Unintended consequences of health information technology: a need for biomedical informatics

Elmer V. Bernstam, MD, MSE[1], **William R. Hersh, MD**[2], **Ida Sim, MD, PhD**[3], **David Eichmann, PhD**[4], **Jonathan C. Silverstein, MD, MS**[5], **Jack W. Smith, MD, PhD**[6], and **Michael J. Becich, MD, PhD**[7]

[1] Associate Professor, School of Health Information Sciences and Internal Medicine, The University of Texas Health Science Center at Houston, Houston, TX

[2] Professor and Chair, Department of Medical Informatics & Clinical Epidemiology, Oregon Health & Science University, Portland, OR

[3] Associate Professor, Division of General Internal Medicine, Department of Medicine, University of California, San Francisco, California

[4] Associate Professor, School of Library and Information Science, University of Iowa, Iowa City, IA

[5] Associate Professor, Department of Surgery, Radiology and Computation Institute, University of Chicago, Chicago, IL

[6] Professor and Dean, School of Health Information Sciences, The University of Texas Health Science Center at Houston, Houston, TX

[7] Professor and Chair Department of Biomedical Informatics, University of Pittsburgh School of Medicine, Pittsburgh, PA

In all science, error precedes the truth, and it is better it should go first than last.

-- Sir Hugh Walpole (English novelist, 1884–1941)

Health information technology (HIT) can address important problems in clinical care and biomedical research. These problems include lack of compliance with clinical practice guidelines [1], insufficient use of preventative medicine services [2] and numerous impediments to clinical/translational research [3]. However, front-line patient care information systems that can influence care may worsen outcomes as well as improve them. Increasingly, there is evidence of significant, unintended and deleterious effects of well-meaning HIT efforts [4]. In this paper we present examples of such deleterious effects and argue that: 1) HIT is a tool that can influence health care and biomedicine (for good or ill) and 2) biomedical informatics efforts are needed to ensure that HIT fulfills its promise in biomedicine.

Corresponding author: Elmer Bernstam, MD, School of Health Information Sciences, The University of Texas Health Science Center at Houston, 7000 Fannin Street, Suite 600, Houston, TX 77030; Phone: 713 500 3901, Fax: 713 500 3929, email: Elmer.V.Bernstam@uth.tmc.edu.

Examples of unintended negative consequences of HIT

e-Iatrogenesis is "patient harm caused at least in part by the application of health information technology." [5] e-Iatrogenesis can result from a variety of factors involving any type of HIT. Examples include a software error that caused several lethal radiation overdoses [6] and fragmented displays that prevent coherent views of all currently prescribed medications leading to prescribing errors [7]. Perhaps the most dramatic example is a report of delays in the care of critical patients causing increased patient mortality in a pediatric intensive care unit after introduction of a commercially-available electronic health record (EHR) that required clerical staff to "admit" a patient before orders could be entered [8]. Interestingly, a subsequent study from a different institution using the same EHR found no increase in mortality [9], suggesting that clinical outcomes depend on the details of implementation in addition to the generic properties of EHR software.

Who has the expertise to prevent e-iatrogenesis?

Health care is an unusually complex environment, specifically with respect to the number of interacting disciplines [10]. Manipulation of complex systems may result in catastrophic consequences that may be difficult to predict [11]. One example of such consequences is the so-called "butterfly effect" that refers to changes in far-removed weather caused by the flapping of a butterflies' wings [11]. We submit that e-iatrogenesis is another example. Specifically, that manipulation of a health care delivery system without adequate consideration of its complex nature leads to unintended deleterious consequences.

The knowledge and skills to address the causes of e-iatrogenesis span the boundaries of traditional disciplines. Computer scientists can formally prove that certain algorithms are sound and implemented correctly (albeit at limited scales of algorithm complexity). Human factors engineering experts can ensure that interfaces match the users' tasks and capabilities so that errors are minimized. Similarly, organizational specialists can help design efficient workflows and manage organizational change. All of these are necessary but not sufficient to ensure safe application of HIT. Indeed, HIT must be evaluated at multiple levels. Specifically, to address the problem of e-iatrogenesis we must understand how data, information and knowledge can improve (or worsen) the performance of humans performing health care tasks. In other words, HIT that is technically sound at the hardware and software levels may still cause e-iatrogenesis.

