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ORIGINAL SCIENTIFIC REPORT WITH VIDEO

Comparison of Training Efficacy Between Custom-Made Skills Simulator (CMSS) and da Vinci Skills Simulators: A Randomized Control Study

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Abstract

Background To compare the effectiveness of a custom-made skills simulator (CMSS) with the commercially available da Vinci® skills simulator (DVSS) that help improving surgical skills for effective and safe robotic surgical interventions.

Methods A randomized control study was conducted to determine the performance of participants after undergoing robotic surgical training. Total 64 students who had no previous experience with robotic surgery enrolled this study. After 5 min—introduction of robotic surgical system, the participants got random-assignment into two groups to perform either CMSS-or DVSS-exercises. After 15 min-practicing the corresponding simulator, task-execution performance and individual questionnaires were compared between participants trained with the CMSS and those trained with the DVSS.

Results Regardless of simulator the participants used, the system understanding and manipulation ability of the participants was found to be higher than after completing the simulation-based robotic surgical training ($p < 0.05$). However, there were no significant differences in terms of the required time to complete the tasks, and improvement of understanding the concept of robotic surgery, or surgical skill capacity between two groups ($p > 0.05$).

Conclusions The training effectiveness of CMSS was not significantly different to DVSS. It can be synergetic tool to DVSS for novice trainees of robotic surgery to get accustomed to the robotic surgical system and to improve their basic robotic surgical skills.

Introduction

Currently available robotic surgery system aims to overcome common limitations of laparoscopy, such as the unstable two-dimensional surgical field, limited instrument

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movement, fulcrum effect, and excessive tremor during surgical procedures [1]. In addition, it is expected to provide a fast learning curve given their unique characteristics that outperform conventional laparoscopic systems [2, 3]. In fact, robotic surgery is useful for surgical procedures requiring fine, delicate, and minimally invasive interventions. For instance, the currently available da Vinci® robotic surgical system (Intuitive Surgical, Inc., Sunnyvale, CA, USA) is being actively applied in complicated surgeries such as those of esophagus [4], stomach [5], hepatobiliary organs and pancreas [6], as well as urologic [7, 8] and cardiovascular interventions [9].

The interventions performed using robotic surgery systems have similar outcomes as those using laparoscopy because the surgical principles to treat the target condition are essentially the same (but the approach may be different). However, the surgical techniques used in these two types of interventions are notably different. Hence, surgeons need to become familiar with robotic surgery systems first to exploit the benefits of robotic-based interventions and lessen the learning curve.

Currently, several simulators are available to develop skills for robotic surgery. For instance, portable standalone simulators include the da Vinci® Skills Simulator–DVSS (Intuitive Surgical, Inc., Sunnyvale, CA, USA), dV-Trainer (Mimic Technologies, Inc., Seattle, WA, USA), Robotic Surgery Simulator (Simulated Surgical Systems, LLC, San Jose, CA, USA), and RobotiX Mentor (Simbionix USA Inc., Cleveland, OH, USA) [10]. Using this type of simulator, novice surgeons are supposed to be able to train the necessary movements and acquire surgical concepts through modules based on virtual reality. In addition, the simulators usually include multilevel curricula according to the difficulty levels for helping novice trainees to develop surgical skills and effectively improve the robot surgery outcomes in real settings. To validate the effectiveness of these simulators, several studies have been proposed, reporting positive impact of training efficacy [10–13]. However, the high cost of robotic surgery simulators and systems limits extensive evaluations. In fact, such simulators have reported prices ranging between US$100,000 and US$500,000 [14]. Therefore, only a few institutions can benefit from the simulator to train novice practitioners.

In Korea, 83 robotic surgery systems were already installed at 57 institutions by January 2019; however, only a few systems were equipped with the DVSS. Consequently, surgeons who need a robotic surgery simulator have to spend additional time commuting to an institution with available simulators, thus limiting the widespread practice of robotic surgery.

In August 2017, the Ministry of Food and Drug Safety (MFDS) of Korea approved the clinical application of revo-i (Meerecompany Inc., Seongnam, Korea), a Korean robotic system for minimally invasive surgery [15, 16]. Likewise, it is highly expected that other new version of robotic surgery systems will be developed and clinically available in near future, which will make a convenient cost–benefit be reached. Then, robotic surgery is expected to be adopted widely soon. Therefore, it is necessary to develop suitable, comfortable, effective, and affordable surgical simulators that help improving surgical skills for effective and safe robotic surgical interventions.

In this study, we developed custom-made skill simulator (CMSS) for beginning robotic surgeons, and compared the its training efficacy with that of DVSS by a randomized control study with medical students without any experience of robotic surgical systems.

