The Laryngoscope
Lippincott Williams & Wilkins, Inc.

Quality and Safety in a Complex World: Why Systems Science Matters to Otolaryngologists

David W. Roberson, MD; Erna Kentala, MD; Gerald B. Healy, MD

Almost all modern medical care is delivered in the setting of many overlapping systems. Each system may consist of multiple providers and in most cases electronic and mechanical components. Even "simple" outpatient care is delivered by teams of providers, administrators, and devices. Critically ill inpatients are cared for in extraordinarily complex systems with hundreds of human and non-human elements. The science of complex systems has exploded in recent decades, and there is a large body of knowledge about how such systems function effectively or ineffectively. Many principles of systems science are simple to understand and apply, but few Otolaryngologists are well educated about them. A basic knowledge of systems science will greatly improve the Otolaryngologist's ability to function in complex health care systems and to provide the best care for his or her patients.

***Laryngoscope*, 114:1810–1814, 2004**

INTRODUCTION

Almost all modern medical care is delivered in the setting of many overlapping systems, each consisting of multiple providers and in most cases electronic and mechanical components. Even "simple" outpatient care is delivered by large teams of providers, administrators and devices. Critically ill inpatients are cared for in extraordinarily complex systems with hundreds of human and non-human elements.

Medical education in the United States is based primarily on the apprenticeship training advocated by Flexner's report almost 100 years ago. At that time, almost all medical encounters consisted entirely of one doctor and one patient. Therefore, medical training focuses exclusively on the student and resident learning how to work alone to diagnose and treat individual patients, one at a time. Only a small number of American physicians have received formal instruction about systems analysis as part of their medical education.

The science of complex systems has exploded in recent decades, and there is a large body of knowledge about how systems function effectively or ineffectively.[1–7] Medicine has been slow to incorporate this knowledge. Since physicians practice, by default, in complex systems, most have learned some basic systems principles by trial and error. Too often, however, physicians attempt to solve systems problems with skills that are appropriate for patient interactions but are destined to fail in complex systems. We believe that a basic knowledge of systems science can greatly improve the Otolaryngologist's ability to function in the complex health care world. The importance of systems science led to the Accreditation Council on Graduate Medical Education's decision to include "systems-based practice" as one of the core competencies that all residents must learn.[8]

This article presents a brief background in systems science with medical examples. We discuss an operational definition of a system, types of systems that are relevant to the Otolaryngologist, and principles for improving safety and performance in complex systems.

WHAT SYSTEMS ARE

An operational definition of a system is "a set of interdependent elements interacting to achieve a common aim."[3] Systems range from the gigantic ("the US health care system") to the very small ("the system we use to book appointments").

The importance of very large systems (e.g., Medicare) to patients and physicians is obvious. Although an individual physician will rarely affect these systems at a national level, application of good systems practices may lead to substantial local improvement, even without national changes. An important observation of systems science is that appropriate local change may have positive impact out of proportion to the size of the change.

Very small systems ("how we sterilize our instruments") will often respond to interventions in predictable

From the Department of Otolaryngology, Children's Hospital, and the Department of Otology and Laryngology, Harvard Medical School, Boston, Massachusetts, U.S.A. (D.W.R., G.B.H.), and the Department of Otolaryngology, Helsinki University Central Hospital, Helsinki, Finland (E.K.).

Supported in part by the Joshua Shapiro fund for Surgical Education.

Editor's Note: This Manuscript was accepted for publication March 18, 2004.

Send Correspondence to David W. Roberson, MD, Department of Otolaryngology, Children's Hospital Boston, 300 Longwood Ave, Boston, MA 02115, U.S.A. E-mail: david.roberson@tch.harvard.edu

fashion; the application of systems science to such small systems may not provide a great deal of added value.

