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Management of Bleeding Complications in Virtual Reality Laparoscopy

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The aim of this study was to compare the impact of induced bleeding complication training with regular training on a virtual reality laparoscopic (VRL) simulator. Although bleeding complications occur rarely during laparoscopic surgery, they usually arise without warning and may have severe consequences for the patient because complication management training is not currently widespread. Third-year medical students (n = 41) were randomly selected for 2 curricular courses on how to perform a bimanual task on a VRL simulator. Both the regular training group (RTG) and the induced bleeding complication training (ICT) group performed 2 regular training sessions and 9 training sessions. For the ICT group the training sessions were with a bleeding complication. The 2 groups were comparable regarding their initial performance levels and improved significantly in task time and handling economics throughout the course ($P < 0.001$). When a bleeding complication occurred during the initial phase, performance parameters were significantly worse ($P < 0.05$). During a bleeding complication, the ICT group showed a significant improvement in time, handling economics, and blood loss ($P < 0.001$) throughout the training course, whereas the RTG group showed no improvement. Induced complication training has a positive influence on the management of bleeding on the VRL simulator. Structured laparoscopic complication management training should be implemented during surgical education as an add-on to regular procedural training.

Key words: Bleeding complication – Laparoscopic surgery – Virtual reality simulation – Training – Complication management – Education

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Intraoperative bleeding complications during laparoscopic surgery occur rarely, with an incidence of 0.05%–4%. However, these complications may arise unexpectedly at any time during the operation and can cause a disruption in the procedural flow.[1–2] Intraoperative bleeding is among the main reasons for conversion to open surgery and can result in an acute intraoperative crisis with severe consequences for the patient.[3]

Simulation is being used to safely shorten surgeons' learning curves for routine laparoscopic skills.[4,5] Different teaching scenarios have been investigated;[6–7] however, standardized virtual training on laparoscopic complications has not yet been described, although all surgeons need to manage critical intraoperative situations that may change without warning.[8] Unexpected complication management training, which is mandatory in aviation,[9] is being used to train anesthesiologists, sometimes in cooperation with surgeons; however, this has been focused on addressing critical events such as cardiopulmonary resuscitation (CPR) during surgery.[10–12] Virtual reality laparoscopic (VRL) simulation may provide an opportunity to simulate and analyze surgical complications and their management.

This study was designed to compare the impact of induced bleeding complication training with regular training for novices on a VRL simulator.

Materials and Methods

Curricular course and study population

As part of 2 four-day curricular courses during 2012 and 2013, 41 randomly selected third-year medical students were prospectively included and divided into groups, one of which received training in induced bleeding complications and the other regular training. Both groups received a demonstration of the VRL simulator including instrument handling, task requirements, and possible complications and their management. During the first course in the regular training group (RTG), students performed a manual task on the VRL simulator twice (regular session 1 and 2) as a primary assessment then practiced the task nine times (training session 1–9) on the 3 following days. The induced complication training group (ICT) performed the task twice as a primary assessment then were trained on an induced bleeding complication simulation 9 times over 3 days (Fig. 1). All participants were supervised throughout the course by a member of the surgical department in a standardized setting.[6]

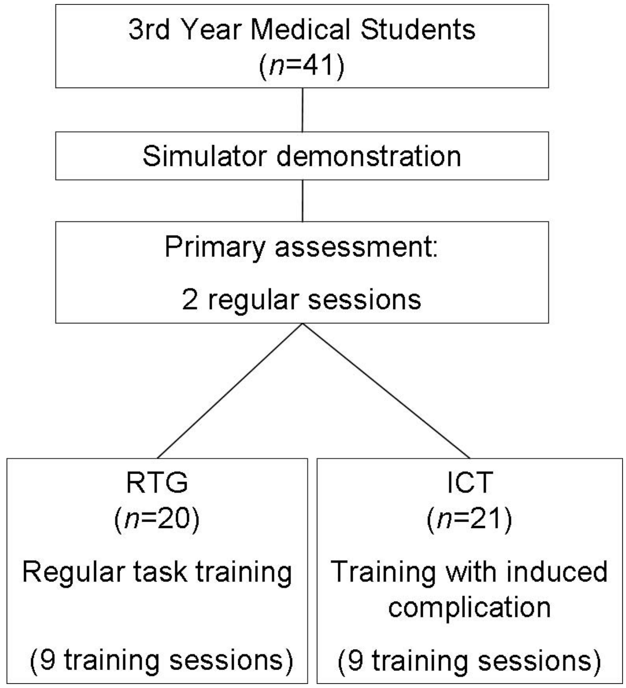

Fig. 1 Study design. RTG, regular training group; ICT, induced complication training group.

