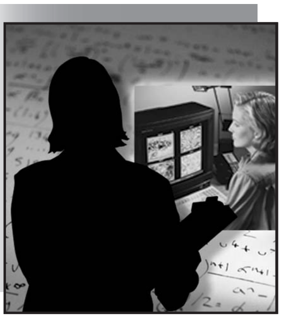

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Clinical Engineers: Stewards of Healthcare Technologies

Implications of Technology Adoption and Integration on Healthcare Delivery Processes

BY STEPHEN L. GRIMES

Clinical engineers need to act as stewards of healthcare technology. They must facilitate the adoption of new technologies where appropriate; standardize effective technologies; and strive to achieve tighter integration between diagnostic, information-processing, and therapeutic systems. It is in this role that clinical engineering has the opportunity to make its most significant contribution to the healthcare process.

The Nature of Technology

The nature of "tools" is to extend natural human abilities. From prehistoric man's use of the club for hunting to the application of nanotechnology to perform surgery at a cellular level, humankind has and will always identify and create tools to leverage and extend our natural mental and physical abilities.

Tools, or what we more broadly refer to as *technology*, have enabled us to travel greater distances in shorter spans of time, to operate in such diverse and harsh environments as the lowest depths of our oceans and on the surface of our moon, to be able to view individual atoms, and to peer into the furthest reaches of our universe.

Unarguably, technology has enabled us to do great things, to extend the length and improve the quality of human life and provide an abundance of other benefits to humankind. But technology has also been applied for darker purposes. Wars and conflicts over history have occurred on ever-grander scales and with more devastating effects because of advances in weaponry and other technologies. Within the memory of this generation, we have achieved the ability to effectively destroy ourselves and a substantial number if not the majority of the life forms on this planet. And there is the "law of unintended consequences" in which adverse effects occur even when our application of technology is well intended or at least benign. Contagions that took years to spread between continents a few generations ago now make the intercontinental jump in hours because technology has made us highly mobile. Over the past 150 years, technological advances have spawned industries that produced gases that some experts suggest will threaten the earth's protective ozone layer and raise the average world temperatures to the point that melting polar ice threatens to raise sea levels and push back continental shorelines.

Technology itself is not innately good or bad; technology's value is in how it is applied and contributes to a process. Its application in a process can be beneficial or detrimental. Because of the "law of unintended consequences," it can often be both to varying degrees. The factor determining technology's ultimate effect is the human element. It is man's knowledge, his understanding of the implications of its application, and his motivation that ultimately determine the degree to which technology's effects are positive or negative.

There are few areas in which technology has been applied with greater benefit and success than in healthcare. Advances in research, diagnosis, and treatment—particularly during the past couple of generations—have significantly contributed to both the length and quality of human life.

While it is the practitioners' knowledge, experience, and commitment that provide the "heart and soul" of healthcare, it is technology that has come to provide the "body," i.e., those elements that dramatically leverage and extend the individual practitioners' abilities.

A History of Healthcare Technology

There is evidence of "healthcare technology" as far back as prehistoric times. Skulls have been excavated from sites of ancient communities that show evidence of successful craniotomies, bearing the marks of primitive surgical tools. For thousands of years, healthcare technology advanced slowly. Where ancient healthcare tools were first likely made of bone and stone, they were replaced in subsequent millennia by copper, bronze, iron, and eventually steel and now the silicon chip. With the change of available materials, medical tools became finer and more specialized but remained still relatively unsophisticated until the relatively recent past. A few of the more notable technological advances in healthcare are illustrated in the following chronology:

- In 1612 the *medical thermometer* was invented by Italian physician Sanctorius.
- In 1660 the *light microscope* was invented by Dutch naturalist van Leeuwenhoek.
- In 1810 the *stethoscope* was invented by French physician Laennec.
- In 1853 the *hypodermic syringe* was invented independently by French surgeon Pravaz and Scottish physician Wood.
- In 1895 the *x-ray image* was first produced by German physicist Roentgen.
- In 1906 the *electrocardiograph* was invented by Dutch physiologist Einthoven.

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- ➤ In 1950 *nuclear medicine* was first applied to imaging.
- ➤ In 1957 *fiber endoscopy* was first applied to examinations of internal anatomy by South African physician Hirschowitz.
- ➤ In 1958 the *implantable pacemaker* was designed by American engineer Greatbatch.
- ➤ In 1960 *ultrasound imaging* of the human anatomy was first applied.
- ➤ In 1972 the *computerized tomography* scanner was invented by British engineer Hounsfield and South African physicist Cormack.
- ➤ In 1980 *magnetic resonance imaging* was first applied.
- ➤ In 1980 the *implantable cardiac defibrillator (ICD)* was first implanted.
- ➤ In 1985 the *positron emission tomography* scan was first applied.

