The Fundamental Manipulations of Surgery:

A Structured Vocabulary for Designing Surgical Curricula and Simulators

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Running Head: Structured Vocabulary for Simulators

Précis. A structured vocabulary is proposed for supporting the design of advanced surgical simulators. It is simple, comprehensive, and will facilitate communication between surgeons and bioengineers developing 'high-fidelity' surgical simulators.

Abstract

Objective. A structured vocabulary is proposed for supporting the design and development of advanced surgical simulators.

Design. Historically linked to Sushruta, the 'Father of Surgery' (500 BC).

Main Result. Nine fundamental surgical instrument-tissue actions or manipulations are defined, and common synonyms provided. The vocabulary focuses on 'target skills' that are familiar to surgeons, in comparison to 'enabling skills' from the lexicon of instructional designers and psychometricians.

Conclusion. The adoption of this vocabulary will facilitate communication between surgeons and bioengineers developing 'high-fidelity' surgical simulators.

A. Introduction

Although medical and surgical education has changed dramatically in the last 100 years, it remains a process that can be characterized by a "see one, do one, teach one" approach. This long-standing "apprenticeship model" of training has particular limitations and missed opportunities for contemporary academic surgery. Using the operating room as a principal tool for teaching basic surgical skills is impractical and raises issues of cost-effectiveness and patient safety[1-3].

Computer technology is beginning to change the way in which many surgeons are trained. In particular, entirely new training approaches are necessary for minimal access surgery (MAS). With computer-based virtual environments, the repetitive execution of basic MAS maneuvers can be learned and practiced by residents, and evaluated by teachers, before proceeding to the operating room (OR). Recent studies incorporating simulation-based instruction with *part-task* trainers have demonstrated the enhanced performance of trainees in either animal or human OR settings[4,5]. In one study in which safety was considered, the number of surgical errors was also reduced [5].

In this paper, we outline a new perspective that extends the activities incorporated into *part-tasks* training to the higher level of complexity characteristic of MAS instrument-tissue manipulations. To accomplish this goal, we draw on a historical set of fundamental surgical manipulations that we consider comprising the *technical curriculum of surgery*. These fundamental manipulations are being introduced into advanced, second-generation surgical simulators being designed for trainees who have mastered basic skills.

B. Fundamental Manipulations and Technical Curriculum:

Eight fundamental manipulations of surgery have served as the building blocks for the technical component of surgical procedures for about 2500 years. These basic manipulations, taught since the time of Sushruta[6,7] are *Exploration, Aspiration/Injection, Incision, Excision, Evacuation, Extraction, Scarification,* and *Closure*. A ninth manipulation (*Implantation/Transplantation*) has been added to reflect practices of the modern era. The vocabulary, the definition of terms, and common synonyms are provided in Table 1.

The first term, *exploration*, is sub-divided to accommodate both the visual and haptic senses, a new consideration introduced in several advanced surgical simulator designs. Applications of the structured vocabulary as it was implemented millennia ago, as applied in modern *in vitro* trainers, and as used in virtual reality simulators of today, are compared in Table 2. The materials utilized for instruction in *in vitro* trainers have changed little from antiquity to the present; in fact, some 'part-task trainers' continue to incorporate animal parts, fruit, and vegetables into training exercises. Some of the manipulation terms of this vocabulary are incorporated into a proposed curriculum for gynecologic laparoscopic surgery[8].

Examples of the application of the vocabulary for tubal sterilization and laparoscopic cholecystectomy appear in Table 3. Initial steps are *Exploration* both visually and by palpation, followed successively by identification and grasping the site of proposed tissue injury (*Scarification)* and completing that manipulation. In developing a curriculum, the string of progressive terms toward procedures is *steps* (several manipulations), *methods,* and then *procedures*. This latter nomenclature of curricular development is similar to that recently proposed by Rosen, et al.[9].

C. Discussion

Historically, surgical training has been accomplished by observation, demonstration, and assisting during surgery, and by practicing on animals. (Figure 1A). Until the last decade of the 20th century, this was the exclusive paradigm used by all surgical trainees, and it remains the standard today. However, this pathway is slow, unfocused, and expensive in time and resources. Ethical issues are also involved. Recent approaches for laparoscopic training incorporate stations with bench exercises of motions and gestures practiced with inanimate objects or animal tissues[10]. These training paradigms were begun as an assessment tool (Objective, Structured Assessment of Technical Skills, OSATS)[11].