Materials and methods

Study design

This study was conducted after approval from the Institutional Review Board of the Severance Hospital, and its protocol is registered at ClinicalTrials.gov under the identifier NCT03067532. We had no previous data to help us predict the difference that we would observe. Using an α value of 0.05, a β value of 0.2, and a δ value of 1.5 standard deviations and with a power of 0.8. sample size yielded a group size of 26 in each group. Considering the drop out rate, we expected to include a total 64 participants in this study.

Sixty-four medical college students without prior experience in robotic surgery participated in this prospective controlled study. We excluded a participant who had any experiences of robotic surgery simulation and did not voluntarily participate. To begin with, we asked the participants to complete an initial questionnaire concerning their experience with robotic surgery (Table 1). Then, after briefly introducing the general robotic system, we used block randomization to assign the participants to either of the two groups, namely, training using the CMSS or the DVSS [17]. The participants practiced using the platform of their corresponding groups for 15 min with the instruction and feedback of both the two groups from the research team who has enough experience of robotic surgery. After finishing the practice with the feedback time about the practices, the participants were tested to evaluate their ability to control three robotic arms. Meanwhile, the individual time spent for executing six different tasks was recorded and a global rating scale were recorded for the task (Table 2). After completing test, the participants were asked to complete the second questionnaire to determine the efficacy of two different training system (see Fig. 1). The pre-and post-training assessments are a subjective

Table 1 Pre- and post-training self-assessment questionnaire

	Strongly disagree										Strongly agree
*Pre-training											
I understand robotic surgery	0	1	2	3	4	5	6	7	8	9	10
I can precisely manipulate a robotic surgery system	0	1	2	3	4	5	6	7	8	9	10
*Post-training											
I understand robotic surgery	0	1	2	3	4	5	6	7	8	9	10
I can precisely manipulate a robotic surgery system	0	1	2	3	4	5	6	7	8	9	10
This training system is portable	0	1	2	3	4	5	6	7	8	9	10
This training system is available in an in situ operation room	0	1	2	3	4	5	6	7	8	9	10
This training system resembles a real robotic surgery scenario	0	1	2	3	4	5	6	7	8	9	10
This training system improves the 3rd robotic arm movement skills	0	1	2	3	4	5	6	7	8	9	10
This training system improves clutch operation skills in a comfortable hand position	0	1	2	3	4	5	6	7	8	9	10
This training system improves camera movement skills	0	1	2	3	4	5	6	7	8	9	10
This training system improves wrist movement skills	0	1	2	3	4	5	6	7	8	9	10

Table 2 The global rating index for technical skills

1	2	3	4	5
Respect for tissue				
Frequently unnecessary force on tissues or caused damage by inappropriate use of instruments		Careful handling of tissue but occasionally caused inadvertent damage		Consistently handled tissue appropriately with minimal damage to tissues
Efficiency of motion				
Many unnecessary moves		Efficient time/motion, but some unnecessary moves		Economy of movement and maximal efficiency
Instrument handling				
Repeatedly makes tentative or awkward moves with instruments by inappropriate use of instruments		Competent use of instruments but occasionally appeared stiff or awkward		Fluid moves with instruments and no awkwardness
Knowledge of instruments				
Frequently asked for wrong instrument or used inappropriate instrument		Knew names of most instruments and used appropriate instrument		Obviously familiar with the instruments and their names
Flow of operation				
Frequently stopped operating and seemed unsure of next move		Demonstrated some forward planning with reasonable progression of procedure		Obviously planned course of operation with effortless flow from one move to the next
Knowledge of specific procedure				
Deficient knowledge. Needed specific instruction at most steps		Knew all important steps of operation		Demonstrated familiarity with all aspects of operation
Bimanual dexterity (laparoscopy only)				
Use only one hand, poor coordination between hands		Use both hands but dose not optimize their interaction		Expertly uses both hands to provide optimal exposure

questionnaire about how the students understood about the robot's working method after a short training and testing, rather than the actual robotic surgery for treatment.

Developing and simulator training (CMSS)

The proposed CMSS has the following features: (1) Randomly assigned numbers are placed outside the simulator

