Perspective: **Autonomic Care Systems for Hospitalized Patients**

Pascal J. Goldschmidt-Clermont, MD, Chunming Dong, MD, Nancy M. Rhodes, MPH, Diana B. McNeill, MD, Martha B. Adams, MD, Catherine L. Gilliss, DNSc, Michael S. Cuffe, MD, Robert M. Califf, MD, Eric D. Peterson, MD, MPH, and David A. Lubarsky, MD, MBA

Abstract

With advancements of medical technology and improved diagnostic and treatment options, children with severe birth defects who would otherwise have no chance of surviving post birth survive to go home every day. The average lifespan in the United States has increased substantially over the last century. These successes and many other medical breakthroughs in managing complex illnesses, particularly in frail, elderly patients, have resulted in an increasing percentage of patients with comorbidities. This, coupled with a policy change by Medicare (i.e., Medicare will no longer reimburse hospitals for costs associated with treating preventable errors and injuries that a patient acquires while in the hospital), creates an enormous challenge to health care providers. To meet the challenge, the authors propose a new model of health care—the autonomic care system (ACS)—a concept derived from the intensive care unit and the autonomic computing initiative in the computer industry. Using wound care as an example, the authors examine the necessity, feasibility, design, and challenges related to ACS. Specifically, they discuss the role of the human operator, the potential combination of ACS and existing hospital information technology (e.g., electronic medical records and computerized provider order entry), and the costs associated with ACS. ACS may serve as a roadmap to revamp the health care system, bringing down the barriers among different specialties and improving the quality of care for each problem for all hospitalized patients.

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In the case of health care, the cliché that necessity is the mother of invention is more applicable than ever before. Necessity has taken the form of financial pressures placed on health care providers asserted by those paying for health care[1] (including the government), combined with an increasingly informed and sick patient population who demand and deserve better care.[2] Greater consumer inquiry into quality of care, self-referral to better-performing institutions, and the payer push to eliminate imperfect care that leads to preventable injury (the Centers for Medicare and Medicaid Services' "never" events) necessitate a new way to approach the delivery of health care. What is this new path to better care? The greatest advancements are rarely leaps of knowledge; more often, they are the comingling of concepts from different fields. With that in mind, we propose a new model of health care—the autonomic care system (ACS)—a concept derived from a conceptual marriage of the model of an intensive care unit (ICU) and information technology's (IT's) autonomic computing initiative. Our hypothesis is that implementing the ACS will provide a roadmap for a system-based approach that—akin to introducing the ICU in 1854—will vastly change the way care is delivered by streamlining the care of patients with comorbidities.

Please see the end of this article for information about the authors.

Correspondence should be addressed to Dr. Goldschmidt-Clermont, Leonard M. Miler School of Medicine, 1600 NW 10th Avenue, RMSB 1140 (R-699), Miami, FL 33136; telephone: (305) 243-6545; fax: (305) 243-4888; e-mail: (pgoldschmidt@med.miami.edu).

The ICU, Supercomputers, and Hospital Management

When Florence Nightingale was sent to the battlefield of the Crimean War in 1854, she and her nurses found that seriously and lightly wounded soldiers were mixed together. In addition to their battle wounds, the soldiers suffered from mass infections, including typhus, typhoid, cholera, and dysentery. Without being able to prioritize, overworked medical staff were unable to care for these patients well. Staff did not separate patients on the basis of their diagnoses (wound versus infection) or the severity of their illnesses. As a result, death rates were high. During Nightingale's first winter there, 4,077 soldiers died. Moreover, 10 times more soldiers died from infections than from battle wounds. After witnessing this, Nightingale separated seriously wounded soldiers from those who were less seriously wounded and cared for the infected differently. The battleground mortality rate dropped from 40% to 2%, and the concept of intensive care was thus created, marking a revolutionary change in the history of medicine. One hundred fifty-five years of further iterative refinements have led to progressively lower ICU and hospital mortality rates.