The focus of this article is therefore on medical systems of intermediate size. Examples include a practice group, a hospital committee, an operating room team, and an intensive care unit (ICU). Although these systems have been called "micro-systems" to emphasize their small size relative to national systems,[6] they are extremely complex. An operating room team may include several surgeons and assistants, anesthesiologists, and nursing and support staff, and multiple mechanical and electronic devices. Each system element interacts repeatedly with many of the other elements. The nurse who provides lunch relief interacts with the relieved nurse, the scrub nurse, the surgeon and anesthesiologist, and dozens of devices. Every interaction is influenced by the clinical scenario and each individual's role, training, and personality. The immense complexity of the interactions makes it impossible to accurately predict all aspects of the system's behavior, particularly in unusual or stressful situations.

WHY SYSTEMS SCIENCE MATTERS TO THE OTOLARYNGOLOGIST

There is a well-defined body of knowledge about systems, and its application to medical systems is of immense practical value. Although the behavior of complex systems can never be predicted in detail, certain principles almost always hold true. Strategies that are effective for navigating and improving systems are often different from strategies effective for managing one-on-one interactions such as patient encounters.[3]

A simple, but critical, example is that there is a minimum human error rate that can never be entirely eliminated. Any system that relies on a single individual for critical decisions will have an irreducible minimum of errors. In the crash of two 747 jets in Tenerife in 1977, the co-pilot twice warned the pilot that the other jet might not be clear of the runway. The captain, the chief pilot trainer for KLM, ignored the warnings. The futility of trying to prevent such events by "improved pilot training" is obvious. This individual was the best-trained pilot in his airline. Like all humans, however, he was subject to rare errors. Unfortunately, he was operating in a hierarchical culture with no buffer between his error and catastrophe.

Systems science, applied to the cockpit, has led to a change in the system of decision-making. All airline crews now undergo training in collaboration and team decision-making ("crew resource management"). Junior crew learn to raise safety concerns clearly; senior crew learn the value of having a check on their own errors.[9] The manner in which the co-pilot's input is sought will vary with the situation. Prior to takeoff, a co-pilot's safety concern might trigger a complete, unhurried re-evaluation. In an airborne emergency, it is obviously impossible to hold prolonged discussions, but the co-pilot is still expected to quickly communicate key concerns, and the pilot to listen to focused input on critical issues.

The situation in the airline industry has clear parallels in medicine. One is a frequent reliance on (and cultural expectation of) individual decision-making, even in circumstances where error could be catastrophic and additional input readily available. Another is a hierarchical culture, in which subordinates may withhold input because they may fear criticism or reprisal.[10,11]

Obviously, aviation and medicine are not identical, and not every practice that works in the cockpit would work in the ICU.[12] The larger point is that some features are almost universal in highly effective systems.[4] Objective study of a variety of outstanding medical systems has shown that they share many features with high performing systems in other industries.[6]

WHAT IS KNOWN ABOUT HIGH-PERFORMANCE SYSTEMS

Common Aims Are Essential

If an otolaryngologist's primary goal is to start the challenging last case of the day by noon, and the resident's primary goal is to practice suturing technique during the simpler morning cases, and the nurse's primary goal is to ensure that sterility is maintained and counts are correct, all will probably be frustrated by day's end. The otolaryngologist may believe that "system change" consists of simply ordering the others to work faster. However, if the others have different (usually legitimate) aims, ongoing conflict is inevitable. Even if the surgeon can force the others to speed up, the frustrated team is unlikely to work well together to produce outstanding care during the challenging afternoon case.

The only course likely to lead to genuine improvement is to identify all parties' aims and collaborate to try to meet at least some of them. The attending otolaryngologist could devote some focused time to teaching the skills the resident is most eager to learn; the surgical team could work with the nurse to facilitate sterility and counts; and all could work together to start the last case promptly. If there is a history of difficult interactions, this type of open discussion may be difficult initially, but it is the only way to bring about durable improvement.