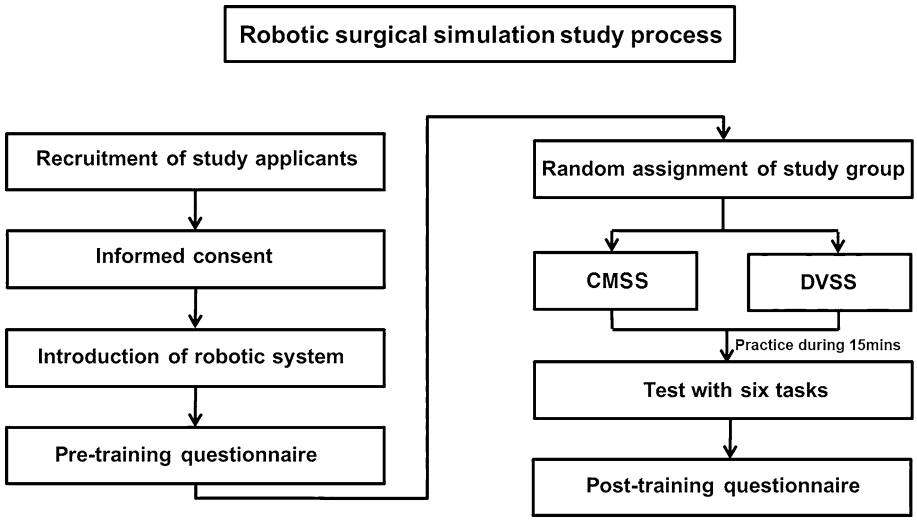

Fig. 1 Robotic surgical simulation study process

for the user to move the camera and center the required numbers on the surgical view, thus improving the camera movement skills. (2) Likewise, by moving the camera into required numbered holes in the surgical simulator, the camera operation can be improved. (3) By adjusting the length of the handle on a box leaflet, the action radius of the hand movement is supposed to be exaggerated to open the leaflet presented in the simulator. Hence, the user can understand, learn and improve the clutch function.

After setting the CMSS to the pelvic model and docking four robotic arms, the participant was able to easily move the camera and center the required numbers on the surgical view. In addition, the participant had to pull the yellow ribbon to open the small cover and hold it using the 3rd robotic arm. Then, the participant employed the two arms to pick up and place letter, number, and figure blocks within holes following the researcher directions. During the experiment, the researcher asked for 3rd robotic arm movements, as illustrated in Fig. 2c, d and shown in the Supplementary Video (1, 2).

Simulator training (DVSS)

Among software program, using the EndoWrist® Manipulation 2 set to the Match Board 3 program, the participant grabbed a transverse plate with the 3rd robotic arm until before the instrument color was changed. Then, the participants were asked to open the vertical plate and put a shining number or letter within the empty space, as illustrated in Fig. 2e, f, and shown in the Supplementary Video (3).

Evaluating task performances

The evaluated tasks are illustrated in Fig. 2g, h and shown in the Supplementary Video (4). After docking four robotic arms over the test board on the patient cart, we measured the time taken by each participant to perform the following tasks:

Task 1: Fix the colored rubber band to number 1 in the red column using the 3rd robotic arm
Task 2: Hang the yellow rubber band on hook number 3 using the 1st and 2nd robotic arms
Task 3: Hang the red rubber band on hook number 4 using the 1st and 2nd robotic arms
Task 4: Move the colored rubber band from number 1 to 2 in the red column using the 3rd robotic arm
Task 5: Pick the red rubber band from hook number 4 and the yellow rubber band from hook number 3, and hang the yellow rubber band on hook number 4 using the 1st and 2nd robotic arms
Task 6: Hang the yellow rubber band on hook number 3 using the 1st and 2nd robotic arms.

Global rating scale of operative performance

An evaluation tool, hereafter referred to as the global rating index for technical skills (GRITS), was designed. This was based on global rating scale (GRS) previously validated in other settings: the objective structured assessment of technical skill (OSATS) and the global operative assessment of laparoscopic skills (GOALS). GRITS consisted of 7 items, each scored from 1 to 5 (Table 2). The scores of each participants evaluated with the global rating scale were collected and studied in relation to each group [18]. Two raters, blinded to subject identity, independently

