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Training efficacy of robotic duct-to-mucosa pancreaticojejunostomy simulation using silicone models for surgical fellows

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Purpose: In the era of minimally invasive surgery (MIS), robotic pancreatoduodenectomy (PD) is actively performed, and clinical fellows need to thoroughly prepare for MIS-PD during the training process. Although pancreaticojejunostomy (PJ) is a difficult anastomosis that requires repeated practice, there are obstacles preventing its practice that concerns patient safety and limited time in the actual operating room. This study evaluated the efficacy of simulation-based training of robotic duct-to-mucosa PJ using pancreatic and intestinal silicone models using a scoring system.
Methods: Three pancreatobiliary clinical fellows who had never performed a real robotic PJ participated in this study. Each trainee, who was well acquainted with master's video created by a senor surgeon, performed the robotic PJ procedures 9 times, and 3 independent pancreatobiliary surgeons assessed the videos and analyzed the scores using a blind method.
Results: The mean robotic PJ times for the 3 trainees were 42.8 and 29.1 minutes for the first and 9th videos, respectively. The mean score was 13.8 (range, 6–17) for the first video and 17.7 (range, 15–19) for the 9th video. When comparing earlier and later attempts, the PJ time decreased significantly (2,201.67 seconds *vs*. 2,045.50 seconds, $P = 0.007$), whereas test scores increased significantly (total score 14.22 *vs*. 16.89, $P = 0.011$).
Conclusion: This robotic education system will help pancreatobiliary trainees overcome the learning curves efficiently and quickly without raising ethical concerns associated with animal models or direct practice with human subjects. This will be of practical assistance to trainees preparing for MIS-PD.
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Key Words: Simulation training, Professional education, Robotics, Pancreaticojejunostomy, Physical education and training

INTRODUCTION

In the current era of minimally invasive surgery (MIS), there is a growing interest in robotic pancreatoduodenectomy (PD). Successful implementation of this technique requires extensive training of clinical fellows or junior staff who perform MIS-PD. However, they face significant obstacles such as patient safety concerns and limited time in the actual operating room. Surgical trainees required to learn not only open but also MIS skills have limited time to acquire these skills during their short education period, especially in low-volume centers [1,2]. One of the most challenging aspects of performing MIS-PD is

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pancreaticojejunostomy (PJ), the most important procedure for preventing severe morbidity or mortality related to pancreatic fistulas. Repetitive practice is required to achieve proficiency.

To address this challenge, an alternative to training is needed; however, animal models have ethical issues and cost problems when practiced multiple times [3]. We previously demonstrated the efficiency of practicing open PJ using silicone models [2]. Simulation-based training can overcome patient safety concerns and time constraints in the operating room by providing a safe and controlled environment for trainees to practice this difficult procedure using silicone models. This study examined the impact of simulation-based training on robotic duct-to-mucosa PJ using silicone models of the pancreas and intestine with a scoring system; and aimed to evaluate the effectiveness of this training approach in enhancing the technical skills of clinical fellows in performing PJ during MIS-PD.

METHODS

This study protocol was approved by the Institutional Review Board of the Seoul National University Hospital (No. H-2304-082-1423). It was performed in accordance with the Declaration of Helsinki and written informed consent was waived due to its retrospective nature.

Participants

This was an uncontrolled, observational, prospective study. Three pancreatobiliary clinical fellows (2 sophomores and 1 junior) performed a modified Blumgart open duct-to-mucosa PJ using a double-layer intestine and pancreatic silicone model (SINI Inc.). Although the fellows had participated in surgery as a first assistant multiple times, they had never performed robot PJ or open PJ in the real surgical field prior to the simulation. The fellows followed the master video to perform the PJ simulations. Each fellow performed 9 simulations recorded using a video camera. No supervisor feedback was provided until the end of the 9 simulations. All video files were randomly rearranged to eliminate biases. Three pancreatobiliary professors assessed trainee surgical skills by watching videos, using a blind scoring system.

Master video and modified Blumgart method

Prior to the simulation-based training, a master video was created by a highly experienced pancreatobiliary professor (JYJ) who had performed over 300 robotic pancreatoduodenectomies. He performed a modified Blumgart PJ using intestinal and pancreatic models, while recording the entire procedure. In the modified Blumgart method, 2 transpancreatic U-shaped sutures, a few millimeters distal from the cut surface of the pancreatic stump, penetrate from the ventral to the dorsal side in the full thickness of the pancreas using 4-0 polypropylene instead of suturing the outer layer. Next, the seromuscular layer of the jejunal loop was sutured using the same stitch that had penetrated the pancreatic stump back from the dorsal to the ventral side. Each transpancreatic U-suture was positioned on the superior and inferior borders of the pancreatic duct and tied down but left uncut to avoid the pancreatic duct. Duct-to-mucosa anastomosis was then performed using 5-0 polydioxanone in 5–6 different directions. The ventral side of the jejunal loop was sutured to the seromuscular layer using uncut transpancreatic U-sutures to conceal the resected surface of the pancreatic stump. Finally, an interrupted suture reinforcing the PJ was placed between 2 transpancreatic U-sutures in the central and ventral parts of the PJ [2,4]. The trainees familiarized themselves with the video and performed the PJ procedure 9 times (Fig. 1), after which 3 pancreatobiliary surgeons assessed the videos and analyzed the scores.

