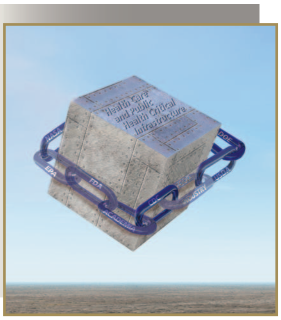

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From Clean Dishes to Clean Hands

Novel Perspectives in the Fight Against Infections

BY ABEL KHO, MARTA SALES-PARDO, AND JEFFREY WILSON

In the United States, hospital-acquired infections account for around 99,000 patient deaths per year [1]. These infections are increasingly caused by drug-resistant bacteria such as methicillin-resistant *Staphylococcus aureus* (MRSA), which accounts for 19,000 patient deaths per year [2]. Fresh perspectives with tools adapted from other disciplines may provide the insight to identify opportunities for local and regional prevention efforts. For the past several years, we have researched novel methods to understand the nature of infectious spread. In one example, we applied a geographic information system (GIS) to clearly demonstrate flawed hospital processes, including inappropriate patient placement and poor hand washing by providers. Recently, we applied a shared community health record to identify the complex web of interhospital interactions and coordinate a regional infection control intervention.

From Clean Dishes…

Like much research, our work was made possible by the vision of our predecessors. The Regenstrief Institute was founded by its namesake Sam Regenstrief, an industrialist and inventor of the low-cost dishwasher. Sam founded the Regenstrief Institute as a means to bring the principles and efficiencies of manufacturing to the health-care industry. His vision was carried forward by pragmatic medical informatics pioneers, like Clement McDonald, who created the Regenstrief Medical Record System, the longest running electronic medical record system [3]. Today, McDonald's work continues in the Indiana Network for Patient Care, a robust health information exchange created by the persistence and trust between Regenstrief investigators and the surrounding community of health-care institutions to share clinical information for the benefit of patients throughout Indianapolis [4].

During a National Library of Medicine Medical Informatics fellowship at the Regenstrief Institute, I (Abel Kho) concentrated on developing electronic tools to combat hospital-acquired infections. I began by trying to understand the nature of the hospital environment that enabled the ready transmission of infections. By attending on the wards, and shadowing the activities of the lone infection control nurse, I learned that simple human processes, e.g., the failure of staff to wash hands adequately or recognize the infectious status of patients, contributed significantly to the problem. How could we quantify this, when the lone infection control nurse was overwhelmed with integrating data on patient location, microbiology results, and historical clinical records?

GIS technologies are most commonly used at relatively broad scales (e.g., cities, counties, countries, continents) to map and analyze spatial data. Numerous articles had shown that GIS technologies could be a useful tool to track infections to their source within communities. I hypothesized that we could use GIS to track infections within the hospital, but I would need help.

I met with Jeff Wilson, a faculty member in the Geography Department at Indiana University Purdue University Indianapolis (IUPUI), who had just started a new GIS graduate program on our campus. We discussed how our interests in health and GIS could be combined to improve understanding of hospital-acquired infections. Together with Kelly Johnston, Jeff's first graduate student in the program, we set out in what was a new, but exciting, direction for all of us.

Senior colleagues including Steve Wilson and Catherine Souch helped us along the way by providing advice and inspiration. Catherine, another geography professor at the IUPUI, is an accomplished natural scientist and helped us think about ways to evaluate our work. As an expert in infection control and epidemiology, Steve Wilson inspired us by drawing parallels between our work and the groundbreaking research of John Snow in 19th century London. Snow visually demonstrated an association between cholera infection and residential proximity to the Broad Street pump using what we now might consider simple mapping of disease cases. Snow's method of using maps to help understand disease inspired subsequent work in medical geography, including ours.