There is no substitute for common aims. If system elements have genuinely divergent aims, no system will ever work well. If a hospital administration cares only about finances, and medical staff care only about quality care, dysfunction will persist indefinitely. To improve function, the first step is to find common goals to build on.[13] Everyone's aims need not be identical, but there must be some shared goals and collaboration so that everyone's goals are respected. If physicians want administrators to pay more attention to care quality, the best first step may be to demonstrate that they will pitch in to address financial issues.[14]

Outstanding Systems Are Constructed from Outstanding Elements

Medicine has focused on training high quality system "elements"—doctors, nurses, and other providers. A major feature of training is the acceptance of individual responsibility. Physicians may fear that introducing a "systems approach" will encourage individuals to shirk responsibility for their own performance.[15,16]

In reality, high performance systems can only be constructed of outstanding elements. High-performing industries invest heavily in education, training, and continual retraining. An outstanding ICU team can only be created from outstanding physicians, nurses, respiratory therapists, and administrators.

Therefore, the trainee who truly understands systems will understand that his or her individual performance is critical to successful system performance. The systems-educated trainee should continue to take responsibility for his or her own performance, but will have the added advantage of being able to analyze and improve his or her interactions with other system elements to create a whole that is greater than the sum of the parts.

Complex Systems Are Unpredictable

Complex systems are too large to model deterministically, and they may exhibit unintended or unexpected consequences following changes. The appearance of unexpected consequences is known as "emergent behavior" and is essentially universal in large systems.[17] This pitfall may be particularly easy for the otolaryngologist to fall into. He or she may be used to simpler cause-and-effect behavior ("when I place tubes, the hearing improves") and may expect a complex system such as an ICU team to respond to interventions in similar straightforward fashion. Complex systems, however, almost always exhibit unintended consequences. Therefore, it is wise to make changes incrementally, to test them on a small scale when possible, and to be alert for unanticipated sequelae during periods of change.[18]

A more pleasant corollary is that small appropriate changes can have large positive effects. A practice that institutes a feedback process between nurses and physicians, shortens transcription time, and introduces a standardized mechanism for following up on laboratory reports may find that improvement in overall practice function far exceeds their expectations from these modest changes.

Feedback Loops Improve Performance

To be most effective, feedback should be direct, rapid, specific, and constructive. Relaying feedback through a third party, on a written form or after a long delay, is unlikely to be effective. Feedback loops should operate all the time, for good as well as bad performances.[13]

A resident who is told immediately and calmly following rounds every day what he did well and what he needs to work on will often improve; a resident who is given a written form with a single numerical score at the conclusion of a rotation may improve, but it will not be because of the form.

Standardization Improves Function for Repetitive Processes

If every surgeon in a group orders different preoperative laboratory studies, confusion is likely. A patient may be brought into the operating room with pending or abnormal results because operating room personnel do not know which surgeons order which tests. If every member of a practice has a different way of checking pathology reports, failures are more likely. The effectiveness of clinical practice guidelines is probably often due not only to the superiority of the guideline, but also to the standardization itself.

Standardization should be brought to bear on repetitive processes. It should also be instituted intelligently and input from front-line workers is critical. The former Soviet Union is a powerful example of how standardization can be applied from the top down in a catastrophic fashion.

Standardization should be avoided for rare processes. It not only would be inefficient, but also would lead to inappropriate care, to standardize the diagnostic workup for a disorder seen only once a year in a given practice.

Standardization Is Only the Baseline

In high-performing systems, front-line personnel typically have great freedom of action when dealing with unexpected situations.[19] On aircraft carrier decks, for example, junior officers can change orders on the spot for unexpected safety concerns.[4] Since human physiology, illness, and treatment is almost infinitely complex, physicians will always have to act with a high degree of autonomy.[5,6] Standardized diagnostic or treatment protocols should never limit the physician confronting the unusual or unexpected situation.

It should be emphasized that deviation from standardized care should result in better care, not substandard care. In medicine today, "customization" is too often a euphemism for care that falls below the baseline of best current standards.[5] The physician who deviates from a protocol when confronting an unusual or complex situation, and who has a clear rationale for the deviation, is probably performing in an exemplary fashion. The physician who simply refuses to participate in or follow standardized care protocols is unlikely to be delivering best quality care.