However, as medicine's capacity for care improves, the sickness of patients increases. The current delivery system is not perfectly suited to improve the outcomes of increasingly sick patients with increasingly complicated diagnoses because of the increasing incidence of comorbidities in each patient and the unlikelihood of any one person on the medical team having enough knowledge to optimally manage so many concomitant issues all at once. Similar to the necessity of separating individuals with serious wounds from those with light wounds and separating patients with infection from those with noninfectious entities 155 years ago, the sheer volume of comorbid patients today warrants prioritization of, and separate optimization teams for, each medical condition and for each patient in order to optimize outcomes. The ACS is an electronic IT system designed to automatically prioritize a patient's clinical conditions, placing emphasis on the most unstable condition.

The design and ongoing maintenance of the Blue Gene supercomputer, which has an 884,736-processor (i.e., processing power 1,000,000 times greater than that of personal computers) and a 216-rack cluster system packed in a multitude of cabinets (which is comparable to the enormous complexity of processing and repair that is the human organism), represent a substantial intellectual challenge.[3] At any given time, computer chips may fail because of the natural obsolescence of the material. Inspired by the study of biological organisms and their dependence on the autonomic nervous system to control important bodily functions (e.g., respiration, heart rate, blood pressure, tissue repair) without the need for focused, conscious cognitive intervention, the computer industry designed a self-managing system dubbed the "autonomic computing initiative" (ACI). An ACI computer has the ability to manage itself, enabling it to identify a failing chip and automatically switch to a redundant circuit, thus correcting problems without negatively impacting system uptime.
In this self-managing, autonomic computing system, the human operator takes on a new role. He or she does not control the system directly; instead, the operator defines general policies and rules that serve as input for the self-management process. Health care needs an autonomic health care initiative, similar to ACI, to confront today's challenges, in particular the increasing number of patients with comorbidities. We envision that such a system—the ACS—would be a computerized system that automatically prioritizes patients' conditions on the basis of built-in algorithms and calls for the appropriate primary, secondary, and tertiary attending teams. The human operator would come into action at the time of data entry into the system and also when a conflict in the prioritization process needed to be reconciled.

Dealing Health Priorities Within the ACS

With advancements of medical technology and improved diagnostic and treatment options, children with severe birth defects who would otherwise have no chance of surviving post birth survive to go home every day.[4] The average lifespan in the United States has increased substantially over the last century.[5] These successes and many other medical breakthroughs in managing complex illnesses, particularly in frail, elderly patients, have resulted in an increasing percentage of patients with comorbidities.

As the rate of patients with comorbidities in the United States continues to grow, providing optimal health care services for them has become increasingly important. Indeed, 61 million Americans (21% of the entire population) in 2000 had multiple chronic conditions.[6] Furthermore, the prevalence of multiple conditions increases with age. According to data from the 1998 Medical Expenditure Panel Survey, 62% of people aged 65 years and older have multiple chronic conditions, and the percentage is even higher among women.[6] When the baby boomers reach retirement age, the burden of comorbidities is going to be astronomical. Hence, arranging the best care for patients with comorbidities, in particular those in the hospital, is a daunting challenge for the health care industry. Current practice entails generating a thorough problem list for a given patient at the time of his or her clinical visit or admission. The most threatening clinical disorder is addressed first and determines which ward unit the patient will be admitted into. This prioritization is critical to restore the homeostasis of various systems for the unstable patient in a timely fashion. For example, a patient with an acute myocardial infarction (AMI) and consequent pulmonary edema may also have a skin ulcer. Although the skin ulcer can be debilitating, the AMI demands the clinical attention of the care team. To date, attending physicians perform the prioritization; however, in their traditional "artisan" role (i.e., treating each problem as an individual task unrelated to a system-wide solution and working as an individual without regard to the whole system), these physicians may have difficulty not only focusing on the succumbing patient's priority disease but also simultaneously taking care of secondary and tertiary issues that have been downgraded to lesser priorities because of the critical nature of the primary condition. This may lead to the inadequate management of secondary and tertiary issues that could compromise the recovery of the patient. The ACS aims to seamlessly integrate, in an autonomic fashion, focused care for the specific disorder that requires hospitalization and preventive or treatment maneuvers for less severe and/or urgent conditions. This system will allow for optimal management of patients with comorbidities by assigning the care of each condition to the appropriate team according to disease severity and urgency.

