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Evidence-Based Medical Information Technology: The Next Generation

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US Health care is again in crisis. Our patients are stuck in a quagmire of worsening access to quality care (Fig. 1). The 2000 Institute of Medicine (IOM) report "To Err is Human" identified hospitals to be unsafe environments. Medical errors are rampant.[1–3] By conservative estimates, these "errors of commission" are responsible for 44,000 to 98,000 deaths per year. In 2001, IOM published a second report entitled "Crossing the Quality Chasm", which emphasized that despite our professed interest in providing evidence-based care, many patients do not receive proven therapies.[4] A recent study assessed the frequency of these "errors of omission" by documenting 439 indicators of quality care for 30 acute and chronic health conditions in 12 US metropolitan areas and found that only 55% of patients received the appropriate therapies (e.g., β-blockers after an acute myocardial infarction).[5] An inherent flaw of our system is that it takes 10 to 15 years for a proven therapy to become standard of care. In addition, this IOM report emphasized that we the providers (i.e., physicians and hospitals) are incapable of fixing these problems. In fact, current methods of reimbursement reward the status quo (e.g., we get paid for taking care of preventable complications). The IOM recommended legislation and regulations to insure that hospitals become safe environments (similar to the Federal Occupational Safety and Health Act). In addition, they recommended that the payers or patients be leveraged into choosing the providers that have a track record of delivering safe and evidence-based care that is customized to the individual patient's desires. As a result of these two IOM reports, a number of external forces (with increasing recognized acronyms such as AHRQ, IHI, NQF, Leapfrog, SCIP, P4P) are merging their efforts with the intent of radically changing the way health care is practiced.[6–8] Most physicians are now experiencing how pervasive this influence is on their day to day practices.

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In June 2006, the IOM published three reports focused on access to emergency and trauma care. The one entitled "Emergency Hospital Based Care: At the Breaking Point" is most pertinent to our practices and nicely outlined the increasing frustration that I experienced during the last several years as Medical Director of a busy Level I Regional Trauma Center in Houston Texas.[9] The basic tenet for reform is that inadequate hospital capacity and inefficient use of inpatient beds are causing an admission gridlock resulting in unacceptable emergency department (ED) overcrowding, diversion and poor care. Similar to the previous IOM reports, these 2006 reports will undoubtedly attract additional external forces that will mandate changes that we as trauma, emergency surgery, and surgical critical care providers will find unnecessarily intrusive. We need to seize the opportunity to

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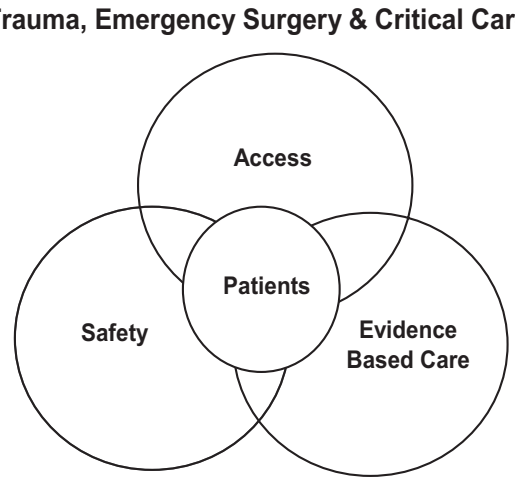

Fig. 1. *The current crisis in our health care system.*

exert leadership in arenas in which we have sufficient ownership to influence future development. Examples include (a) Trauma Systems should evolve to include all emergencies and designated levels of intensive care unit (ICU) care, (b) Acute Care Surgery should develop as a training and practice paradigm that insures ready access to high-quality emergency surgical care, (c) Surgical Critical Care should embrace creation of intensivist lead multidisciplinary ICU teams, and (d) evidence-based guidelines should be used to develop local protocols to deliver consistent, safe and high-quality care with documentable improvements in patient outcomes.

This address will focus evidence-based guidelines and how medical information technology can be used to advance their implementation and refinement to improve patient outcomes. The discussion is broken into five parts: (1) evidence-based surgery and my early experience with bedside protocols, (2) evidence-based medicine, (3) evidence-based guidelines and the trauma surgeon's leadership role in developing them, (4) "proof of concept" that computerized clinical decision support (CCDS) can implement and refine a complex ICU care processes, and (5) CCDS: why now.

EVIDENCE-BASED SURGERY

Training

Evidence-based surgery was an important component of General Surgery training at the University of Colorado. When I started internship in 1979, I was given a book entitled "Surgical Decision Making" edited by Dr. Ben Eiseman.[10] This book contained annotated algorithms to guide decision-making concerning management of common surgical problems based on the best available data and expert opinion. A similar book was published 1984 entitled "Critical Decisions in Trauma" edited by my brother Ernest "Gene" Moore and Ben Eiseman.[11] I memorized many of these algorithms as a survival strategy for surgery Morbidity and Mortality conferences (M&Ms). During my career, I have authored many annotated algorithms (most for local patient care protocols) and firmly believe that this exercise is an excellent test of your true understanding of a clinical problem. As a resident, I also participate in a monthly "Parkland Series" journal club. Each month, we receive by mail a packet of the "Selected Readings in General Surgery" by Robert McClelland. This included an "expert opinion" type overview of the literature related to the selected topic plus reprints of the key articles. Each month was dedicated to a specific topic in General Surgery (e.g., peptic ulcer disease, diverticulitis, etc.) and these topics are recycled every 5 years. In our journal club, each resident was assigned one or two articles to critique and discuss with attending surgeon supervision. This was how I learned to critically appraise the literature, and by faithful participation during my residency, I was exposed to the best available evidence related to General Surgery. My third and most entertaining exposure to evidence-based surgery began in 1984 when Dr. Alden Harken (our new Department Chairman) started weekly Surgical Debates as part of the Surgery Department educational program.[12] These were especially enticing when visiting professors were present. Dr. Harken would choose a focused question related to the visiting professors area of expertise (e.g., Dr. Shires: crystalloid resuscitation, Dr. Shoemaker: supranormal oxygen delivery, Dr. Cerra: branch chain amino acids, etc.). The resident chosen to argue the pro side would give background information and favorable review of available evidence (including key publications of the visiting professor). Next, the con side resident would provide a different negative review of the same available evidence and then the visiting professor would be invited to comment. This exercise was generally received well by the visiting professor. Because of their insight in the nuances of the debate, they could differentiate what we "do know" from what we "do not know" and identify the "gray zones" where they could best speculate on what was most likely true.