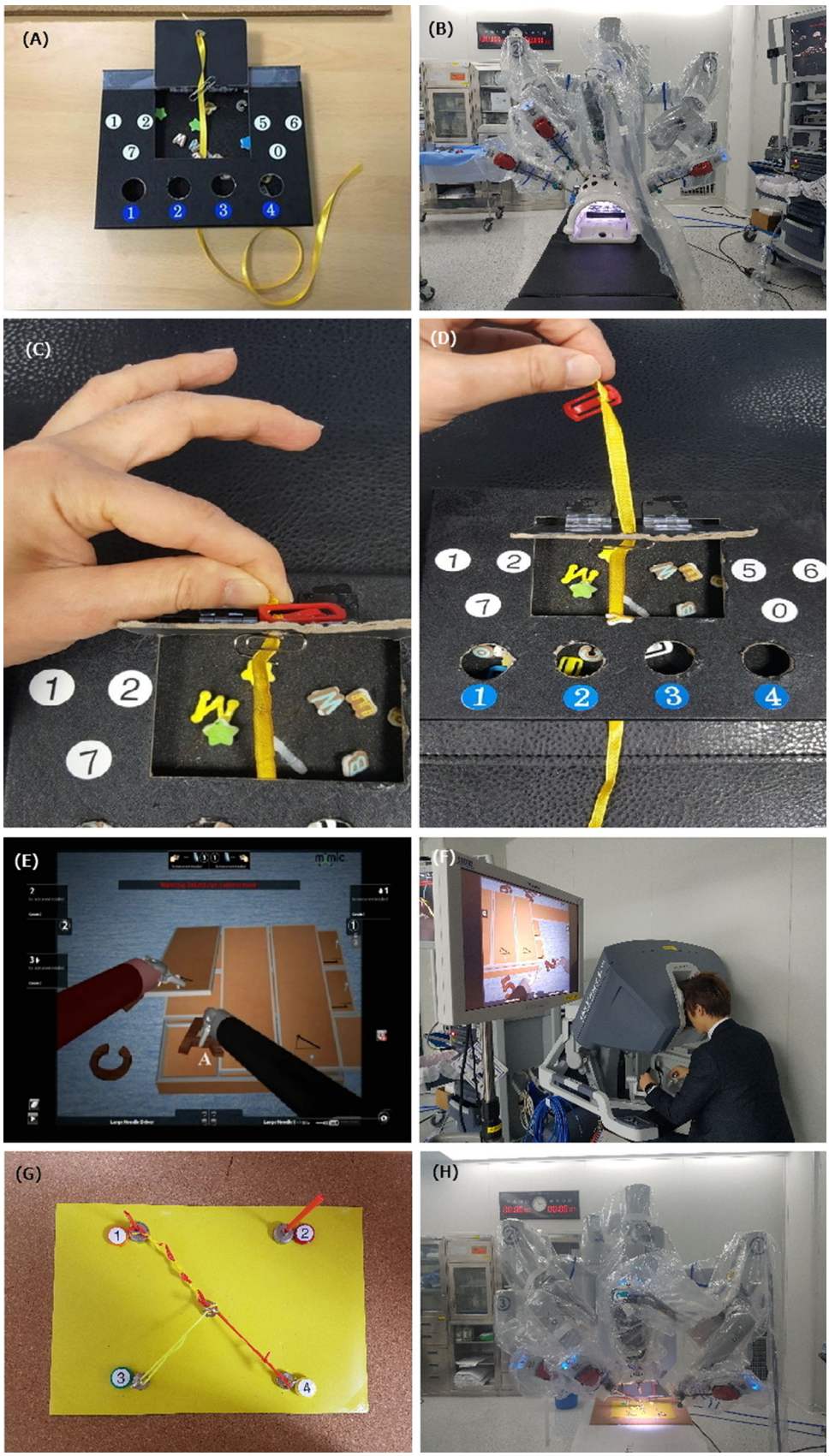

Fig. 2 Illustration of the CMSS and DVSS. **a** CMSS appearance. **b** Setting the CMSS to the pelvic model and docking four robotic arms. c and d special function of CMSS; adjusting the length of the handle on a box leaflet to exaggerating the motion of surgeon's movement in the console, leading to understanding and improving the clutch function. **e** DVSS: the EndoWrist® Manipulation 2 set to the Match Board 3 program. **f** Participant who exercise the DVSS program on a console. **g** Test board to evaluate the performance capacity for the tasks. **h** Docking four robotic arms over the test board on a patient cart

viewed the 64 videos of console and outside view and scored each subject with GRITS. Two raters are surgeon who had performed >500 robotically assisted procedures. Each rater submitted 5 scores for each subject.

Statistical analysis

Continuous variables were expressed as mean ± standard deviation, and categorical variables were expressed as frequency (%). R package version 3.4.3 (https://www.R-project.org) was applied for statistical analysis. Mann–Whitney *U* test and *t* test were used to identify the differences between the two groups. *p* value less than 0.05 was considered as statistically significant.

Results

Participant characteristics

Characteristics of the participants are listed in Table 1. There were no statistical differences among the CMSS and DVSS group participants with respect to age ($p = 0.469$), gender ($p = 0.790$), and level of education ($p = 0.739$, Table 3).

Task performance

When analyzing the time for the participants to complete each task, there were no statistical differences between the two groups ($p > 0.05$). However, the CMSS group participants finished task 4 faster than the DVSS group participants did ($p = 0.033$, Table 4).

Table 3 Distribution and characteristics of the participants

Parameter	CMSS	DVSS	*p* value
Number of participants	32	32	
Age	24.4 ± 2.7	24.3 ± 3.4	0.469
Gender			0.790
Male	21 (65.6%)	22 (68.8%)	
Female	11 (34.4%)	10 (31.3%)	
Academic level			0.739
Premedical course, 1st year	1 (3.1%)	0 (0.0%)	
Premedical course, 2nd year	3 (9.4%)	3 (9.4%)	
Medical course, 1st year	5 (15.6%)	6 (18.8%)	
Medical course, 2nd year	7 (21.9%)	8 (25.0%)	
Medical course, 3rd year	10 (31.3%)	12 (37.5%)	
Medical course, 4th year	6 (18.8%)	3 (9.4%)	