Biomedical informatics

Informaticians, in contrast to computer scientists and information technology (IT) professionals, are focused not on technology but on utilizing scientific discipline to help identify, define and address information problem(s). Examples of information and knowledge-level questions that must be answered include:"Does the HIT fulfill users' information need (s)?" and "Do users have the knowledge to make the correct decision based on the information provided by HIT?"

To answer such questions, informaticians are inherently multi-disciplinary. They are trained in domain-independent disciplines such as computer and cognitive sciences and application domains such as the clinical care of patients. In general, informatics training programs attract students from a variety of backgrounds [12]. There is no "typical" background for a student matriculating into an informatics program and no specific undergraduate feeder program. Thus, informatics education must be individualized to each matriculating student. Indeed, the authors of this paper include PhDs in computer science, practicing physicians and researchers.

To address unintended consequences, we must adopt an objective, analytic perspective focusing both on the nature of the unintended consequence and its underlying causes. Training

that is focused solely on technology fails to identify or address the often diverse causes of e-iatrogenesis. To be effective, informaticians must combine theoretical understanding (education) with practical training. The distinction between training and education is not new [13], but in the case of HIT, it has been under-recognized.

Upon graduation, informaticians may work in academia or industry. Effective design and use of HIT requires both academic and applied informaticians. Like other scientists, academic informaticians develop new theory and methods. On the other hand, applied informaticians are skilled practitioners and may contribute to the "science of implementation" [14].

How biomedical informaticians can prevent e-iatrogenesis

Biomedical informatics is inherently multidisciplinary, drawing on quantitative disciplines such as computer science and statistics, qualitative disciplines such as organizational and social science as well as biomedical domains such as biology or clinical science. Thus, collaboration with others, including technologists and non-technical experts is crucial. However, informaticians bring a unique perspective that combines information science with a deep understanding of domain-specific workflows; often from a user perspective (e.g., an informatician who is also a physician). Although informaticians may not be able to prevent all e-iatrogenesis, they can minimize errors that are due to inadequate understanding of how technology will integrate into the domain (i.e., clinical processes and workflows).

Implications for academic health centers

In spite of the need to collaborate with other disciplines, biomedical informatics has a distinct culture and its own success criteria. For example, academic (as opposed to applied) informaticians are generally judged by traditional academic metrics, namely success in obtaining research funding and publishing results in prestigious venues. However, the prestige of different venues varies widely in different academic disciplines. Highly competitive, peer-reviewed conference proceedings may be quite prestigious in computer science, yet are generally considered less prestigious than journals in biomedical disciplines. Thus, evaluation of academic informaticians who may contribute to both computer science and biomedical literatures may be difficult within traditional academic units. Within the field of biomedical informatics this is clearer. While the field has its own primary journals such as the Journal of the American Medical Informatics Association and Journal of Biomedical Informatics, some meeting proceedings such as those from the annual proceedings of the American Medical Informatics Association are indexed in the traditional repository for biomedical journals (MEDLINE) and have some of the gravitas of biomedical journal articles.

Need for distinct units of informatics

In order to successfully integrate academic and applied biomedical informatics into academic health centers, institutions must tangibly recognize informatics as a multidisciplinary yet distinct academic discipline. An administratively-recognized unit of biomedical informatics is an effective demonstration of recognition and support. The informatics unit may be a section or division (within a traditional department), a department or a school. Regardless of administrative level, successful academic units that are able to attract and retain excellent employees (especially faculty) share several key features. First, they must establish scientific collaborations and not just service agreements with other academic units.

Collaboration implies recognition of scientific contribution including co-authorship on publications and co-investigator status on grants. Collaborations with both domain-independent and application domain-specific scientists are required. We note that collaborations are not a substitute for leading research efforts focused on biomedical

informatics. In other words, it is not sufficient for all informaticians to be collaborators without driving their own independent research agendas in informatics.

