A Methodology to Identify Systemic Vulnerabilities to Human Error in the Operating Room

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A methodology to identify systemic vulnerabilities to human error in surgical procedures was developed and applied to the initial stages of laparoscopic cholecystectomy. A database of generic human tasks and errors was developed and applied to four task descriptions developed from an IDEF0 model of the process. Over 30 vulnerabilities to human error were identified and prioritized.

INTRODUCTION

As healthcare leadership examines the delivery of healthcare in America, a glaring deficit is the lack of knowledge and means to reduce the injuries inflicted in the delivery of care. The physicians, nurses, and support staff are not careless; rather it is now apparent that the entire system is *vulnerable* to the errors of innately *fallible* human beings (Wiener, 1987). In 2000, the Institutes of Medicine released a report that estimated that 3.7 percent of all hospitalizations are marred by an adverse event (Kohn et al, 2000). Forty three percent of those adverse events occurred in surgery, a disproportionately high rate compared to all hospitalized patients. Analysis of the events indicates that 70 percent of them were preventable, and a significant number of patient deaths are attributed to medical error, 44,000 to 98,000 per year overall.

Systemic vulnerabilities to surgical error are emergent properties of the operating room system arising from the dynamic interactions of many complex system elements and processes. Therefore, systemic vulnerabilities cannot be identified, except incidentally, by waiting for adverse events to happen. Even analysis and research, when it is narrowly focused on small parts of system structure and process, will miss most systemic vulnerabilities. Instead, a systems approach that formally defines and documents system structure and process and systematically identifies vulnerabilities will be required before effective countermeasures can be developed to significantly reduce human error in the OR. Furthermore, such an approach would provide an avenue for surgeons to share the insight of painful experience without personal stigma.

OBJECTIVES

The broad objectives of our research are to develop, validate, and apply a methodology to identify systemic vulnerabilities to human error in the operating room (OR) so that countermeasures can be developed and errors reduced. The purpose of this paper is to report on the current prototype methodology and its initial application.

METHOD

We are developing the methodology around a modeling and analysis process that uses domain knowledge about the OR and a human performance database to yield a formal model of the OR, detailed descriptions of OR tasks, and a list of systemic vulnerabilities to human error. Our team consists of subject matter experts (surgeons) and human factors engineers. All team members participated actively in all phases of the work. The following sections describe the development and application of the methodology in more detail.

Domain Knowledge

We interviewed our surgeons and other subject matter experts, conducted observations in the OR, and compiled information from OR documents and the literature to compile a set of domain knowledge about laparoscopic cholecystectomy, a very common, minimally invasive surgical procedure to remove a diseased gall bladder. This domain knowledge is the basis for a model of the surgical procedure in the context of the OR system.

Task Glossary and Human Performance Database

We reviewed the basic human factors, ergonomics, and group performance literature (e.g., Helmreich & Merritt, 1998; Konz & Johnson, 2004; Tudor, Trumble, & Diaz, 1996; Wickens & Hollands, 2003; Wickens et al., 2003) to develop a task glossary and a human performance database. The task glossary contains verb phrases to describe simple physical and mental actions performed by human actors (e.g., surgeons, nurses, etc.). It specifies, for each action, the actor (*individual* or *group*), the primary stage of human information processing involved in the action (e.g., *attend, observe, remember, think, act*), a verb that describes the action (e.g., *decide between/among*), and the object of the verb (e.g., *multiple alternatives*). The glossary provides the terminology for formal descriptions of tasks in the model (see below).

The human performance database contains a taxonomy of generic human errors (e.g., *decide incorrectly*) and the human fallibilities that can contribute to those errors (e.g., *confirmation bias*). This database is keyed to the verbs of the task glossary so that a task described in the terms of the glossary can be analyzed with respect to information in the database to identify potential errors.