Global rating index for technical skills

The calculated each and total score was similar with each groups. The mean score of respect for tissue were 2.14 ± 0.68 in CMSS and 2.31 ± 0.91in DVSS ($p = 0.384$), efficiency of motion were 1.97 ± 0.58 in CMSS and 2.13 ± 0.60 in DVSS ($p = 0.292$), instrument handling were 2.22 ± 0.71 in CMSS and 2.03 ± 0.58 in DVSS ($p = 0.251$), knowledge of instruments were 2.41 ± 0.59 in CMSS and 2.53 ± 0.67 in DVSS ($p = 0.431$), flow of operation were 2.08 ± 0.58 in CMSS and 2.20 ± 0.61 in DVSS ($p = 0.404$), knowledge of specific procedure were 2.00 ± 0.65 in CMSS and 2.06 ± 0.61 in DVSS ($p = 0.691$), and bimanual dexterity were 1.80 ± 0.49 in CMSS and 2.13 ± 0.83 in DVSS ($p = 0.040$). And the mean score total global rating index were 14.56 ± 3.27 in CMSS and 15.31 ± 3.51 in DVSS ($p = 0.662$) (Fig. 3).

Pre- and post-training questionnaire

Regardless of the simulator used, the participants reported a considerable improvement on the understanding of robotic surgery and robotic manipulation ability (fluency) after the training period (CMSS, concept understanding: 3.8 ± 1.8 before training vs. 7.2 ± 1.6 after training, $p < 0.001$; CMSS, surgical fluency: 1.6 ± 1.9 before training vs. 5.4 ± 1.8 after training, $p < 0.001$; DVSS, concept understanding: 3.1 ± 1.8 before training vs. 6.8 ± 1.5 after training, $p < 0.001$; DVSS, surgical fluency: 1.4 ± 1.8 before training vs. 5.4 ± 1.9 after training, $p < 0.001$, Fig. 4a).

Likewise, the effectiveness of the training with the two simulators is similar, as suggested by the overall improvement in terms of concept understanding and robot manipulation ability (concept understanding: 3.3 ± 1.9 using CMSS vs. 3.8 ± 1.9 using DVSS, $p = 0.368$; surgical fluency: 3.8 ± 2.1 using CMSS vs. 4.0 ± 2.4 using DVSS, $p = 0.691$, Fig. 4b).

The self-assessment questionnaires also helped to determine subjective characteristics of the two simulators. Hence, the CMSS was perceived as portable ($p < 0.001$) and suitable for use in operation room ($p < 0.001$). The remaining characteristics showed no significant differences among the simulators (Table 4).

Discussion

With the adoption of laparoscopy and robotic surgery in current clinical practice, surgical training becomes increasingly relevant given the rapid growth of robotic surgery, especially over the last decade, across all

Table 4 Training effectiveness and self-assessment scores after surgical simulation training

	CMSS	DVSS	*p* value
Training effectiveness (time-min; s; ms, mean ± SD)			
Time to complete the six tasks	03:53.50	04:10.21	0.225
Time to complete task 1	00:30.16	00:33.02	0.198
Time to complete task 2	00:35.80	00:35.09	0.816
Time to complete task 3	00:35.69	00:36.10	0.850
Time to complete task 4	00:32.19	00:39.11	**0.033**
Time to complete task 5	01:05.45	01:13.08	0.210
Time to complete task 6	00:34.22	00:33.82	0.634
Self-assessment score after surgical simulation training (score, mean ± SD)			
Portability	6.8 ± 3.1	1.0 ± 1.6	**< 0.001**
Available in an in situ operation room	8.4 ± 1.3	5.0 ± 3.2	**< 0.001**
Resemblance to actual robotic surgery scenario	7.2 ± 1.8	7.2 ± 1.8	0.886
Improvement in 3rd arm movement	8.2 ± 1.4	8.0 ± 1.6	0.737
Improvement in clutch operation	8.5 ± 1.5	7.8 ± 1.9	0.145
Improvement in camera movement	8.3 ± 1.3	7.0 ± 51.9	0.091
Improvement in wrist movement	7.6 ± 1.6	6.9 ± 1.4	0.189

The bold mean *p* values is under 0.05

specialities [10, 19]. Consequently, practitioners should not only invest in the appropriate equipment but also in the corresponding training to integrate this innovative technology in their interventions. Training using virtual reality for surgical education was first introduced in the late 1980s [20]. Since then, simulation-based training in surgery has continuously evolved, and several studies have evaluated its educational potential [11, 21–24]. And with the aim of standardization in robotic surgery training, a proficiency-based progression curriculum, the fundamentals of robotic (FRS), was developed and accepted standard for training and certification [25].

