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Hierarchical Decomposition of Laparoscopic Procedures

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Abstract

The purpose of this report is to outline the hierarchical decomposition of surgical procedures, from surgical steps through tasks and subtasks to tool motions, and highlight implications for surgical training systems. Three common laparoscopic procedures were analysed: cholecystectomy, inguinal hernia repair, and Nissen fundoplication. In laparoscopic training workshops and operating rooms, our observational research included split screen videotaping of both the endoscopic view and our video camera's view of the primary surgeon. Videotapes were extensively annotated and analysed to yield timelines of each procedure, with component surgical steps, substeps, tasks, and subtasks duration as a function of procedure. The hierarchical decomposition of surgical procedures provides a framework for structuring a systematic approach to training, in the real and simulated environment. An example comparing variations in the fundoplication procedure is presented. Our results also have important implications for the design and assessment of new technology and intelligent tools in endoscopic surgery.

1. Introduction

Traditionally, surgeon training has followed an apprenticeship model, where many hours are spent in the operating room observing another skilled surgeon at work, and eventually assisting in surgery, until the apprentice is competent to operate on her own. However, endoscopic skills can not be acquired through observation alone. Due to the nature of the surgical technique, hands-on practise is essential for developing the visuomotor co-ordination in performing endoscopic manipulations. Consequently, surgical training is moving away from the apprenticeship model, and towards a more pragmatic approach. Simulators and virtual environments are being developed as training tools which offer surgeons the option to practise basic skills or entire procedures repeatedly, or to practise isolated steps of a procedure that are particularly tricky. These training tools offer certain practical advantages over training with animal models.

Presently, there lacks a unified methodology for this novel approach to surgical skill training. There is yet no structure to the efficiently train surgeons in endoscopic surgery. One of the problems with such novel and evolving technology is that we do not fully understand the nature of the impact that technology has on skill acquisition. Depending on the knowledge, level of skill and experience of the human, appropriate attunement to relevant information in the environment can facilitate learning. For example, in learning any motor skill, a novice would pay attention to fine details at a lower level of control, while a more experience learner would pay more attention to higher levels information to get the bigger picture. The novice is concerned about acquiring landmark knowledge, while the more experienced individual is concerned about route knowledge [1]. Therefore, an effective training system would allow the student to select a training module that is at an appropriate level of detail. We propose a hierarchical decomposition of surgical procedures which forms a framework for structuring the relationship between environmental constraints and action selection at different levels of analysis. It has important implications for developing training systems, and standardisation tests for assessing skills and technology. Here, we describe our methodology for performing a decomposition hierarchy in laparoscopic surgery, and illustrate how such a hierarchy can be useful for developing training systems for surgeons. Discussion of results is at the level of surgical steps only due to limited space.

2. Methods

Our observational research was conducted in two different settings: laparoscopic training workshop and the operator room. Each provided a different perspective with respect to skill level of the surgeons, difficulties encountered with the tools and instrumentation of laparoscopic surgery, interactions between surgeons performing the tasks, and insights from surgeons in general. The workshops were geared toward instructing residents on the use of endoscopic tools and performance of basic surgical tasks on anaesthetised pigs. Surgery in the operating rooms allowed for observation of expert surgical skills and spontaneous responses to live situations, in the context of actual operations. Three different laparoscopic procedures were observed: Fundoplication, Trans-abdominal Pre-peritoneal Laparoscopic Repair, and Laparoscopic Cholecystectomy.

Videotaping:

A camcorder (Panasonic, VHS) on tripod was positioned adjacent to the video monitor displaying the endoscopic view to the practising surgeons. The camera recorded the motions of the surgeons' hands at all times. An image from the endoscopic video monitor was recorded simultaneously. These two images were fed into a digital mixer, creating a picture-in-picture effect, then recorded on a VHS tape at SP speed (30 frames per second). Due to spatial constraints in the operating room, the camcorder was usually positioned near the head of the patient.

Video Analysis:

Videotapes were annotated using MacSHAPA, a computerised video annotation software. For consistency, all videotapes were analysed by the same individual, following a set of criteria -- operationally defined beginnings and endings of events. Operational definition of events were developed for each procedure, at the level of steps, substeps, tasks, subtasks, and motions. Inter-observer reliability checks were done to ensure that the set of criteria was a valid tool for the analysis of video events.

