Implementing an animated geographic information system to investigate factors associated with nosocomial infections: A novel approach

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Background: Two million Americans acquire an infection in the hospital each year, resulting in an estimated 88,000 patient deaths per year.
Objective: Our objective was to describe our initial experience using an animated geographic information system (GIS) to investigate factors associated with nosocomial transmission of resistant organisms. We used a descriptive study at a university-affiliated, county, teaching hospital. We studied all patients and nursing staff on 4 adult, general medicine wards from June through August 2004.
Results: We developed and implemented GIS software. GIS-generated animations demonstrated inappropriate patient placement for 19% of patients with methicillin-resistant *Staphyloccocus aureus* and insufficient time for hand hygiene in 14% (6248) of health care provider-patient contacts.
Conclusion: Animated GIS can uncover previously hidden factors that contribute to the spread of nosocomial infections. This technology may become a useful adjunct for the prevention of nosocomial transmission of infectious agents. (Am J Infect Control 2006;34:578-82.)

Two million Americans acquire an infection in the hospital each year, resulting in an estimated 88,000 patient deaths per year.[1] Current methods for detection of these infections are often delayed by manual paper review of microbiology data, and, ultimately, they are based on the ability of infection control practitioners to recognize complex temporal and geographic patterns of nosocomial transmission.[2] Once detected, determining the factors contributing to an outbreak requires further data collection, often through the direct observation and interviewing of staff. Current techniques of direct observation and investigation are prone to observational bias.[3] Morever, infection control practitioners do not have the resources to carry out hospital-wide audits and observations. Development of new tools to help track the spread of nosocomial infections would be of great benefit in this regard.

Geographic information system (GIS) technology provides the potential to integrate and analyze multiple data sources in spatial and temporal context and rapidly produce composite images. Although GIS technology continues to grow as an important tool in public health and spatial epidemiologic applications,[4-6] few studies have explored the utility of GIS technology in nosocomial infection outbreak detection and analysis. We hypothesized that animated GIS technology would be a useful tool to both visualize patterns of nosocomial transmission and potentially determine environmental factors contributing to the spread of resistant organisms in the hospital. In this paper, we describe a prototype system to capture staff movement and nosocomial infection data and present these data in an intuitively visual format to highlight clearly the factors known to contribute to nosocomial infections.

METHODS

The Regenstrief medical record system was developed over 30 years ago as one of the first electronic medical record systems.[7] It is a comprehensive electronic medical record, containing data on patient demographics, diagnoses, laboratory studies, medications, imaging studies, and pathology reports. It has

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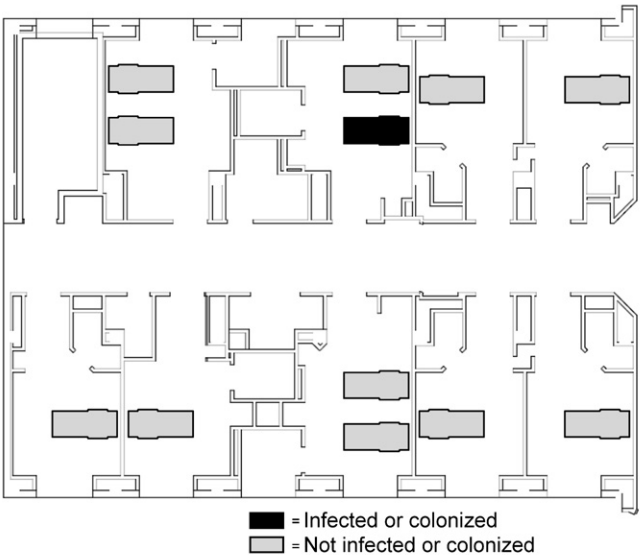

Fig 1. A patient infected with methicillin-resistant *Staphylococcus aureus* placed into a shared room.

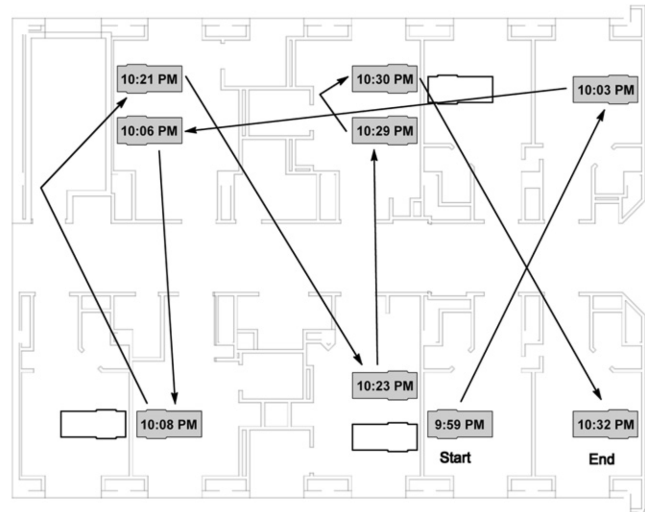

Fig 2. A nursing aide checking vital signs on 9 patients within a time span of 33 minutes.

been in use in the routine clinical care of patients at Wishard Memorial Hospital, a large, county, teaching hospital on the Indiana University Medical Center campus, for many years.

