

# Robotic suturing on the FLS model possesses construct validity, is less physically demanding, and is favored by more surgeons compared with laparoscopy

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Received: 20 November 2009 / Accepted: 23 May 2010 / Published online: 24 December 2010  
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## Abstract

**Background** The value of robotic assistance for intracorporeal suturing is not well defined. We compared robotic suturing with laparoscopic suturing on the FLS model with a large cohort of surgeons.

**Methods** Attendees ( $n = 117$ ) at the SAGES 2006 Learning Center robotic station placed intracorporeal sutures on the FLS box-trainer model using conventional laparoscopic instruments and the da Vinci<sup>®</sup> robot. Participant performance was recorded using a validated objective scoring system, and a questionnaire regarding demographics, task workload, and suturing modality preference was completed. Construct validity for both tasks was assessed by comparing the performance scores of subjects with various levels of experience. A validated questionnaire was used for workload measurement.

**Results** Of the participants, 84% had prior laparoscopic and 10% prior robotic suturing experience. Within the allotted time, 83% of participants completed the suturing task laparoscopically and 72% with the robot. Construct validity was demonstrated for both simulated tasks according to the participants' advanced laparoscopic experience, laparoscopic suturing experience, and self-reported laparoscopic suturing

ability ( $p < 0.001$  for all) and according to prior robotic experience, robotic suturing experience, and self-reported robotic suturing ability ( $p < 0.001$  for all), respectively. While participants achieved higher suturing scores with standard laparoscopy compared with the robot ( $84 \pm 75$  vs.  $56 \pm 63$ , respectively;  $p < 0.001$ ), they found the laparoscopic task more physically demanding (NASA score  $13 \pm 5$  vs.  $10 \pm 5$ , respectively;  $p < 0.001$ ) and favored the robot as their method of choice for intracorporeal suturing (62 vs. 38%, respectively;  $p < 0.01$ ).

**Conclusions** Construct validity was demonstrated for robotic suturing on the FLS model. Suturing scores were higher using standard laparoscopy likely as a result of the participants' greater experience with laparoscopic suturing versus robotic suturing. Robotic assistance decreases the physical demand of intracorporeal suturing compared with conventional laparoscopy and, in this study, was the preferred suturing method by most surgeons. Curricula for robotic suturing training need to be developed.

**Keywords** Robot · Suturing · SAGES learning center · FLS · Workload · Simulator

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Intracorporeal suturing is one of the most difficult advanced laparoscopic skills to accomplish. Mastery of this skill may enable surgeons to expand the spectrum of advanced laparoscopic procedures they can offer to their patients [1].

Robotic surgery is a promising new technology with a number of advantages over standard laparoscopy; in addition to making operations from a distance feasible, it offers improved visualization through a three-dimensional imaging system and surgeon-controlled camera manipulation, improved instrumentation with increased range of motion,

and downscaling of surgeon's movements that increase precision and improved ergonomics [2, 3]. The advantages of robotic assistance over standard laparoscopy have been demonstrated by several studies for novice learners [4–7], but they are less clear for experienced surgeons. In addition, currently, no significant clinical advantages have been realized in general surgery by the introduction of robotics [2].

The purpose of this study was to assess the effect of robotic assistance on experienced surgeons' performance and preference on a well-defined task (intracorporeal suturing and knot tying) compared with standard laparoscopy.

## Methods

Attendees at the robotic station at the SAGES 2006 Learning Center participated voluntarily in a simulator-based study protocol comparing laparoscopic with robotic suturing. Study details were fully disclosed to station participants, and they were informed that the collected data might be published. To maintain confidentiality, data collection was anonymous, and data were recorded on coded sheets without identifiers linking participants' names to the data. The only exclusion criterion for the study (but not for participation in the station) was unwillingness to give verbal consent.

After verbal consent was obtained, participants were randomly assigned a number and completed the demographic data portion of the questionnaire (see "Appendix"). To minimize bias, all instructors were blinded to the participants' demographics.