To Clean Hands…

With a common goal, we started with computer-aided design (CAD) drawings to create two-dimensional (2-D) and three-dimensional (3-D) models of the hospital floor plans and bed locations. We collected electronic data on patient location, microbiology culture results, and contact isolation orders. However, we were missing a critical piece of the puzzle. It is well known that providers passing between patients without taking appropriate precautions (e.g., washing hands) may be a significant source of infectious spread within the hospitals. We noted that on four wards of the hospital, a prior researcher

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had installed a set of bedside computers for the automated capture of vital signs data [5]. After providers log on to the Vitalnet system, and place appropriate measurement equipment on the patient (e.g., blood pressure cuff), the VitalNet system's time and date stamps all vital signs captured at the bedside by nursing staff. Importantly, this definitively documents a point of physical contact between the health-care provider and the patient. We integrated the various data elements together on the 2-D and 3-D templates of hospital bed locations to create time-sequence animations of the bed locations of patients with MRSA and the health-care providers involved in their care. Over a three-month period, our simple animations clearly demonstrated instances of poor staff hand hygiene (Figure 1) and inadequate ordering of contact isolation precautions [6]. Conservatively estimating a minimum of two minutes to check a full set of vital signs and one minute to wash hands and move between patients, we identified 6,248 instances where providers moved between patients with inadequate time (less than three minutes) to perform adequate hand hygiene. Images convey a powerful message, and we utilized these to spur increased hand hygiene among providers and create subsequent computerized reminders to dramatically improve contact isolation rates [7]. Over the past three years, we observed an almost 50% decrease in rates of hospital-acquired MRSA cases at our study hospital.

A Perspective Outside the Box

Early on in this process, we suspected that patients and providers interact dynamically not only within but also between hospitals. In parallel with our work in one hospital, we enlisted the support of other institutions within Indianapolis and, with funding from the Agency for Healthcare Research and Quality (HHSA290200600013 task order #1), created tools within the Indiana Network for Patient Care to share critical infection data between the infection control providers at all participating institutions [8]. Currently, we deliver electronic alerts on all known patients with MRSA to ensure that infection control providers at admitting hospitals have up-to-date information on infection status and can appropriately institute contact isolation precautions and strict hand hygiene. To date, we have delivered more than 5,000 messages covering over 95% of all inpatient care delivered in Indianapolis.

In addition to clinicians and researchers, we have enlisted the help of industrial engineers, statisticians, and, most recently, engineering experts in complex systems. Our results demonstrated the clear interdependence of hospitals within a region on the infection control efforts of others [9]. As illustrated in Figure 2, the fraction of infected patients treated varies among hospitals, but, most importantly, there is a significant flux of infected patients between hospitals within a region. For some hospital systems, more than 30% of infected patients had been previously treated in another hospital system in the same region, which highlights a need for a coordinated infection control strategy at a regional level. With help from an expert in complex biological networks, we hope to identify means to optimize our coordinated efforts.

Discussion

Bacteria innovate and cooperate. They evolve and adapt to resist antibiotics and can transfer genetic traits between strains. To stay a step ahead, we will have to do likewise. By transferring perspectives and tools from other disciplines, we

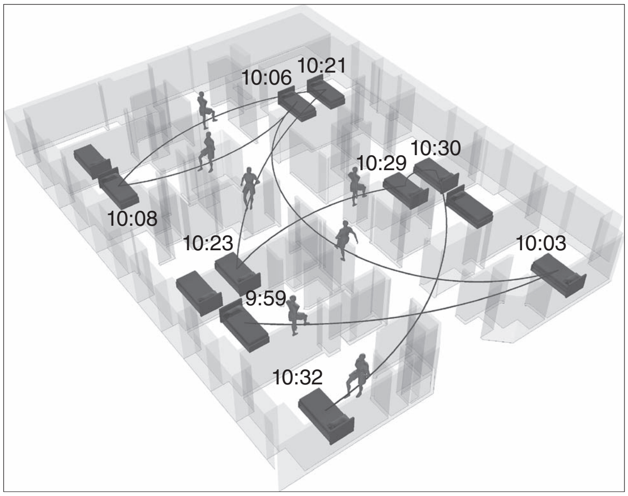

Fig. 1. Visualizing provider movement between patients. In 14% of patient or provider contacts, there was inadequate time for hand hygiene between patients.