Assessment tool

The "SNUH-BP modified Blumgart PJ checklist" in Table 1 is an assessment tool used to evaluate the surgical skills of pancreatobiliary surgeons during a simulator training program. The checklist was developed and modified based on an objective structured assessment of the technical skills of surgical residents [2]. The checklist included 12 items divided into 4 categories: needle driving, out-layer suture, duct-to-

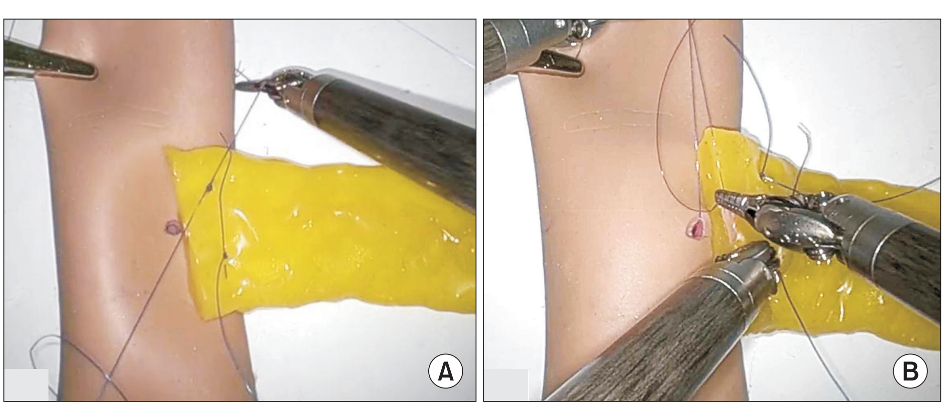

Fig. 1. The still-cut images of the video. (A) Two transpancreatic U-suture was positioned on the superior and inferior border of the pancreatic duct, and tied. (B) Duct-to-mucosa sutures were performed in the dorsal side.

Table 1. Objective surgical skill assessment tools for modified Blumgart pancreaticojejunostomy developed by Seoul National University Hospital

SNUH-BP modified Blumgart pancreaticojejunostomy checklist	Score	Total score
Needle driving		
1. Needles are positioned on the needle holder (1/2–2/3 circle).		1
2. Needles and forceps do not damage tissues.		1
Out-layer suture		
3. Out-layer strings are penetrated perpendicularly during suture.		1
4. Out-layer strings penetrate the entire pancreas parenchyma.		1
5. Out-layer stitch intervals are proper. (0–2)		2
6. Surgical knots are not loosened after tying. (0–2)		2
Duct-to-mucosa (in-layer) suture		
7. In-layer strings are penetrated perpendicularly during suture.		1
8. In-layer strings are penetrated the p-duct and small bowel mucosa with proper intervals. (0–3)		3
9. Surgical knots are not loosened after tying. (0–2)		2
Overall performance		
10. Strings penetrating the P-duct and the parenchyma are well-deployed and not tangled.		1
11. The duration of PJ anastomosis takes less than 20 minutes.		1
12. The flow of entire procedures is generally smooth. (0–4)		4
Total score: / 20		20
Procedure time: min		