Participants watched a video tutorial of suturing and knot tying and were asked to perform at least one repetition with conventional laparoscopic instruments and one with the da Vinci<sup>®</sup> robotic system (Intuitive Surgical Inc., Sunnyvale, CA) on a Karl Storz videotrainer box using the FLS suturing model (Fig. 1). The da Vinci surgical system is a telemanipulator using robotic technology with an important distinction from other robotic systems in that it does not take action by itself. It consists of a console, a patient-side cart with three or four robotic arms, and a video tower, and it uses tremor filtration, motion scaling, three-dimensional view, and longer instruments that provide a full seven degrees of freedom due to an extension/flexion and a tilt function of the tip [8, 9] (Fig. 2).

Half of the participants were randomly assigned to start on the robotic and half on the laparoscopic simulator. Task duration, errors, and knot security were recorded, and a score was calculated based on the following formula:  $300 - (\text{time} + \text{accuracy error} \times 10 + \text{approximation error} \times 10 + \text{security error} \times 100)$ . The time limit was 5 min



**Fig. 1** Setup of robotic surgery station at 2006 SAGES Learning Center



**Fig. 2** The da Vinci robotic system

(300 s) per task. Details about the calculation of this objective score have been published previously [10]. After completion of both laparoscopic and robotic suturing tasks, subjects completed the second part of the questionnaire pertaining to task workload and suture modality preference. The validated NASA-TLX questionnaire [11], which rates the mental, physical, and temporal demand of a task as well as the performance, effort, and frustration of the subject, was used for workload measurement. Construct validity for both tasks was assessed by comparing the performance scores of subjects with various levels of experience. To further assess the effect of experience on performance, workload, and suturing preference, we also analyzed separately and compared the results of two groups: laparoscopic suturing experts defined as participants who indicated that they had used laparoscopic suturing in more than 50 cases and novices who had not performed laparoscopic or robotic suturing before.

Data were analyzed using the SigmaStat<sup>®</sup> software (SPSS Inc., Chicago, IL). ANOVA on ranks, the Mann–Whitney rank sum test, and the  $\chi^2$  test were used for statistical comparisons. A  $p < 0.05$  was considered significant.

## Results

One hundred seventeen Learning Center attendees participated in the study. Eighty-four percent had prior laparoscopic suturing experience, but only 10% had prior robotic suturing experience. Participant characteristics are given in Table 1. Within the allotted time of 5 min, 83% of participants completed the suturing task laparoscopically and 72% with the robot. Construct validity was demonstrated for both simulated tasks according to the participants' advanced laparoscopic experience, laparoscopic suturing experience, and self-reported laparoscopic suturing ability and according to prior robotic experience, robotic suturing experience, and self-reported robotic suturing ability ( $p < 0.001$  for all comparisons, see Table 2). While participants achieved higher suturing scores with standard laparoscopy compared with the robot ( $84 \pm 75$  vs.  $56 \pm 63$ , respectively;  $p < 0.001$ ), they found the laparoscopic task to be more physically demanding (NASA physical demand subscale score  $13 \pm 5$  vs.  $10 \pm 5$ , respectively;  $p < 0.001$ , Fig. 3) and favored the robot as their method of choice for intracorporeal suturing ( $62$  vs.  $38\%$ , respectively;  $p < 0.01$ ). Differences between the expert and novice groups with regard to performance, workload scores, and suturing modality values are shown on Table 3.

## Discussion

Advancements in technology have allowed many surgical procedures to be performed using minimally invasive techniques. With the use of novel energy source and stapling devices, many complex procedures can now be performed

**Table 1** Participant characteristics

Number of station attendees	133
Number of attendees who completed both tasks	117
Age (years)	$38 \pm 9$
Men	88 (75%)
Right-handed	103 (88%)
Attendings	51 (44%)
Fellows	32 (27%)
Residents	27 (23%)
Novices	7 (6%)
Laparoscopic fellowship trained	53 (45%)
Prior simulator experience	$7 \pm 7$ (h)

