Original communications

Analysis of errors enacted by surgical trainees during skills training courses

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Background. *Despite the emphasis on medical error as a major cause of hospital morbidity and mortality, there has been little published work on errors committed by trainees. This issue is particularly relevant to the training of surgeons and was addressed by our study.*
Methods. *Sixty simulated laparoscopic cholecystectomies performed on restructured pig tissue models by 60 surgical trainees provided the study material. The unedited videotapes were analyzed by observational HRA of the component steps of the procedures. Ten generic forms of observable error types were used to categorize patterns of failure. Error probabilities with specific instruments were also calculated.*
Results. *A total of 1067 errors were identified by observational HRA: 331 consequential and 736 without consequence (ie, total error rate of 18 [SD ± 10]) per procedure. The study documented a wide variation in the number of errors between the 60 trainee surgeons. The important underlying factors for the trainee errors were (1) omission of important steps, (2) execution of steps in the wrong sequence, and (3) use of excessive force. These 3 errors accounted for 92% of consequential errors.*
Conclusions. *This study has shown that trainees vary considerably in their propensity to commit errors. This variability indicates that the surgical training in component skills for laparoscopic surgery should be flexible and individualized. Three mechanisms account for the majority of errors and indicate that skills training in surgery has to be structured, menu driven, and tailored to individual needs. (Surgery 2005;138:14-20.)*

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SURGICAL TRAINING has been based traditionally on the apprenticeship system with the operating room serving as the only venue for the acquisition of technical skills used in operative procedures. Training in dedicated skills laboratories has been introduced gradually over the last 3 decades and will, undoubtedly, play an increasingly role with the reduction in the work hours of trainee doctors imposed by legislation, such as the Revised European Working Time Directive[1,2], this mandate will effectively reduce the number of work hours per week for every trainee to 48 hours per week by the year 2009.

The big push for surgical skills training rapidly followed the introduction of laparoscopic surgery[3-6] when the surgical profession was caught unprepared for this technical advance. Indeed, for a time, there were no trainers, and the chiefs of surgery (or at least the majority of them) required training themselves. Not surprisingly, iatrogenic bile duct and other injuries, some fatal, increased sharply.[7,8] The hard lessons learned from this period contributed to the establishment of skills laboratories, which are now embedded in the surgical curriculum. In addition to patient outcome, relevant economic factors of health care, including operating room costs[4] and the substantial resource utilization necessitated by these iatrogenic injuries,[9-11] have added to the importance of surgical technical proficiency and, hence, skills training. *In surgical practice, being a good doctor is not enough.*

The published studies on surgical training have focused largely on development and objective

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Fig 1. Nonlive animal model for simulated laparoscopic cholecystectomy.

assessment methods of surgical skills,[12-15] and validation of training courses.[4-6] However, little work has been reported on the analysis of the performance process during training itself. Indeed, there have been few studies of trainee errors and their underlying causative mechanisms. This topic is important as errors have a positive impact on learning, especially on the acquisition of technical skills, but only if they are realized, understood, addressed, and hence avoided by trainees.

Human reliability assessment (HRA) techniques have been used widely over many decades in high-risk industries to improve performance and safety by preventing human errors.[16,17] This HRA methodology was modified for use in laparoscopic surgery by Joice et al[18] and has gradually evolved into a validated system of observational clinical HRA.[19] Our study used this methodology to study and describe the technical errors committed by surgical trainees during skills training courses on simulated laparoscopic cholecystectomy at the Cuschieri Skills Centre (CSC), Dundee, Scotland, a training unit operational since 1992.

MATERIAL AND METHODS

HRA techniques were used to analyze 60 unedited video recordings by 60 surgical trainees performing simulated laparoscopic cholecystectomy on restructured animal tissue model developed by the CSC staff for this purpose. All the trainee surgeons performed these operations at the CSC as part of a basic skills training course in laparoscopic surgery.

Ergonomics of the setup. We used a model of laparoscopic cholecystectomy restructured from porcine liver with an intact gallbladder and cystic pedicle (Fig 1). The tissue block was mounted on a plastic grid inside a laparoscopic trainer. Standard laparoscopic instruments and a video endoscopic system with a 2-dimensional monitor were used to perform the simulated laparoscopic cholecystectomy. Instruments were introduced into the trainer box with a 60° manipulation angle, an elevation angle of 45° to 60°, and equal azimuth angles.[20]

Subjects and procedure. Sixty surgical trainees were recruited for the study, the vast majority of whom were in the first year of their higher surgical training program (equivalent to first-year resident in the United States). The course consisted of didactic lectures (approximately 20% of course time) with considerable (80% of total course time) intensive hands-on operative skills exercises in a structured program. The operative skills training comprised component generic skills such as port insertion, endoscope orientation, diagnostic laparoscopy, dissection techniques with different instruments, clip application, and extracorporeal knot tying. On the third day, the trainees put this all together and performed a simulated laparoscopic cholecystectomy after receiving a didactic lecture on laparoscopic cholecystectomy. The 60 procedures performed by 60 surgical trainees were videotaped, which provided the material for the observational clinical HRA.