On 4 general medical wards of the hospital, bedside computers, known as the VitalNet system, electronically import pulse, blood pressure, temperature, and pulse oximetry values after placement of the appropriate measurement equipment on the patient.[8] Vital signs captured at the bedside by nursing staff are time and date stamped by the VitalNet system, which definitively documents a point of physical contact between the health care provider and the patient. Nursing staff (nurses and aides) must log in to each workstation to capture electronically the vital sign data, and log-in names and passwords cannot be shared.

We obtained a list of all positive culture results for methicillin-resistant *Staphylococcus aureus* (MRSA) and vancomycin-resistant *Enterococcus* (VRE) during the study period from the microbiology laboratory. Infection control personnel determined whether these cultures represented new nosocomial cases by cross-checking a list of patients with a history of infection or colonization with MRSA and VRE, respectively, and defining as nosocomial any positive culture result >48 hours after admission to the hospital.

We collected data on patient location and orders for contact isolation from the electronic medical record from June 1, 2004, through August 31, 2004. We *de*-identified all patient information including name, medical record number, and admission and discharge dates. We replaced medical record numbers with a nonderived study number. Admission and discharge dates were replaced with relative dates of admission (eg, day 1, day 2). We collected nursing staff log-in data from the VitalNet bedside computer system as documented time and sites of patient-nurse contact. All data were stripped of identifiers and replaced with a study number. Data were stored in Microsoft Access (Microsoft Corp, Redmond, WA) table format for compatibility with ArcMap 9.0 GIS software (ESRI, Redlands, CA) equipped with the Tracking Analyst extension. We superimposed patient bed assignment, contact isolation status, MRSA/VRE status, and nursing staff movements onto computer-aided design floor plans of the hospital to create time sequence animations of the locations and movements of patients with MRSA or VRE and the health care providers involved in their care. The Institutional Review Board of Indiana University-Purdue University, Indianapolis, approved this study.

RESULTS

From June through August 2004, there were 2622 total admissions to Wishard Hospital. Hospital wide, there were 22 nosocomial MRSA cases and 1 nosocomial VRE case during the time of the study. There were 55 community-acquired MRSA cases, of which 14 had a prior history of colonization. On the 4 wards with the VitalNet system, there were 42 cases of MRSA admitted during the 3-month study period representing 36 unique patients. Five cases were classified as nosocomial, 11 as previously colonized, and 24 as community acquired. There were 44,485 log-ins for captured vital signs for all patients on the 4 wards.

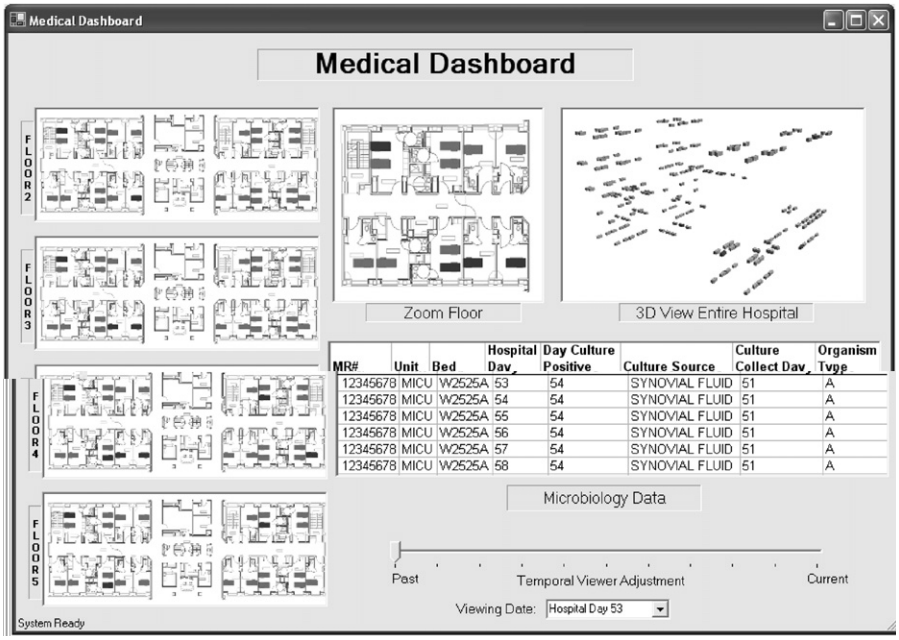

Fig 3. "Dashboard" view of data on patient location and microbiology status with a slidebar to scroll through time segments.

Visualizing these complex data as simple animations explicitly revealed factors known to contribute to the spread of infection. During the 3-month study period, the GIS visualizations (Fig 1) demonstrated inappropriate placement of a patient with MRSA into a shared room in 8 (19%) of 42 instances. In 5 of these MRSA patients, no contact isolation orders were written. In the other 3 cases, isolation orders were written 3, 7, and 13 days after admission.

