors. A major technological challenge was the misalignment between the typical flow of activities and the layout of the flowsheet. Medical resuscitations are

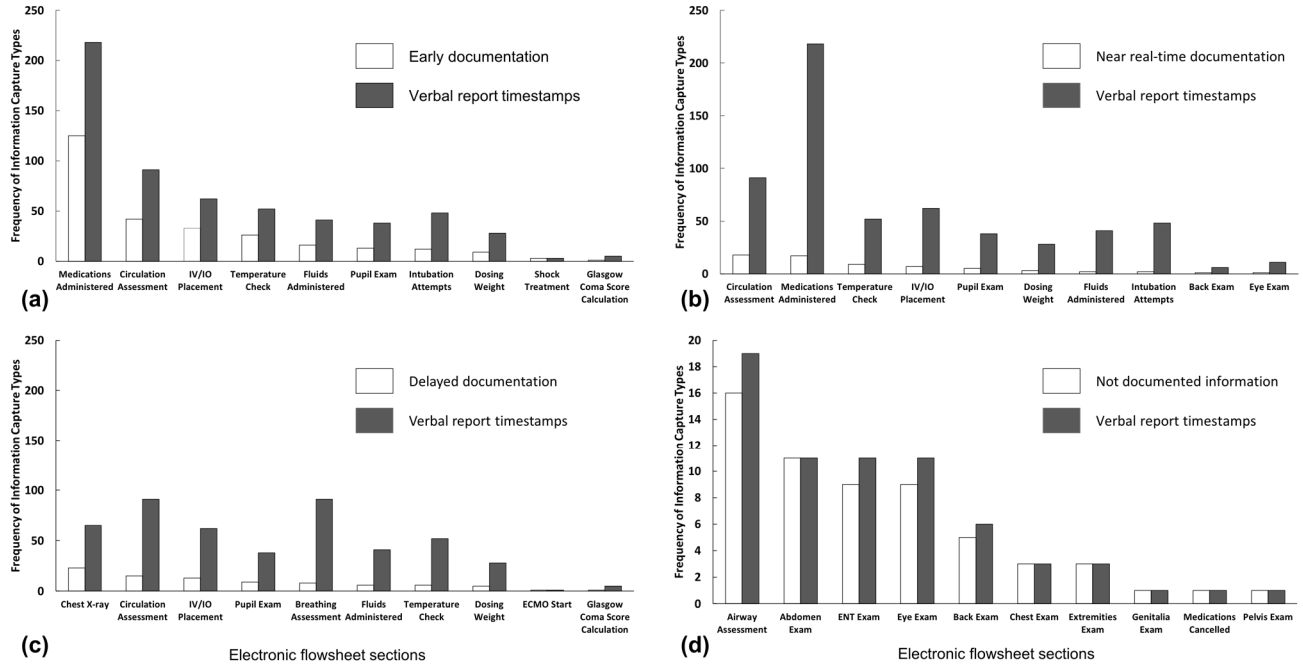

Figure 2: Temporal patterns of data capture and data that were not documented in EHR across all 58 resuscitations: (a) early documentation—before the report; (b) near real-time documentation—within one minute of the report; (c) delayed documentation—one minute or more past the report; and (d) not documented in EHR. X-axis represents the top ten flowsheet sections (out of 23) for each documentation pattern.

structured processes, starting with assessments of patient's physiological systems, followed by treatments, and ending with a head-to-toe exam and imaging studies (e.g., X-ray). The electronic flowsheet, however, does not follow this same flow (Figure 1). For example, the assessment and head-to-toe evaluation sections are placed on the bottom of the flowsheet, requiring the documenters to first scroll through other activities that are rarely performed. It was for this reason that evaluation of abdomen, chest, extremities, genitalia, pelvis, back, ear-nose-throat, and eyes were not documented in most cases. Nurse documenters explained this mismatch during the interview:

> *"It would be nice if it were a little more intuitive - meaning the flow of [electronic flowsheet]. I know that there is so much information and it's hard to organize, but it is not ordered like the paper flowsheet or the resuscitation process itself. It just goes from top to bottom."* [Nurse 43]

> *"There are a lot of items on the left-hand menu. [Nurse points to a section which is rarely used.] How often do we do this during a code? Not at all. This are a lot of buttons and I have to look for the button I want to select. That's impossible during a code. So I just write on paper so that I don't get backed up with what's going on. I like to stay on top of what people are saying."* [Nurse 23]

The multi-level categorization of flowsheet sections also made the system navigation during fast-paced resuscitations challenging. Because the nurses needed to click through multiple subsections to record the commonly occurring activities, they simply skipped entering information or relied on workarounds to document those activities, such as pen-and-paper and free-text fields. A nurse explained these navigational challenges as follows:

> *"This [electronic flowsheet] is very long, lots of scrolling and clicking. I need to click so many things before I could document an assessment. This is not what you want to see when your patient is coding in front of you! I would rather type in the Observations field or write on paper quickly."* [Nurse 6]

The use of workarounds not only affected the temporal rhythms of the nurse documenter, but also those of the electronic flowsheet. The information recorded on paper or in free-text fields had to be transferred back to the designated flowsheet fields, and this transfer occurred during idle times in the resuscitation room or later, during nurses regular ED shifts—a process that our interviewed nurses referred to as "backcharting." Backcharting affected

the nurses' workload because they had to document the same information twice or because they had to document at the time when other duties were awaiting. In addition, the flowsheet fluctuated between dormant and active, depending on when the information was documented. To support the resuscitation process and real-time decision making, the flowsheet must be active at all times. Backcharting the information, therefore, also affected the rhythms of the process. Information that was not documented at the time it was produced had to be requested later, which in turn led to delays in task completions or distractions. In cases where documenters did not note the timestamps on paper, they estimated the times while backcharting, causing inaccuracies in the patient record.

We also observed that the workflow requirements of the flowsheet itself added another layer of complexity. For example, documenting an administered medication requires the presence of two registered nurses and their individual sign offs on the ordered medication in the EHR. Most of the time, however, only one documenter was available at the computer, causing a major barrier to documenting medications in real time:

> *"So, the medication nurse is drawing up these medications. I am the documenter, and everybody is calling out reports. I have to document when it is given. But you will need a second nurse to come over, who didn't even draw up the medication, to verify it on the system. While I am working to verify the medication, it has already been given and I still did not document it. And often times, another nurse is not available to sign off. So it is kind of a stop in the process."* [Nurse 7]

Required fields, pop-up warnings, and error messages for certain sections (e.g., Medications and Assessments) were also imposing a rigid workflow requirement. We observed the nurse documenters rarely reading those pop-up messages during resuscitations, and simply closing the windows and skipping documenting those sections. Ignoring the warnings and error messages could lead to errors in documentation, e.g., incorrect doses of administered medications and fluids. A vignette from our observation log explains this challenge:

> The nurse documenter was entering the medications and an alert popped up, saying, "*New order has been placed for this patient.*" The nurse looked at it and closed it. Upon entering more medications, the alert popped up again and again. The nurse was clearly frustrated and kept closing the alert without reading it. A new alert popped up about the dose and the nurse exclaimed, *"Oh! Come on!"* and instead entered the medication information in the free-text field. [Event 4]

The errors and missing information from the EHR caused by technological factors affected the rhythms of the flowsheet by producing inaccurate accounts of the resuscitation process.