Several simulators of the da Vinci robotic surgery system are currently available. It is a "virtual simulator," which can be regarded as having a cost benefit because it does not require the actual use of robotic cart and instruments. However, their ultimate high cost of set-up and the consequent limited availability makes the training less accessible. Hence, we developed an affordable CMSS to help novice trainees easily developing the concept of robotic surgery and basic surgical skills for robotic procedures. We verified its potential clinical usefulness through a self-assessment questionnaire applied to participants in a training experiment and by analyzing the time required to complete simple tasks.

The present randomized control study suggests that; (1) the training effectiveness of the CMSS in novice medical students was comparable to that of the commercially available DVSS; (2) for task 4, the performance of the CMSS group participants were superior to those of the DVSS group participants; (3) the CMSS offers a portable solution that can be used even in the operation room, and makes it easy to set-up.

Moreover, the study results show comparable improvement in the robotic surgical skills and understanding concept of robotic surgery in both CMSS and DVSS group participants. Likewise, it was found that there was no significant difference in the time required to complete the proposed tasks among groups. The questionnaire results also show that the two evaluated robotic surgery skills simulators improved the understating of actions such as the 3rd robotic arm movement and wrist-like motion of the end-effector instruments, which is thought to be one of very important surgical capacity in performing advanced minimally invasive surgery in real clinical practice.

Regarding the superior ability of the CMSS group participants to perform task 4, i.e., the rubber band displacement, it can be noted that this task requires more clutch operations than the other tasks. In the statistical analysis, the CMSS showed higher score in understanding clutch function. As mentioned before, third characteristics of the present CMSS, function of adjusting the length of the handle on a box leaflet, is thought to actually played some role in enhancing the action radius of the hand movement, which making the participants cannot help using clutch function for properly proceed surgical procedure. Hence, the user seemed to be able to easily understand, learn and improve the clutch function.

However, there are still limitations in the CMSS. First, the DVSS is providing training tools with various detailed