Process Modeling

We chose IDEF0 (Integrated DEFinition Language 0) as our modeling language and augmented it to suit our needs. IDEF0 is a graphical convention for modeling complex systems that uses boxes to represent transformation processes and arrows to represent information and objects that are transformed, people or equipment that perform the transformations, and factors that guide or constrain the transformations (NIST, 1993). Our enhancements to IDEF0 are mainly a set of conventions for identifying and naming boxes and arrows. We used our domain knowledge and the augmented IDEF0 method to model laparoscopic cholecystectomy from the most general processes (*plan surgery*, …, *perform surgery*, …, *restore surgical system to neutral state*) down to detailed tasks (*elevate abdominal wall, insert Verres needle*, *check needle displacement*).

Task Analysis

We used domain knowledge to analyze four OR tasks from the IDEF0 process model, including those named in the previous paragraph. Each task description consists of a table containing a detailed description of the task written in terms from the generic task glossary and translated to domain-specific clinical terminology.

Vulnerability Identification

We used the IDEF0 process model, the task descriptions, and the human performance database to identify systemic vulnerabilities to human error in these four tasks and produce a preliminary systemic vulnerability list. To perform this identification, we used the generic verb portions of the task descriptions to retrieve, from the database, generic errors and fallibilities associated with those verbs. We translated the generic descriptions of the identified errors into the surgical domain and considered each potential error in turn. If the error was determined to be extremely unlikely or inconsequential, we moved on to the next error. Otherwise, we considered its circumstances to be a systemic vulnerability, and continued analysis of the error. Using detailed domain knowledge from the process model and information from the database, we estimated the frequency of the error, the probability that it would be detected if it occurred, and its likely consequences if it occurred but went undetected. We prioritized the vulnerabilities based on these estimates.

RESULTS

This is a work-in-progress, but we have developed several preliminary products. The current task glossary contains a list of over 290 verbs that can be used to describe generic tasks. These verbs are linked to nearly 150 generic errors and associated human fallibilities from the human and group performance literature. The glossary and database are implemented in a Microsoft Excel workbook. Table 1 shows a sampling from the human performance database.

Our current IDEF0 model of laparoscopic cholecystectomy covers just the initial part of the procedure, but represents 56 processes and subprocesses, including 13 tasks. It identifies OR system states, processes, process interactions, and constraining factors at a level of detail necessary for the extraction of potential errors from the database. Figure 1 is the top-level (context) diagram from the IDEF0 model, which represents the process of laparoscopic cholecystectomy when considered at the most general level.

The box represents the process itself. Arrows entering the box from the left represent inputs, things that are transformed or changed by the process: the patient, ready to be prepared for surgery, the surgical system, ready to be prepared, and patient and case documents, open for updating. Arrows entering the top of the box are called controls and represent information and other factors that guide, limit, control, or otherwise affect the process. Here, the surgical goal is primary, patient factors and surgical system factors influence the process, and surgical philosophies, policies, procedures, and practices guide it. Arrows exiting from the right of the box represent outputs, the result of transforming inputs, subject to controls. Model outputs at this level include the recovering patient, the surgical system restored to a neutral state and ready to be prepared for the next surgery, updated patient and case documents, surgical specimens that may go to the pathology lab, and waste. Arrows entering the bottom of the box represent mechanisms: actors (people and machines) that perform the process. For this model we chose to limit mechanisms to the surgical team: physicians, nurses, and medical technicians.

Figure 2 is an IDEF0 diagram representing the top-level process shown in Figure 1, decomposed one level to show the major subprocesses of laparoscopic cholecystectomy. In the complete model, the *perform surgery* subprocess is decomposed and modeled five levels below that shown. Note that one of the major advantages of IDEF0 is that modeling of inputs, controls, outputs, and mechanisms allows the modelers to explicitly show important relationships among subprocesses, at all levels of the model. Such explicit process relationship modeling is typically not done in traditional hierarchical task analysis.

Four tasks in the *insert Verres needle* subprocess (required to "inflate" the patient's abdomen to prepare for the placement of laparoscopic instruments) were analyzed. The detailed descriptions of these tasks, contained in an Excel workbook, consist of three to 13 verb phrases that link to the human performance database. Three of the four *insert Verres needle* subtasks are shown in Table 2.