The first generation of simulators (Figure 1B) was designed for repetition and mastery of the psychomotor gestures (*enabling skills*) utilized in performing surgical procedures. This approach has been useful for learning some of the elementary actions needed for conducting surgical procedures. In the reductive process of procedure deconstruction and "task analysis"[12], these enabling skills are mastered by performing exercises on 'part-tasks' trainers. As such, practice results in the acquisition of psychomotor gestures, which are the "enabling skills" utilized in performing surgery. For example, learning with a 'part-task' trainer to navigate a grasper, grasping a peg, and transferring the peg to a different site on a pegboard is a useful "enabling" exercise worthy of practice. However, in surgical practice, more complex surgical actions (manipulations) are comprised of multiple, aggregated movements, many of which can be learned from 'part-task' trainers: A surgeon moves the grasper tip to an anatomic site and grasps it for stabilizing or exposing it, so that a corollary action, such as cutting with a scissors or scalpel, can be accomplished. The training regimen of competitive figure skaters offers a broader analogy. The movements of the skaters' body, particularly the feet, must be learned and practiced repeatedly (enabling exercises) before the specific steps and jumps (target exercises) can even be attempted. Simulation of this more complex action involves cognitive processes that seek to answer the questions; "Why am I doing this exercise?" and "How is it best done?" This thought process informs the psychomotor systems on how to proceed efficiently in accomplishing the manipulations.

Obviously, the practice of enabling skills with first generation simulators falls short of the subsequent steps necessary for surgical proficiency. For example, part-tasks identified and defined during 'task analysis' must be integrated back into a total performance, a process relying on a cognitive 'executive sub-routine'[13]. Once skills are learned, practiced, and integrated into manipulations, implementing them into procedures becomes semi-automatic[14].

To address this challenge, technological advances have recently spawned a second generation of surgical simulators (Figure 1C), allowing the practice of manipulations (*target skills*) that more closely resemble discrete surgical actions. These newer technologies offer advanced simulation features with the greater realism afforded by virtual 3D models of tissues and organs. In the process of simulator design, engineers benefit from the structured vocabulary by intuiting how an instrument ‘collides with the polygons’ positioned at the virtual tissue site where a user causes a virtual instrument to touch. In order to simulate a virtual *incision*, for example, the simulator software must recognize the arrival of the instrument and respond proportionally to the strength and direction of the interaction. The software then changes the surface and deeper structures both visually and mechanically as they are divided by a straight line, and simulated blood must emerge. The changing position must also be identified by the “haptics” component of the simulation, to provide an appropriate amount of force feedback to the users’ instruments.

Adoption of the vocabulary presented in Table 1 offers several advantages for the design of advanced surgical simulators and training curricula. These manipulations describe actions at the instrument-tissue interface, and apply to both surgical instruments and tissue manipulations. Thus, this vocabulary is consistent with how surgery is traditionally taught: The attention of students is focused primarily on the actions of instrument tips affecting tissues, and little on the motion of how the instrument tip arrived at it’s desired destination. The vocabulary also incorporates terms similar to the language used by surgeons at the operating table during surgery. Finally, these terms are familiar to surgeons, compared to the terms of the psychometrics literature that pervade much of the formative literature of surgical performance, (i.e., ‘pick-and-place’, ‘time-to-target’, ‘overshoot errors’, etc.)[13].

The methods of surgical training over time have changed, and continue to change. Table 2 compares and contrasts the methods used in antiquity by Sushruta and those utilized in the modern era. Currently employed methods focus heavily on endoscopic surgical training with images viewed directly or displayed on video monitors. An example of a difference is the removal of a pebble placed within an animal bladder, representing a bladder stone, through an incision through the bladder wall followed by scooping the pebble out with a ladle forceps, compared to the excision and extraction of seeds from within a bell pepper using a cupped forceps guided by a videoendoscope; a second-generation simulator would offer a firm, smooth virtual object that is grasped with a blunt forceps (also virtual), and pulled outward through the urethral opening of a virtual bladder modeled from cadaveric slices of a human pelvis.

An important conclusion illustrated in Figure 1 is that “enabling skills” learned with ‘part-task’-trainers, although very useful in OR performances are not the “target skills” of second generation simulations or surgery. Rather, the “target skills” utilized during surgery are encompassed by the comprehensive group of fundamental instrument-tissue manipulations defined in the proposed vocabulary. The terminology of the ‘enabling tasks’ lacks a sufficient match to surgical actions for engineers to efficiently develop simulators that will accomplish the required visual and haptic changes in real-time.

Evidence exists for the benefit of acquiring enabling surgical skills by training on first-generation simulators[4,5,10,11] using both physical simulators and computer-based trainers. It remains to be determined whether acquiring target surgical skills will hasten the learning curve of trainees, improving their surgical proficiency and safe performances. Another important question is whether second-generation simulators can be incorporated into surgical curricula independently of first-generation methodologies. Still another question is whether advanced trainees will be attracted to utilize such learning technologies.

In conclusion, modern surgical training continues to draw on aspects of each training paradigm. A structured vocabulary *based on target skills* will help surgeons and engineers communicate more effectively during the design of the next generation of complex, highly biofidelic surgical simulators[15]. In addition, the technical curriculum derived from such a shared vocabulary will help resolve an elusive problem in surgical education: the development of a robust tool for objective assessment of performance and quality assurance in surgical practice[3,10,16,17].

Table and Figure Legends

Table 1. Proposed structured vocabulary comprised of nine surgical instrument-tissue manipulations. Each term is defined after Sushruta, and synonyms are listed. Other and additional synonyms may be preferred in some regions by individual surgeons.