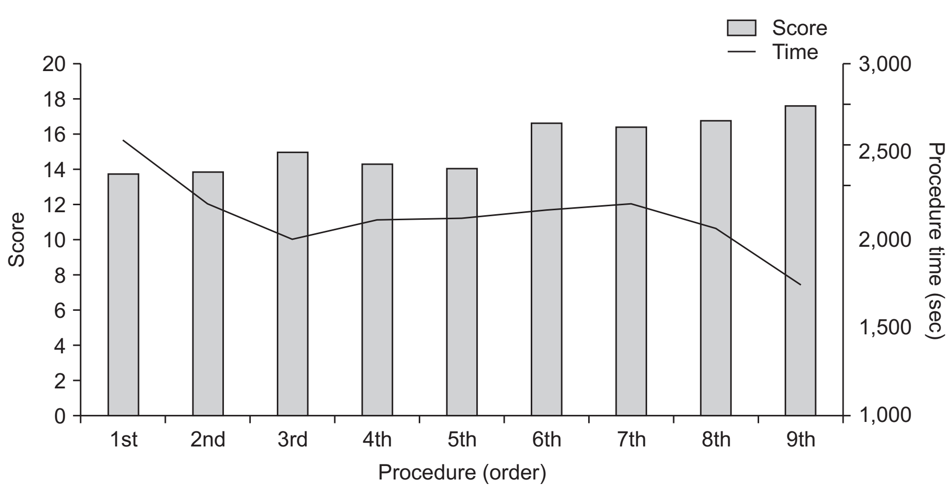

Fig. 2. The tendency of total score and procedure time of all trainees.

mucosa (in-layer) suture, and overall performance. The total score was 20. Three independent pancreatobiliary professors assessed the surgical skills of the trainees by watching videos of their performances using this scoring system. The evaluators assessed trainee performance without knowing who performed the videos or the order in which they were recorded. The scores were analyzed to evaluate the training program's effectiveness in improving participant surgical skills.

Statistical analysis

The 9 simulations conducted by each trainee were divided into earlier and later attempts based on the 5th simulation. Earlier attempts referred to simulations from the first to the 5th, and later attempts referred to simulations from the 6th to 9th. The total score, scores for each category, and time were analyzed separately for the earlier and later attempts using the Wilcoxon signed-rank test. Statistical significance was set at a P-value of <0.05. All statistical analyses were performed using IBM SPSS Statistics version 25.0 (IBM Corp.).

RESULTS

Total score and time trend

Fig. 2 shows a bar graph comparing the total scores of all the trainees. The mean score increased from 13.8 to 17.7. The initial score range was too broad, ranging from 6 to 17. However, all trainees showed similarly high scores at the last video, ranging from 15 to 19. The mean robotic PJ time decreased from 42.8

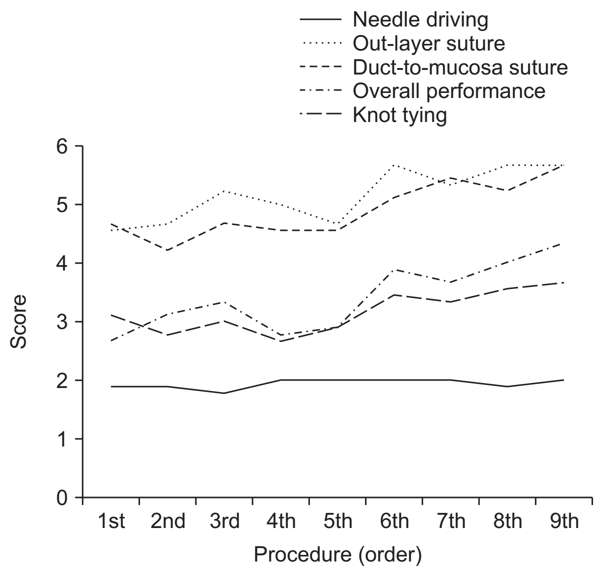

Fig. 3. The tendency of score of each category of all trainees.

minutes initially to 29.1 minutes at the end.

Scores of each category

Fig. 3 shows the trends in the scores divided by each category. Out-layer sutures, duct-to-mucosa sutures, and overall performance showed increasing trends, except for needle driving. Needle driving had a total score of 2, with initial and final mean scores of 1.9 and 2.0, respectively. This difference was not significant because the score was high from the beginning. Additionally, by adding items 6 and 9 of the assessment tool "surgical knots are not loosened after tying," knot tying was further compared and a similar increasing trend was observed.

Comparison between the earlier and later attempts

Table 2 reports the score comparison results and durations between the earlier and later attempts of all trainees. Total (14.22 *vs.* 16.89, P = 0.011), overall performance (2.96 *vs.* 3.97, P = 0.012), knot tying (2.89 *vs.* 3.50, P = 0.033), duct-to-mucosa suture (4.53 *vs.* 5.36, P = 0.033), and out-layer suture (4.82 *vs.* 5.58, P = 0.036) scores showed statistically significant increases from earlier to later attempts. In the order of overall performance, knot tying, duct-to-mucosa suture, and out-layer suture, the increase in score in later attempts was high. The needle driving score did not show a statistically significant difference between earlier and later attempts (1.91 *vs.* 1.97, P = 0.102). The time decreased significantly from earlier to later attempts (2,201.67 seconds vs. 2,045.50 seconds, P = 0.007), indicating that the participants became faster at performing the procedure over time.