**Table 2** Construct validity parameters for the simulated laparoscopic and robotic suturing tasks

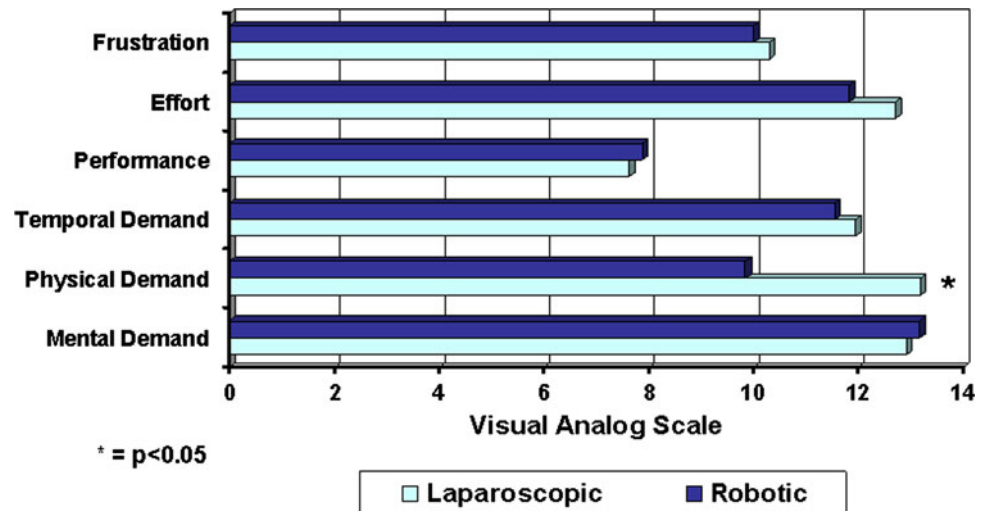
Parameter	$n^a$	Score (mean $\pm$ SD)	$p$ Value
Laparoscopic suturing ability self-rating			
0–1	14	$11 \pm 29$	<0.001
2–4	26	$38 \pm 42$	
5–7	37	$97 \pm 66$	
8–10	37	$136 \pm 72$	
Robotic suturing ability self-rating			
0–1	83	$39 \pm 48$	<0.001
2–4	7	$85 \pm 84$	
5–7	11	$94 \pm 62$	
8–10	4	$209 \pm 24$	
Number of advanced laparoscopic cases performed			
None	18	$18 \pm 30$	<0.001
1–10	30	$49 \pm 62$	
11–50	26	$67 \pm 64$	
51–100	18	$92 \pm 62$	
>101	38	$146 \pm 64$	
Number of robotic cases performed			
None	100	$47 \pm 56$	<0.001
>1	15	$116 \pm 76$	
Number of laparoscopic suturing cases performed			
None	18	$29 \pm 39$	<0.001
1–10	37	$54 \pm 59$	
11–50	25	$97 \pm 74$	
>51	32	$146 \pm 60$	
Number of robotic suturing cases			
None	102	$50 \pm 57$	<0.001
>1	12	$110 \pm 88$	

<sup>a</sup>  $n$  does not always equal the total number of participants (117) as a few participants failed to indicate their prior experience

laparoscopically. Intracorporeal suturing is an important and necessary skill that all surgeons performing advanced laparoscopy should master [1]. Laparoscopic suturing is a difficult task to learn, as it is subject to the known limitations of laparoscopic surgery, including the loss of haptic feedback, limited degrees of freedom, the fulcrum and pivoting effect, and a two-dimensional view [2, 3].

Robotic systems have been developed to address the aforementioned constraints associated with laparoscopy and to improve precision. Such systems allow three-dimensional vision, motion scaling, camera control, automatic instrument change out, and tissue collision detection and thus may make difficult laparoscopic tasks such as suturing and knot tying easier, thus decreasing operator workload [2]. Indeed, in a recent study from our group that examined the benefits of robotic assistance during suturing by novice learners, we demonstrated that robotic assistance led to improved suturing performance, limited the number of inadvertent injuries

