Developing a Simulation Training Tool from a Medical Protocol

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ABSTRACT

This paper discusses the multidisciplinary effort for the development of a web-based simulation training tool that incorporates a medical protocol of patient blood management for a surgical procedure. The significance of the type of simulation tool development lies in the fact that medical simulation is able to execute training in a multiplicity of modes, it can house large digital libraries for a breadth of experiences, and it can accommodate a repetition of exercises to reinforce learning. This simulation training tool is built upon engineering and mathematical modeling. The tool is populated with simulations are drawn from actual patient case studies. The targeted trainees (users) are skilled anesthesiologists and surgeons in need of an initial introduction to this medical protocol via an expedient means to train. The tool is developed for web-based access with continuous simulation capability and hands-on exercises.

1. INTRODUCTION

Simulation training facilitates a *permission to fail environment* whereby the practitioner is taught in a multiplicity of modes [1]. It can house a *large digital library* of case studies that allows for random access to training scenarios and it can accommodate a repetition of exercises. All simulation training facilitates learning from errors and this is especially important in the field of medical training as the training takes place on a patient image, not the patient himself. The breadth of training enables a medical practitioner to methodically move from novice to master. In sum, *simulation training* incorporates both fundamental tasks and new tasks that serve to advance exposure to various patient cases and and develop expertise. It can support *re-training* that is, training experts who know what to do, but who are learning something new. That re-training capability is core to this project, *Developing a Simulation Training Tool from a Medical Protocol.*

This paper describes the methodology, modeling paradigms, and programming development to create a web-based simulation tool to train anesthesiologists and surgeons on a patient blood management medical practice. Part 2, *Why This Tool, Why This Protocol, Who to Train* discusses why the tool is needed, who will benefit from this medical practice, and who is the targeted trainee audience. Part 3, *Who to Train, What to Train* describes the trainee and the philosophy and the practice of patient blood management techniques. Part 4, *How to Build It* speaks to the methodology, modeling paradigms, and computer programming steps taken to develop the web-based tool. Part 5, *Future Work*, provides concluding comments and further tool development opportunities. It explains how the methodology, design, and tool itself adheres to the unequivocal fundamentals of modeling and simulation (M&S): verification and validation.

2. WHY THIS TOOL, WHY THIS PROTOCOL, WHO TO TRAIN

There is a strong case endorsing the use of M&S in training among medical institutions and research centers—the sheer need for a larger body of health-care professionals who are trained in an effective and expedited manner leads that discussion.[1] Additionally, anesthesiologists and surgeons expert in the field of bloodless surgery have informed the developer community that a tool of this sort does not exist in a form they prefer. Essentially,

[1]As of 2008 the American College of Surgeons certification requires three student categories who are to be taught using simulation

we believe a foremost, unmet need in medical simulation tools exists. Moreover, the medical sub-field of patient blood management as a whole is growing exponentially and simulation training instrument development is wide-open and timely.

Findings in medical literature have proven that many once excepted treatments, including blood transfusions, often carry more risk than benefit. Blood transfusions carry the risk of blood-borne illnesses including HIV, Hepatitis B, Hepatitis C, Human Lymphocytotrophic Virus, Cytomegalovirus, West Nile, sepsis, and others. One study showed that transfusion of greater than 4 units of blood increased the risk of peri-operative infection by a factor of 9.28 [2]. Furthermore, the cost in dollars of transfusion is greater than once thought.

One study compared the various costs of one unit of blood ranging from $522 to $1183 [3]. The hospitals cited in that study had an annual expenditure on blood and transfusion related activities limited to surgical patients ranging from $1.62 to $6.03 million per hospital. Conversely, by implementing a blood management program Englewood Hospital (Englewood, New Jersey) was able to reduce blood use by 42% over the course of 4 years. Doing so has significantly lowered first and foremost patient morbidity and mortality and it has affected hospital financial costs [4] [5]. This tool serves as a training instrument for anesthesiologists and surgeons in the field of patient blood management techniques.

It was apparent that the targeted audience, anesthesiologists and surgeons, possessed an elevated proficiency requiring a sophisticated tool that would be readily accessible and user-friendly for very busy medical professionals. The tool should comprise exercises that require the anesthesiologist and surgeon to make medical decisions relating to blood management during the three phases of patient management with each phase containing appropriate decision points.

3. WHAT TO TRAIN

As with research required for any modeling task, the modelers needed to have a reasonable comprehension of the blood management philosophy *vis-à-vis* standard medical surgical procedure during the three surgical phases: pre-, intra-, and post-operative. These three phases lay the foundation for the patient blood management practice.