Practicing

Evidence-based surgery was an important component of my junior faculty development at University of Colorado. In 1986, I joined the faculty and was appointed Medical Director of the Surgical Intensive Care Unit (SICU) at the Denver General (DG) Hospital. One of my assignments was to develop protocols to standardize processes of care in the SICU. This was relatively easy at DG because there were already other protocols in place that standardized care in the ED and operating room. I recruited a clinical specialist in respiratory care (Jim Haenel RT), and we first focused on protocols to standardize mechanical ventilation. Over years, we refined a standardized approach (intermittent mandatory ventilation with pressure support with optimal positive end-expiratory pressure [PEEP]) with escalating use of unconventional interventions in patients who progressed into refractory acute respiratory distress syndrome (ARDS) (including inverse ratio pressure-controlled ventilation, permissive hypercapnia, tracheal gas insufflation, inhaled nitric oxide, and late

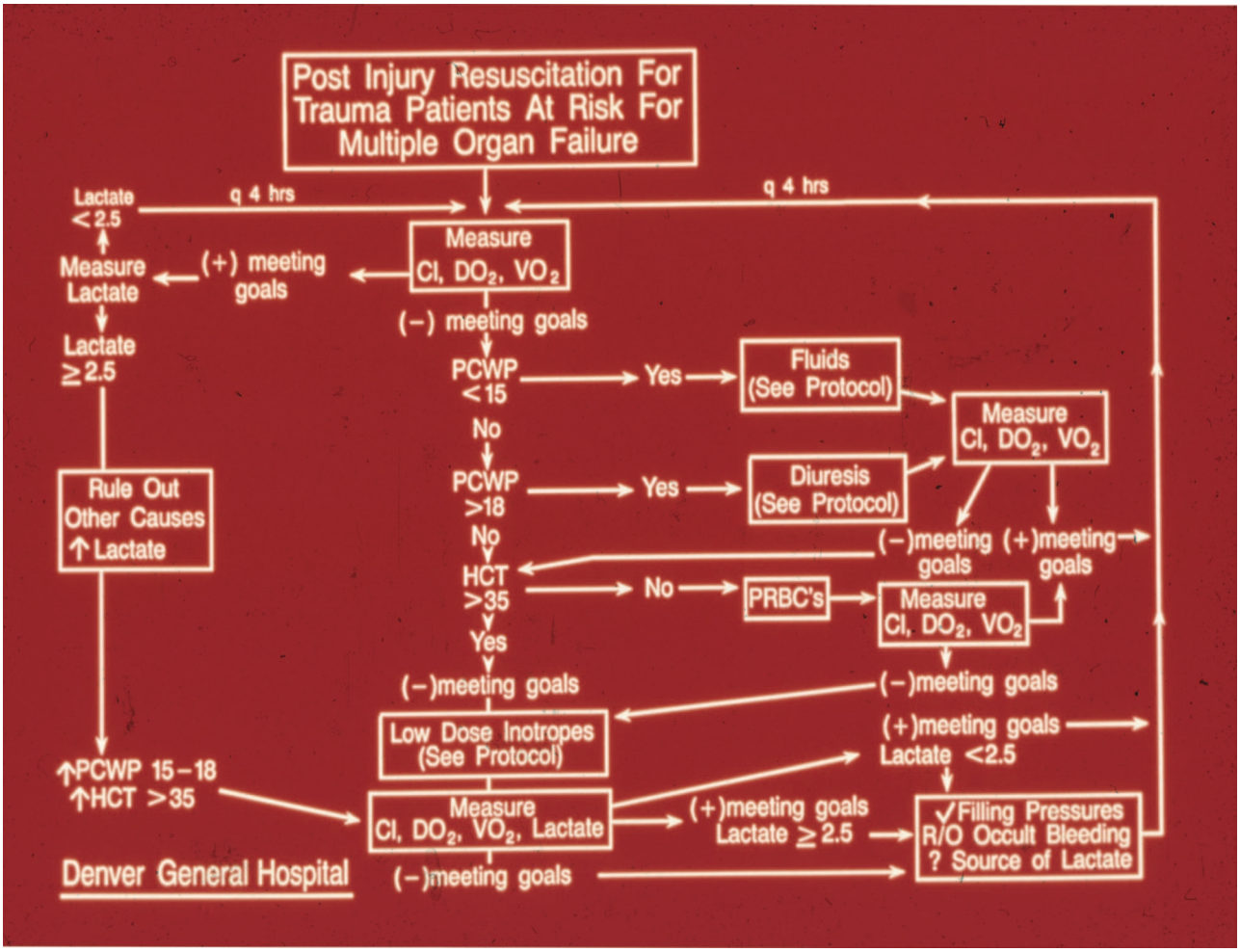

Fig. 2. *Shock resuscitation protocol; CI, cardiac index; DO_2, oxygen delivery; VO_2, oxygen consumption; PCWP, pulmonary capillary wedge pressure; HCT, hematocrit; R/O, rule out.*