In the vulnerability identification phase we identified over 30 vulnerabilities to human error in these tasks. Further assessment and prioritization of them yielded several potentially important ones, including the following:

Vulnerabilities in the *insert Verres needle* subprocess

– Vulnerabilities in the *plan & assess Verres needle* task to
  - inaccurately visualize underlying anatomy
  - miss important cue relevant to needle placement
  - fail to recognize that the patient's state is not suitable to proceed
  - choose bad location even after reviewing cues
  - choose wrong angle for non-umbilical (e.g., intercostal) insertion
– Vulnerabilities in the *elevate abdominal wall* task to
  - fail to get sufficient grip to achieve adequate abdominal wall elevation, sufficient tension, or proper needle trajectory
  - fail to elevate properly
  - fail to support elevation process
  - release grip prematurely

DISCUSSION

In this exploratory study we developed a prototype methodology to identify systemic vulnerabilities to human error in the operating room and applied it to the initial part of the laparoscopic cholecystectomy surgical procedure. The results, though preliminary, and the methodology, though only a prototype, make several contributions to surgical patient safety.

First, the task glossary provides a standard set of terms for describing generic human tasks that can be related to domain-specific terminology. Second, the human performance database provides a mechanism to link specific task descriptions to generic human errors and the fallibilities and, potentially, system factors that can contribute to those errors. Medical professionals and human factors engineers, even comfortably seated in a quiet meeting room, are fallible humans and their ability to consider likely errors using detailed task descriptions is limited. They need memory assistance and the human performance database provides it.

Third, the IDEF0 model covers only the initial part of the surgical procedure, but this part is representative of surgical procedures in general and this specific model provides a formal, unambiguous representation of laparoscopic cholecystectomy processes and subprocesses for purposes of communication, analysis, training, and, ultimately, design. Fourth, the same is true of the task descriptions.

Fifth, the vulnerability identification method, though at this stage rather time consuming, provides a systematic means of bringing general human performance knowledge to bear on specific medical processes and tasks in an interdisciplinary, interactive team environment. By focusing the team's attention on the surgical processes represented in the model and aiding the team by bringing to mind potential errors, systemic vulnerabilities to those errors can be more completely considered.

Sixth, the prioritized vulnerabilities identified by application of the methodology provide opportunities for reducing patient morbidity and mortality. Most surgeons would acknowledge the vulnerabilities we identified and critics might argue that we invested a lot of time and effort in "discovering" what was already known. But while these vulnerabilities may be acknowledged, they are not routinely considered or systematically guarded against and their relative importance was formerly unknown. Moreover, the process and task models coupled with identified and prioritized error vulnerabilities provide a framework for surgical training and practice and for the collection, organization, and analysis of surgical errors.

Seventh, and perhaps most important, the methodology provides a way to carefully examine new procedures and equipment before unfortunate experience reveals their vulnerabilities to human error.

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Table 1. A sample from the human performance database, showing a few errors, the task glossary verbs with which they are associated, and human fallibilities that may contribute to them.

Verb	Object	Generic Error	Fallibilities
Grasp	object	fail to grasp target object	speed-accuracy trade-off, absolute judgment limitations
Move	object	fail to move to exact location	speed-accuracy trade-off, movement compatibility, increased index of difficulty, absolute judgment limitations
Attend to	multiple tasks	Fail to divide attention	Limited ability to divide attention
Detect	signal	False alarm	payoff bias, response bias (high beta), limited memory, sluggish beta
Distinguish between	two or more stimuli	Fail to distinguish different stimuli	discriminability thresholds, decision biases
Decide among	alternatives	make wrong/suboptimal decision	recognition primed decision making, stress induced narrowing of attention, perception biases , selective attention , information overload, satisficing, cue modulation, anchoring heuristic, overconfidence bias, sunk cost bias, availability heuristic , framing effect, comfort zone biases, recency bias, motivation bias
Communicate with	group member(s)	fail to communicate within team	excessive deference to position, limited ability to overcome cultural differences (both ethnic and organizational)