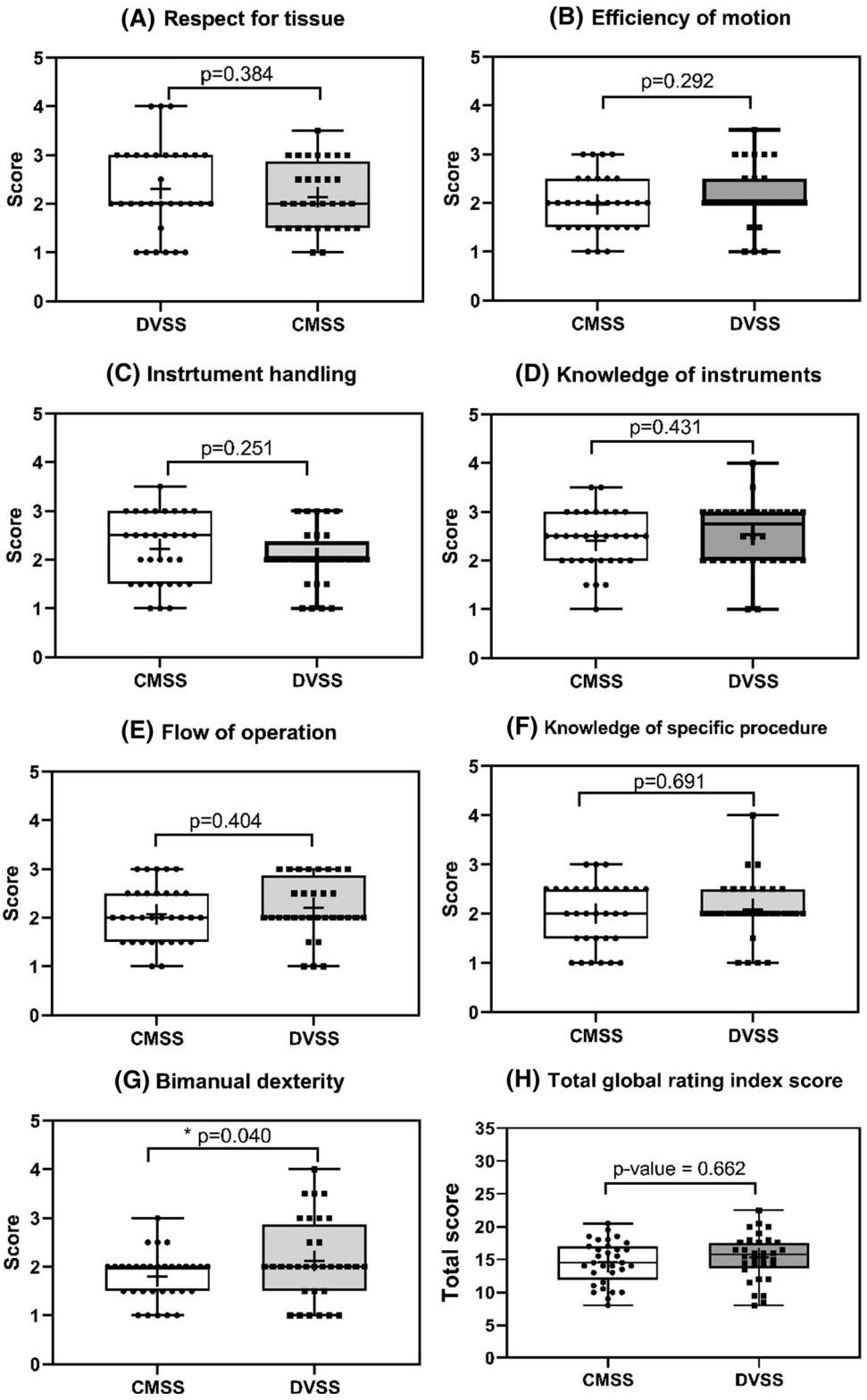

Fig. 3 Global rating index for technical skills analysis. **a** Respect for tissue. **b** Efficiency of motion. **c** Instrument handling. **d** Knowledge of instruments. **e** Flow of operation. **f** Knowledge of specific procedure. **g** Bimanual dexterity. **h** Total global rating index score

programs and difficulty levels with color change or other warning sign. In contrast, the CMSS does not provide training on intense procedures such as those using energy devices or surgical sutures. Second, actual robotic cart and robotic instruments ("not for clinical use") are necessary while using the CMSS, which potentially leads to