steroids).[13] Through these efforts, we learned a lot about mechanical ventilation, eliminated the need to consult pulmonologists, and improved outcomes.[14–18] We attempted to same thing for other important care processes in the SICU.[19,20] The most complex protocol that we implemented was shock resuscitation (SR).[21] As one of Dr. Harken's visiting professors, William Shoemaker visited DG on several occasions in the late 1980s. His concept that unrecognized flow dependent oxygen consumption was an important cause of multiple organ failure (MOF) was particularly enticing to our group because of DG's long-term interest in this then deadly syndrome.[22–24] The idea that oxygen delivery needed to be pushed to supranormal levels to eliminate the phenomenon made a lot of sense based on our understanding of the pathophysiology of shock. We pursued this project with great enthusiasm and with progressive protocol refinement exposed an inherent problem. As protocols become more complex, the bedside clinicians have a difficult time remembering what to do. We solved this problem by developing a bedside documentation form that depicted the algorithm on one side (Fig. 2) and a data collection sheet on the other side. Jim Haenel RT was available to help walk the PGY-2 residents through the protocol. It became an expectation that the resident would fill out the data sheets and present the resuscitation events on morning ICU rounds. This provided a fairly detailed record of what actually happened. We recognized different patterns of responses and used them to predict outcome.[21] By collecting data in near real time, we gained new insights into the resuscitation process. We recognized with increasing frequency that these patients (especially those who had undergone liver packing) were at high risk of developing abdominal compartment syndrome (ACS).[25,26] Also blood transfusions, a key component of resuscitation, were identified to be a strong independent risk factor for infections and MOF.[27]

EVIDENCE-BASED MEDICINE

In 1972 Archie Cochrane, a Scottish epidemiologist, published a short but portentous monograph entitled "Effectiveness and Efficiency Random Reflections on Health Services".[28] He identified serious shortcomings in medical

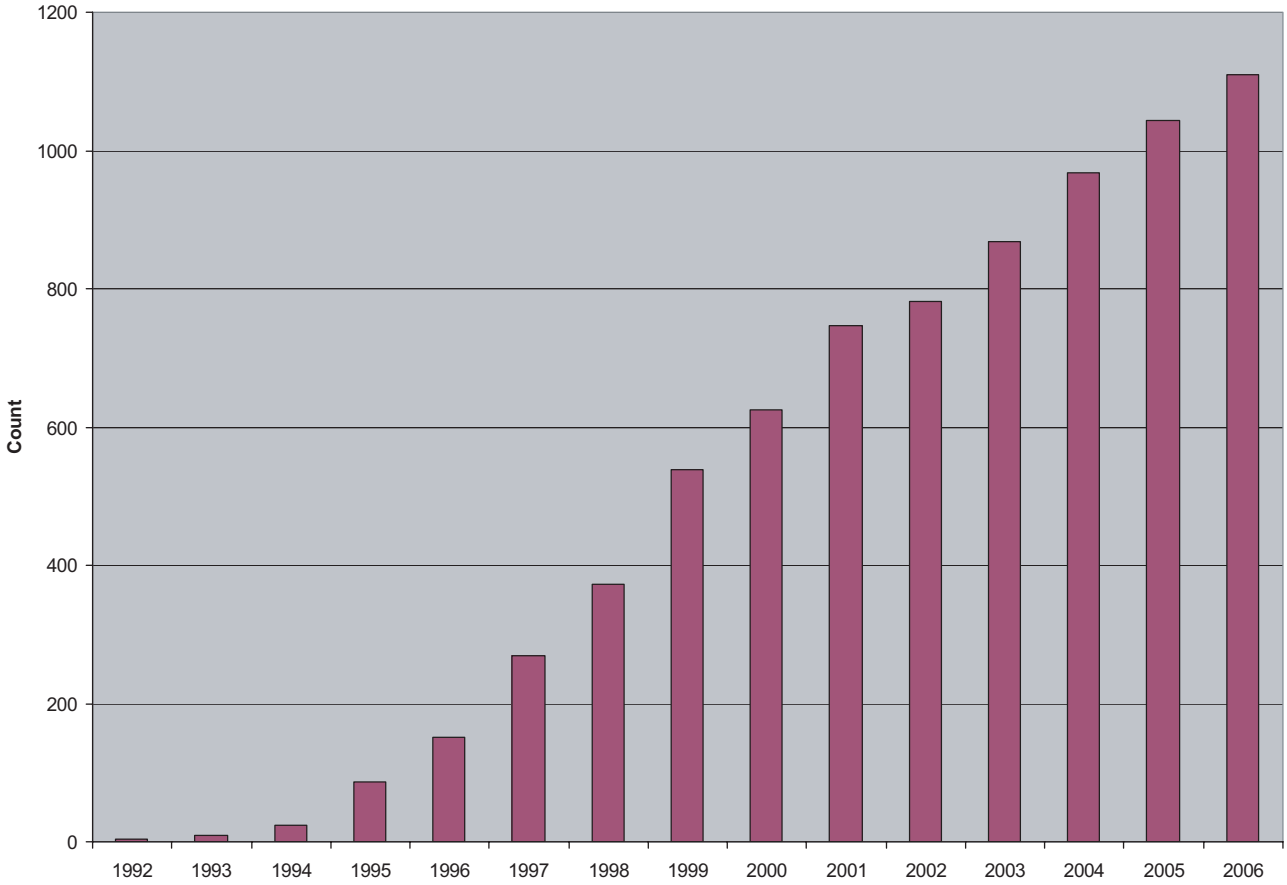

Fig. 3. *Appearance of articles with "evidence based" in titles indexed in PubMed.*