Major developments, advances, and significant refinements in healthcare technology have occurred at an ever-increasing pace over the past 40 to 50 years. New technologies are constantly emerging and obsolescing the old. Technologies are increasingly integrating to improve efficiency and interoperability. As a consequence, the ability to effectively select, acquire, operate, and maintain the variety of available technologies has gone beyond the capability of most individual healthcare practitioners. That trend is certain to continue.

Stewards of Healthcare Technology

Clinical engineering was conceived nearly 40 years ago to address the need for a professional who would "support and advance patient care by applying engineering and management skills to healthcare technology" [definition of "clinical engineer," American College of Clinical Engineering (ACCE)]. The majority of clinical engineers serve as part of the healthcare team along with physicians, nurses, technologists, and other hospital staff. The clinical engineer's role is to insure that other team members have adequate and effective technology for the time delivery of quality healthcare. In essence, clinical engineers must act as the "stewards" of healthcare technology. As effective stewards, clinical engineers need to understand the practitioners' intent, they need to possess knowledge with respect to both existing and developing healthcare technology, and they must also understand the various implications of applying the technology. Only when forearmed in this manner can clinical engineers hope to serve as successful stewards and help insure healthcare technology is applied for the greatest benefit.

Adopting and Integrating Technology in Healthcare Processes

In two landmark reports issued in recent years by the Institute of Medicine (IOM), that organization clearly makes the case for increasing the adoption and integration of information technology to improve both clinical and administrative processes [1]. Many of the reports' recommendations can be accomplished only through the effective integration of information and clinical or biomedical technologies. The IOM points out to "increasingly sophisticated and complex technologies as a contributory factor" to a significant number of medical errors that occur [2]. They recommend that technology be "recognized as a member of the [healthcare] team" and that among its roles are enhancing human performance and automating processes so as to remove opportunities for humans to make errors. System failures will occur, and where technology is employed, humans must still find ways to effectively monitor the processes they automate.

Technology must be continually adopted and integrated into healthcare processes. The goal is to continually improve on:

- ➤ healthcare quality
- ➤ patient safety
- ➤ process reliability
- ➤ healthcare availability
- ➤ speed and efficiency of healthcare delivery
- ➤ cost effectiveness of the process.

The technology components that play a role in healthcare delivery process can be generally categorized as follows:

- ➤ *Diagnostic Systems*
  technology used to identify the nature of an illness, disorder, or problem (i.e., imaging systems, clinical laboratory, physiologic monitoring systems)
- ➤ *Therapeutic/Treatment Systems*
  technology involved in the treatment of disease or disorders (i.e., respiratory therapy, defibrillators, pacemakers, radiation therapy, infusion therapy)
- ➤ *Information Processing Systems,* including:
  - *clinical decision support systems (DSS),* which are computer-based information systems used to integrate clinical with patient information and provide practitioners with support for decision making in patient care. Clinical DSS present consequences of different decision alternatives based on context, past experience, and available data.
  - *expert systems,* which are artificial-intelligence-based computer programs utilizing knowledge and a set of rules developed from consultation with medical experts. Expert systems provide answers based on that supplied knowledge and rules set and then simulate the problem solving behavior of humans.

Figure 1 illustrates the how these technology components fit into the overall healthcare delivery process. There are four levels corresponding to the degree to which technology is integrated:

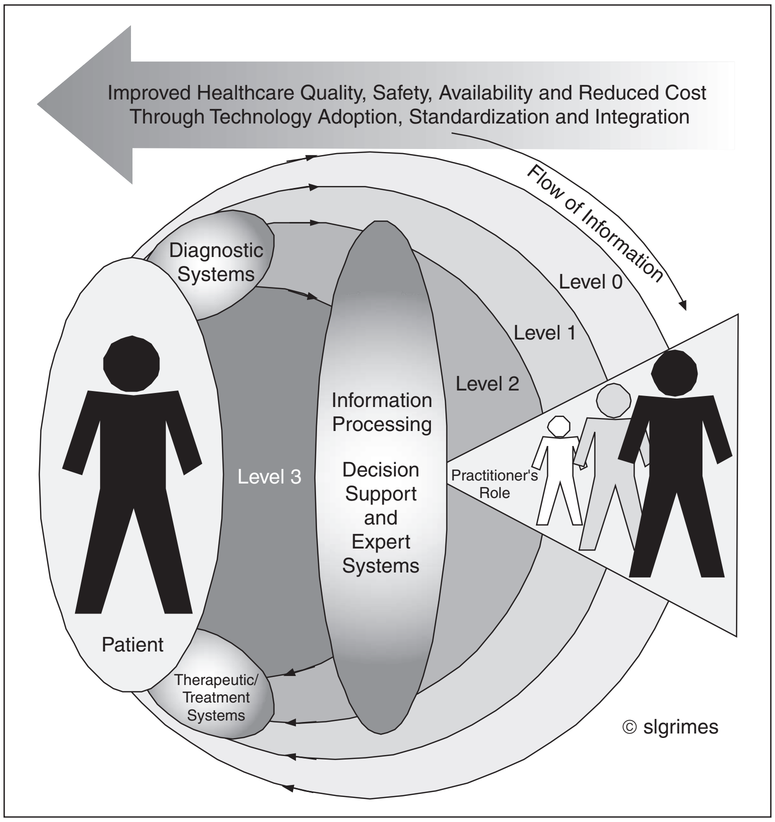

Fig. 1. Healthcare delivery processes: levels of technology adoption and integration.

- Level 0: Unassisted Diagnosis and Therapy (i.e., no or minimal technology)
  - diagnosis by direct observation
  - practitioners micromanage care
  - direct treatment (provided manually)
- Level 1: Technology Assisted Diagnosis and Therapy
  - technology assisted diagnosis
  - providers micromanager care
  - technology-assisted treatment
- Level 2: Technology Assisted Diagnosis, Interpretation, and Therapy
  - technology-assisted diagnosis
  - provider's use of information processing (decision support and expert systems) to help interpret diagnostic data and provide guidance in treatment
  - technology-assisted treatment
- Level 3: Technology *Integrated* Diagnosis, Interpretation, and Therapy
  - technology-enhanced diagnostic systems supply data to information processing (e.g., expert systems)
  - information processing (expert systems) analyze, interpret, and deliver therapy thought technology enhanced treatment systems.

In the healthcare process illustrated by Figure 1, information flows clockwise from the patient to the practitioner where the diagnosis is made and, following a determination on the course treatment, information returns to the patient. At Level 0, nothing more than rudimentary technology is employed for diagnosis, decision support, or treatment, and the practitioner must perform these functions "manually." At Level 1, the practitioner is aided by diagnostic and therapeutic tools (e.g., monitor for diagnosis and defibrillator for therapy) but no decision support tools or expert systems. At Level 2, the practitioner has not only diagnostic and therapeutic tools but also decision support systems to assist in the diagnosis and treatment determination. At Level 3, technical systems provide diagnostic information, expert systems analyze that information and determine a course of treatment, and therapeutic systems provide the appropriate treatment. Implantable cardiac defibrillators (ICD) and automated external defibrillators (AED) are "simple" examples of Level 3 integration.

As the process moves from Level 0 to Level 3 with the adoption, standardization, and tighter integration of technology, information tends to flow and be processed more quickly and accurately with less opportunity for human error. The abilities of the individual practitioner are leveraged, and the goals of increased healthcare quality, patient safety, process reliability, healthcare availability, efficiency, and cost effectiveness are realized.

As stewards of healthcare technology, clinical engineers should facilitate the adoption of new technologies where appropriate, standardize effective technologies, and strive to achieve tighter integration between diagnostic, information-processing, and therapeutic systems. This will require that clinical engineers enrich their existing skill sets by acquiring a deeper understanding and working knowledge of the information-processing, decision-support, and expert systems and how these systems can complement the diagnostic and therapeutic technologies. In this role, clinical engineering has the opportunity to make its most significant contribution to the healthcare process.

Stephen L. Grimes is a senior consultant and analyst specializing in clinical engineering and technology management issues. He has served the past 20 years as president of GENTECH, a clinical engineering and computer services firm in upstate New York. Prior to that, he spent six years with ECRI and its International Shared Services group, where he developed risk management and other consulting services and served as regional director for their New York operations. He is a graduate of Purdue University's Biomedical Engineering Program and a Fellow of the American College of Clinical Engineering.

Address for Correspondence: S.L. Grimes, GENTECH, 139 Henry St., Saratoga Springs, NY 12866 USA. Phone: +1 518 587 4000. Fax: +1 360 234 8894. E-mail: slgrimes@nycap.rr.com.

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