Error identification. In the current study, we considered any action (or omission) that (1) resulted in a negative consequence such as bleeding, cystic duct injury, liver injury, and so on or (2) increased the time of the procedure by necessitating a corrective maneuver as a consequential error. We defined the inconsequential error as an action or omission that increased the likelihood of negative consequence and under different circumstances could have had a consequential effect.

We used a modified HRA technique, which is based on the external error modes in the *S*ystemic *H*uman *E*rror *R*eduction and *P*rediction *A*pproach[21] (Table I). The applicability of this approach to laparoscopic surgery had been confirmed in a previous study.[18] The 10 external error modes were classified into 2 separate groups with respect to their generic type. External error

Table I. External error modes

External error modes
1. Step is *not done.*
2. Step is *partially* completed.
3. Step is *repeated.*
4. Second step is done *in addition* to first step.
5. Second step is done *instead of* first step.
6. Step is done *out of sequence.*
7. Step is done with *too much* (force, speed, depth, distance, time, rotation).
8. Step is done with *too little* (force, speed, depth, distance, time, rotation).
9. Step is done in *wrong* (orientation, direction, point in space).
10. Step is done on/with the *wrong object.*

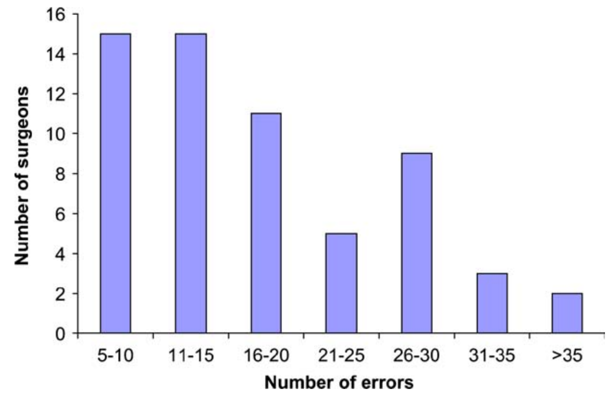

Fig 2. Variation in the number of errors committed by surgeons.

modes 1 through 6 corresponded to the ability of the surgeon to carry out the component steps of the procedure in the correct order; errors of this generic type were classified as *procedural.* In contrast, external error modes 7 through 10 reflected the inability of the surgeon to manipulate the instruments to achieve a specific step of the operation; these errors were therefore designated as *executional.* At the level of the individual trainee, this distinction is of practical importance because it determines the corrective training needed to improve skill level and execution. Thus, executional errors will be overcome by practice of the respective component skills (until the trainee is able to do it). Procedural errors are avoided by enforcing operative rules, ensuring proper sequential conduct of the operation (menu-driven execution). The objective is for each trainee to reach the stage of *proficiency* when he/she *knows how to perform* an operation correctly and *is able to execute it* flawlessly.

Task analysis. The simulated laparoscopic cholecystectomy was divided into the following component task zones (1) dissection of cystic pedicle, (2) clip application and division of the cystic artery and duct, and (3) separation of the gallbladder from its liver bed. A clinical research fellow with clinical endoscopic surgical experience carried out direct observational HRA of the unedited videotapes. Before the study, he undertook 8 months of training by an accredited human factors specialist in association with academic surgeons who had an interest in surgical ergonomic and human factors. The clinical research fellow and the human factors expert assessed the inter-rater consistency of the observational HRA in the initial 20 procedures and found the consistency rate to be 0.85. Errors were analyzed for each task and instrument used. The error probability for each task was calculated as follows: (total number of enacted errors)/(number of steps performed to complete the task) $\times$ 100%. Similarly, the instrument error probability was calculated as follows: (total number of observed errors)/(number of the steps using the instrument) $\times$ 100%.

RESULTS

The mean execution time per simulated laparoscopic cholecystectomy was 38 ± 11 minutes. The analysis of the 60 procedures identified 1067 errors: 331 with consequences and 736 without. The mean (SD) of the total errors was 18 ± 10, whereas the mean of the consequential errors was 6 ± 7. There was a wide variation in the number of errors committed by the trainee surgeons (Fig 2).