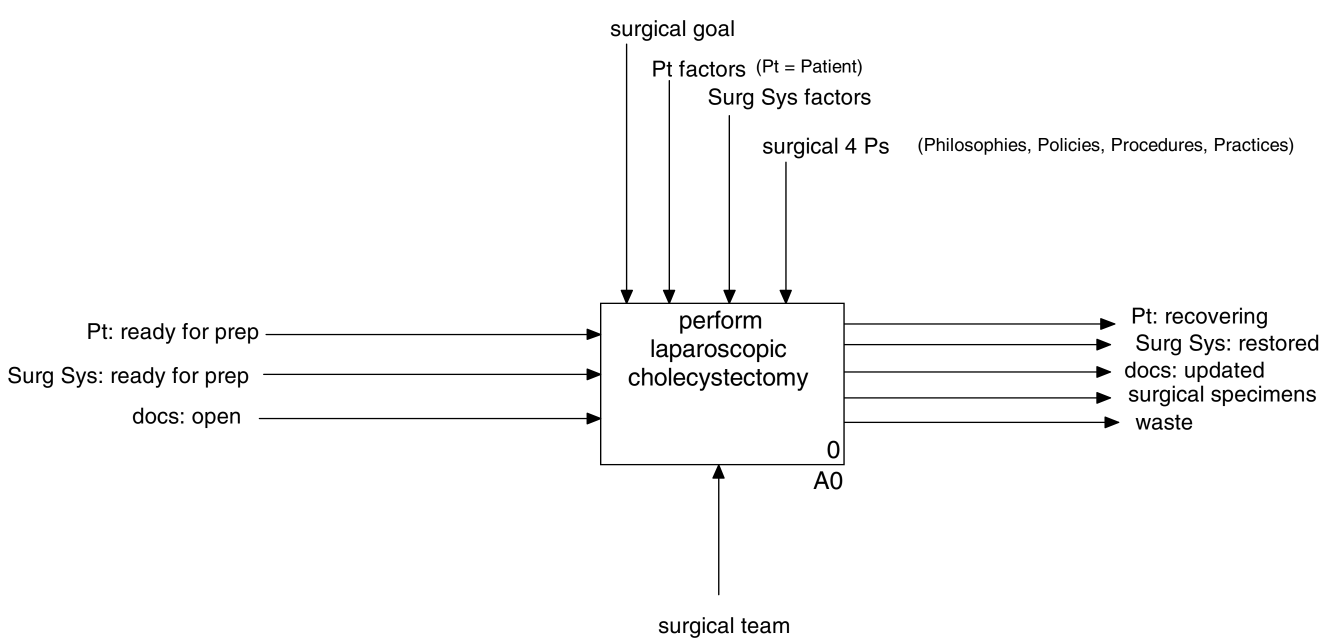

Figure 1. IDEF0 model of the top-level process, "perform laparoscopic cholecystectomy (context)". This diagram provides context for the rest of the model, part of which is shown in Figure 2.

