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Published in:
Surgical endoscopy and other interventional techniques

DOI:
10.1007/s00464-013-2862-2

Publication date:
2013

Surg Endosc (2013) 27:2947–2954
DOI 10.1007/s00464-013-2862-2

Effective and efficient learning in the operating theater with intraoperative video-enhanced surgical procedure training

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Received: 25 October 2012 / Accepted: 28 January 2013 / Published online: 23 February 2013

Abstract

Background INtraoperative Video Enhanced Surgical procedure Training (INVEST) is a new training method designed to improve the transition from basic skills training in a skills lab to procedural training in the operating theater. Traditionally, the master–apprentice model (MAM) is used for procedural training in the operating theater, but this model lacks uniformity and efficiency at the beginning of the learning curve. This study was designed to investigate the effectiveness and efficiency of INVEST compared to MAM.

Methods Ten surgical residents with no laparoscopic experience were recruited for a laparoscopic cholecystectomy training curriculum either by the MAM or with INVEST. After a uniform course in basic laparoscopic skills, each trainee performed six cholecystectomies that were digitally recorded. For 14 steps of the procedure, an observer who was blinded for the type of training determined whether the step was performed entirely by the trainee (2 points), partially by the trainee (1 point), or by the supervisor (0 points). Time measurements revealed the total procedure time and the amount of effective procedure time during which the trainee acted as the operating surgeon. Results were compared between both groups.

Results Trainees in the INVEST group were awarded statistically significant more points (115.8 vs. 70.2; $p < 0.001$) and performed more steps without the interference of the supervisor (46.6 vs. 18.8; $p < 0.001$). Total procedure time was not lengthened by INVEST, and the part performed by trainees was significantly larger (69.9 vs. 54.1 %; $p = 0.004$).

Conclusions INVEST enhances effectiveness and training efficiency for procedural training inside the operating theater without compromising operating theater time efficiency.

Keywords Cholecystectomy · Education · INVEST · Laparoscopy · Minimally invasive surgery · Training

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Minimally invasive surgery (MIS) is difficult to learn and to teach. Compared to open surgery, learning curves for mastering procedures appear to be longer. MIS confronts the operating team with ergonomic conditions and technical skills that are not employed in open surgery [1, 2]. Surgeons work with long instruments that pivot on the abdominal wall. This results in inverted instrument movement inside the abdomen, limited haptic feedback, and less degrees of freedom [3]. The visual feedback of the surgeon's actions is displayed on a 2-dimensional video screen that lacks depth perception and is moved away from the patient, disturbing the natural eye-hand-target axis [2, 4]. Surgeons and residents in surgery have to master these technical skills and challenges before they can perform any MIS procedure appropriately and safely [5].

Traditionally, surgery has been taught following the master–apprentice model (MAM). In this model, surgical trainees learn to perform surgical procedures under the supervision of a qualified surgeon. The supervising surgeon instructs the trainees, and when necessary, the surgeon temporarily takes over the procedure to demonstrate how a difficult step is performed.

Nowadays, work-hour regulations for residents on one hand and the necessity to master more difficult MIS procedures on the other, lead to the development and validation of various training programs [6, 7]. The mainstay of each of these programs is to teach the important elements of MIS effectively and efficiently while the exposure of patients to a trainee's early learning curve is avoided [8, 9]. The basic laparoscopic motor skills can be practiced repeatedly on box trainers, virtual reality (VR), and augmented reality trainers. VR trainers allow repeated practice of various exercises and record parameters such as instrument path length, collisions and time to objectively score the trainee's performance on these exercises. A disadvantage of most VR trainers is the lack of haptic feedback for instrument- and tissue handling [10]. Box trainers do provide haptic feedback, and use real laparoscopic instruments [11]. They are used to train basic laparoscopic skills but can also serve for training procedure-specific skills with cadaver organs inside the box. A disadvantage of the box trainer is the absence of an automated and objective scoring system, necessitating the presence of a qualified trainer when the box trainer is to be applied for certifying a proficient amount of skills of the trainees [6].

Animal model and cadaver training is very helpful to practice entire procedures once the basic skills are mastered. It allows procedural training without exposing patients to the beginning of a learning curve, but it is also requires resources and is not available on demand. However, the most important element in training a specific surgical procedure remains the training on a real patient with an experienced surgeon at the trainee's side. Initially the supervising surgeon will perform a large portion of the procedure to demonstrate the sequence of steps and their important aspects. A major disadvantage of this training model is that steps can only be performed once per procedure either by the trainee or the supervising surgeon. When the supervisor takes over, that part is lost for the trainees, who have to wait for the next operation to perform the step themselves.