Simulator

The VRL simulator was a LapSim (Surgical Science, Gothenburg, Sweden) with Software Version 2011 and a Samsung Sync Master 22-inch wide-screen monitor (Samsung Electronics, Seoul, South Korea). The specific hardware included the Simball 4D Joystick by G-coder Systems AB with a double footswitch (G-coder Systems AB, Västra Frölunda, Sweden).

Task

The clip applying task required a complex bimanual manoeuvre. The objective was to apply 2 clips correctly on a simulated blood vessel and cut the vessel in between the clips afterwards (Fig. 2a). Excessive stretching of the vessel at any time during this task can result in a rupture followed by bleeding. (Fig. 2b). This complication would then have to be controlled by correct application of a clip on the bleeding vessel. In case of impaired view due to a pool of blood, the instrument had to be changed to a suction device in order to drain the blood (Fig. 2c). All dropped clips had to be collected in order to

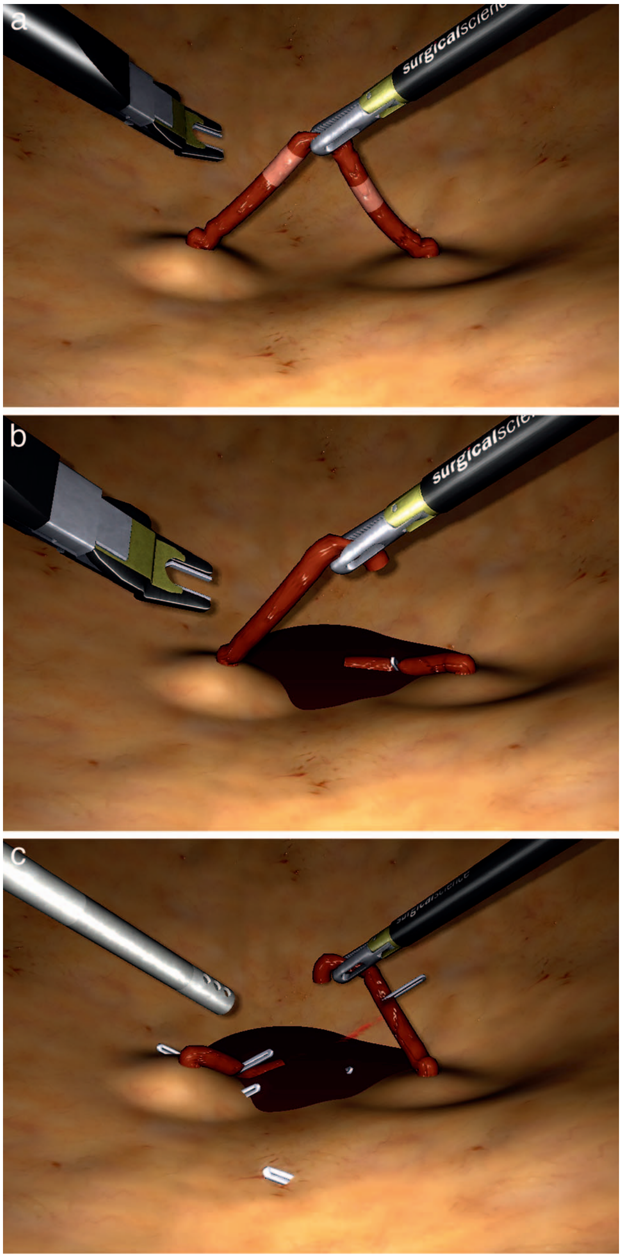

Fig. 2a Task of applying clips.
Fig. 2b Bleeding complication.
Fig. 2c Handling of a bleeding complication with lost and poorly placed clips.

complete the exercise. For the ICT group, bleeding was induced by cutting the vessel primarily on purpose. Items measured by the VRL simulator included total time, incomplete target areas, poorly placed clips, instrument path length (left and right), instrument angular path (left and right), maximum stretch damage, blood loss, instrument outside view (left and right), and time instrument outside view (left and right).