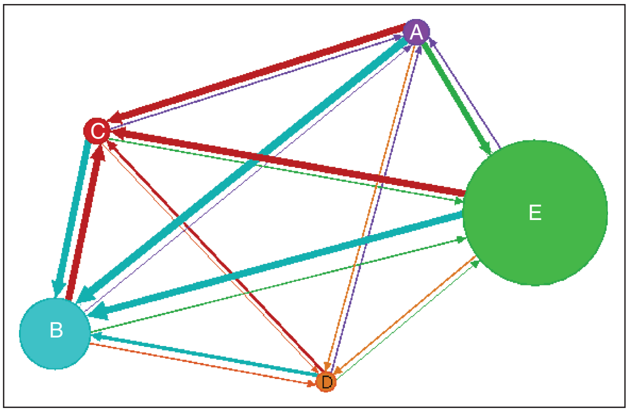

Fig. 2. Movement of MRSA patients between hospital systems within a city. Nodes represent hospital systems. The size of each node is proportional to the percent of total admissions in that hospital with MRSA. Arrow thickness and direction indicate the proportion and flow of patients with MRSA between hospital systems.

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can evolve innovative methods, and by cooperating across institutions, we can turn the tide. Within a hospital, we applied an old principle (mapping diseases to places) using a new technology (GIS) in a novel way to create data visualizations that clearly identify deficient processes. By thinking broadly, we extended our efforts to integrate infection data between hospitals to create the infrastructure for coordinated regional infection control efforts. Along the way, we have shared our challenges with experts in other disciplines, who have unselfishly stepped forward with fresh perspectives and expertise.

Our work has focused on efficiently integrating and visualizing infection data from within and between hospitals and then building interventions to address the problems we find. Tools we develop may be useful to address other problems, and we continue to explore ways to expand our work to involve other institutions and investigators. We have reasons to be encouraged. Our network of collaborators continues to grow, and with funding from the Agency for Healthcare Research and Quality and the Centers for Disease Control, we have teams investigating MRSA spread in both the hospital and community and developing means to disseminate successful interventions widely.

Forty years ago, Sam Regenstrief envisioned industrializing health care to run with the efficiency and safety of a dishwasher factory. Today, instead of a dishwasher in every household, we are working to automate processes to reduce infections across communities. In our experience, developing and disseminating effective interventions to prevent the spread of infections will require a similarly pragmatic approach and an open mind to the tools and expertise of disciplines outside of health care.

Abel Kho completed his medical degree at the Medical College of Wisconsin and a residency and chief residency in internal medicine at the University of Wisconsin. He completed a National Library of Medicine Medical Informatics Fellowship at the Regenstrief Institute, Inc. He is currently an assistant professor of medicine at Northwestern University, where he is the codirector of the Medical Informatics Division. He continues work in Indianapolis as an affiliated scientist at the Regenstrief Institute, Inc. His research focuses on developing novel informatics methods to track and control drug-resistant infections.

Marta Sales-Pardo obtained her Ph.D. degree in physics from Universitat de Barcelona, Spain, in 2002. In 2004, she was awarded a Fulbright Scholarship to pursue her postdoctoral work at Northwestern University. She is currently an assistant research professor at Northwestern University, with joint appointments at the Clinical and Translational Sciences Institute, the Northwestern Institute on Complex Systems, and the Department of Chemical and Biological Engineering. Her research focuses on complex systems, with an emphasis on the analysis of the topological properties of complex interaction networks in biological systems.

Jeffrey Wilson received a bachelor of science in education in 1991 and a master of arts in geography and regional planning in 1994 from the California University of Pennsylvania, Pittsburgh. He received a Ph.D. degree in geography from Indiana State University in Terre Haute in 1998. The same year, he joined the faculty of the Department of Geography the School of Liberal Arts at IUPUI, where he started a graduate program in geographic information science. He is currently an associate professor and chair of geography at IUPUI. His research interests focus on the use of environmental remote sensing, GIS, and global positioning technologies in health and medical applications.

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