The ACS presents two key challenges. One is designing and engineering the comorbidity algorithm. A prototype for the ACS may lie in the recent development of rapid response teams for patients "circling the drain." These teams automatically respond when critically ill patients meet certain conditions of physiologic deterioration.[7] Another possible solution may be adaptation of the Charlson comorbidity index. Although this index was developed for deciding which disease(s) should *not* be treated, it could be modified to prioritize the list of illnesses that *should* be treated.[8,9] Indeed, the ACS algorithm could be based on the combination and further expansion of the rapid response team system with a modified Charlson comorbidity index. Importantly, the ACS can be integrated with electronic medical records (EMRs), computerized provider order entry (CPOE), and other electronic information systems that augment these systems and that are already deployed in many major hospitals across the United States. The second challenge relates to who should be the coordinating operator of this automatic system-based approach to care. Similar to autonomic computing systems, in which the human operator does not control the system directly but, rather, defines general policies and rules that serve as input for the self-management process, the human operator of the ACS would come into play only when there is a conflict in the prioritization process. Ideally, in the long term, like specially trained intensivists who staff ICUs, the human operators for ACS would be specially trained ACSists. These ACS operators would have additional training to their medical care education to include systems management, trend identification, conflict resolution, negotiation, and leadership. In the short term, we could argue that the attending physician should be the person who is first called. But it is appropriate to consider alternatives, such as a team leader, be that person a hospitalist or a highly trained nurse.

We propose that developing and implementing the ACS will require a phased-in approach. In the first phase, specialized types of ACS, such as pediatric ACS, surgical ACS, neurological ACS, and myocardial ACS—analogous to specialized ICUs (i.e., the pediatric ICU, surgical ICU, neurological ICU, and cardiac care unit, respectively)—will be developed. We envisage that the ACS will ultimately result in the convergence of all the fields in medicine, in such a way that all of the medical conditions of a given patient and all of the patients will be managed in a systematic and autonomic fashion.

The ACS as Systems-Based Care

To illustrate how ACS would work in a real-world hospital setting, we will examine how it would benefit the aforementioned patient with AMI and the skin ulcer wound. The skin ulcer, although not as acute as the AMI, may nevertheless have significant implications in the outcome of the patient during or immediately after the acute destabilization period. If not properly managed, the skin ulcer could become infected and compromise the otherwise successful care of the patient. The significance of caring for the skin ulcer is further underscored by a Medicare policy change—that is, Medicare will no longer reimburse hospitals for costs associated with treating preventable errors, including skin ulcers and injuries that a patient acquires while in the hospital.[10] Historically, the skin ulcer and other secondary and tertiary diseases have been managed by the expert team managing the AMI. However, the AMI team, typically composed of an attending physician, extender, and nurse (plus trainees for academic hospitals), may not be the most knowledgeable or efficient care providers for the skin wound. Even worse, the AMI team may ignore the skin ulcer altogether in the context of the substantial challenge of managing the AMI. Hence, the availability and timely deployment of a team specializing in wound care could systematically address the skin ulcer in the case of the patient with AMI—and in every other case in which such a wound might affect the patient's outcome. The wound care team would typically comprise experts—physicians, nurses, physician assistants, technical associates—in that field. The wound care team would round daily to address all wound-related illnesses or complications in any hospitalized patients who require wound care, and the team would provide the most appropriate and advanced treatment strategies. The treatment of other secondary and tertiary problems would be addressed similarly by other appropriate teams.

But the challenge is coordinating the care of these secondary and tertiary problems, such that the treatment of these will not interfere with the primary problem, and that mutually exclusive approaches to care (e.g., deep vein thrombosis prophylaxis in a patient with a friable and frequently bleeding skin ulcer) will be resolved. Experience with CPOE suggests that computer-based algorithms noting where potential conflicts in care might arise are one way to promote timely and efficient care of all comorbidities, preventing them from flaring up and negatively impacting the patient's outcome. The ACS is designed to coordinate the process of care activities for secondary, tertiary, and other comorbid conditions so that they intersect with, but do not overlap, the daily rounding by the attending for the primary problem.