In order to minimize the frequency of intervention by the supervisor and to maximize the operating time for the trainees, we created a new training method called INtra-operative Video Enhanced Surgical procedure Training (INVEST). Short instructional videos demonstrate all the key elements and essential tips and tricks of the procedure. This is done step by step and on demand inside the operating theater.

In previous research, we demonstrated that INVEST had a positive effect on the learning curve assessed on an OSATS global rating scale [12, 13]. The aim of this study was to further evaluate whether this positive effect of INVEST was due to an increased effectiveness and efficiency of surgical procedure training inside the operating theater in comparison to the traditional MAM. It was hypothesized that this type of video instruction would reduce interventions by the supervising surgeon and increase the number of steps that can be performed by trainees during their initial experience with laparoscopic procedures.

Methods

In a randomized trial with repeated measurements, trainees were randomly assigned to a structured curriculum to train 6 laparoscopic cholecystectomies (LC) utilizing either INVEST or the usual MAM.

Patient selection and supervision

Sixty patients with uncomplicated symptomatic gallstone disease were selected for this study. All patients were asked to give informed consent for recording the procedure for research purposes and for the fact that a resident would perform the procedure under the supervision of a qualified surgeon. Patients were also informed about INVEST and explained that the procedure itself did not differ between the experimental and control groups.

Three dedicated laparoscopic surgeons were also randomly assigned to supervise the procedures in both groups. They were conversant with the latest guidelines and approved the content of the instructional video. The supervising surgeons were blinded for the progression of the trainees in the curriculum of 6 cholecystectomies. The surgeons guarded the safety and the flow of the procedure, they gave verbal instructions, and when necessary, they temporarily took over the procedure. The timing and reason for temporarily taking over the procedure was decided on the supervising surgeon's professional autonomy.

Trainee selection

Ten trainees were included in this study. All trainees were registered residents in surgery, they were in the early phase of their training and resided at the Department of Surgery at Leeuwarden Medical Center. Criteria for inclusion were at least 6 months of experience in open surgical techniques and the successful completion of a training course in basic surgical skills. Exclusion criteria were any hands-on experience with LC and a cumulative experience of >5 cases in other laparoscopic procedures.

Trainee preparation

Because the trainees had minimal previous exposure to laparoscopic techniques, they also had no practical experience with the basic motor skills that are unique to laparoscopic surgery. These skills should be mastered before anyone can be safely and efficiently trained in a specific laparoscopic procedure. Therefore, before random assignment to INVEST or MAM, all residents scheduled for this study developed their basic laparoscopic motor skills on the Simendo laparoscopy trainer (Simendo, Rotterdam, the Netherlands). This validated VR simulator has a variety of exercises using abstract tasks to develop hand–eye coordination and laparoscopic motor skills. Additionally, it is equipped with a proficiency-based technical skills training curriculum [14, 15]. Successful completion of the Simendo training curriculum indicates a sufficient level of basic laparoscopic technical skills to allow safe participation in laparoscopic procedures inside the operating theater under the supervision of a qualified surgeon. As an additional result of this curriculum, the technical skills of all the trainees were calibrated at an equal level.

After completing the Simendo curriculum, residents were randomly assigned to one of the two arms of this study by drawing a sealed envelope.

In both groups, each resident performed six LCs within 2 weeks. Residents prepared themselves for these procedures in standard fashion using textbooks, anatomy books, and online information. During the procedure itself, the control group was trained using MAM. The experimental group, in addition to being supervised by a qualified surgeon, was trained with INVEST. We controlled for equal levels of surgical skills at baseline in order to avoid differences in outcome that were due to initial differences among participants.

Operating theater setup

All procedures were performed in a dedicated MIS suite. This is a fully integrated operating theater in which laparoscopic equipment and multiple flat-screen monitors are permanently installed to be operational on demand. In the INVEST setting, two monitors were facing the operating trainee and the supervising surgeon, providing an ergonomically safe posture. One monitor displayed the operative image; the other was used for the video instruction. A third monitor displayed the operative image for the scrub nurse. The 7 video clips were presented on demand as soon as the operating team was ready for the next stage of the procedure.