4.2.2 Environmental Factors. Resuscitation settings are inherently dynamic and complex. Some cases, however, are more acute than others. Because the composition of the team depends on the patient acuity and clinicians' shift schedules, the dynamics between the team members affected the rhythms of the resuscitation process. For example, we observed that the documenters communicated more effectively with team members they knew well. We also observed how the number of people in the resuscitation bay increased with the complexity of the scenario, causing distractions to other team members, including the nurse documenter. The inability to hear verbal reports often led to missing information in the EHR, affecting the temporal rhythms of both the resuscitation process and the EHR. In cases with rare or lost verbal reports, the documenters would repeat their questions about activities or clarify multiple times before documenting. These actions, in turn, affected the rhythms of the process itself because team members had to repeat their reports, all while treating a patient. A nurse expressed the concern about the missing information from the EHR:

> *"It was chaotic today. Things were getting done, but they did not communicate a lot. They have to tell when the medications are given, so me being a documenter, I can document that. But today I did not hear anything. It was also because of the crowded room. I might have missed someone's report and I was not able to document that."* [Nurse 43]

The role of a nurse documenter is often overwhelming because they are constantly seeking and recording information from multiple sources at different times. In addition, they are tasked with signing off paperwork from Emergency Medical Services (EMS) crew during patient handoffs, which is the most critical period of the process. Our results showed that 40% of the verbal reports were

within the first ten minutes of the resuscitation. These additional tasks during the initial moments sometimes contributed to the delayed or unfilled assessment sections in the EHR. The following vignette depicts a situation where the documenter missed recording the information:

> The EMS crew member came to the nurse documenter and gave some papers to sign and he started giving her some additional information. Meanwhile, the documenter missed a lot of verbal reports from the team because she was distracted by the EMS crew member. She documented the EMS information in the Observations field. Once the EMS crew left, she asked a bedside nurse, *"Was his belly distended or fine?"* The bedside nurse answered, *"Abdominal FAST negative"* and she wrote this on paper. [Event 8]

4.2.3 Procedural Factors. A key procedural factor contributing to near real-time documentation of activities such as circulation assessment, temperature check, or IV/IO placement, was their occurrence within the first few minutes of the resuscitation, when nurse documenters had less requests and backcharting was minimal. Although some of these activities were also documented before reports and with a delay, we found they had the highest number of real-time entries among other activities.

Early documentation was mostly due to the nature of the resuscitation activities. We observed documenters writing notes about medications on a piece of paper when the medication nurses announced their administration. The documenters then entered the information in the EHR as soon as the team started the administration process, without waiting for verbal reports that medications have indeed been given. Because medications need sign-offs, which in turn require time until another nurse is available to complete the documentation, this early recording ensured that the information was recorded in the EHR. Nurses are also more likely to document medications early because administering medications takes several steps—they need to be ordered, prepared and then administered. Other lengthy activities include IV/IO placement, fluids, and intubation. Our data showed that the documenters filled out these sections by relying on their observations of the environment; they started entering the data as soon as they saw the start of activities. Similarly, the documenters entered data for multi-step activities such as circulation assessment, GCS calculation, and pupil exam, as soon as the first verbal report was heard but before the activities were completed. These factors contributed to early documentation and affected the rhythms of the electronic flowsheet and the resuscitation process in two ways. First, rather than waiting for these treatments to be completed, nurses recorded the activity information upon the first sign of the activity start. This early documentation caused problems when medications needed to be administered in a particular order or in regular time intervals (e.g., every three minutes), leading to inaccurate accounts of these activities. Second, the differences in rhythms of the individual resuscitation activities and the times when the results of the activities were verbally reported affected the overall rhythm of the resuscitation process.

4.3 Workarounds to Achieve Timeliness

To overcome the challenges in real-time documentation during resuscitations, the nurse documenters used workarounds like paper-based note taking and free-text charting in the EHR to construct their own temporal accounts. These accounts were then used to (1) visualize time, (2) keep track of time, and (3) communicate temporal information to the team.