information. Standard of care interventions were incompletely tested and poorly analyzed. In addition, available information was badly organized and not readily available. He stressed the importance of randomized controlled trials (RCTs) in generating the most reliable information and proposed an institute (ultimately founded in 1992) that would prepare, maintain, and disseminate systematic reviews RCTs of the effects of health care.[29] Each review explores the evidence for and against the effectiveness and appropriateness of treatments (medications, surgery, education, etc.) in specific circumstances. Cochrane reviews have become known internationally as sources of high-quality, reliable health information and are updated quarterly. Evidence-based medicine is a byproduct of Archie Cochrane's legacy of using the best available data to make clinical decisions. The term was coined by the faculty at the McMaster University in Hamilton, Ontario, in the1980s to describe a method of training physicians for future clinical practice. Figure 3 depicts the sharp rise in publications related to evidence-based medicine starting in the 1990s as it gained widespread popularity. Evidence-based medicine has been variably defined and continues to evolve. A well-articulated definition can be found in 1996 editorial by David Sackett, in which he stated "evidence based medicine is the conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients".[30] There four steps in evidence-based medicine. First, a pertinent clinical question is formulated. Second, a rigorous search of the literature is done to identify relevant publications. Third, these publications are "critically appraised", and the evidence is classified based on its quality and quantity (from Level I [extremely convincing]to Level V [expert opinion with no supporting data]). This in turn is used to make levels of recommendations (from level A [clearly justified] to D [questionable practice]). The fourth step is implementation of useful findings into clinical practice.[31] Implementation can be done through a variety of mechanisms, but "evidence-based guidelines" has emerged as a recognized end product of this process.[32]

EVIDENCE-BASED GUIDELINES

Why Do We Need Evidence-Based Guidelines?

Evidence-based guidelines (EBGs) have garnered prodigious interest because they provide potential solutions for major health care issues.[33,34] First, there has been an explosion in health related information. Conventional continuing medical education strategies are ineffective in rapidly bringing new proven therapies into routine bedside care.[35] Busy clinicians simply cannot keep up. EBGs can be a valuable tool in addressing this ever-increasing challenge. Second, despite tremendous and increasing health care expenditures,

there is an unacceptable variability and inequality in the delivery of care. EBGs provide a tool to appropriately allocate valuable resources and eliminate unnecessary care. They can substantially decrease variability in care and provide a platform for performance improvement (PI) projects. Third, EBGs identify the "gray zones" of clinical practice in which there are a lack of data on which to base definitive decisions (unfortunately frequent).[36] These represent future research opportunities, and until this research is performed, traditional expert clinician decision making is required and therefore acceptable.

Why Do Physicians Resist EBG?

Although it is hard to argue against the principles of evidence-based medicine, EBGs have been resisted by physicians for a variety of reasons. First, EBGs threaten physician autonomy. They are perceived as "cook book" medicine that devalues the expert clinician in decision making and potentially increase the risk of litigation. Surgeons, in particular, are wary of EBG because we commonly use intuitive thinking to make decisions. In surgical practice, decisions are frequently made with incomplete data through pattern recognition-based extensive clinical experience. Being able to make decisive intuitive decisions is integral part of the surgical ego. In addition, there is the unfortunate tradition that experienced surgeon's decisions are not questioned, and the manner in which they practice is not open for debate. It is striking how resistant surgeons are to changing routine practices based on newly published data (e.g., early removal of nasogastric tubes after colon surgery, short duration of perioperative antibiotics, futility of intra-abdominal drains, use of lower transfusion triggers, etc.). Through apprenticeship training and ongoing clinical experience, surgeons learn safe and effective practices and are unwilling to risk poor outcomes by changing routines.

What Are the Limitations Of EBGs?

It is easy to resist EBGs especially those derived by national or international professional organizations. Because of a dearth of definitive class 1 data, there are very few Level I recommendations.[37] Lower-level recommendations are watered down with "weasel words" such as "may consider" or "could be appropriate".[38] In addition, because of the lack of class 1 data, the final recommendations made by the EBG committees are prone to be biased by the most vocal and dominant participants. EBGs on the same topic generated by different organizations analyzing the same data can come up with conflicting recommendations. This is an inherent risk of "group thinking" and is difficult to control. If the real thought leaders in a particular field are included in the EBG development committee, there is a risk that these experts will sway the committee's recommendations because they are very articulate in expressing their passionate views. Conversely, if these experts are excluded, then the committee may not be capable making insightful recommendations because they do not understand the nuances of particular issues. The value of meta-analysis is overemphasized.[39,40] Meta-analysis is a valid statistical tool, but as with any statistical methodology, it can be manipulated to render variable results. Adequate assessment of meta-analysis requires statistical expertise that many committee members simply do not have. In addition, the results of meta-analysis are only as good as the primary data on which it is based (i.e., "garbage in" equals "garbage out"). Meta-analysis is a good tool to generate a hypothesis not mandates policy. The final limitation of EBGs is that process is time consuming and potentially expensive. Time from development to publishing to local implementation can take years. In that time, the evidence may have changed, and therefore to remain valid, EBGs need to be continually updated and disseminated. One recent concern voiced over this process is the potential for pharmaceutical companies to influence the recommendations by financing the EBG development and using EBG dissemination as an effective advertising ploy.[41]

Why Have Trauma Surgeons Embraced EBGs?