**Fig. 3** Comparison of participant subjective workload ratings on the validated NASA-TLX workload questionnaire between laparoscopic and robotic suturing modalities



to structures outside the operating field, shortened the learning curve of the task, and decreased operator workload in a live animal Nissen fundoplication model [12]. In another study, Moorthy et al. [13] demonstrated that the presence of a “wristed” instrument, tremor ablation, and motion scaling enhanced dexterity by nearly 50% compared with laparoscopic suturing and that three-dimensional vision enhanced dexterity by an additional 10–15%. Marecik et al. [14] evaluated robotic, laparoscopic, and hand-sewn suturing on porcine small intestine by residents. They reported that the robotic suture line created by midlevel residents was superior to laparoscopy although the times were equivalent. They also reported that the suturing was considered difficult by 92% in the laparoscopic group versus 17% in the robotic group [14]. In another experimental study on robotic suturing, Ruurda et al. [15] compared robotic and laparoscopic suturing on an end-to-end small intestine anastomosis model. They reported no difference in anastomosis time, number of stitches, and number of knots between the robotic and laparoscopic groups. They did, however, report shorter times per stitch and more suture ruptures in the robotic group and more stitch errors in the laparoscopic group [15]. A recent review by Kenngott [2] on robotic suturing reported that robotic systems in experimental studies had superior suturing capabilities compared with laparoscopic suturing and attributed the benefits to the three-dimensional visualization and the full seven degrees of freedom afforded by the robot.

While these benefits of robotic assistance to the inexperienced laparoscopist have been well documented in the literature [4–7], their importance for more experienced laparoscopists is a lot less clear. We therefore undertook the current study and chose to conduct it at the SAGES Learning Center to assess the impact of robotic assistance on a larger group of surgeons with more and variable laparoscopic experience. We found that robotic suturing was less

**Table 3** Comparison of performance and workload based on prior laparoscopic experience

Parameter	n	Laparoscopic	Robotic	p value
Prior experience	117	84%	10%	<0.001
Task completion	117	83%	72%	0.06
Overall suturing scores	117	84 ± 75	56 ± 63	<0.001
Overall NASA scores <sup>a</sup>	117	69 ± 23	64 ± 25	0.11
Overall value <sup>a</sup>	117	15.5 ± 3.5	16.7 ± 3.3	<0.001
Novice suturing scores	13	31 ± 44	23 ± 49	0.81
Novice NASA scores <sup>a</sup>	13	89 ± 23	73 ± 16	0.24
Novice value <sup>a</sup>	13	14.5 ± 3.3	17.6 ± 2	0.01
Expert suturing scores	32	146 ± 60	73 ± 65	<0.001
Expert NASA scores <sup>a</sup>	32	55 ± 22	64 ± 27	0.20
Expert value <sup>a</sup>	32	16.7 ± 3.4	16.4 ± 4.2	0.91

<sup>a</sup> Ratings on a 1–20 VAS scale. Experts defined as having performed more than 50 laparoscopic suturing cases and novices as never having performed laparoscopic or robotic suturing

demanding physically and the preferred method of suturing by the majority of our participants. We also demonstrated, however, that suturing scores were higher with standard laparoscopic instruments compared with robotic assistance. This finding is not unexpected, as most of our participants had significant prior advanced laparoscopic and laparoscopic suturing experience but minimal prior robotic experience. Furthermore, our subanalysis of experts in laparoscopic suturing and novices (Table 3) revealed that experts performed significantly better with standard laparoscopy and experienced higher workload when working with the robot, while novices had similar performance but less workload with the robot. Interestingly, while novices clearly indicated higher value to the robotic suturing system, experts assigned a similar value to both suturing modalities. In our opinion, these findings are indicative of a new learning curve for robotic suturing for expert laparoscopists, which is

likely related to the different instruments and control of the instruments and the complete loss of haptic feedback, which is unique to the robotic task, rather than differences in the suturing task itself. Thus, experienced laparoscopists report a higher workload when they are trying to learn the new technique but still perform better than novices with robotic assistance, indicating a partial skill transfer. Despite this difficulty with the newer technique, the value ratings of experts were essentially identical for the two modalities, indicating that they realized some benefit with the robot. On the other hand, novice ratings were clearly in favor of the robot likely due to the easier accomplishment of the task. Prior studies corroborate our findings. In a group of eight physicians with variable laparoscopic experience, Yohannes et al. [4] demonstrated faster learning during the performance of laparoscopic dexterity tasks using robotic assistance compared with standard laparoscopy. The differences encountered were less pronounced for more experienced laparoscopists. In addition, Chang et al. [16] demonstrated that experienced laparoscopists registered initially inferior performance with the robot compared with conventional laparoscopy when performing intracorporeal suturing and knot tying. However, their robotic performance improved and surpassed that of laparoscopy after dedicated training. Thus, it is probable that expert laparoscopists have learned to overcome the constraints of laparoscopy, have little room for improvement, and experience a new learning curve when trying to adopt a new technique. This may be one of the reasons, in addition to increased cost, that surgeons hesitate to adapt the robotic technology.