4.3.1 Visualizing Time. The documenters used pieces of paper rather than designated flowsheet sections for recording certain temporal information, such as vital signs every three to five minutes, administered medications, and changes in patient status (e.g., increased heart rate). The nurses also timestamped it to indicate when the events occurred. This timestamped information was arranged on paper, based on its type to allow for an at-a-glance overview of all the information. For example, all timestamped vitals were written one below the other to easily visualize the changes in vitals across time. We also observed the use of free-text fields ("Observations") in the EHR because these fields are easily accessible and visible at all times (Figure 1). When information is entered in the "Observations" field, it is automatically timestamped and placed in the event log timeline at the center of the screen, with the most recent entry showing on top. This timeline allowed the documenters to see the information in a chronological view. The following vignette from our observation log explains the use of paper to visualize time:

> The bedside nurse called out "100 over 80". The documenter wrote this on a piece of paper with the time of report. She wrote down other vitals including heart rate and pulse from the vital signs monitor at the same time. After five minutes, she wrote down another set of vitals by looking at the monitor and noted down below the previous set of vitals with timestamps. [Event 21]

4.3.2 Keeping Track of Time. The timestamped information on paper helped nurse documenters fulfill their role as a time-keeper. For example, the nurses wrote down administered medications by manually timestamping them to stay aware of when the next medication dose was due. We also observed how nurses used the free-text charting in the flowsheet as a time-keeping mechanism because the notes were automatically timestamped in the EHR. These notes appeared in the event log timeline at the center of the screen (Figure 1). The notes included specific references to time such as "now" and "at this time" to make it easier for backcharting the information to the respective flowsheet sections. The timestamp on the free-text entry was used as the actual time of the activity occurrence during backcharting. The following excerpts from interviews and observation log illustrate the time-keeping activities:

> *"I would have to write down if they ordered a lot of medications. If there is a lot going on, I don't think I would be able to keep up so I definitely would have to write them down with timestamps so that I have it in front of me and I know when the next medication is coming up"* [Nurse 40]

Notes in the "Observations" field were usually recorded as follows (emphasis added):

> Note 1: *00:13:00 Patient **now** being bagged*
> Note 2: *21:35:42 Log roll **at this time**. Patient awake and crying*
> Note 3: *08:15:00 To CT **at this time***

4.3.3 Communicating Temporal Information to the Team. One reason for timestamping information on paper was the need to communicate the time to the team. For example, the information about administered medications written down in three- to five-minute intervals was used to communicate when the next dose was due. We also found that nurse documenters calculated and wrote down timestamps in advance for several consecutive medication administrations (e.g., every three to five minutes) and then used these notes to alert the team when the time came. For example, they wrote 9:30, 9:33, 9:36 and then communicated to the team at these times, reminding them to administer the doses. Other team members also sought this temporal information from the nurse documenter, as shown in the vignette below:

> A medication was administered and the team leader verbalized "Epinephrine is in." The documenter wrote down the time on a piece of paper after glancing at the clock on the wall. After a few minutes, the team leader looked at the documenter and asked, *"Are we ready for next Epi yet?"* and the nurse responded, *"One more minute"* as she glanced at the clock. After a minute, she alerted the team that the next dose was due. [Event 75]

Our analysis showed that free-text charting accounted for 18% of the 58% of information documented in the EHR. Even though free-text observations are not recorded in the designated sections, they are still a part of the patient's record. Through an open coding analysis, we identified 19 categories of free-text notes, of which 14 were related to the flowsheet sections (e.g., Airway Assessment, Breathing Assessment). Most commonly found information types in the free-text fields included Intubation Attempts (29% of all verbal reports about intubation were recorded as free-text), Ear-Nose-Throat Exams (18%), Bolus Administered (17%), Back Exam (16%), and Medications Administered (13%). Other five categories included notes about errors in previous data entries, family presence in the room, patient disposition, and notes with timestamps. Upon analyzing the temporal distribution of the free-text field entries (i.e., when in the process this information was typed in the flowsheet), we found that 50% of these entries were documented within the first 20 minutes of the resuscitation. Both free-text fields and paper-based workarounds contributed to duplicate accounts of resuscitation activities. These duplicate accounts not only led to inaccuracies and missing information in the official record (EHR), but also doubled the nurses' workload as they documented the same information twice. The workarounds, however, were important for maintaining the rhythm of the resuscitation process because documenters relied on them for real-time information capture and sharing.