3. *Results and Discussion*

Our detailed analysis resulted in a decomposition hierarchy of surgical procedures, with increasing levels of details, from surgical steps, substeps, tasks, sub-tasks, down to the level of motions. Logical breakdown into procedural steps and tasks was verified by three expert surgeons independently. Figures 1 to 3 show the decomposition hierarchy performed on the 3 laparoscopic procedures: Cholecystectomy, Laparoscopic Inguinal Hernia Repair, and Fundoplication. Each procedure was carefully broken into steps of surgically meaningful events. Surgical steps were clearly defined by operational definition of beginnings and endings (see Tables 1, 2, 3). These steps in sequence represent the high level surgical procedure in each respective operation. At this high level, surgeon's diagnostic and surgical decisions are not concerned with information and constraints specified at the lower levels.

Each step was further decomposed into substeps, which were action sequences taken to accomplish the surgical goals defined in the above step. At this level of decomposition, more details are specified in terms of constraints for the goal of the particular step at the level above. For example, in dividing the peritoneum in a fundoplication, the substeps were locate and divide (see Figure 3). These substeps have specific safety and precision constraints which dictate how the goal at the step level can be achieved. Similarly, these substeps are constrained by basic surgical tasks that are clearly and individually distinct. For example, suturing and tying knots were two basic surgical tasks to join the crura in a fundoplication.

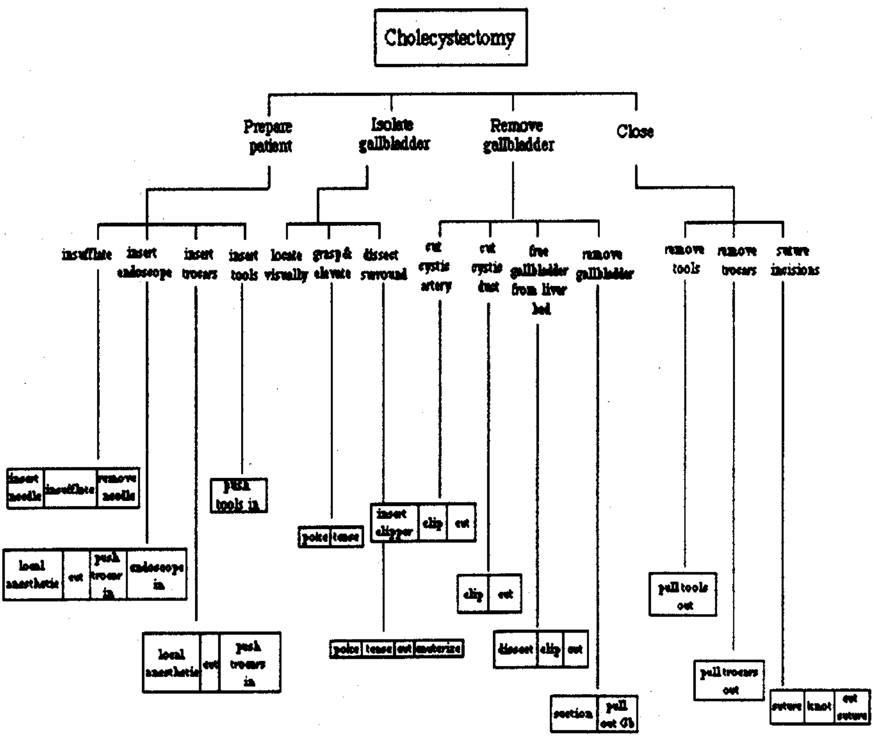

Figure 1. Decomposition hierarchy of laparoscopic cholecystectomy from steps to substeps and tasks.

Table 1. Operational definition of surgical steops in Cholecystectomy.