In other animations, superimposed log-in data demonstrated a nursing practice of 1 individual rapidly checking vital signs across a host of patients (9 patients within 33 minutes), thereby increasing the risk of provider-to-patient transmission of MRSA or VRE (Fig 2). Time between log-in events was as little as 1 to 2 minutes, leaving inadequate time for handwashing after accounting for time to log in, apply the vital sign equipment to the patient, and travel between rooms. Alcohol-based handrubs were available on the study floors, but they were located outside patient rooms in the hallway. Conservatively estimating a minimum of 2 minutes to check a full set of vital signs, and 1 minute to wash hands and move between patients, a time between log-ins of less than 3 minutes between different patients occurred 6248 times (14% of all electronically documented contacts) during the 3-month study period. Nursing aides accounted for 5585 (89%) of these instances. This evidence quantified anecdotal observation of nursing aides going quickly from room to room to check patient vital signs and helped distinguish problem areas from the majority of instances when nursing staff adhered to assigned patients, at a ratio of not greater than 6 patients per nurse, with greater than 3 minutes between patient contacts.

DISCUSSION

It is widely speculated that the most common cause of hospital outbreaks is between-patient transmission by providers.[9] We used computer-generated log-in data to document clearly the patterns of contact between providers and patients. Our findings are particularly relevant in light of recent evidence that the antecubital fossa and the blood pressure cuff are efficient sites of transfer of resistant organisms to patients.[10]

Although our infection control practitioners monitor patients with cultures positive for MRSA and VRE daily, determining health care provider movements and patterns of nosocomial transmission poses a daunting challenge when only paper records are available. By electronically merging multiple data sources and presenting them in an intuitive visual format, previously undetected trends can become obvious. Our infection control practitioner presented these clear examples to the nurse management committee for use in staff education. Since this study, we have also implemented a computerized reminder system to streamline and dramatically improve the isolation rates of patients admitted to the hospital with a history of infection or colonization with MRSA or VRE.[11]

A great deal of effort was dedicated to completely de-identifying both the patients and providers for our analysis. Our aim was not to identify individual transgressions but rather to determine general patterns of behavior that might contribute to the spread of infection and thereby institute system-wide changes.

An early challenge in creating time-sequence animations involved selecting an appropriate time resolution. We were fortunate to have data at the resolution of at least minutes for all of our data sources. However, increasing temporal resolution increased the time between events in the animations and increased the review time for practitioners viewing the animations. Future work will be focused on determining means to compress event data and incorporate statistical tools that capture the ''gestalt'' pattern recognition of experienced infection control practitioners (Fig 3). We are expanding on this work to collect automatically the electronic data in real time from the microbiology laboratory, admissions tracking system, and VitalNet system to create a historical geo-temporal record of staff-patient interactions. This system will not replace the diligent ''boots on the ground'' investigations of infection control practitioners, but, rather, it will serve as a valuable adjunct in future outbreak investigations. Animated GIS tools may be particularly useful in tracking hardy environmental contaminants such as *Clostridium difficile*,[12] which may concentrate in particular areas or rooms in a hospital.

There were a number of limitations to this study. This was a retrospective study designed to determine the feasibility of this technique and focused only on a short time frame. In addition, physician-patient contact could not be correlated with log-ins because their computer documentation was done at workstations separate from the patient rooms. Some aspects of our system were unique, in particular, the VitalNet system, which allowed us to track provider-patient points of contact. However, all other information we utilized is readily available at virtually all modern hospitals, eg, admission, discharge, and transfer messages (ADT messages) from the electronic registration system, computer-generated floor plans, and electronic microbiology laboratory data.

This report also highlights one of the potential dangers of new technologies. By streamlining and automating some of the collection of bedside vital signs, the VitalNet system has increased efficiency but also transferred this duty, which involves direct patient contact, to less experienced nurses aides, thus, potentially increasing the likelihood of interpatient spread of infections.

In 19th Century London, John Snow plotted cholera cases on a map of London to identify a contaminated water pump as the source of a cholera outbreak.[13] Modern GIS tools can speed this process to create similar maps in near real time. Today, statistical tools and algorithms address the issue of outbreak detection,[14] but we postulate that the ability to visualize patterns of nosocomial spread and environmental factors such as provider movement may be as equally powerful a tool today as in the days of John Snow.

In this study, we described a novel application of GIS technology to document processes known to facilitate the transmission of nosocomial pathogens from one patient to another. Emerging theoretic work on data structures, visualization techniques, and statistical analysis methods focused on health applications of GIS suggest that this technology will continue to develop as an important tool in nosocomial infection management.[15-19] In an era of emerging infectious threats, and increasing antibiotic resistance, we believe that the application of animated GIS to the hospital setting is an exciting new development. Even in its preliminary stages of development at our institution, we have found it to be a useful tool for infection control. If future research and development confirms our initial optimism, we believe this technology could and should become widespread in nosocomial infection surveillance.

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