Second, informaticians must have access to data. The data may come from a variety of sources including providers of clinical care (clinical informatics), biologists (bioinformatics) and public health agencies (public health informatics). Of course both academic and applied informatics can be integrated in departments that are structured similar to clinical departments that have discovery, education and clinical service missions.

Third, informatics units require a strong leader with sufficient stature to serve as a role model, create opportunities for junior faculty and applied informaticians, gain and maintain the respect of senior institutional leaders as well as to obtain and manage resources. The leader must be able to identify projects that result in value for the organization and articulate that value to senior leaders. He or she must be comfortable in both the "domain world" of clinical science or biology and the "technology world" of IT and computer science. As such, the informatics leader must serve as a bridge between traditional silos. Finally, the leader must be able to articulate a compelling vision of biomedical informatics to non-informaticians and, equally important, to members of the informatics unit.

Conclusion

Biomedical informatics is a vital discipline for realizing the promise of HIT while avoiding its negative consequences. The causes of e-iatrogenesis span the boundaries of traditional disciplines. Thus, a combined understanding of computation, workflow and clinical health care is required. Academic centers are a focal point for growing biomedical informatics. However, this growth requires distinct academic units that are able to recruit and promote faculty recognizing both the biomedical and computer science roots of the field. In short, biomedical informatics is not optional for academic health centers that wish to lead in advancing the safe and proper use of HIT in clinical care and research.

Acknowledgments

References

1. Kucher N, Koo S, Quiroz R, Cooper JM, Paterno MD, Soukonnikov B, Goldhaber SZ. Electronic alerts to prevent venous thromboembolism among hospitalized patients. N Engl J Med 2005;352:969–77. [PubMed: 15758007]

2. Dexheimer JW, Talbot TR, Sanders DL, Rosenbloom ST, Aronsky D. Prompting clinicians about preventive care measures: a systematic review of randomized controlled trials. J Am Med Inform Assoc 2008;15:311–20. [PubMed: 18308989]

3. National Institutes of Health. National Center for Research Resources, Electronic Health Records Overview. McLean, VA: Center for Enterprise Modernization, MITRE Corporation; 2006.

4. Stead, WW.; Lin, HS., editors. Computational Technology for Effective Health Care: Immediate Steps and Strategic Directions. Washington, DC: Committee on Engaging the Computer Science Research Community in Health Care Informatics; National Research Council; 2009.

5. Weiner JP, Kfuri T, Chan K, Fowles JB. "e-Iatrogenesis": the most critical unintended consequence of CPOE and other HIT. J Am Med Inform Assoc 2007;14:387–8. discussion 389. [PubMed: 17329719]

6. Levenson NG, Turner CS. An Investigation of the Therac-25 Accidents. IEEE Computer 1993:18–41.

7. Koppel R, Metlay JP, Cohen A, Abaluck B, Localio AR, Kimmel SE, Strom BL. Role of computerized physician order entry systems in facilitating medication errors. JAMA 2005;293:1197–203. [PubMed: 15755942]

8. Han YY, Carcillo JA, Venkataraman ST, Clark RS, Watson RS, Nguyen TC, Bayir H, Orr RA. Unexpected increased mortality after implementation of a commercially sold computerized physician order entry system. Pediatrics 2005;116:1506–12. [PubMed: 16322178]

9. Del Beccaro MA, Jeffries HE, Eisenberg MA, Harry ED. Computerized provider order entry implementation: no association with increased mortality rates in an intensive care unit. Pediatrics 2006;118:290–5. [PubMed: 16818577]

10. Leape LL, Berwick DM. Five years after To Err Is Human: what have we learned? JAMA 2005;293:2384–90. [PubMed: 15900009]

11. Manson SM. Simplifying complexity: a review of complexity theory. Geoforum 2001;32:405–14.

12. Hersh W. Who are the informaticians? What we know and should know. J Am Med Inform Assoc 2006;13:166–70. [PubMed: 16357354]

13. Winston BE, Patterson K. An Integrative Definition of Leadership. International Journal of Leadership Studies 2006:6–66.

14. Karsh BT. Beyond usability: designing effective technology implementation systems to promote patient safety. Qual Saf Health Care 2004;13:388–94. [PubMed: 15465944]