It is also important to note that this is one of the first studies to demonstrate construct validity of the laparoscopic and robotic suturing tasks on the FLS model, as

more experienced surgeons clearly outperformed the less experienced. This indicates that the SAGES/ACS-endorsed FLS suturing model is an excellent educational tool to teach both robotic and laparoscopic suturing.

A limitation of this study is that our participants had limited prior robotic experience compared with their laparoscopic experience. Thus, it was not possible to assess the value of the robot in a group of surgeons who were experts in both laparoscopic and robotic surgery. Furthermore, our pool of novices was small, not giving us the power needed to detect statistical differences for some parameters. In addition, the demographic data collected are subject to reporting and possibly recollection bias, but we do not believe that our results were affected significantly by these parameters. Finally, we did not assess the benefits of other suturing assisting devices that are available at a significantly lower cost than the robot.

In conclusion, construct validity was demonstrated for robotic suturing on the FLS model. Robotic assistance decreases the physical demand of intracorporeal suturing compared with conventional laparoscopy and, in this study, was the preferred suturing method by most surgeons. Curricula for robotic suturing training need to be developed.

**Acknowledgments** The authors thank Chris Bell, MD, Lee Ann Lau, MD, Marc Zerey, MD, Makram Gedeon, MD, Andrew Harrell, MD, and George Walker, RN, for their help with the conduct of this study and data acquisition. We also thank Anahita Mostafavi and Amanda Walters, BS, for their help with data entry and analysis.

**Disclosures** Dimitrios Stefanidis, William W. Hope, and Daniel J. Scott have no conflicts of interest or financial ties to disclose.

**Appendix: Robotic suturing questionnaire**

SAGES Learning Center 2006 -		Robotic Station		ID#		
				Instructor Initials _____		
1.	Age: _____	Gender: ♀ ♂	Handedness?	Left	Right	Both
2.	What is YOUR level of training?	Attending	Fellow	Resident- PGY ___	Other _____	
3.	If attending, number of years	a) since training completion ___	b) practicing laparoscopy ___	c) practicing robotics ___		
4.	Are you fellowship trained in laparoscopy?	YES	NO			
5.	How many lap cholecystectomies have you performed?	0	1-10	11-25	26-50	51-100
6.	How many ADVANCED laparoscopic cases have you performed? <small>(e.g. incisional/inguinal hernia, Nissen, splenectomy, gastric bypass, etc.)</small>	0	1-10	11-25	26-50	51-100
7.	In how many cases have you used laparoscopic suturing with intracorporeal knot tying?	0	1-10	11-25	26-50	>50
8.	Rate your laparoscopic suturing and knot tying ability (0-10):	0	1	2	3	4
9.	How many robotic cases have you performed?	0	1-10	11-25	26-50	>50
10.	In how many cases have you used robotic suturing with intracorporeal knot tying?	0	1-10	11-25	26-50	>50
11.	Rate your robotic suturing and knot tying ability (0-10):	0	1	2	3	4
12.	How many hours of simulator experience have you had in the past?	0	<1	1-3	3-5	5-10
13.	How many hours have you practiced on the videotrainer box?	0	<1	1-3	3-5	5-10
14.	Rate your suturing and knot tying ability on the videotrainer simulator (0-10):	0	1	2	3	4
8.	<b>Practice session:</b> please complete at least one trial on each simulator			Trial 1	Trial 2	
		Laparoscopic				
		Robotic				