The error probability for dissection of the cystic pedicle, division of the cystic artery and duct, and separation of the gallbladder from the liver bed was 7.7%, 15.2%, and 5.6%, respectively. The nature of the consequential and inconsequential errors and their underlying modes are shown in Tables II and III. Only 3 error modes were associated with the majority of errors: omission of steps, wrong sequence of steps, and the use of excessive force/distance accounted for 92% and 57% of consequential and inconsequential errors, respectively. A summary of the external error modes is outlined in Table IV. Procedural errors accounted for 38% and 50% of consequential and inconsequential errors, respectively.

Table V shows the number and probability of errors for different instruments. During dissection, the hook dissector had the highest error probability, whereas the pledget had the lowest. A high error probability also was observed during use of the holding grasper by the nondominant hands and during deployment of the clip applicator to

Table II. Consequential errors and their underlying error modes during 60 simulated laparoscopic cholecystectomies by surgical trainees

Errors	*Description of error mode*	*Mode category*	*No. of errors*
Perforation of gallbladder	Omitting to visualize instrument tip	1	11
	Wrong sequence of steps using heel of hook for dissection	5	37
	Use of excessive force with instrument moving a longer distance than optimum	7	21
	Use of little force to left up tissue	8	2
	Wrong instrument direction	9	2
Liver injury	Omitting to visualize instrument tip	1	20
	Wrong sequence of steps using heel of hook for dissection	5	22
	Use of excessive force with instrument moving a longer distance than optimum	7	155
	Wrong instrument direction	9	2
	Dissection in a wrong tissue plane	10	13
Cystic duct injury	Omitting to visualize instrument tip	1	12
	Wrong sequence of steps using heel of hook for dissection	5	3
	Use of excessive force with instrument moving a longer distance than optimum	7	5
Cystic artery injury	Use of excessive force with instrument moving a longer distance than optimum	7	1
Diathermy burn to liver	Use of excessive force with instrument moving a longer distance than optimum	7	5
	Failing to lift up the tissue with instrument prior to applying current	5	2
	Activation of current between steps	6	2
	Wrong instrument direction	9	1
Inappropriate clipping	Omitting to visualize tips before application	1	11
	Omitting to apply clip before dividing duct	1	1
	Inadequate force to hold the clips	8	2
	Wrong direction of clip applicator	9	1

occlude the cystic artery or duct. Use of excessive force and the wrong sequence of steps were associated with the majority of consequential and inconsequential errors committed with the hook. The criteria for the identification of use of excessive force involved uncontrolled movement of the tip of the hook dissector, resulting in accelerated motion beyond the aimed target tissue, or the tip of hook dissector veering out of endoscopic view. Omission of important steps accounted for a large proportion of consequential and inconsequential errors involving the scissors and clip applicator. Excessive force caused the majority of consequential errors involving the pledget, holding graspers, and scissors.

DISCUSSION

This observational study used HRA techniques to identify and quantify errors enacted during basic skills training for laparoscopic surgery. Perhaps the most important finding was the wide variance in technical error rates between the 60 surgical trainees, indicating different levels of innate abilities for manipulative tasks. If the study sample is a fair representative of the initial skill level of surgical trainees, the results of our study imply that the training in laparoscopic skills should be more flexible and individualized as the innate ability for manipulative work varies amongst trainees—in other words, some will achieve competence before others.

Close supervision with appropriate feedback during practical sessions, as well as the use of laparoscopic mechanical and virtual reality simulators that provide tasks of increasing difficulty, will play a major role in surgical training. Although the errors of the novice surgical trainee reflect incompetence, they have to be considered an integral

Table III. Inconsequential errors and their underlying error modes during 60 simulated laparoscopic cholecystectomies

Errors	*Description of error mode*	*Mode category**	*No. of errors*
Overshooting (instrument movement a longer distance than optimum)	Use of excessive force	7	63
	Wrong direction towards vital structure	9	1
Non-visualization of instrument tip during dissection	Omitting to visualize instrument tip	1	135
Inadequate retraction to identify tissue planes before dissection	Partially blind insertion of the instrument tip into tissue plane	5	12
	Inadequate tension applied from non-dominant hand	2	9
Applying current to cut tissue without the instrument out of view	Current applied prior to the contact with tissue	6	7
	Too little retraction to lift up the tissue from underlying structure	8	5
Instrument movement out of endoscopic view	Omitting to keep instrument in view	1	115
	Excessive force to move instrument	7	7
Inappropriate use of instrument	Use of heel of hook for dissection with inadequate retraction	5	86
	Use of excessive force for dissection	7	1
	Instrument movement with active current towards vital structure	9	1
Wrong instrument insertion into tissue planes	Inadequate force to exposure tissue planes	8	49
	Wrong instrument orientation or direction	9	135
Slippage on holding gallbladder	Use of little force or small bite to hold gallbladder	8	104
	Wrong orientation to hold the gallbladder	9	1
Use of wrong instrument type	Use of suture scissors for dissection	10	5

*The categorization of error modes was based on their classification in Table I.