Table 2. The results of comparing the scores and times between the earlier attempts and the later attempts of all trainees

Variable	Earlier attempts	Later attempts	P-value
Score			
Overall performance	2.96	3.97	0.012
Knot tying	2.89	3.50	0.033
Duct-to-mucosa suture	4.53	5.36	0.033
Out-layer suture	4.82	5.58	0.036
Needle driving	1.91	1.97	0.102
Total	14.22	16.89	0.011
Time (sec)	2,201.67	2,045.50	0.007

Earlier attempts refer to simulations from the first to the 5th, and later attempts refer to simulations from the 6th to the 9th.

DISCUSSION

PD is a complex surgical procedure involving the resection of the head of the pancreas, duodenum, and other related structures, as well as anastomosis of the resected structure to the intestine. It is a challenging surgical procedure requiring immense skill and experience. For these reasons, PD has a high rate of complications, even when performed in high-volume centers by experienced surgeons, and complications associated with PD, such as postoperative pancreatic fistulas, are particularly difficult to resolve [5]. According to a randomized control study conducted by small-volume centers performing approximately 20 cases of PD, the complication-related mortality rate of MIS-PD was reported to be approximately 5 times higher [6]. Because PJ performed by inexperienced trainees may pose a risk to patient safety, practical tools are necessary for trainees to improve their proficiency to a level that can be safely applied to patients.

Considering the complexity and high complication risk associated with PD, surgeons should have sufficient training and experience with this procedure [7]. Repeated practice of PD can help lower complication risk and improve patient outcomes. Although the reported results vary, most studies report that more than 30 standard PD cases are necessary to overcome the learning curve [5,8-10]. Therefore, surgical education and training programs are vital in helping surgeons develop the necessary skills and experience to successfully perform this procedure.

Three categories of training models are commonly used to train surgeons for PD and other surgical procedures: animal, simulation, and virtual reality. Animal models have long been used for surgical training, but they present ethical and cost-related issues that make them suboptimal for surgical training [3]. Furthermore, animal models do not fully replicate human anatomy and physiology, which may limit their usefulness as training tools.

Conversely, virtual reality models provide a more realistic environment for surgical training and are a means to efficiently improve training without raising ethical concerns [11,12]; however, they lack the tactile feedback provided by actual surgical instruments and procedures. This can hinder the training process, as surgeons need to feel the resistance of tissues and instrument feedback to develop the dexterity needed for surgery [13,14].

Simulation models that use silicone to replicate the human anatomy are promising alternatives for surgical training. These models provide a realistic environment for surgical training while also allowing surgeons to feel the instrument feedback and develop the necessary tactile skills required for surgery. It also increases efficiency and the training costs are relatively low compared to those of the aforementioned methods.

Simulation training can be effective in improving surgical skills for PD and other procedures [2,10,15]. Recent studies evaluated a simulator training program for pancreatobiliary surgeons and found that the program was successful in improving participant's surgical skills [10,16]. We previously revealed the efficiency of practicing open PJ using silicone models and identified a decreasing tendency in total procedure times and an increasing tendency in scores [2]. In the present study, the mean robotic PJ time decreased from 42.8 minutes initially to 29.1 minutes at the end, and the mean score increased from 13.8 to 17.7. The initial score range was too broad, ranging from 6 to 17. However, all trainees showed similarly high scores at the end, ranging from 15 to 19. When dividing the attempts into earlier and later attempts based on the 5th simulation, the total score significantly increased in the later attempts compared to those associated with the earlier attempts, and the time spent on the procedure was significantly reduced. Even when each category was divided, the scores improved through simulation-based training in terms of the overall performance, duct-to-mucosa sutures, and outer-layer sutures. Knot tying showed the same increasing trend in scores. The needle driving score was almost perfect from the start. This is likely because the current trainees who had been exposed to robotic surgery since the beginning of their training, had already received basic training through the virtual simulation program of the da Vinci system prior to this study. Based on these results, simulation-based training using silicone models not only in open PJ but also in robot PJ, helps trainees overcome the learning curve efficiently and adequately. Once the trainees had become familiar with robotic PJ through this practice, they performed robotic PJ on actual patients during the operation at our institution. Fellows who participated in this study also successfully performed their first robotic PJ on patients.

In conclusion, simulation training using silicone models is a promising alternative for surgical education, particularly for complex procedures such as MIS-PD. Simulation models can help improve surgical skills and reduce the risk of complications by simulating a realistic environment for surgical training and allowing surgeons to feel the feedback from their instruments. As surgical technology continues to evolve, simulation training is expected to play an increasingly important role in surgical education and training. With sufficient training, experience, and effective surgical education and training programs, robotic PD can be performed safely and effectively with fewer complications and improved patient outcomes.

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Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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