Trauma surgeons have historically been leaders in evidence-based surgery and have embraced the concept EBGs for several reasons. First, trauma is a team sport and chaotic by nature. EBGs help coordinate care by facilitating routine practices and letting everyone know what to expect next. Second, ongoing PI is an important part of being a designated trauma center. EBGs can serve as platform for effective PI projects. Third, trauma surgeons have witnessed the tremendous success of Advanced Trauma Life Support (ATLS).[42] The first edition was published by the American College of Surgery's Committee on Trauma in 1980 and is now in its seventh edition. This "cook book" medicine has saved many injured patients' lives worldwide and has served as a platform for trauma-related PI for a generation of trauma surgeons.

In his 1994 presidential address at Eastern Association for the Surgery of Trauma (EAST), Michael Rhodes urged EAST to begin a process for developing trauma-related EBGs, and EAST has lead the trauma community in this effort.[43,44] Dr. Rhodes thought that these would be helpful in developing local management protocols, but acknowledged that they need to be modified by local consensus to gain acceptance. In his experience, making local clinical management protocols is relatively simple, but the real challenge is implementation. He emphasized the need for strategic phasing, audiovisual support, a high profile workbook, daily coordinator rounds, and a collaborative process that seeks the input from all bedside clinicians. Finally, he recognized that by "incorporating quality improvement, cost containment, research and quality improvement into the process of development, implementation and analysis of protocols makes an otherwise labor-intensive process palatable and productive".

In 1995, I was recruited to Houston, Texas, to become the Medical Director of Trauma Services at Hermann Hospital. At that time, managed care was increasing in the Hous-

Table 1 Specialty Protocols

Orthopedic surgery
Pediatric surgery
Emergency medicine
Neurosurgery
OMSF/ENT/plastics
Neurology
Critical care
Psychiatry
Internal medicine
Rehabilitation service

Table 2 ED Protocols

Tiered response
Airway management
C-Spine evaluation
Laboratory studies
Sedation and analgesia
ETOH screening
Blunt abdominal trauma
Operating room notification
Massive transfusion
FAST/Back up DPL
Whole Body CT scanning

Table 3 Multidisciplinary ICU Team Protocols

ICP management
Sedation and analgesia
ETOH intervention
Ventilator wean
Respiratory therapy
VAP bundle
Shock resuscitation
Enteral feeding
Stress gastritis prophylaxis
DVT prophylaxis
CRS prevention
Electrolyte replacement
Antibiotic use

ton health care market, and I was hired to make trauma services at Hermann Hospital more cost efficient. With Dr. Rhode's principles in mind, we developed a cost containment program that was tightly linked to a comprehensive PI and research program in which protocols played a central role defining (a) how the trauma service would function and how it would interact with other specialty services including mutual expectations of performance (Table 1), (b) standardized approaches to ED management (Table 2), and (c) an intensivist lead multidisciplinary ICU team that would care for the most severely injured patient using protocols that standardized common processes of care (Table 3). This approach resulted to a marked and sustained reduction cost for case (Fig. 4A) and length of hospital stay (Fig. 4B) for the Trauma Service Line at Hermann Hospital. Simultaneously, our ongoing PI program documented improved quality of care related to protocol implementation. This time consuming process initially required biweekly group meetings evolved into a Friday noon Guidelines Committee meeting that was followed by a clinical research meeting. Several of our protocols were intentionally designed with the approval of institutional review board (IRB) to generate data for peer-reviewed publications.[45–49]

Overall, this was a rewarding process, but we learned several lessons along way. First, it is important that everyone understands that when a new protocol is implemented, it is likely not correct. It should be piloted in the spirit of trying to determine what works and what does not work. The protocol is then updated and piloted again. Some protocols are in continual piloting mode (e.g., glucose control, enteral feeding, and SR). For these, a "clinical champion" is identified to be the "go to person" when questions arise and is responsible for informing the group of new published information. Conversely, other protocols stagnate or garner little interest, but need to be reviewed on a regular basis. This can be accomplished by assigning a date of expiration and then setting a schedule for protocol review. A second lesson we learned was that our initial laminated protocol book did not work very well in disseminating the protocols. Because of ongoing protocol modifications, we needed a rapid way disseminating protocol changes. We therefore developed an intrahospital trauma Web site where we posted all of the protocols. Making the information readily available is of key importance for their acceptance and use. Third, new practitioners need intense indoctrination concerning the protocols. If they have never been in a protocolized environment, they will resist the protocols. This indoctrination can be done on ICU rounds, M&M conference, Grand Rounds, and multidisciplinary conference by continually referring to the protocols and explaining their rationale. Take every opportunity to advertise success and remind everyone that "cook book" medicine does work. Occasionally, recalcitrant clinicians require one-on-one counseling. Everyone needs to understand that the protocols are an integral component how the trauma service runs. If someone does not agree with a protocol, they are encouraged to be put the topic on the agenda for Guidelines Committee and get consensus to change the protocol.