3.1 The Blood Management Philosophy

The blood management philosophy can be expressed in terms of three pillars executed throughout three phases of patient care [6]. Below is a brief explanation of each pillar.

Pillar 1 Optimize Formation of Blood Cellular Components (haemopoiesis) This is done by producing or encouraging conditions in the body to generate healthy levels of blood cellular components.

Pillar 2 Lessen Blood Loss
This ranges from identifying and managing the risk of blood loss to the mechanical aspects of surgery to avoiding secondary hemorrhage.

Pillar 3 Channel / Optimize Patient's Tolerance of Anemia
Important to this pillar is the realization of patient's actual blood loss with his tolerable blood loss.

Various aspects of these three pillars are employed during three designated phases of patient care:

Phase 1 Pre-operative – During this phase simple measures can be taken to satisfy Pillar 1 such as detecting and treating anemia. Pillar 2 might include obtaining the autologous blood donation for hemodilution. Pillar 3 might see the implementation of a patient-specific management plan using appropriate blood conservation modalities. In short, the pre-operative phase is premised on *patient-readiness for the surgery*.

Phase 2 Intra-operative – Timing of the operation is key to addressing Pillar 1 and that requires optimizing the formation of blood cellular components. During the surgery meticulous care is taken, aka the mechanics of surgery, to satisfy the requirement of Pillar 2 in lessening blood loss. Pillar 3 focuses on optimizing the patient's ability to tolerate anemia and in intra-operative phase this can be done through appropriate ventilation and oxygenation. In the intra-operative phase minimizing bleeding is core to the patient blood management philosophy.

Phase 3 Post-operative – This phase is a critical period for the patient. Pillar 1 necessitates much care be taken to note drug interactions that can increase anemia. Pillar 2 calls for monitoring post-operative bleeding and avoiding secondary hemorrhage. Pillar 3 concludes patient blood management by determining any post-operative anemia prescriptions This phase pays close attention to *blood composition and volume*.

3.2 Individualized Strategies and Decisions

To develop the prototype tool it was decided that 12 case studies would be sufficient for providing a range of experiences. These case studies facilitate an opportunity to execute the trainee's individualized strategy / decisions for each procedure. These cases would be *elective surgeries* (as opposed to urgent or emergent) because elective surgeries offer greater opportunity for patient / physician interaction and preparation for the surgery in the pre-operative phase.

Information necessary to fully represent (model) a de-identified case study would include: the pre-operative note, any blood management orders/forms, and the post-operative note. Incorporating as much patient data as available would result in a complex characterization of the procedure.

With an understanding of the blood management philosophy, introduction to the blood management techniques employed, and the determined number and variety of patient case studies needed to provide a breadth of training experience, the developers made a few broad, preliminary assumptions on what the tool would entail:

1) it will be constructed as a web-based interface (for accessibility) and it will contain real patient case studies with an assessment capability (for lessons learned)

2) the simulations will unfold in real-time (for decision-making experience)

3) there would be an end-of-the session assessment whereby the trainee could compare his decisions / actions to the actual case study.

4. HOW TO BUILD IT

Developing a tool premised on a patient blood management protocol requires diverse modeling skills. For example, included in the model is the mapping soft or fuzzy data (human factors) such as patient subjective data and procedural decision-making on the part of the surgeon. Grounding the soft data characterization is the mathematical modeling used to accurately chart physiological changes of the case study based on a range of things like patient response to a procedure and unexpected or inadvertent bleeding.

Model development began by employing a *system dynamics modeling* paradigm as a means of crafting a visual representation of the factors and their correlative and/or causal relationships. This enabled the developers to take a holistic approach to tool design. This modeling methodology was followed by significant mathematical modeling to ensure precise measurements of patient vital signs like blood pressure, blood volume (loss), and other physiological reactions such as heart rate, oxygen saturation (SPO2), and respiratory rate.

4.1 System Dynamics Modeling

The developers started by mapping out a system dynamics model to provide an explanation and validation of the tool. And because the model is all about blood management, the dependent variable would be blood volume. Independent variables include drugs, fluids, surgery, ventilation or oxygenation – all factors that could affect blood volume. As with any system dynamics model the first step is to craft a causal loop diagram. Mapping the causal loops led to representing the relationships between and among variables needed into stock and flow representations. These representations establish the feedback loops which serve to indicate the dynamic system that captures how the body functions from a mathematical standpoint. Figure 1 is the initial attempt at the system dynamics model.