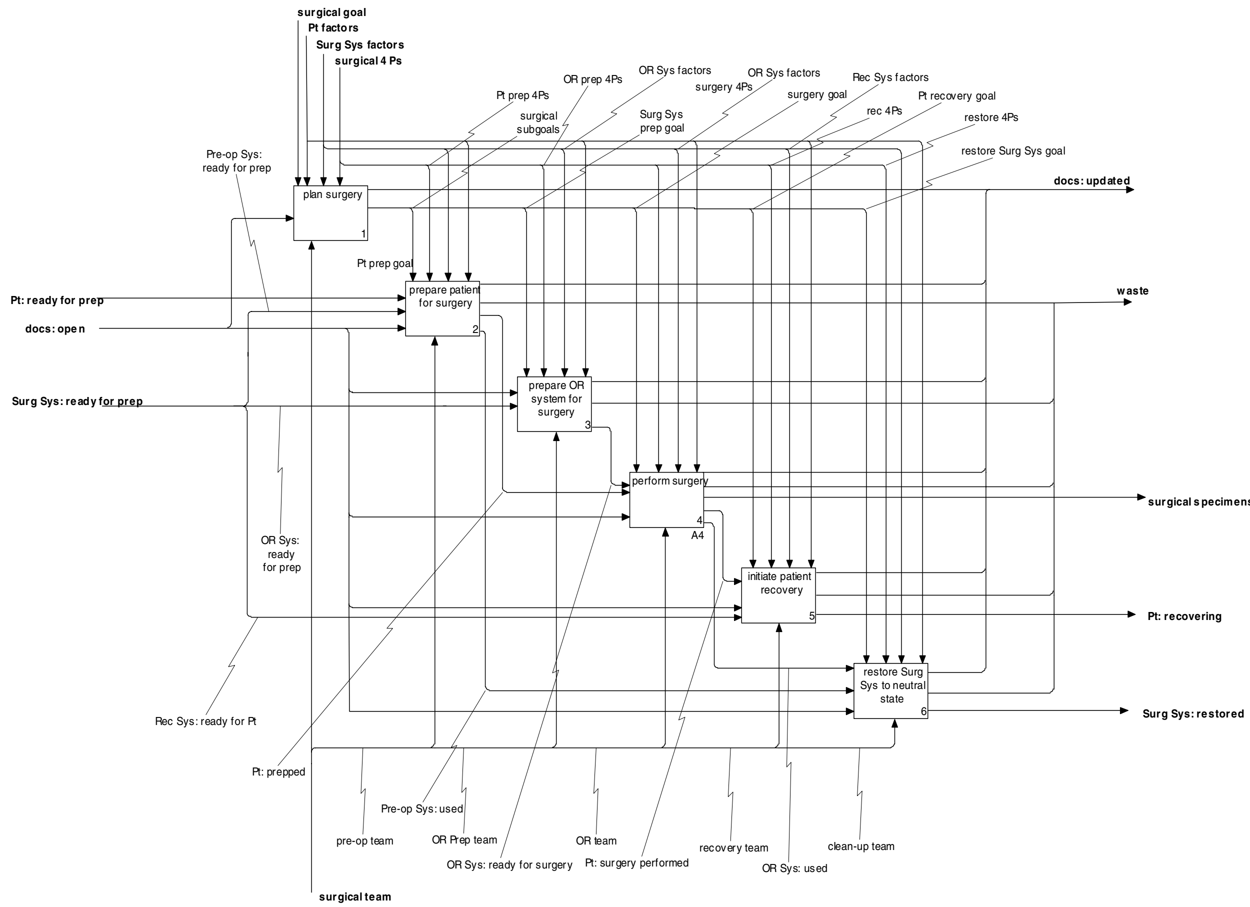

Figure 2. IDEF0 model of the subprocesses of the model in Figure 1, showing decomposition of Figure 1 inputs, outputs, controls, and mechanisms, and relationships among subprocesses.

Table 3. Task descriptions of three tasks of the insert Verres needle subprocess. (S = Surgeon, FA = First Assistant)

A4522321: plan & assess verres needle			**A4522322: elevate abdominal wall**			**A4522323: insert needle**		
Actor	**Verb**	**Object**	**Actor**	**Verb**	**Object**	**Actor**	**Verb**	**Object**
S	visualize	underlying anatomy						
S	decide	location for insertion						
S	decide	angle for insertion						
S	visualize	needle insertion path						
S	anticipate	needle feedback (resistance, clicks, timing, distance, etc.)						
S	request	needle						
						S	grasp	needle
S	assess	needle (sharpness, obturator action, etc.)						
	plan	abdominal elevation process						
			S/FA	grasp	lower abdominal wall			
			S/FA	elevate	abdominal wall			
						S	insert	needle (perpendicular to fascia)
S	sense	resistance, needle response, clicks, etc.				S	push	needle into abdomen
						S	terminate	insertion
			S/FA	release	abdominal wall			