Statistical analysis

To evaluate the students' VRL performance, the recorded items were transferred from the simulator to a SPSS database and processed in anonymous form. Statistical analysis was performed with SPSS Statistics 20 (Statistical Package for Social Sciences program, Chicago, Illinois). Performance was analyzed using the nonparametric Mann–Whitney U-test. A P value <0.05 was considered significant.

Results

A total of 41 participants were included. Twenty students were in the RTG (9 males) with a median age of 23 years (range: 21–29 years). The ICT group consisted of 21 students (8 males) with a median age of 23 years (range: 22–31 years).

Both courses were comparable regarding the participants initial performance level in regular sessions 1 and 2 ($P > 0.05$ for all recorded items). During the first two sessions (82 performed tasks), bleeding complications occurred in 48.8% (n = 40; RTG, n = 20; ICT, n = 20). Analysis of the simulator's parameters of all participants revealed a significant difference in all analyzed parameters ($P < 0.05$) when a bleeding complication occurred (Table 1). No significant difference in performance was observed between the RTG and ICT group when a bleeding complication was presented in regular sessions 1 and 2 (Table 2).

When comparing the results of the 9 training sessions, both groups improved significantly in task time and handling economics throughout the course ($P < 0.001$). The ICT improved significantly in blood loss ($P < 0.001$; Fig. 3).

Considering the 9 training sessions where bleeding complications occurred, complication management in the ICT group showed significant improvements in time, handling economics, and blood loss ($P < 0.001$). According to the assessed parameters, the RTG showed no improvement in time, handling economics, or blood loss during a case of bleeding ($P > 0.05$).

A significant difference in time and handling economics between the RTG and ICT group was observed in case of bleeding during the final training sessions 8 and 9 (Table 2).

Table 1 Comparison of task performance with or without bleeding complications. Tasks were performed by 41 participants in the 2 regular sessions within the primary assessment

Variables	Tasks with bleeding (n = 40) Median (IQR)	Tasks without bleeding (n = 42) Median (IQR)	*P*
Total time applying clip (s)	323.5 (219.0; 557.6)	197.6 (141.5; 260.1)	<0.001
Incomplete target areas (n)	1.0 (1.0; 2.0)	0.0 (0.0; 0.0)	<0.001
Poorly placed clips (n)	1.0 (0.0; 1.0)	0.0 (0.0; 1.0)	0.025
Dropped clips (n)	1.0 (0.0; 2.0)	0.0 (0.0; 0.0)	<0.001
Pathway length, left instrument (m)	4.0 (2.4; 5.8)	1.7 (1.3; 2.2)	<0.001
Angular pathway, left instrument (degree)	712.9 (429.0; 1073.3)	335.6 (192.5; 415.6)	<0.001
Pathway length, right instrument (m)	4.4 (3.2; 6.7)	1.9 (1.4; 2.6)	<0.001
Angular pathway, right instrument (degree)	726.8 (499.2; 1268.3)	370.7 (215.0; 475.8)	<0.001
Maximum stretch damage (%)	100.0 (100.0; 100.0)	55.4 (43.9; 72.2)	<0.001
Blood loss (l)	0.7 (0.4; 1.7)	0.0 (0.0; 0.0)	<0.001
Left instrument out of view (n)	2.0 (1.0; 5.0)	0.0 (0.0; 1.0)	<0.001
Left instrument out of view (s)	2.1 (0.3; 14.7)	0.0 (0.0; 1.9)	<0.001
Right instrument out of view (n)	2.0 (0.0; 4.5)	0.0 (0.0; 1.0)	0.001
Right instrument out of view (s)	3.9 (0.0; 16.0)	0.0 (0.0; 1.6)	0.001

IQR, interquartile range; s, seconds; n, number; m, meters; l, liters.