Shortened Cycle Time Improves Function

Errors will be reduced and efficiency will rise if charts are available more promptly, dictations are completed sooner, and phone messages are delivered promptly. Shortened cycle time at any point in a system process will improve function, often out of proportion to expectations.[3,20]

System Features Should Be Driven by System Goal

Features that work well in one system may fail in another. If a system goal is to ensure that all pathology reports are called to the patient, system features should include multiple checks, and fault tolerance (a built-in method for "catching" and fixing errors). Since human errors are inevitable, the failure rate can only be reduced toward zero by some form of redundancy.

If another system goal is to reduce the waiting time for new patient appointments, redundancy and multiple checks may impose an unreasonable administrative burden. A small failure rate may be preferable to the administrative burden associated with reducing the failure rate to zero.

Human Error Is Ubiquitous

Roughly 60 to 80% of airline, industrial, and medical accidents involve some preventable human error.[1,21] Physicians and pilots share an unrealistic perception of their abilities under stress; in one study, one-third of ICU staff denied ever making errors.[22] Unfortunately, denial of fallibility can prevent error mitigation. A physician who is ashamed to acknowledge a misdiagnosis cannot draw on colleagues' experience and support to cope with the consequences.

Therefore, most high-performing systems have a culture that treats individual error as normal and expected.[19] These systems are designed to "absorb" errors, and/or mitigate their consequences.[4] Examples of "fault-tolerant" medical systems are computerized pharmacy dosage checks and "read back" protocols in which nurses repeat verbal orders to doctors.

Although errors in judgment are normal and must be accepted, high-performing systems rarely tolerate egregious misconduct or haphazard deviation from protocols designed to reduce errors or ameliorate consequences.[19] In medical culture, however, following protocols may be considered mundane, and bending or breaking rules covertly admired. For example, in one of the author's hospitals there was significant resistance to a new policy requiring surgeons to initial the operative site prior to induction.

Respect for Persons Improves System Performance

High-performing systems typically respect their personnel. They may be hierarchical but they respect junior team members, solicit their input, and ensure that their contribution is valued. A system that uses all members' skills to the maximum will outperform one in which junior personnel are expected to "shut up and work."[13,19]

A hierarchy of authority is essential to medical practice. In a code team, there must be a leader with authority to direct resuscitation efforts. However, a hierarchy of communication, in which junior team members may be criticized or penalized for speaking up—a "blame and shame" culture[10,11]—undermines superior performance.[13]

Strong, Constructive Leadership Is Essential

Real-world systems will not implement effective practices without effective leadership.[13,23,24] If feedback loops are absent, someone must take charge of putting them in place and determining whether improvement follows. If system members have divergent aims, someone must take responsibility for identifying common goals and building on them. Since physicians make many of the critical decisions in health systems, physician leadership is an indispensable component of health care system improvement.[14,25]

Effective leadership in the high-performance system may have hierarchical features, but it is quite different from what is traditionally considered hierarchical leadership. In high-performing complex systems, effective leaders lead by example, actively solicit input from front-line workers, and create a culture in which excellence and continuous improvement is the norm. Leadership by decree may create systems that perform quite well—many excellent medical and surgical departments are currently led in fairly authoritarian fashion—but it will not, in general, create the highest possible performance. Consider again the leadership on the KLM 747 in Tenerife. The captain led by decree, and his system performed at an extremely high level. Had he been more willing to solicit input, his authority would not necessarily have been weakened, but his system likely would have performed at a slightly higher level at a crucial moment.

CONCLUSIONS

Physicians are trained to manage individual interactions and to expect straightforward responses to interventions. Physicians who unsuccessfully address a system problem with one-on-one strategy may oversimplify the reason for failure ("the administration doesn't care") or accept dysfunction as inevitable.

In reality, medical care is provided in complex systems that cannot respond simply to interventions. Otolaryngologists who understand basic systems science will be less frustrated when they encounter this reality. They will then be able to analyze issues in these systems and take actions likely to bring about real and lasting improvement.