Table IV. Summary of external error modes underlying committed errors

Error modes	*Inconsequential errors** *N = 736*	*Consequential errors** *N = 331*
Step is not done	250 (34%)	59 (18%)
Step is done in wrong sequence	107 (15%)	64 (19%)
Step is done out of sequence	12 (2%)	2 (1%)
Step is done with too much force/distance	64 (9%)	183 (55%)
Step is done with too little force/distance	154 (21%)	4 (1%)
Step is done in wrong direction	144 (20%)	6 (2%)
Step is done with/on wrong object	5 (1%)	13 (4%)

*The number in parentheses is the percentage of error modes to the total consequential or inconsequential errors.

part of the training/learning process; if the errors are constrained and absorbed by the training system, they can expedite the transition to the skilled proficient operator.

The average number of errors committed by surgical trainees per simulated laparoscopic cholecystectomy in our study was almost twice that observed during clinical laparoscopic cholecystectomy.[19] Hence, training in skills laboratories is to be considered a prelude to supervised training of clinical operative skills in the operating room. The best model for this was developed, piloted, and audited by the Minimal Access Therapy Training Unit of Scotland.[22] In this intercollegiate exercise, funds for the Training Initiative List Scheme were awarded to 9 hospitals in Scotland to train junior staff in dedicated operative sessions. During these sessions, 817 operations/procedures were per-

Table V. Number of errors committed with different instruments

Instrument	*No. of steps*	*No. of total errors*	*No. of consequential errors*	*Error probability*
Hook	4421	395	168	9%
Scissors	5883	379	99	6%
Pledget	1989	19	8	1%
Clip applicator	333	78	28	23%
Holding grasper	1964	197	28	10%

formed with a 4% conversion rate and an overall 5% minor complication rate, confirming that properly supervised operating on patients by trainees, if anything, improves patient outcome.

Because of their frequency and generic nature, inconsequential errors are perhaps more useful than consequential errors for detailed study and analysis of error mechanisms. The same approach has been used in high-risk industry to minimize errors that are rare but can have a catastrophic consequence.[23] In our study, instrument movement outside the endoscopic field, overshooting, nonvisualization of the instrument tip during dissection, inappropriate instrument use, and wrong insertion of instruments into tissue planes were regarded as inconsequential. However, all these may have serious consequences if committed during certain crucial steps of the operation involving important anatomic structures. For instance, in clinical practice, use of uncontrolled (excessive) force with the hook dissector may translate in overshooting with serious consequence if the tip of the hook dissector impinges on an important structure such as the bowel or common bile duct.

The analysis of errors committed with different instruments and their underlying modes provide detailed information for training in essential laparoscopic component skills. The error probability quantifies the risk with use of different instruments and hence stresses the relative "damage potential" during dissection near vital structures, especially during the early learning curve. In our study, laparoscopic dissection by trainees using the hook had the highest error probability, while pledget dissection had the lowest. Errors committed with the hook and pledget were executional errors attributed to employing excessive force with the instrument or overshooting. To minimize those errors, a module has been designed to train surgeons in using appropriate force during tissue dissection.

Poor instrument design and functionality may account, in part, for the nature of errors committed by surgical trainees and the underlying modes of the errors. The force applied by the operator is influenced by the exact location of the invariant point (at the abdominal wall) and by the instrument length (ratio of intracorporeal to total shaft length). The difficulty in gauging the right force to avoid trauma at the instrument-tissue interface is further compounded by diminished tactile feedback and especially by the friction between the shaft of the instrument and its port. Hence, it is not surprising that trainees experience difficulties with these instruments and initially induce tissue damage by using excessive force. One of the essential features of skills training is for trainees to gain the delicate feel of the tissues during manipulation and dissection, overcoming what Lord Moynihan[24] described so aptly as "the heavy hands" of the beginner.

CONCLUSION

This study has shown that trainees vary considerably in their propensity to commit errors. This variability indicates that surgical training in component skills for laparoscopic surgery during in vitro laparoscopic training should be flexible and individualized. Three mechanisms account for the majority of errors, indicating that skills training in surgery has to be structured, menu driven, and tailored to individual needs.

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