Discussion

In laparoscopic surgery, VRL simulator training can positively influence the learning curve for laparoscopic skills.[4] The simulation training of complications, especially unexpected complications, is currently not widespread in surgical education programs. The handling of a laparoscopic bleeding complication is a skill that is learned rather late in the operating room. Major bleeding complications are rare, episodic events that make effective, structured, and ethical real-time training nearly impossible.[2,13] Thus, the requirement for adequately learning how to handle complications cannot be met. The occurrence of minor or major intraoperative bleeding may start a chain reaction, possibly causing consequences for the patient since it leads to a disruption of the procedural flow, making additional instrument changes necessary in order to locate and stop the bleeding. In addition, the surgeon is even more dependent on well performed camera navigation and the surrounding operating room team.[1,14]

The current results demonstrate that for a laparoscopic novice, a bleeding complication in the beginning of training results in a large amount of

Table 2 Comparison of the regular training group (RTG) and induced complication training (ICT) group in cases with bleeding complications

Variables	Regular sessions 1 and 2: RTG (n=20) Median (IQR)	Regular sessions 1 and 2: ICT (n=20) Median (IQR)	*P*	Training sessions 8 and 9: RTG (n=4) Median (IQR)	Training sessions 8 and 9: ICT (n=42) Median (IQR)	*P*
Total time applying clip (s)	321.3 (217.4; 589.7)	329.6 (222.1; 513.3)	0.947	125.1 (96.8; 196.2)	63.6 (41.8; 84.3)	0.004
Incomplete target areas (n)	1.5 (1.0; 2.0)	1.0 (0.5; 2.0)	0.445	1.0 (0.5; 1.0)	2.0 (2.0; 2.0)	<0.001
Poorly placed clips (n)	1.0 (0.0; 1.0)	1.0 (0.0; 1.0)	0.738	0.0 (0.0; 0.0)	0.0 (0.0; 0.0)	0.836
Dropped clips (n)	1.0 (0.0; 3.0)	1.0 (0.0; 1.5)	0.529	0.0 (0.0; 0.5)	0.0 (0.0; 0.0)	0.749
Pathway length, left instrument (m)	4.2 (3.1; 6.0)	4.0 (2.3; 5.2)	0.414	1.4 (1.0; 2.2)	0.5 (0.4; 0.6)	0.001
Angular pathway, left (degree)	769.3 (564.0; 1201.5)	623.4 (400.3; 933.6)	0.157	177.8 (139.4; 358.5)	101.9 (79.7; 124.0)	0.006
Pathway length, right instrument (m)	4.0 (2.7; 8.0)	4.7 (3.2; 6.7)	0.461	2.1 (1.2; 3.5)	1.3 (1.0; 1.6)	0.173
Angular pathway, right (degree)	719.7 (482.5; 1403.2)	863.2 (499.2; 1268.3)	0.799	262.6 (168.6; 549.7)	173.0 (132.6; 242.4)	0.200
Maximum stretch damage (%)	100.0 (100.0; 100.0)	100.0 (100.0; 100.0)	0.602	100.0 (78.1; 100.0)	39.5 (20.3; 58.0)	0.004
Blood loss (l)	0.7 (0.4; 1.6)	0.7 (0.4; 1.9)	0.904	0.2 (0.1; 0.4)	0.3 (0.2; 0.3)	0.693
Left instrument out of view (n)	3.5 (1.5; 6.0)	1.5 (1.0; 5.0)	0.242	0.0 (0.0; 3.5)	0.0 (0.0; 0.0)	0.585
Left instrument out of view (s)	4.4 (0.3; 40.1)	1.8 (0.4; 10.9)	0.341	0.0 (0.0; 15.2)	0.0 (0.0; 0.0)	0.585
Right instrument out of view (n)	2.0 (0.0; 4.0)	2.5 (0.5; 5.0)	0.429	0.0 (0.0; 0.5)	0.0 (0.0; 1.0)	0.836
Right instrument out of view (s)	2.8 (0.0; 14.3)	3.9 (0. 7; 17.4)	0.698	0.0 (0.0; 0.2)	0.0 (0.0; 0.2)	0.866

IQR, interquartile range; s, seconds; n, number; m, meters; l, liters.