The complete procedure was digitally recorded, including audio channels from the trainee and the supervising surgeon. The open introduction and closure of the abdominal wall and skin were recorded with a room overview camera. The uncompressed image of a high-definition CCD camera connected to a 30° laparoscope was recorded nonstop during the laparoscopic part of the procedure. To facilitate the postoperative video analysis, the supervising surgeon was instructed to visually mark each transition from one stage to the next by pulling the laparoscope into the trocar for a few seconds. This was also done when the role of operating surgeon changed from trainee to supervisor and vice versa.

The INVEST instructional video

We created a step-by-step instructional video in conformity with the guidelines for LC as formulated by the Association of Surgeons of the Netherlands [16]. These guidelines are similar to the guidelines formulated by the Society of American Gastrointestinal and Endoscopic Surgeons and the European Association for Endoscopic Surgery with additional emphasis on the importance of the critical view of safety (CVS) [17]. We identified 14 separate steps in the standard LC that were selected to be included in the instructional video (Table 1). All 14 steps of the procedure that are described in the guidelines were incorporated chronologically into seven video clips. Each video clip describes a clearly identifiable stage of the procedure: 1 open introduction of the first trocar, 2 inspection and accessory trocar placement, 3 opening of peritoneal envelope, 4 creation of the CVS, 5 clipping and division of cystic duct and artery, 6 retrograde

Table 1 Description of the 14 steps of the procedure that were included in the INVEST video clips

INVEST video clip no.	Step
1.	1. Open introduction
2.	2. Diagnostic laparoscopy
	3. Accessory trocar placement
3.	4. Positioning of the gallbladder
	5. Incision peritoneum medially
	6. Incision peritoneum laterally
4.	7. Dissection of cystic duct
	8. Dissection of cystic artery
	9. Identification + documentation CVS
5.	10. Clipping + division cystic artery
	11. Clipping + division cystic duct
6.	12. Retrograde cholecystectomy
7.	13. Gallbladder and trocar removal
	14. Closure of abdominal wall and skin

INVEST INtraoperative Video Enhanced Surgical procedure Training, *CVS* critical view of safety cholecystectomy, and 7 gallbladder removal and closure. For each of these seven stages, a 1-min video clip was created, demonstrating anatomical landmarks, key elements, and operative techniques essential to that particular step and stage of the procedure. Video clips were displayed on demand on a second screen next to the operative screen when the trainee was ready for the next step of the procedure. For safety reasons, neither the trainee nor the supervising surgeon was allowed to continue the procedure while the instructional video was playing. After completion of each video clip, a written summary appeared and was displayed on the accessory screen while the trainee performed the next step.

Assessment

Assessment of the 60 procedures was performed by one observer after the procedures were randomly numbered. The observer was blinded for whether the LC was performed in the INVEST of MAM curriculum and for the order of the 6 procedures in the training curriculum. To blind the analysis of the recorded procedures, the segments that were recorded while the INVEST video was displayed and the actual operation was on hold were cut. However, the durations of these deleted segments were included in the time measurements.

Effectiveness

The effectiveness of procedural training can be described by the relation between the possible amount of training opportunities in a procedure and the amount of training that was actually realized.

The effectiveness of the INVEST and the MAM training curriculum was estimated by measuring the amount of active participation of the trainees across 6 LCs. The blinded observer determined for each of the 14 separate steps of the LC whether it was performed entirely by the trainee (2 points), partially by the trainee (1 point) or by the supervisor (0 points). Consequently, for each procedure, trainees could receive a score between 0 and 28 points. The amount of steps performed by the trainee, the individual scores per procedure and the summed scores of the 6 procedures within the curriculum were calculated and compared between the INVEST and MAM training method in order to visualize the longitudinal score development as well as the overall effect of the curriculum.

Efficiency

The efficiency of a training method can be described by the relation between amount of training given to the trainees and the amount of operating theater time that was consumed for these purposes. We determined this relation in several ways.

In the first place we measured operating theater time efficiency. With the procedural videos we measured the total procedure time (TPT) and the amount of time in which the trainee acted as the operating surgeon, the effective procedure time (EPT). Operating theater time efficiency was assessed as the ratio between EPT and TPT, which expressed the relative amount of operating time that was consumed by the trainee without supervisor intervention.

In the second place we investigated the efficiency of the training method itself. To determine the operating pace of a trainee (OPT), we calculated the relation between the EPT used by the trainee and the amount of points earned while he was operating. Finally, we determined for the INVEST and MAM training method how much operating theater time (TPT) had to be spent to allow the trainee to earn a point (TPT_{point}) or to participate in a step (TPT_{step}).