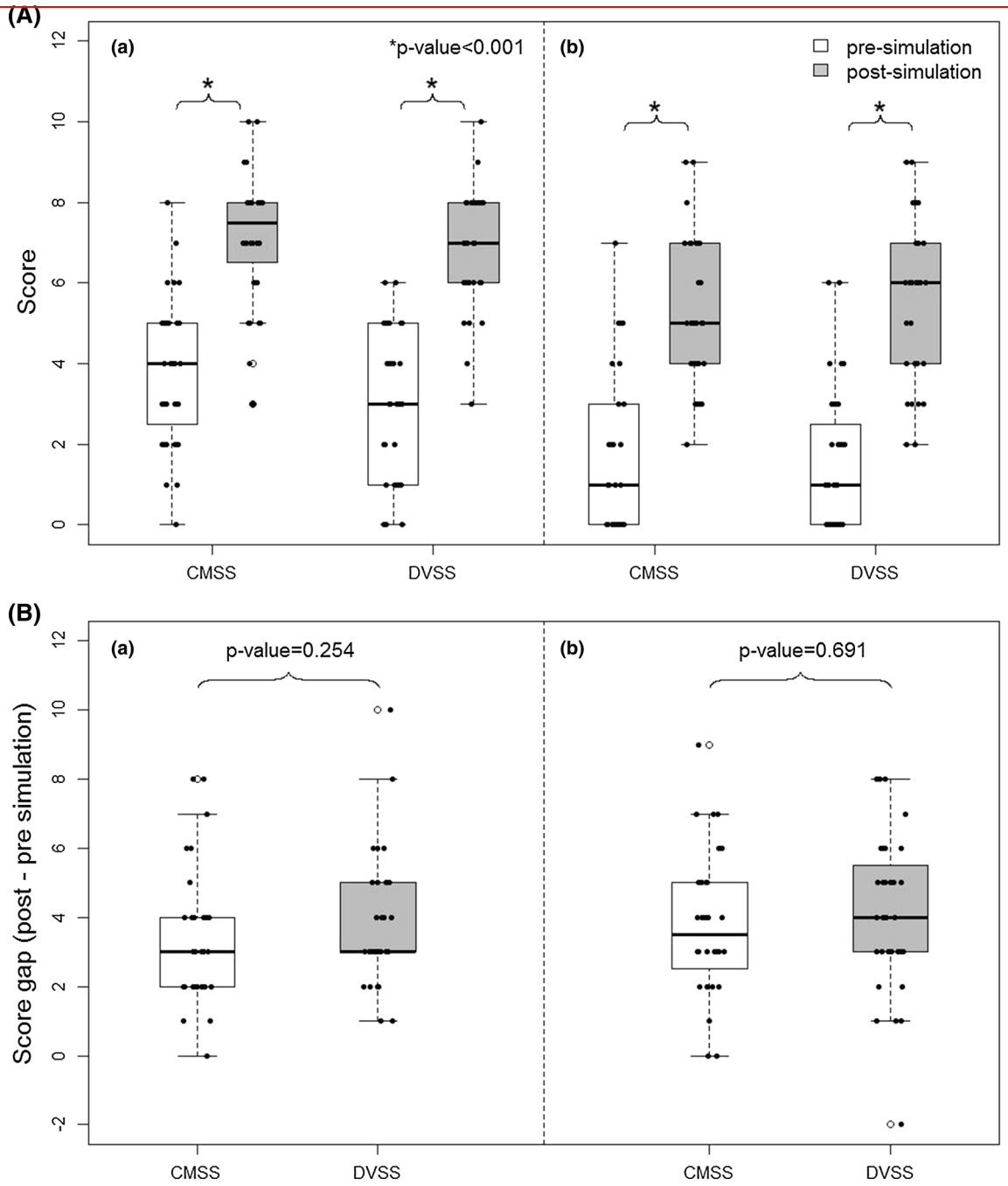

Fig. 4 Individual questionnaire analysis. **A** Pre-and post-simulation exercise questionnaire scoring compare analysis according to the simulation systems about **a** understanding of robotic surgery and (**b**) robotic manipulation fluency. **B** The effectiveness (evaluated by the scoring gap of pre- and post- simulation exercise) comparing of the two simulator systems about **a** understanding the concept of the robotic surgery and **b** robot manipulation fluency

additional expenses. Lastly, the CMSS does not have metrics which are measured such as instrument conflict and pressure. During the CMSS training session, the instructor should give the verbal cautions and feedbacks. Nevertheless, the CMSS is thought to provide basic training circumstances on the movement of the robotic camera and three robotic arms, especially the 3rd arm that is highly useful for advanced surgery. Moreover, the proposed CMSS is small and portable, and hence it can be used in the operation room. It is thought that the mutual direct

communications and feedbacks from instructors would be the one of the strong point of the current CMSS. Compared to the high installation cost of the DVSS and given the similar outcomes reported in this study, it is carefully concluded that the CMSS is a suitable alternative and synergic to the currently available DVSS for basic training, leading to easy access to robotic surgery training and fast familiarity with robotic surgery in a short time.

As we are in the transition to the fourth industrial revolution, robots will become a key technology in the medical field, and the society will demand precise and effective robotic surgery. In fact, medical robots are being actively developed, and practitioners are gaining interest in acquiring fluency in this area. Then, regular and intense practice will enable the lessening of the learning curve related to robotic surgery. Hence, it is believed that this kind of robotic surgical simulator also need to be developed to compensate the unmet needs.

This study harbors some limitations. (1) The task couldn't measuring the exact robotic surgical skills. In fact, we were not trying to measuring robotic surgical skill, but measuring the capacity of understanding the principles of robotic surgical system. Robotic surgical skill is individualized and finally can be based on accumulating surgeon's experiences. Therefore, before implementation of robotic skill, the novice surgeons need to fully understand the fundamental mechanism of robotic surgical system, and get idea how they use it fluently in real clinical practice. From that point of view, it is thought that the current CMSS is simple and can play potential role as DVSS. (2) We evaluated only one task-performance by the time they spent after just 15-min exercise of each individual surgical simulators. It is surely difficult to conclude that this one task-performance can represent the training efficacy of individual surgical simulators. We just evaluated one aspect of training effectiveness of surgical simulators within a short time based on not standardized take results. And there are many ways and viewpoints to evaluate the effectiveness of developing surgical simulator. The training effectiveness will be increasing even if the novice surgeons can understand the principles of robotic surgical system in spite of their shorter training time. Longer training time may not be always necessary to build the appropriate proficiency. We don't think the present CMSS is the best for training the novice surgeons, but our data showed that their performance and understanding ability of the robotic surgical system is comparable to DVSS even after short time education. More detailed, and repeated take performances would have been more helpful to determine the efficacy of CMSS and DVSS. (3) In spite of the prospective randomized control study, the study population size used in the study is small. In addition, the subjects of our study were novice medical students, not surgeons. Therefore, the potential role and suitability of the CMSS in more experienced subjects remains unclear.

Based on the present encouraging data showing potential role of CMSS, further study is mandatory with improved CMSS and validated training protocol. And to evaluate the users correctly, our own variety evaluation tool implementation is demanded.

In conclusion, several types of robotic simulators are available for training practitioners in robotic surgery. In this study, CMSS was developed and the training efficacy was tested by prospective randomized control study. It was found that the training efficacy of the CMSS was not significantly different to the DVSS, however CMSS would be thought to be able to play synergic role in robotic surgical training.

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Authors' contributions CR Lee and CM Kang made conception and designed the study; SY Rho, SH Han,Y Moon, SY Hwang, and YJ Kim collected and interpretation of the data; CR Lee drafted the paper; CR Lee and CM Kang critically revised subsequent drafts. All authos have read and approved the submission manuscript.

Compliance with ethical standards

Conflict of interest All of the authors (Cho Rok Lee, Seoung Yoon Rho, Sang Hyup Han, Young Moon, Sun Young Hwang, Young Joo Kim, and Chang Moo Kang) have nothing to disclose.

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