Surgical Steps	Beginning	Ending
1. Prepare Patient	moment the insufflation needle contacts abdomen	moment first tool contacts abdomen
2. Isolate Gallbladder	moment first tool contacts abdomen	moment clipper pliers contacts abdomen
3. Remove Gallbladder	moment clipper pliers contacts abdomen	removal of gallbladder from abdomen
4. Close	moment gallbladder is removed from abdomen	last open suture is completed

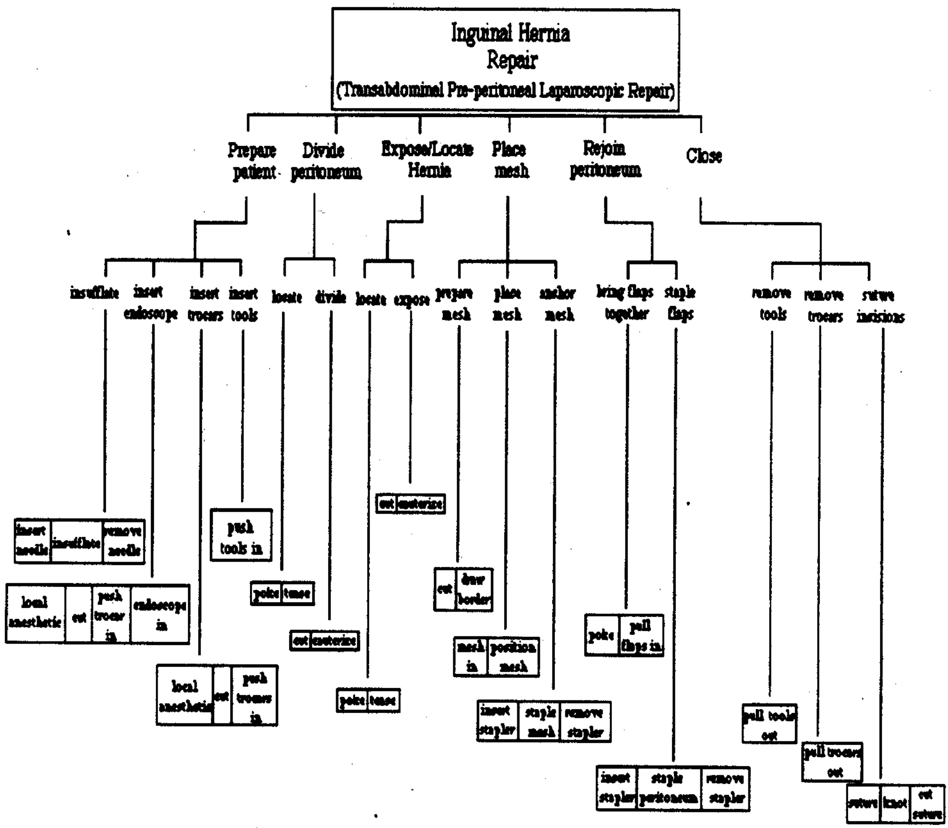

Figure 2. Decomposition hierarchy of inguinal hernia repair from steps to substeps and tasks.

Table 2. Operational definition of surgical steps in Inguinal Hernia Repair.

Surgical Steps	**Beginning**	**Ending**
1. Prepare Patient	moment insufflation needle contacts abdomen	moment first tool contacts abdomen
2. Divide Peritoneum (into two level flaps)	moment first tool contacts abdomen	last cut of peritoneum
3. Expose/Locate Hernia	last cut of peritoneum	removal of scissors
4. Placement of Mesh	removal of scissors	after last staple fired to stabilise mesh
5. Rejoin Peritoneum	after last staple fired to stabilise mesh	removal of stapler after last staple fired
6. Close	moment stapler is removed	last open suture is completed