Statistical analysis

Because of the small sample size and the risk of chance capitalization by multiple testing, we did not analyze longitudinal effects within both training groups. Although each variable that was used in the analysis was normally distributed (Shapiro–Wilk test, $p > 0.05$), the Wilcoxon–Mann–Whitney test for independent samples was conducted to evaluate the hypothesis that trainees assigned to the INVEST group would perform better, on average, than those assigned to the MAM group. Statistical significance was set at $p < 0.05$. Effect sizes (ES) were calculated only for statistically significant differences, because it makes no sense to estimate clinical relevance of a result that may be based on random variation. Cohen's ES for independent samples was used to estimate the magnitude of these differences [18]. According to Cohen's thresholds, an ES of <0.20 indicates a trivial difference, 0.20–0.50 a small difference, 0.50–0.80 a moderate difference, and >0.80 a large difference.

Results

Ten trainees were randomly assigned to the two arms of the study without dropout after inclusion. All trainees were in their first of second year of surgical training and met the inclusion criteria. Their median experience was 10 months with no statistical differences between the two groups. Each trainee completed the basic skills training curriculum on the Simendo successfully to the preset level of proficiency before randomization. There were no significant differences in training time to acquire the proficiency level between both groups. Each resident performed 6 LC within the set period of 2 weeks, and all the procedures were successfully recorded. There were no technical problems with displaying the instructional video in the INVEST group. All 60 LC were completed successfully without conversions. There were no major complications in the perioperative period. Minor complications did occur ($n = 3$); all were superficial umbilical wound infections, and the incidence was not statistically different between the two groups.

Effectiveness

Each LC was assessed on 14 steps with a maximum achievable score of 28 points per procedure if all steps were entirely performed by the trainee. Therefore, the curriculum of 6 LCs contained 84 steps with a maximum achievable score of 168 points. In the analysis of the individual procedures, the trainees trained with INVEST were granted significantly higher scores for procedure 1, 3, 5, and 6. Procedures 2 and 4 did not show statistically significant differences (Fig. 1).

The medians of summed scores across 6 procedures were 117 and 65 points in the INVEST and MAM group, respectively, and were statistically significant higher among INVEST trainees. The mean ranks of INVEST and MAM were 8.0 and 3.0, respectively ($W = 15$, $Z = -2.61$, $p < 0.05$) (Table 2). Analysis of the 84 steps indicated that in the MAM group, significantly more steps were only partially performed by the trainee (1 point) or were performed by the supervisor (0 points). The median of steps that were entirely performed by the trainee was higher among INVEST trainees (49 vs. 17; $W = 15$. $Z = -2.63$, $p < 0.05$). Differences between both training models were large, with ES of >0.80 (Table 2).

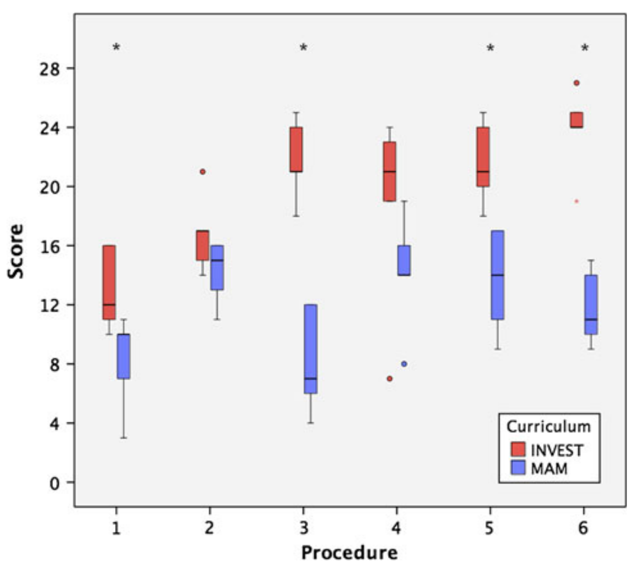

Fig. 1 Box plot presenting the scores (minimum 0, maximum 28 points) per procedure in the curriculum achieved by the trainees in the INVEST and MAM groups. *Asterisk* statistically significant difference