Computerized Clinical Decision Support

My Exposure to CCDS

When I moved to Houston in 1995, I was appointed Medical Director of the Shock Trauma ICU at the Hermann Hospital and became one of four intensivist who shared the responsibility of supervising the ICU team. Shortly after my arrival, I encountered a patient on my rounds who had refractory ARDS. After an "educational moment" with the ICU team in which I discussed the potential sequence alternative nonconventional interventions that we might employ, I proposed a course of action for the day. To my disbelief, I was told that I could not change the ventilator setting because the

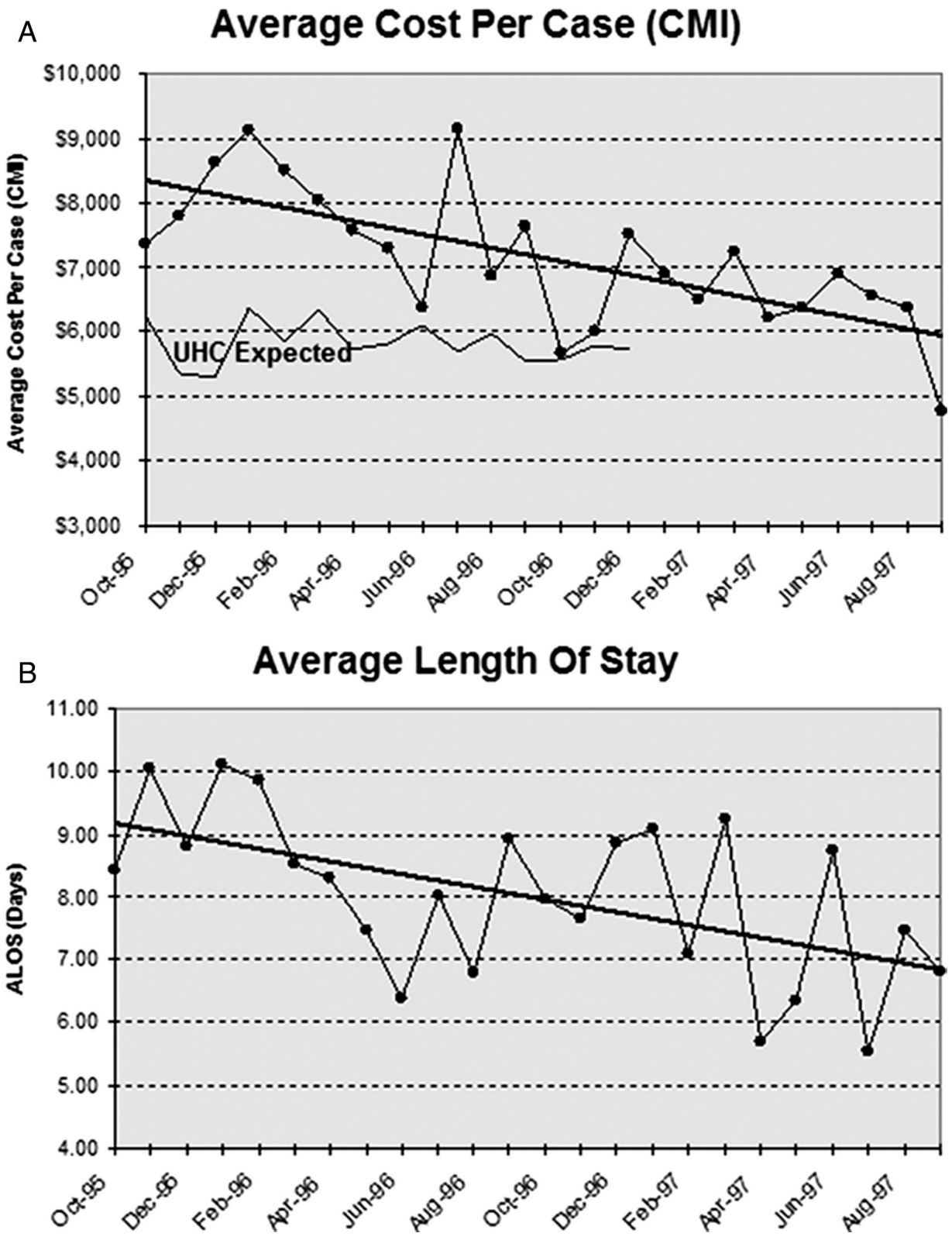

Fig. 4. (A) *Total cost per case adjusted for case mix index (CMI) for the Trauma Service Line.* (B) *Length of stay for Trauma Service Line.*

patient was enrolled in an IRB-approved RCT testing CCDS for mechanical ventilation of patients with ARDS and had been randomized to CCDS. After rounds, I made a point of locating the local principal investigators (Drs. Alan Tonnesen and Bruce McKinley) who assured me that this was a safe and well tested CCDS application that was being exported to multiple institutions as part of a study funded by grants from the Agency for Health Care Policy and Research and the National Institute of General Medical Science. They arranged for the Utah principle investigators (Drs. Alan Morris and Thomas East) meet with me in Houston. After a convincing discussion, I agreed this was a valid scientific endeavor and that I would fully support the clinical trial in the Shock Trauma ICU. We ultimately randomized 81 of our patients into this trial. I watched the CCDS managed patients closely and identified no safety issues. This comprehensive protocol was developed at the University of Utah/LDS Hospital and involved an interactive bedside computer application. In brief, the protocol used a low tidal volume (tidal volume = 6 mL/kg of ideal body weight) and "permissive hypercapnia" strategy to prevent excessive ventilator pressures. Assist control mode was used and optimal PEEP was determined by a fairly simple logic. Arterial blood gas and pulse oximetry determinations along with standard mechanical ventilator parameters were entered into the bedside computer and the medical logic modules would generate instructions for how the ventilator should be adjusted and when to reassess the patient (Fig. 5). The RT with consulting physicians could decline the instruction but needed to indicate why the instruction was not appropriate (99.8% of instructions were accepted). Once oxygenation improved and the patient was stable on low PEEP settings, daily spontaneous ventilation breathing trials were done to assess whether mechanical ventilator support could be discontinued. Patients who were not randomized to CCDS were managed by the intensivist lead ICU critical care team. The trial ended in December 1998. Although CCDS did not improve patient outcome, CCDS patients were much more consistently managed.[50] Their targeted Vt as well as levels of SpO_2 and $Paco_2$ had striking less variability compared with those of the patients managed by the ICU team. I was struck by the ability of CCDS to safely control a complex process of care in this very critically ill patient cohort.