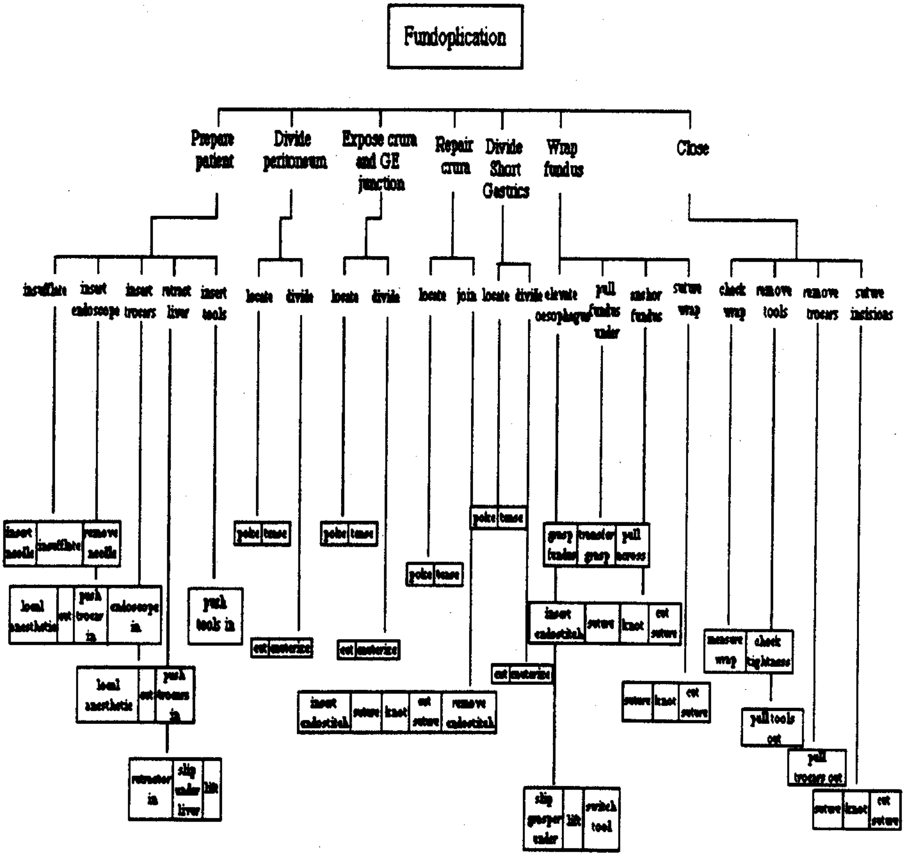

Figure 3. Decomposition hierarchy of a fundoplication from steps to substeps and tasks.

Table 3. Operational definition of surgical steps in Fundoplication.

Surgical Steps	Beginning	Ending
1. Prepare Patient	moment the insufflation needle contacts abdomen	liver in place and liver elevator is stable
2. Divide Peritoneum	moment the tool moves toward the peritoneum to cut	last cut of peritoneum
3. Expose crura and G.E. Junction	last cut of peritoneum	last cut of tissue and when scissors are removed
4. Repair Crura	moment the endostitch contacts abdomen	completion of cut suture and removal of endostitch
5. Divide Short Gastrics	moment scalpel contacts abdomen	last cut and scalpel removed
6. Wrap Fundus	moment oesophageal elevator contacts abdomen	completion of last suture - endostitch is removed
7. Close	when endostitch is removed	completion of last open suture

With operationally defined beginnings and endings, each step could be timed and usec to measure performance or to evaluate variations in surgical techniques. For example, the cholecystectomy procedure was decomposed into 4 surgical steps (see Figure 1): 1) prepare patient, 2) isolate gallbladder, 3) remove gallbladder, and 4) close. Operational definitions of these steps (see Table 1) allowed for a timeline analysis of the procedure. Of the four surgica steps in this procedure, the major steps were 2) isolate gallbladder and 3) remove gallbladder. which took an average of 18.5 and 16 minutes, respectively (Figure 4, left panel). By comparison, a resident performing the same procedure took longer to isolate the gallbladder than the experienced surgeon (see Figure 4, right panel). It was expected that the inexperienced resident would be affected by the safety constraints in handling the different target tissues. Differences between experienced and inexperienced surgeons also showed up at the task and subtask levels (not shown). By working up and down the hierarchy, it is possible to delineate the critical element at each level of the hierarchy which sets the expert apart from the novice surgeon. In so doing, training can be designed to target critical areas to improve performance. The beauty of the decomposition hierarchy is that it allows for an elegant and objective comparison of like elements in an otherwise complex and uncontrolled environment. Once the environmental constraints are specified in the appropriate level of analysis, the decomposition hierarchy is potentially a powerful tool for structuring interdependent relationships in a complex environment such as endoscopic surgery.