Efficiency

The time measurements to compare operating theater time efficiency between both groups showed no statistical significant difference for TPT. The procedure time that was available for the trainees (EPT) was significantly longer in the INVEST curriculum. Moreover, when calculating the relative amount of operating time, the trainees in the INVEST group performed a significantly larger part of the procedure than trainees in the MAM group (Table 3). Analysis of the efficiency of the training method revealed that while acting as the operating surgeon, the trainees in the INVEST group performed at a faster operating pace. They were able to perform more steps of the procedure and scored more points per minute, expressed in OPT. The overall efficiency calculations indicated that the INVEST curriculum required less TPT to allow the trainee to score a point, resulting in a lower TPT_{point}. Similarly, it required less TPT to allow a trainee to participate in the partial or complete performance of a step of the procedure, resulting in a significantly lower TPT_{step} in the INVEST curriculum (Table 3).

Discussion

INVEST is a new concept for procedural training inside the operating theater. With this study, we confirm that

Table 2 Differences between the INVEST and MAM groups on overall performance across all steps and the cumulative number of times trainees scored 0 points, 1 point, or 2 points

Score	INVEST, median	MAM, median	Z value	p	ES
Total performance score	117	65	2.61	0.01	4.05
Performance					
0 points (entirely performed by supervisor)	16	31	2.62	0.01	2.95
1 point (partially performed by trainee)	22	36	2.31	0.02	2.26
2 points (entirely performed by trainee)	49	17	2.61	0.01	4.31

INVEST INtraoperative Video Enhanced Surgical procedure Training, *MAM* master–apprentice model, *ES* effect size

Table 3 Efficiency for the INVEST and MAM groups

Characteristic	INVEST, median	MAM, median	*Z* value	*p*	ES
TPT, min	412	453	0.94	0.34	NS
EPT, min	279	239	1.98	0.04	0.59
EPT/TPT ratio, %	70.54	52.57	2.61	0.01	2.57
OPT, EPT/point	2.43	3.41	2.40	0.02	2.00
TPT_{step}, min	5.94	8.16	2.61	0.01	3.36
TPT_{point}, min	3.45	5.94	2.61	0.01	3.33

INVEST INtraoperative Video Enhanced Surgical procedure Training, *MAM* master–apprentice model, *ES* effect size, *TPT* total procedure time (6 procedures), *EPT* effective procedure time (6 procedures), *OPT* operating pace of trainee (indicating the EPT needed per point scored), TPT_{step} overall efficiency in TPT needed to let a trainee participate in a step, TPT_{point} TPT needed to let the trainee score a point

compared to the traditional MAM, INVEST can create a more effective and efficient learning environment for surgical residents in the early phase of their learning curve for the laparoscopic cholecystectomy.

Effectiveness of the training curriculum is significantly enhanced. The INVEST video clips demonstrate the procedure step by step and on demand inside the operating theater. Immediately after watching the instruction, the trainee applies the instructed material in practice. As a result of this, out of the 84 available steps in the curriculum, trainees in the INVEST group could participate as operating surgeon in 71 steps (82 %). They performed 49 (55 %) of these steps without the interference of the supervising surgeon, and only 16 (18 %) of the steps were completely performed by the supervising surgeon. The procedures performed with INVEST were granted more points throughout the curriculum (Fig. 1). Although we did not relate the effectiveness of a curriculum to a possible learning curve, there is an obvious trend, indicating that the amount of points that were scored increased per procedure in the curriculum. In procedure 6, trainees in the INVEST group are the operating surgeon during 86 % of the procedure time during which they are awarded 85 % of the available points (Fig. 1).

Efficiency is important for both the work flow inside the operating theater and the learning curve of the trainee, who is bound to the increasing working-hour restrictions. Our time measurements demonstrate that INVEST does not compromise operating theater efficiency, making it suitable for training in daily practice. A trainee can watch the instructional videos and perform the role of operating surgeon during a significantly larger part of the procedure without lengthening of the TPT. Although we cannot conclude anything about the overall result of this curriculum on the learning curve, this study shows that INVEST can increase the part of the procedure used for training by 18 % (Table 3). Within the trainees' operating time, INVEST allows them to be involved in a significantly larger amount of steps, that can be performed by the trainees at a faster pace. Therefore, the total amount of operating theater time that has to be invested to allow trainees to perform a step or to be awarded a point is substantially reduced.