CCDS to Implement and Refine EBGs: Proof of Concept

In addition to being the Medical Director of Trauma at Hermann Hospital I was recruited to the University of Texas Houston Medical School (UTHMS) to develop a translational research program for its National Institute of General Medical Sciences (NIGMS)-sponsored Trauma Research Center. I initially received a UTHMS institutional grant and later a NIGMS grant (RO1GM59571) for a clinical project related to SR. The goals of this project were (a) use CCDS to control and refine the SR process, (b) develop a database to analyze how SR and patients responses to escalating interventions relate to patient outcomes, specifically ACS and MOF, (c) use this information to generate ideas for novel resuscitation strategies that can be tested in the laboratory, and (d) develop a well characterized cohort of critically injured patients in which to test basic laboratory observations for their clinical relevance. This project became the Clinical Core of a renewal Trauma Research Center (TRC) grant proposal (P50 GM59571) that was funded. With this funding I was able to recruit Bruce McKinley, PhD, into my Division of General Surgery. After we visited Alan Morris and Thomas East at the LDS hospital in Utah, we recruited one of their medical informatics trainees Matthew Sailors to Houston. We next developed a working group to pursue the task of developing CCDS for ICU SR. We used the SR algorithm that we had developed at DG as a starting point and developed comprehensive flow diagrams for the logic for escalating interventions in nonresponding patients. The basic logic is depicted is

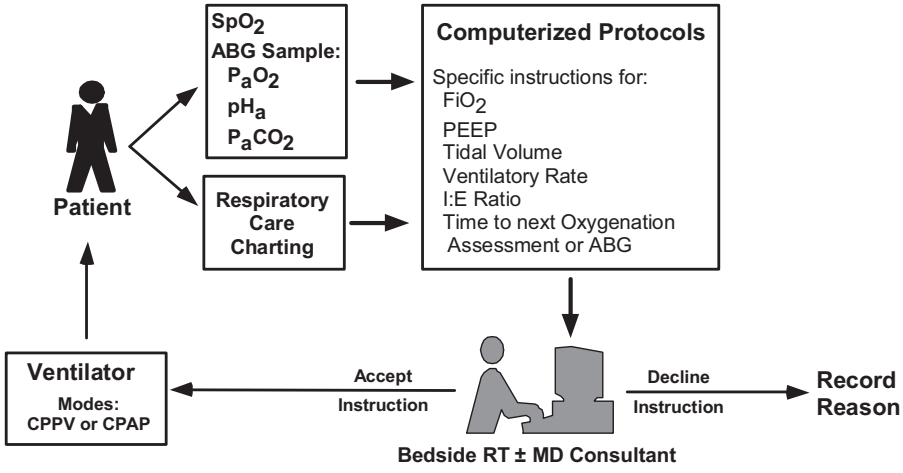

Fig. 5. *SpO_2, oxygen saturation by pulse oximetry; ABG, arterial blood gas; Pao_2, oxygen tension in arterial blood; $Paco_2$, carbon dioxide tension in arterial blood; pHa, arterial pH; PEEP, positive end expiratory pressure; I/E, inspiratory to expiratory; CPPV, continuous positive pressure ventilation; CPAP, continuous positive airway pressure; RT, respiratory therapist; MD, medical doctor.*

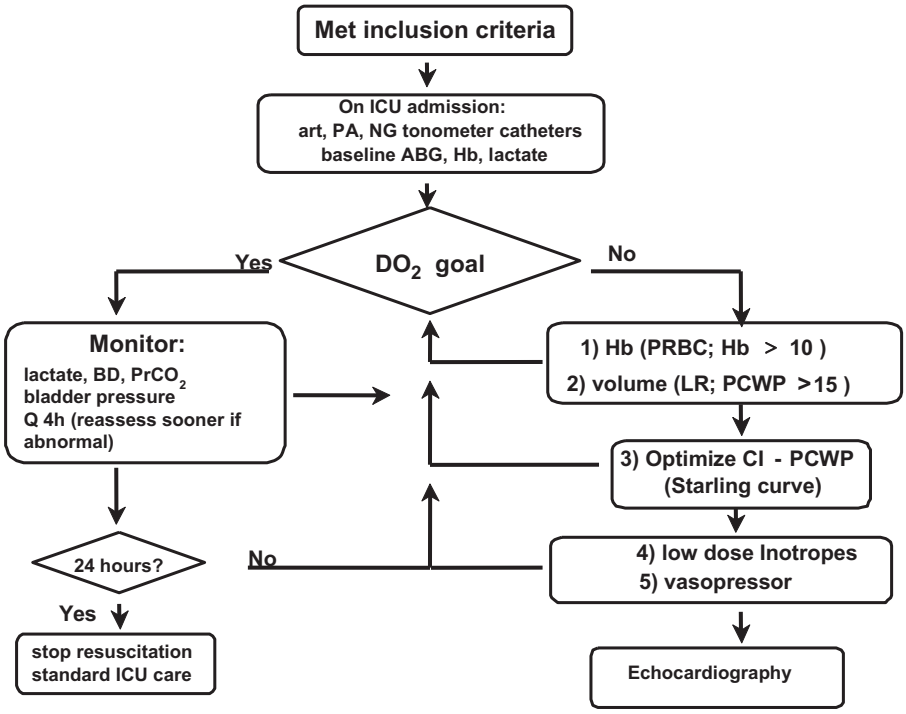

Fig. 6. *Overview of resuscitation protocol. art, arterial; PA, pulmonary artery; NG, nasogastric; ABG, arterial blood gas; Hb, hemoglobin level; DO_2I, oxygen delivery index; PRBC, packed red blood cells; LR, lactated Ringers; CI, cardiac index; BD, base deficit; $PrCO_2$, regional CO_2 tension measured by gastric tonometry.*