9. Please answer the following questions; on the visual analog scales please mark your response with an "X".

	<u>Laparoscopic Suturing</u>	<u>Robotic Suturing</u>
a. Overall value of the simulator as a training and/or testing tool	<div style="display: flex; justify-content: space-between;"> <div>_____</div> <div>_____</div> </div> <p style="text-align: center;"><b>poor</b> <span style="margin-left: 100px;"><b>excellent</b></span></p>	<div style="display: flex; justify-content: space-between;"> <div>_____</div> <div>_____</div> </div> <p style="text-align: center;"><b>poor</b> <span style="margin-left: 100px;"><b>excellent</b></span></p>
b. Mental Demand (how much mental & perceptual activity was required? Was the task easy or demanding, simple or complex?)	<div style="display: flex; justify-content: space-between;"> <div>_____</div> <div>_____</div> </div> <p style="text-align: center;"><b>low</b> <span style="margin-left: 100px;"><b>high</b></span></p>	<div style="display: flex; justify-content: space-between;"> <div>_____</div> <div>_____</div> </div> <p style="text-align: center;"><b>low</b> <span style="margin-left: 100px;"><b>high</b></span></p>
c. Physical Demand (how much physical activity was required? Was the task easy or demanding, restful or laborious?)	<div style="display: flex; justify-content: space-between;"> <div>_____</div> <div>_____</div> </div> <p style="text-align: center;"><b>low</b> <span style="margin-left: 100px;"><b>high</b></span></p>	<div style="display: flex; justify-content: space-between;"> <div>_____</div> <div>_____</div> </div> <p style="text-align: center;"><b>low</b> <span style="margin-left: 100px;"><b>high</b></span></p>
d. Temporal Demand (how much time pressure did you feel? Was the task pace slow & leisurely or rapid & frantic?)	<div style="display: flex; justify-content: space-between;"> <div>_____</div> <div>_____</div> </div> <p style="text-align: center;"><b>low</b> <span style="margin-left: 100px;"><b>high</b></span></p>	<div style="display: flex; justify-content: space-between;"> <div>_____</div> <div>_____</div> </div> <p style="text-align: center;"><b>low</b> <span style="margin-left: 100px;"><b>high</b></span></p>
e. Performance (how successful do you think you were in accomplishing the task? how satisfied are you with your performance?)	<div style="display: flex; justify-content: space-between;"> <div>_____</div> <div>_____</div> </div> <p style="text-align: center;"><b>poor</b> <span style="margin-left: 100px;"><b>good</b></span></p>	<div style="display: flex; justify-content: space-between;"> <div>_____</div> <div>_____</div> </div> <p style="text-align: center;"><b>poor</b> <span style="margin-left: 100px;"><b>good</b></span></p>
f. Effort (how hard did you have to work (mentally & physically) to accomplish your level of performance?)	<div style="display: flex; justify-content: space-between;"> <div>_____</div> <div>_____</div> </div> <p style="text-align: center;"><b>low</b> <span style="margin-left: 100px;"><b>high</b></span></p>	<div style="display: flex; justify-content: space-between;"> <div>_____</div> <div>_____</div> </div> <p style="text-align: center;"><b>low</b> <span style="margin-left: 100px;"><b>high</b></span></p>
g. Frustration Level (how insecure, discouraged, irritated versus secure, content, relaxed did you feel during the task?)	<div style="display: flex; justify-content: space-between;"> <div>_____</div> <div>_____</div> </div> <p style="text-align: center;"><b>low</b> <span style="margin-left: 100px;"><b>high</b></span></p>	<div style="display: flex; justify-content: space-between;"> <div>_____</div> <div>_____</div> </div> <p style="text-align: center;"><b>low</b> <span style="margin-left: 100px;"><b>high</b></span></p>
h. If you had a choice, which modality would you use for intracorporeal suturing and knot tying?	<b>Laparoscopic</b>	<b>Robotic</b>
i. Rate your laparoscopic suturing and knot tying ability (0-10):	0 1 2 3 4 5 6 7 8 9 10	
j. Rate your robotic suturing and knot tying ability (0-10):		0 1 2 3 4 5 6 7 8 9 10

List the **advantages** of the robot:

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List the **disadvantages** of the robot:

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**Other comments** (use reverse side if needed) \_\_\_\_\_

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