Procedural training inside the operating theater is an essential part of the education for young surgeons. Modern skills labs can be used for safe and repetitive training of elementary laparoscopic motor skills and for the first steps of procedural training. During this early phase of a learning curve, trainees learn the basic skills necessary to safely perform laparoscopic surgery. However, after the acquisition of these basic skills, trainees have to learn procedural skills and problem-solving skills by participating in surgical procedures at the side of an experienced supervising surgeon. INVEST contributes to the efficiency and effectiveness of this learning process in a number of ways. By presenting a stepwise instructional video inside the operating theater, trainees receive the instruction at the moment it is needed. Immediately after watching the instructional video, trainees can apply the knowledge to perform the next part of the procedure. Therefore, trainees both see and perform the operation within one procedure. Whether this setup of intraoperative, stepwise, and on-demand presentation enhances the retention of the demonstrated skills compared to watching the instructional videos before the procedure is likely but not proven, and this will be subject of further studies.

An additional effect of INVEST is that it provides a standardized instruction method for procedural training that complies with the national and international guidelines. Therefore, it might partially eliminate the variability of teaching ability and procedural knowledge between staff surgeons while patient safety may be simultaneously enhanced. Also, the staff surgeons also see the instructional video. Because they know what step the trainees will perform next and with which strategy, it is likely that the supervising surgeons are more confident in allowing the trainees to perform the procedure.

In a previous study we demonstrated that surgical residents trained with INVEST had a significantly faster improvement of skills than a similar group of residents trainees with the MAM [12]. In that study, we used the validated global rating scale of the Objective Structures Assessment of Technical Skills (OSATS) [13]. The INVEST group experienced a significantly faster improvement of skills on the OSATS global rating scale. The longitudinal improvement on the OSATS global rating scales had a very similar development as the awarded points for the procedures in this study that are presented in Fig. 1. This emphasizes the fact that surgical skills develop with practice. The more surgical trainees are exposed to practicing a technical or procedural skill, the faster the skill is mastered. INVEST not only allows surgical trainees to perform procedural skills more frequently, but also all the involved procedural skills are repetitively demonstrated immediately before trainees perform these skills.

A weakness of this study is the small group size, which makes the outcome vulnerable for a type I error. In the study design, confounding factors were controlled in the following ways. First, the level of surgical and laparoscopic experience among the trainees was uniform on admission. None of them had noteworthy laparoscopic experience, and before randomization, each trainee was identically prepared with the Simendo basic laparoscopic skills curriculum. Second, trainees were randomly assigned to either group to control for the influence of individual differences. Third, appraisal of the recorded procedures was performed by an independent observer in random order and blinded for INVEST or MAM, for the name of the trainee, and for the number of procedures that the trainee had performed.

Another potential weakness of this study is that the supervising surgeons could not be blinded for the training method. Although the supervisor was blinded for the trainees' progression in the curriculum of 6 procedures, there could have been a bias in the supervisor's decision to take over the procedure. The moment of taking over and the moment of reinstating the trainee as operating surgeon was left to the discretion of the supervisor.

Another important aspect of procedural training is the safety of the patient. With the intraoperative videos, we introduced a potential distraction into the operating theater. To assure that there was always a clear view of the operating field, we used a dual flat-screen setup, with one screen displaying the live image from the endoscope held by the supervising surgeon and the other displaying the instructional video for the trainee. While the instructional video played for the trainee, the supervising surgeon was instructed to watch the patient.

In order to further explore the potential benefit of INVEST, we are planning a multicenter study that investigates the effect of INVEST among a larger group and for different procedures. We are interested in the long-term benefits of INVEST and the potential shortening of the learning curve to master a procedure. The Dutch surgical resident training program is becoming more competency based. Once a skill or procedure is mastered, trainees can start to learn the next procedure. Uniform, effective, and efficient skills training as well as uniform evaluation of acquired skills that can be transferred from one teaching hospital to the other are very important issues in modern surgical resident training.

In conclusion, we recommend INVEST for procedural training inside the operating theater because it provides a uniform, efficient, effective, and stimulating training environment that also addresses patient safety. Compared to the traditional MAM, INVEST enables surgical trainees to perform a substantially larger part of the procedure with less interference by the supervising surgeon. Operating theater efficiency is not compromised by INVEST.

Acknowledgments The authors thank J. M. P. Collins for reviewing the text. They also thank the supervising surgeons and participating residents for their contribution.

Disclosures Drs. M. J. van Det, W. J. H. J. Meijerink, C. Hoff, B. Middel, and J. P. E. N. Pierie have no conflicts of interest or financial ties to disclose.

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