5 DISCUSSION

The dynamic and complex nature of the medical resuscitation setting presented a unique environment for studying the temporal aspects of time-critical documentation. We found that nurse documenters not only shaped their own temporal rhythms, but also continuously affected the rhythms of the process and the EHR. In addition to serving as a complete record to support continuity of patient care *after* the resuscitation, the record served as a major mechanism for supporting team communication and coordination *during* the resuscitation. As described by Bossen and Jensen [9], clinicians "achieve

overview" by gathering patient information, identifying problems, and making clinical decisions. During resuscitations, the nurse documenters are working to achieve an overview of the activities, decisions and interventions to generate a chronological record, support their own understanding of the patient status, and communicate changes in patient status to the team. In doing so, the nurse documenters continuously seek, manage, communicate and archive information.

Zerubavel [33] was the first to mention rhythmic structures of medical work, identifying five major cycles while observing the activities of clinicians in a large teaching hospital—year, rotation, week, day, and duty period. Our findings showed that these five cycles converged during resuscitations, leading to differences in documenters' information behaviors. Reddy et al. [29] later introduced temporal rhythms as a pattern of activities across patients and care providers that helps clinicians to orient themselves and coordinate work. This concept of temporal rhythms was appropriate for our study because it provided a basis for understanding recurring patterns of nurse documenters' activities, interactions with the EHR, and team communications. We next discuss how the nurse documenters contributed to shaping of two new rhythms in medical work—those of the process (i.e., resuscitation) and the record—in addition to the rhythms of their own work.

5.1 Shaping of New Temporal Rhythms

5.1.1 Rhythm of the Process. Our findings showed that real-time electronic documentation during a complex, time-critical scenario was minimal. Although critical for medical decision making, real-time documentation is challenging even with a dedicated documenter role and several mechanisms in place to support it. Due to technological, environmental, and procedural factors, critical patient and process information were mostly documented either early or not documented at all. Longer-lasting, multi-step activities were prematurely documented as soon as the nurses observed their start. Based on experience, nurses overall are aware of the individual rhythms of the activities, so they often anticipate when the reports will be announced and can decide when to document the information. This awareness of the individual activity rhythms allowed them to start backcharting during resuscitations, while the team performed longer, multi-step activities that the nurses already pre-documented. Although this approach sped up the backcharting, it also created issues for the process and information access because the nurses were now delaying the recording of the results for activities that occurred in the meantime. Sometimes, the documenters missed recording the information because they could not hear team communications. The documenters then probed other team members by asking questions and requesting confirmations to enter information in the electronic flowsheet. These probes affected the rhythm of the process because other team members had to slow down and respond to the inquiries, while continuing to treat the patient.

The documenters relied on paper- and free-text workarounds to overcome the misalignments between the EHR interface and the process flow. They recorded temporal information on paper or in free-text fields in EHR to "achieve overview" of the process and share it with the team. The workarounds facilitated real-time information sharing because the documenters used them to gather, visualize, and communicate information to the team. The workarounds are therefore embedded in the work practices of documenters, contributing towards the rhythm of the resuscitation process.

5.1.2 Rhythm of the Electronic Record. The workarounds used for real-time documentation affected not only the rhythm of the process, but also the rhythm of record itself, i.e., the electronic flowsheet (EHR). When the documenters wrote notes on paper, they often timestamped them so they could backchart into the respective flowsheet sections when the time allowed. The use of free-text fields in the EHR to visualize and keep track of time, and to communicate temporal information to the team also supported the backcharting process for sections such as medications. Backcharting produced more complete accounts of patient care in the electronic flowsheet because information that was missed during resuscitation was now added to their respective sections. However, during resuscitations, if the nurses did not record the times on paper, they estimated the times while backcharting, leading to inaccurate accounts of the process. The flexibility provided by the electronic flowsheet to backchart information at a later time caused a "flip over effect," which occurs when one group's *model of* work becomes a *model for* work, and description becomes prescription [8]. Pine and Mazmanian [26] similarly found that the EHR workflow requirements led to perfect accounts, but inaccurate representations of clinicians' work. In their study, the mechanism of backcharting was therefore seen as a solution for the "flip over effect" because it allowed clinicians to decouple their tasks in the workflow. Our findings, however, showed that in the case of backcharting, the flip over effect was not related to the representation of clinicians' work, but to the accurate representation of the process in the patient record.