Table 2. Applications of the structured vocabulary through the Ages. For each term, the method of teaching it over the ages is described. Animal tissues, fruit, and plant components are common objects to be manipulated. Examples of modern uses are grasping and extracting seeds from a bell pepper, incising and suturing the skin of a chicken breast, cannulating the vein of a leaf, or resecting the epithelium of a sheeps' bladder.

Table 3. Structured vocabulary terms applied to (a.) tubal sterilization by electrosurgery; On the SUMMIT Surgical Workbench, the necessary actions for performing the electrosurgical method of the tubal sterilization procedure are named as ordered steps. Each step incorporates several skills required for performing the manipulation. Most of the manipulations are necessary for implementing other methods of accomplishing this goal. Several methods are practiced widely, e.g., partial salpingectomy, Fallope ring placement, Filche clip application. **and (b.) laparoscopic cholecystectomy and common bile duct exploration.** The procedure described uses clips for closure of the cystic artery and duct, but laser dissection and coagulation is another method for doing the procedure.

Figure 1. A simplified schema for the three major training paradigms used for the development and transfer of surgical skills to the operating room. Historically, surgical training was accomplished by observation, demonstration, practicing on animals, and by assisting during surgery (Row A). This pathway is slow, unfocused, and expensive in time and resources. The first generation of simulators (Part-task trainers; Row B) were designed for repetition and mastery of the psychomotor gestures utilized in performing surgical procedures (*enabling skills*). This pathway has been established as useful for learning some of the elementary actions needed for conducting surgical procedures. Technological advances have recently spawned a second generation of surgical simulators (Row C) allowing the practice of manipulations that more closely resemble actual surgical actions (*target skills*). This pathway offers advanced simulation features with the greater realism of virtual 3D models of tissues and organs, and the opportunity of expansion into pathological structures. Modern surgical training continues to draw on aspects of each training paradigm. A structured vocabulary based on target skills not only serves as a practical tool for surgical assessment, but also facilitates communication between surgeons and engineers in the design of the next generation of complex, highly biofidelic surgical simulators.

TABLE 1. The Nine Fundamental Manipulations of Surgery: Definitions and Common Synonyms

1. **EXPLORATION**: Inspection of a structure or space by visualization or palpation. (1a) **Visualization** – looking at 'visual landscapes' scanned by ones eyes directly, or on a monitor displaying the scene captured by an endoscopic camera. *Synonyms*: Inspect, Visualize, Examine, See, Look, 'Scope'– Zoom In, Zoom Out, Measure, Compare
(1b) **Palpation** – inspection of a part by touching or probing, usually with the hand or an instrument, either through entry of a natural ostium (opening) or an incision. *Synonyms*: Probe, Touch, Grasp, Grab, Retract, Dissect (blunt), Push, Pull, Stretch, Palpate, 'Feel', Squeeze, Move, Slide, Dilate, Denude, Mark, Expose, Stabilize, Tease, 'Poke', Nudge, Twist, Flex, Bend
2. **ASPIRATION/INJECTION**: Penetration into a hollow or fluid-filled structure, usually with a sharp tubular tool, followed by the application of a vacuum to the external port of the instrument, or introduction of fluid, with or without chemicals. *Synonyms*: Introduce/Withdraw, Stick (into), Suck (out), Puncture, Hydro-dissect, Probe, Instill, Insufflate
3. **INCISION:** Opening into a structure by cutting. *Synonyms*: Cut, Slice, Divide, Separate, Section, Transect, Spatulate, Snip, Saw
4. **EXCISION***:* Complete removal of a structure from within a body space by a set of incisions, or other manipulations. *Synonyms*: Excise, Cut out, Remove (all)
5. **EVACUATION**: Emptying of an anatomic space, or cavity, or a pathological lesion. *Synonyms*: Suction, 'Suck' (out), Scoop (out), Remove (contents)
6. **EXTRACTION**: Forceful removal of a normal or diseased structure from its location. *Synonyms*: Remove, Extract, Withdraw, Take (out), Pull (off, out),
7. **SCARIFICATION***:* Purposeful injury of tissues and organs, to control hemorrhage, promote new tissue relationships, destroy pathological lesions, etc. This manipulation may utilize any one of several methods of tissue injury. *Synonyms*:,Desiccate, Ablate, Burn, Denature, Destroy, Coagulate, Vaporize, Freeze
8. **CLOSURE***:* Binding together, or apposition of surfaces or the ligature closure of tubular parts, usually with sutures. This manipulation includes all types of sutures, surgical clips, defocused-laser agglutination, and of tissue glue. *Synonyms*: Approximate, Suture, Sew, Tie (knot), Plicate, Apply (clip/staples, screw), Fire (clip, stapler suture device), Thread, Affix, Fasten
9. **IMPLANTATION/TRANSPLANTATION**: Insertion of a medical device or organ for normalizing function, substitution with a healthy organ or artificial structure, or temporary placement of a device for diagnosis (Add: IUD; catheter) *Synonyms*: Position, Place, Fix, Install, Attach