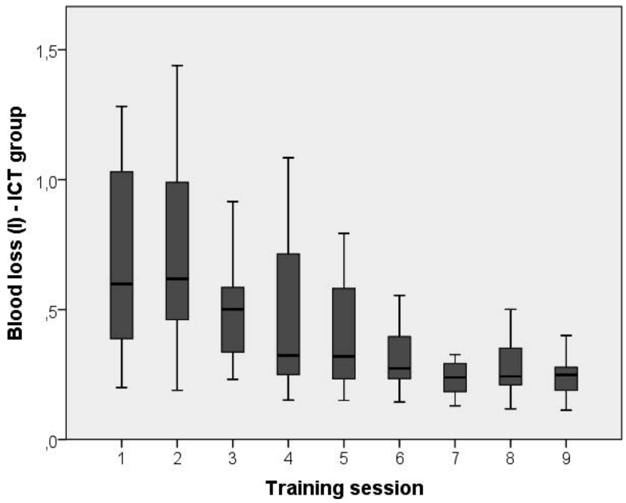

Fig. 3 Improvement of blood loss in the ICT group ($P < 0.001$).

blood loss, a longer operative time, and worse handling economics. In the operating room, this may be a matter of patient safety and often results in a consultant taking over the operation. Our study shows that participants who underwent induced bleeding complication training perform better in such a scenario. Nonetheless, the performance of the RTG also improved throughout the course. Bleeding occurred in fewer cases and less blood was lost, which reveals that complication handling is affected by the general learning curve of laparoscopic skills. However, the ICT group still performed better in a case of bleeding complication during the final sessions. This is in concordance with findings by Opitz *et al*,[2] who stated that surgeons who performed more than 100 laparoscopic procedures had significantly fewer intraoperative bleeding complications. The better performance of the ICT group when faced with a case of bleeding raises the question of including VRL complication management training in surgical education.

Surgical complication management is mostly practiced in scenarios with anesthesiologists, for example, intraoperative CPR due to an intraoperative hemorrhage, and focusing on the management of cardiovascular crises or communication skills. We practice and discuss such training scenarios in curricular educational programs, but these training methods do not usually focus on practical laparoscopic management.[10–12,15]

Team training, checklists, and standardized algorithms for complication management are tools frequently used in aviation and anesthesiology to acquire the skills to manage a crisis without any harm to the patient.[9,16] However, a paper-based checklist alone is not very constructive for handling an intraoperative surgical problem. Structured and coordinated proceedings are essential for the control of laparoscopic bleeding complications.[17] Yet, the operator is not dependent on only his or her own laparoscopic skills and a mental algorithm to control the bleeding. The operator's dependence on the first assistant is higher than in open surgery. Thus, further research on laparoscopic complication management should also focus on the role of the assistant. Extended training methods such as verbal instructor feedback as previously described for regular learning curves[6] also needs to be considered for complication management training as well.

A limitation of the current approach is the factor of surprise. For the RTG, every bleeding complication was unexpected, but for the ICT group every complication (after the first 2 sessions) was expected, since it was induced by the participant according to the commands of the supervisor. An instructor mode with the ability to allow unexpected, random complication training like commercially available flight simulator software is available, yet only rarely included in today's VRL simulators. Other scenarios of bleeding complication management are possible, for example, the sudden take over by the trainee. Nevertheless, it could be argued that a complication is still a procedure that can be trained in a standardized fashion.

This is an aspect of future research and should be considered by surgical teachers, trainees, and the industry for realistic simulator software development. Current curricula for laparoscopic education such as the Fundamentals of Laparoscopic Surgery (FLS) program and its derivatives do not contain complication management.[18]

Further limitations of the study are the small sample size and the lack of a power calculation, which are due to the predetermined group size of the curricular courses. Additionally the setup of the study was limited to the duration of the course, which resulted in the design of 9 training sessions in 3 days. Thus it remains unclear whether the students' learning curve has been completed. Regarding the study population, the current investigation is limited to third year medical students with no previous experience in laparoscopy or VRL simulation. However, medical students and naive surgical interns are comparable regarding their laparoscopic skills as discussed by Strandbygaard *et al*[19] Additionally, Cochrane reviews on laparoscopic training in novices have included studies with medical students and young surgical residents that also implies a comparability of the results.[4,20]

In the presented setup we only mention the bleeding control by the application of clips on blood vessels. Combined dissection and coagulation devices have a wide acceptance in laparoscopic surgery. However, in our opinion clip applying is still the most frequently used technique of the laparoscopic novice in educational surgeries such as laparoscopic cholecystectomy or appendectomy.

In conclusion, induced bleeding complication training has a positive influence on the handling of bleeding complications on the VRL simulator. Practice-oriented laparoscopic complication management should be implemented in surgical education as an add-on to regular procedural training.

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