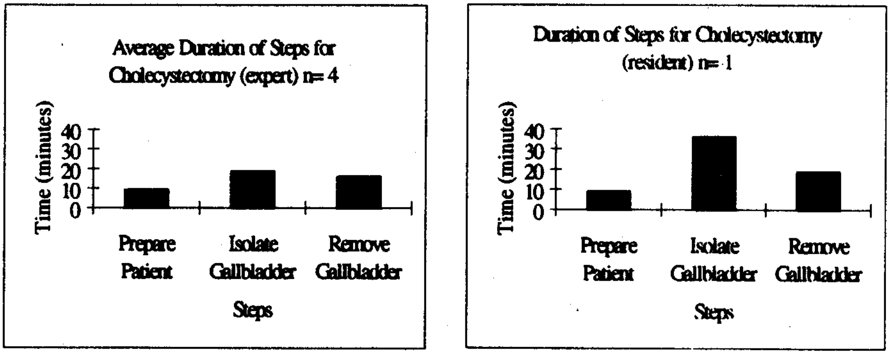

Figure 4. Time duration of surgical steps in cholecystectomy for an expert surgeon, and a novice surgeon (resident).

Another example of the potential power of the decomposition hierarchy technique is demonstrated by the comparison of two different techniques for performing a fundoplication. In one technique, the short gastrics were cut before the step of wrapping the fundus around the oesophagus. In another, the short gastrics were left intact. Figure 5 shows that the subsequent steps to cutting the short gastrics were faster than when the short gastrics were not cut, suggesting that it was more difficult to do the wrap in the latter case. This information can be used in conjunction with patient outcome results to support the choice of one technique over another. Clearly, the decomposition hierarchy of surgical procedures allows for an objective and systematic approach to assessing performance.

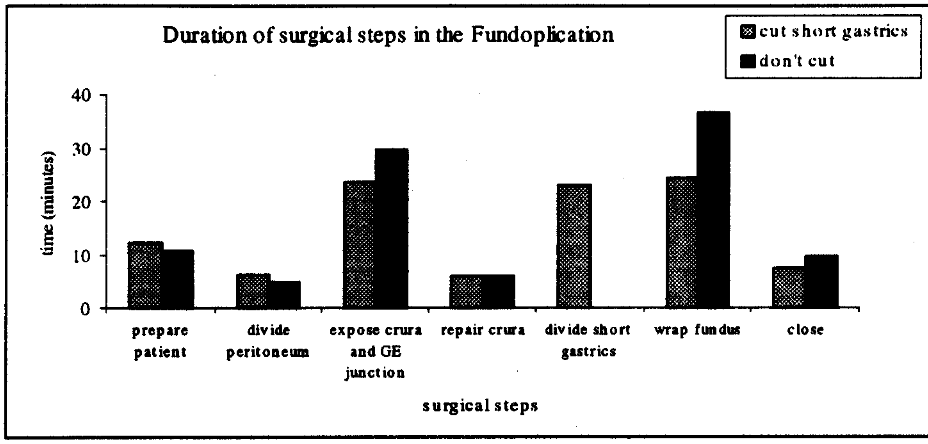

Figure 5. Comparison of durations of surgical steps in fundoplication, with and without cutting the short gastrics before wrapping the fundus.

4. Conclusion

Decomposition hierarchical of surgical procedures is a powerful analytic approach which offers a framework for structuring the complex environment within which the surgeon and technology interact. It can be used to study the relationship between goals and actions at various levels of the hierarchy, with different sets of constraints. This is useful for the design of surgical training systems, with individual modules representing the level of the hierarchy appropriate to the surgical trainee's level of experience. This approach has the advantage of focusing the surgeon's attentional resources to information that is most relevant to her training, given the skill level and past experience. It has the versatility to be extended to measuring surgical skill performance in an objective and quantitative manner. As well, it can be applied in the assessment of new technology, by measuring the impact on surgical performance outcome, which is directly related to patient outcome.

5. Acknowledgement

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6. Reference

[1] Rasmussen, J. (1983). Skills, rules, knowledge: signals, signs, and symbols, and other distinctions in human performance models. *IEEE Trans. Systems, Man and Cybernetics*, SMC-13: 257-267.