Because the electronic flowsheet plays a key role in real-time information sharing and supporting team communication, it must be actively used throughout the process. Yet our findings showed that the flowsheet was often dormant, as nurses relied on paper to document the information. The workflow requirements, such as required fields, frequent pop-up warnings and error messages also made the nurses skip documenting in the flowsheet. In addition, environmental factors, such as inability to hear verbal reports, involvement with additional tasks, and other distractions led to many unfilled flowsheet sections. All these challenges affected the real-time documentation, resulting in a mainly dormant record.

5.1.3 Rhythm of the Nurse Documenter. The nurse documenter is the key agent in shaping the rhythms of the resuscitation process and the electronic flowsheet. Although documenters are dedicated to producing a complete record of the entire resuscitation, they are often involved in other tasks. Within the first few minutes of the resuscitation, the documenters are continuously switching between tasks, paying attention to multiple information sources and recording the information, while also communicating with the team. The mental effort to successfully perform all these activities is immense, significantly affecting the rhythms of the documenter. During resuscitations, the nurses seek and manage information, plan for next activities based on the retrieved information, and share information to keep up with the rhythm of the process. Because they use workarounds to overcome the challenges in real-time documentation, the nurses must also manage and plan their tasks after the resuscitation to backchart the information from paper and free-text notes. Our findings on system usability issues aligned with the rationales for using workarounds described by Blijleven et al. [7], where they associated the workarounds with five work system components: persons, technologies, tasks, organization, and physical environment. We extend this work by also looking at the associations with another work system dimension—time. Depending on the amount of record completion achieved during resuscitations, the nurse documenters have to coordinate their daily tasks and find time to backchart. The use of workarounds, therefore not only contributed to the rhythms of the process and the record, but also affected the nurses' workload. Backcharting itself added to the nurses' workload because they spent additional time locating the appropriate flowsheet sections to transfer their notes.

5.2 Achieving Synchronization of the Rhythms

While important for the overall resuscitation and patient care, the three rhythms we described in this study—of the process, record, and nurse documenter—can negatively affect team situation awareness, workflow and communication because they are largely asynchronous. As we observed, the flip over effect caused by workarounds and backcharting made the resuscitation process and electronic flowsheet proceed at their own pace. This lack of synchronization between the rhythms created barriers to real-time documentation, affecting situation and temporal awareness, as well as information sharing. The electronic record also failed to accurately represent the documentation and communication behaviors of the documenters.

To provide adequate decision support during time- and safety-critical work, the record must be in synch with the process workflow. This requirement is especially important for decision-support systems that rely on the electronic record for automatic data capture and display in real time. Improvements in design of documentation systems for time-critical work should therefore focus on reducing the flip over effect by removing the barriers to real-time documentation. Our study suggested three approaches to achieving this synchronization of the temporal rhythms: (1) minimize the multi-level hierarchical structure of the record, as well as the number of approvals and fields that are required to be completed during the process, (2) align the flow of the process with that of the record, and (3) embed mechanisms for visualizing and keeping track of time. These guidelines represent only the initial directions that researchers and designers can take as they start reconsidering the design of EHRs to improve real-time documentation in high-risk medical settings. At a higher level, our findings showed how time-critical processes, such as treating acutely sick patients, coordinating care or documenting information, create an intricate network of asynchronous rhythms. While synchronization of these rhythms can be achieved through low-tech means such as training, the most critical approach will be through technology design, as the medical field is inevitably moving towards full work digitization.

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