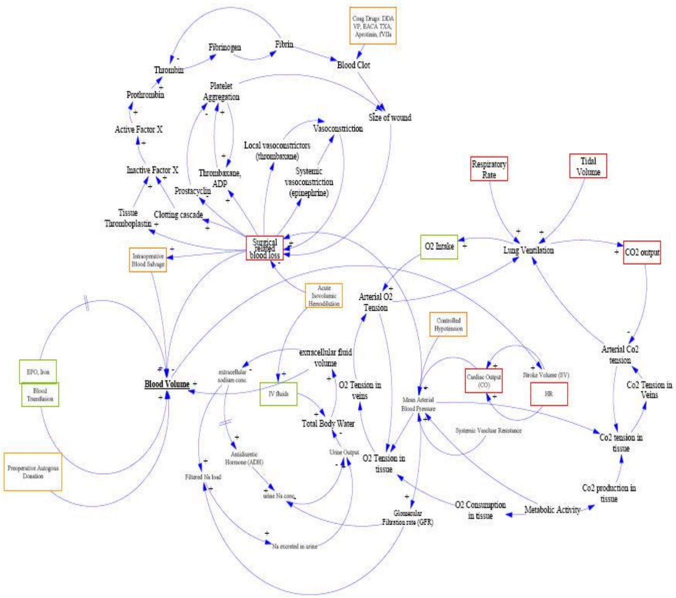

Figure 1 Initial System Dynamics Model

4.2 Mathematical Modeling

All modeling and simulation includes some aspect of mathematical modeling. This is especially true for those who think in terms of computer models and computer simulations.

The developers employed mathematical models and computations to support specific graphs such as the heart rate, oxygen saturation (SPO2), and blood loss. In short, the application of mathematical modeling for this exercise is to accurately represent the patient's initial response to hemorrhage as reflected in the vital signs. It would also monitor the steady state response to hemorrhage reflected in the vital signs as well as graded responses to variable amounts of blood loss coupled with proportionate responses to corrective measures to the blood loss (such as fluid infusion). This modeling resulted in the use of a variety of equations such as that representing pulse oxygen:

Exp[-x^2]*.65 + Exp[-(x - 2)^2]*0.4 + .2

The system dynamics model proffered the design of the tool in that it set out what should be represented in model via a visual representation of all factors needed. The additional effort put forth respective to the mathematical modeling was taken to ensure a high level of fidelity in the learning experience. The final undertaking in the tool development project was to formulate the programming tasks and web interface for the prototype tool.

4.3 Programming Design

It was important that the programming of the simulation precisely follow the three blood management pillars as they overlapped the three phases of the procedure. This began by way of a scripting interface. The approach would be a decision tree structure with artificial intelligence (AI) and computer science integration. The tool would employ parallel systems: one with trainee outcomes and one with actual case study outcomes and the training would take place in a time-compressed fashion with explanations and updates forcing decision points.

This process began with the use of open-source software as the development environment. It followed a game development environment with *drop-box* choices. The initial mapping of design called for a walk-through of the training experience. As a result the tool begins with:

1) a *Welcome* screen that requires a case study selection to initialize the system
2) next, a review of the case study folder of all pertinent data
3) this is followed by information such as labs, x-rays, studies, physical exam, vitals and an assessment plan that suggests what the problem may be and how to proceed

After the training scenario has been initialized, the blood management pillars in the Pre-operative Phase are presented in the form of drop-down boxes with choices of *no surgery* or *move directly to surgery*. If no surgery is selected, the trainee must answer why and then take steps to prepare the patient for surgery. In each case study the trainee will also experience and need to act on patients with *evident potential problems* or patients with *undetected potential problems* of which he should explore.

The Operative Phase display includes what is typically presented on the OR monitor: heart rate, blood pressure, pulse rate, breathing rate. These values will be pre-assumed but with abnormal bleeding needs that require corresponding change. The interface would also need a means to display the electro-cardiogram (ECG) and X-ray readings. These would also be done in a preprocessed manner according to the case study so that image is named then displayed. Blood Loss is visualized as a tank with a bar that goes down with volume loss in real-time.

Finally, in the Post-operative Phase the training tool reflects the same exercises as those provided in the pre-operative phase. Figure 2 below is a screen shot of the web interface.