Notably, many remarkable safety initiatives have developed in top medical centers in response to the Institute of Medicine (IOM) report, "To Err Is Human."[11] For example, physicians have taken substantial measures to eliminate adverse events resulting from drug errors or transfusion mismatches. Many of these initiatives, however, have focused on analyzing the *root causes* of the problem, rather than on developing a comprehensive system for *managing* these problems. The concept of the ACS is to build a system that efficiently and autonomically manages most, if not all, of the problems for a patient, such that medical errors will be significantly reduced or even eliminated. Much of medicine's focus has been on reducing errors of commission— do not do wrong-side surgery; give the right drug to the right patient. Failing to do the right thing can be just as consequential as doing the wrong thing, and avoiding both of these requires a more perfectly designed system. The ACS will eliminate most errors of omission because all the latest available knowledge and care maps will be automatically deployed when a problem is noted. Indeed, many aspects of the care of hospitalized patients could be optimized via the deployment of the ACS (Figure 1). Take the wound care service as an example. The algorithm of the ACS would be built in such a way that the wound care team would receive alerts about the presence of risk and about precipitating factors for ulcers in all patients in the hospital as well as deployment orders for those patients who already have ulcers. The wound care team could be organized such that a specific member of the team (a nurse, for example) would inspect all patients with risk and precipitating factors for the potential emergence of wounds, and that team member would treat the already-affected patients if the wounds were manageable within his or her expertise. For more serious wounds, he or she would communicate with the other members of the wound care team, attending central meetings organized by the wound care team, during which all members would present and discuss cases, review the ongoing progress with regard to the most serious wound problems in the hospital, and interface with infectious disease specialists,

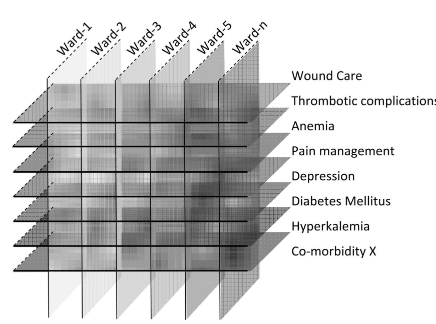

Figure 1 Matrix integration of traditional care and autonomic care systems. Patients are admitted to ward units on the basis of their dominant medical problems, according to the traditional care approach (y-axes). Secondary and tertiary health problems are addressed concurrently in a near-autonomic fashion that is integrated with, but does not overlap, the work of the primary care provider team (x-axes), whose work remains the overarching priority in the hierarchy of clinical activities.

vascular surgeons, and other experts. The wound care team would work together with the primary care team to manage the patients with serious wounds. As a result, patients in the hospital would benefit from the best wound care available.

One could easily identify a list of nearly 20 coexisting problems in many hospitalized patients (Figure 1). The ACS programs could be developed to cover most, if not all, of the items on patients' problem lists so that the secondary and tertiary illnesses would be prevented and cared for concurrently and automatically or autonomically (relative to the care for the primary disease that required hospitalization). Indeed, in many hospitals diabetes mellitus care is already often organized in a way consistent with the ACS model. Specialized teams manage many problems besides glucose control—problems such as an irregular hemostatic system, hyperkalemia, smoking cessation, obesity, pain, and hypertension.