Acknowledgments

The authors gratefully acknowledge helpful discussions with James Bagian, Rick Blum, Larry Duckert, David Gaba, Jordan Halasz, Dan Raemer, Ajit Sachdeva, Molly Zirkle, and many other colleagues. We thank Jeff Cooper, Trevor McGill, Mary-Russell Roberson, and Rahul Shah for comments on the manuscript and Captain Yo Hoffner of United Airlines for reading an early version of the section on airline safety.

BIBLIOGRAPHY

1. Perrow C. *Normal Accidents*. New York: Basic Books, 1984.
2. Reason J. *Human Error*. Cambridge: Cambridge University Press, 1990.
3. Nolan TW. Understanding medical systems. *Ann Intern Med* 1998;128:293–298.
4. Kohn L, Corrigan J, Donaldson M. *To Err Is Human: Building a Safer Health System*. Washington, D.C.: National Academy Press, 2000.
5. Committee on Quality of Health Care in America IoM. *Crossing the Quality Chasm: A New Health System for the 21st Century*. Washington, D. C.: National Academy Press, 2001.
6. Nelson EC, Batalden PB, Huber TP, et al. Microsystems in health care: Part 1. Learning from high-performing front-line clinical units. *Jt Comm J Qual Improv* 2002;28: 472–493.
7. Bar-Yam Y. *Dynamics of Complex Systems*. Reading, MA: Perseus Books, 1997, p. 848.
8. ACGME. Outcomes project. http://www.acgme.org/outcome; Accessed 2003.
9. Helmreich RL, Merritt AC, Wilhelm JA. The evolution of Crew Resource Management training in commercial aviation. *Int J Aviat Psychol* 1999;9:19–32.
10. Liang B. The adverse event of unaddressed medical error: identifying and filling the holes in the health-care and legal systems. *J Law Medicine Ethics* 2001;2:346–368.
11. Shine KI. High care quality and how to achieve it. *Acad Med* 2002;77:91–99.
12. Helmreich RL. On error management: lessons from aviation. *BMJ* 2000;320:781–785.
13. Edmondson AC, Bohmer R, Pisano GP. Speeding up team learning. *Harvard Business Review* 2001;79:125–132.
14. Clemmer TP, Spuhler VJ, Berwick DM, Nolan TW. Cooper-

ation: the foundation of improvement. *Ann Intern Med* 1998;128:1004–1009.
15. Wu A, Folkman S, McPhee S, Lo B. Do house officers learn from their mistakes? *JAMA* 1991;265:2089–2094.
16. Casarett D, Helms C. Systems errors versus physicians' errors: finding the balance in medical education. *Acad Med* 1999;74:19–22.
17. Weick K, Roberts K. Collective mind in organizations: heedful interrelating on flight decks. *Admin Sci Q* 1993;38: 357–381.
18. Norman D. *Things That Make Us Smart: Defending Human Attributes in the Age of Machines*. Menlo Park, CA: Addison-Wesley Publishing, 1993.
19. Reason J. *Managing the Risks of Organizational Accidents*. Burlington, VT: Ashgate Publishing Company, 1997, p. 241.
20. Nelson EC, Batalden PB, Homa K, et al. Microsystems in health care: Part 2. Creating a rich information environment. *Jt Comm J Qual Improv* 2003;29:5–15.
21. Cooper JB, Newbower RS, Long CD, McPeek B. Preventable anesthesia mishaps: a study of human factors. *Anesthesiology* 1978;49:399–406.
22. Sexton JB, Thomas EJ, Helmreich RL. Error, stress, and teamwork in medicine and aviation: cross sectional surveys. *BMJ* 2000;320:745–749.
23. Carroll JS, Edmondson AC. Leading organizational learning in health care. *Qual Saf Health Care* 2002;11:51–56.
24. Simone JV. Understanding academic medical centers: Simone's Maxims. *Clin Cancer Res* 1999;5:2281–2285.
25. Reinertsen JL. Physicians as leaders in the improvement of health care systems. *Ann Intern Med* 1998;128:833–838.