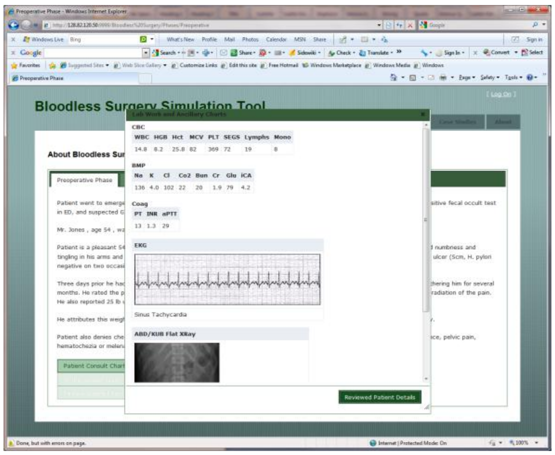

Figure 2 Screenshot of the Web Interface

The prototype tool has proven a viable mechanism for training blood management philosophy and techniques to the specified audience, trained anesthesiologists and surgeons. In actuality, the tool more literally serves to re-train with a view to better blood management practice to be used in the pre-, peri-, and post-operative phases of patient care. As a process or philosophy the developers have taken great measures to integrate and align the training experience with blood management techniques by linking this information with existent surgical decision making and practice. The medical body of literature details a knowledge gap in practice and this tool serves as a way to lessen that gap [16].

The tool design is an XML model that incorporates the comprehensive system dynamics model and the mathematical models. It mirrors the specific procedures used in the patient blood management practice by dividing the training into pre-, peri-, and post-operative phases as these phase act out the various aspects of the 3 practices. The encoded case studies drive the behavior of the tool without the need to re-implement the software. As a result the tool is designed in a scalable fashion and allows the registration of a large number of case studies.

The software that enables this tool is designed with three primary goals.

1. Keep the entry barrier for the medical professional to a minimum
2. Keep development and associated maintenance costs of the software to a minimum
3. Develop a training tool software that is scalable and extendable

The entry barrier was kept to a minimum by designing the tool as a web-based service, with potential trainees being able to access the service via web browsers, e.g., Internet Explorer, Mozilla Firefox, Google Chrome, etc. This also precluded the installation of proprietary software for the trainee.

The software is developed using a standard programming language, C#, available as part of Microsoft's .NET environment. For an interactive user interface, JavaScript was chosen as a language for producing visual artifacts, which range from showing patient demographic information to displaying patient medical status via ECG waveforms, and capturing user input, which includes prescription choices, etc. JQuery, a free-to-use software released under MIT License, is used for conforming to cross-browser JavaScript requirements.

The interactive flows of the training span the three operative phases. These flows are driven by the information specified in the case studies. As a result, depending on the case study selected the specifics of the trainee experience are updated. The tool also allows specifying a large number of case studies, each of which is captured using a data model defined as part of the software build. That data model for capturing case studies can be used for specifying new case studies or modifying existing case studies. Once case study models are registered with the tool, the tool makes them available for training purposes requiring no change either to the software or the deployed tool. This approach to drive the software behavior via case study models meets the extensibility goal and the capability to store a large number of such models meets the scalability goal.

5. CONCLUSION

The initial testing of the tool proved it to operate / function with great ease moving from decision point to decision point and phase to phase. The ability to progress at will or allow the simulation to provide error comments requiring corrective actions allows the physician to train at his own discretion. The assessment values at the close of the exercise allow the trainee to evaluate his own performance.

It is significant to note the multidisciplinary nature of the development of this tool. Expertise was called on from engineering, computer science, and social science disciplines. Integral was the role of medical subject matter experts in to include MDs, RNs (registered nurses), CRNAs (certified registered nurse anesthetists) who shared in the development of the interface, explanation and application of the blood management practice, and testing and evaluation of the tool itself.

Medical simulation training is fast becoming a necessary modality in healthcare education. This tool is the means to providing a comprehensive, effective, and time-sensitive learning experience.

6. FUTURE WORK

As mentioned at the outset, simulation training for medical professionals is an acknowledged means of effective and efficient training as it provides a learning environment with depth and breadth. And although medicine is an evidence-based exercise, the blood management is relatively novel and goes contrary to standard practice. For a variety of reasons, many skilled medical practitioners are uninformed, unable, or unwilling to engage blood management techniques.

The purpose of this training tool is to facilitate that learning exercise for closing the learning gap through simulation re-training of new information and new technique. The fact that blood management practices have a dramatic impact on hospital finances and patient outcome itself serves as valid reasons why this area of medical simulation needs to be developed [7].

Future work along the lines of blood management simulation training can take many directions. First, there are divergent paths in the operating room setting as the medical professionals there, the anesthesiologist, the surgeon, and the nurses, have different roles and as such there can be a mental disconnection between / among them. Developing a tool that represents the roles of each to reflect the knowledge of who carries out different tasks and how to train to those tasks as a multidisciplinary team. A second potential training scenario is a tool that focuses on the mechanical aspects of surgical procedure in the intra-operative phase to include such things as precision with surgical incision, ANH and cell-salvage implementation, patient autologous blood donation for hemodilution (how much and when).

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