in Figure 6. We used the Denver MOF database to generate risk factors that would be used as entry criteria into the protocol. These included (a) list of injuries that resulted in an Injury Severity Score >15, (b) base deficit >5 mEq/L, and (c) >6 units of blood transfusion or age >65 years with two of the previous risk factors.[23,24] Head injured patients (Glasgow Coma Scale score <8 with abnormal head computed tomography scan) were excluded. Patient meeting these criteria had presumptive placement of a pulmonary artery catheter at ICU admission. Initially the logic was tested with "paper protocol" at bedside with senior nurse facilitators. Within 18 months we had a computer application on a pole mounted laptop computer that would be pushed to the bedside of patients when entered the protocol. Patient specific data were then entered into the computer, which then generated recommendations that the bedside clinician could decline (95% of instructions were accepted). The protocol ran for 24 hours. This permitted collection of data including (a) patient entry criteria, (b) reasons for interventions, (c) response to intervention, (d) hourly monitoring of hemodynamic parameters including urine output and urinary bladder pressures and (e) every 4 hours (or more frequently if ordered) laboratory data (including hemoglobin, base deficit, lactate, and coagulation profile). These patients also had their clinical course documented in a separate SR Database. The basic strategy was to implement the protocol, collect data, analyze the data, and then modify the protocol based on group consensus. In brief review we have observed: (1) virtually all patients managed by the ICU SR protocol required emergency hemorrhage control interventions (OR or interventional radiology) and arrived in the ICU roughly 6 hours after ED admit.[51] (2) Most patients (66%) including elderly responded well to initial preload directed volume loading with crystalloids and to blood transfusions.[52,53] (3) A substantial minority of patients (15%) did not respond well to escalating interventions, went on to develop ACS and MOF, and their clinical trajectory could be predicted before ICU admit.[54,55] (4) A "Starling curve" intervention (sequential IV fluid bolus to increase preload to optimize cardiac performance) is feasible, but increases risk of lung failure (ARDS), gut edema (ACS), and MOF.[56,57] (5) Decreasing the hemodynamic performance goal from "supranormal" systemic O_2 delivery index (DO_2I) > 600 to a more normal $DO_2I \geq 500$ mL O_2/min · m^2 was associated with remarkably similar hemodynamic response but with less crystalloid and blood product infusion, and decreased incidence of ACS and MOF.[58] (6) Coagulopathy is present in most SR patients at ED admission and remains uncorrected in those who require massive transfusion, despite SR and ICU standard of care interventions.[49] As a result of these observations, we think that fundamental changes are required in the pre-ICU care of major torso trauma patients who arrive shock and require a massive transfusion (MT). Standard of care ATLS resuscitation is harmful is this subset of patients. These patients can be accurately identified soon after ED admission and they need a different management strategy.[59,60] Isotonic crystalloids

should be used sparingly, MT protocols should be modified to insure ready availability of fresh thawed plasma, which should be administered with the first unit of blood, hemorrhage control is of paramount importance and normalizing blood pressure should be discouraged until this is accomplished. Although ICU resuscitation remains an important intervention to normalize homeostasis after "damage control" interventions, the endpoint of resuscitation should be normal oxygen delivery with the goal of identifying the nonresponders and to provide them with an expert clinician who figures out why they are not responding.

CCDS: WHY NOW

Trauma surgeons have historically been strong advocates for evidence-based care. The current hype over evidence-based medicine has provided us with EBGs. Despite obvious limitations, we have embraced the concept. The real challenge is how we implement this best evidence into our practices. Protocols derived by local consensus refinement of EGDs to guide specific processes of care can control variability in care and allow identification of best practices. These can then be optimized to improve patient outcomes. CCDS is a tool that enhances these activities. Our experiences with mechanical ventilation of ARDS and traumatic SR are "proof of concept" that CCDS can effectively control chaotic processes of care. The opportunity now exists to leverage emerging health information technology to make CCDS available for many different processes of care. In the near future, the electronic medical record (EMR) and computerized provider order entry (CPOE) will be fully implemented and provide the platform for CCDS. We are currently designing CCDS applications to that access the hospital information systems to generate patient specific data. These data will be combined with real-time clinical assessments by bedside clinicians and entered into treatment-specific medical logic modules to generate treatment recommendation. If the recommendation is accepted by the bedside clinician, it will be implemented through CPOE include decision support, alerts, and reminders. Ultimately these CCDS applications will be embedded in the EMR and will seamlessly provide patient specific information, intelligently filtered and presented at appropriate times to assist the bedside clinicians in making treatment decisions. Admittedly, this is a major undertaking, but there are tremendous pressures on us to provide improved access to safe and high-quality care. CCDS can be especially helpful for ICU clinicians who are caring for the sickest patients and are faced with ever-increasing information overload. Working harder is not an option. Evidence-based medical information technology is the next generation in evidence-based care, and we need to seize the opportunity of ushering this into our practices.

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