The Benefits and Costs of ACS

Implementing the ACS will, like the advent of ICUs, change the way medicine is practiced. The ACS is the next step on the roadmap to systematically meeting the goals of patient safety (care should be safe, effective, timely, patient-centric, efficient, and equitable) for every patient. It will bring down the barriers between specialties because central organization and prioritization are key features of the ACS. The ACS will streamline the care of patients with comorbidities in all areas, substantially expanding the current scope of the rapid response teams for critically ill patients and the management of the comorbidities of diseases. The ACS programs could considerably improve the quality of patient care and save the lives of many patients by preventing the recurrence and complications of otherwise less-well-managed secondary and tertiary illnesses. Although an initial investment is required to install the ACS, the timely and expert care for the secondary and tertiary problems will likely shorten the length of stay for hospitalized patients, thus creating an opportunity to sustain the ACS financially through substantial savings. Within the University of Miami Health System, an integrated hospital system of 500 beds, reducing length of stay by 0.1 day can result in annual savings of over a million dollars, or $131,000 per month, in labor costs, an amount sufficient to finance a notification system and multiple teams. Once hospital systems invest in enterprise-wide EMRs, then notification and optimization strategies will require only additional programming costs rather than independent system development, and funding the ACS will be even easier. Regardless, as in the case of wound care, many of the care approaches encompassed in the ACS programs would probably be cost-effective as stand-alone programs. Even if deploying and maintaining the ACS does increase the cost of care slightly, the improved quality of care will be well worth the investment—quality speaks, and ultimately pays, for itself. ACS specialists are the next evolution of hospitalists, and together with the ACS, they will greatly enhance efficiency, which could potentially offset any increase in health care costs. Progressive evolution in reimbursement trends that reward quality could also support the panoply of the ACS programs required for outstanding care. Moreover, care providers who traditionally participate in the care of inpatients in their specialized units may share in a small, but significant, fraction of the emotional rewards of identifying and treating secondary and tertiary problems for patients in other units. In doing so, every care provider, whether physician, nurse, physician assistant, or trainee, will feel increasingly rewarded for his or her contribution to the overall quality of care delivered at the institution. The awareness of individual contribution will increase the well-being, motivation, and enthusiasm of health care providers. This will, in turn, enhance the quality and attitude with which they deliver care and, consequently, increase patient safety and satisfaction.

Concluding Remarks

As described in the IOM report "To Err is Human,"[11] the problem is not that hospital care providers are not committed to improving the health of their patients; rather, the problem is a lack of system implementation and a lack of provider awareness of the systems that do exist to make care safer. Whereas most physicians spend a significant amount of time, sometimes entire careers, in understanding a disease, its progression, and its mechanisms, they commit very little time to understanding hospital systems. To implement the ACS, there has to be a process to ensure that care providers are aware of the system of care. Most hospitals are in the situation of design-in-transition; they are evolving from a "workshop" for individual physician artisans to a more complex, organized system of care. The problem is that they do not have a roadmap. We suggest that ACS—an integrated, automatic solution that delivers safe and quality care for all problems of all patients—is the revolutionary destination toward which hospital systems should strive. The ACS, similar to the self-managing system of a supercomputer, is designed to organize, in a nearly autonomic manner, the most educated and dedicated workforce in each specialty in order to provide the best care for every health problem that plagues every patient in the hospital.

Importantly, this autonomic approach should not remove, in any way, the essential responsibility of the care provider attending an individual patient's needs; nor should this approach impact the patient's right to choose what is done to his or her body. No electronic system could ever replace the effect of the intense human vigilance, expertise, concern, and compassion of doctors and nurses as it relates to safe, quality care of another human being. These human functions represent the cognitive versus autonomic parts of the "brain" of the hospital. Human intelligence is particularly important when the ACS requires additional oversight and input in making prioritization (cognitive) decisions. The ACS can complement seamlessly and harmoniously the work of the expert lead care provider.

Dr. Goldschmidt-Clermont is senior vice president, University of Miami, and dean, Leonard M. Miller School of Medicine, University of Miami, Miami, Florida.

Dr. Dong is associate professor of medicine, Leonard M. Miller School of Medicine, University of Miami, Miami, Florida.

Ms. Rhodes is associate dean, Duke University School of Medicine, Durham, North Carolina.

Dr. McNeil is professor of medicine, Duke University Medical Center, Durham, North Carolina.

Dr. Adams is professor of medicine, Duke University Medical Center, Durham, North Carolina.

Dr. Gilliss is dean, Duke University School of Nursing, Durham, North Carolina.

Dr. Cuffe is vice president, Duke University Health System, Durham, North Carolina.

Dr. Califf is vice chancellor, Duke University Health Affairs, Durham, North Carolina.

Dr. Peterson is associate director, Duke Center for Translational Research and Clinical Research Institute, Durham, North Carolina.

Dr. Lubarsky is senior associate dean, Leonard M. Miller School of Medicine, University of Miami, and Emanuel M. Papper Professor and chair, Department of Anesthesia, Leonard M. Miller School of Medicine, University of Miami, Miami, Florida.

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In 1960, Yale-New Haven Hospital opened the first intensive care unit for newborns in the United States.

For other important milestones in medical knowledge and practice credited to academic medical centers, visit the "Discoveries and Innovations in Patient Care and Research Database" at (www.aamc.org/innovations).