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Performance of robotic simulated skills tasks is positively associated with clinical robotic surgical performance

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Objective

To compare user performance of four fundamental inanimate robotic skills tasks (FIRST) as well as eight da Vinci Skills Simulator (dVSS) virtual reality tasks with intra-operative performance (concurrent validity) during robot-assisted radical prostatectomy (RARP) and to show that a positive correlation exists between simulation and intra-operative performance.

Materials and Methods

A total of 21 urological surgeons with varying robotic experience were enrolled. Demographics were captured using a standardized questionnaire. User performance was assessed concurrently in simulated (FIRST exercises and dVSS tasks) and clinical environments (endopelvic dissection during RARP). Intra-operative robotic clinical performance was scored using the previously validated six-metric Global Evaluative Assessment of Robotic Skills (GEARS) tool. The relationship between simulator and clinical performance was evaluated using Spearman's rank correlation.

Results

Performance was assessed in 17 trainees and four expert robotic surgeons with a median (range) number of previous robotic cases (as primary surgeon) of 0 (0–55) and 117 (58–600), respectively ($P = 0.001$). Collectively, the overall FIRST ($\rho = 0.833$, $P < 0.001$) and dVSS ($\rho = 0.805$, $P < 0.001$) simulation scores correlated highly with GEARS performance score. Each individual FIRST and dVSS task score also demonstrated a significant correlation with intra-operative performance, with the exception of Energy Switcher 1 exercise ($P = 0.063$).

Conclusions

This is the first study to show a significant relationship between simulated robotic performance and robotic clinical performance. Findings support implementation of these robotic training tools in a standardized robotic training curriculum.

Keywords

robotics, education, validation studies, clinical competence, concurrent validity

Introduction

Since the da Vinci Surgical System (Intuitive Surgical, Sunnyvale, CA) was first introduced in 1998, robot-assisted laparoscopic surgery has seen a rapid, widespread adoption. Despite this rapid surge in use, the development and validation of training methods has failed to keep pace. Several training platforms have undergone validation testing, including inanimate tasks [1–5], virtual reality exercises [6–9] and *ex vivo* models [5,9,10]. Validation work in these studies includes demonstration of face (realism of training tool), content (usefulness as training tool), construct (ability to distinguish between different skill levels) and cross-method (correlation across training methods) validity.

Notably absent from the robotic training validation literature, however, is any significant correlation between simulator performance and *in vivo* robotic clinical performance (concurrent validity). Despite the lack of substantial evidence that performance on any given simulator correlates to clinical intra-operative performance, simulation in robotic surgery has been consistently used as a training platform. In the present study, we aim to investigate the relationship between robotic simulation and clinical performance, which will provide the basis for development of a standardized robotic training curriculum.

To this end, we used 12 simulator robotic skills tasks that our group has previously validated. These tasks consist of a set of four inanimate models, collectively called fundamental inanimate robotic skills tasks (FIRST) [5,11], and eight selected virtual reality tasks on the da Vinci Skills Simulator (dVSS) platform [8]. These simulator tasks together encompass all of the basic skills of robotic surgery, including object pick and place, hand-to-hand transfer, instrument wrist manipulation, camera control and clutching, third-arm manipulation, suturing and energy use.

We have previously developed and validated a robotic skills clinical assessment tool, the Global Evaluative Assessment of Robotic Skills (GEARS), which is shown in Fig. 1 [5,10,12]. Composed of six domains rated on a five-point Likert scale, GEARS has been shown to be a reliable assessment tool for robotic clinical performance.

In the present study, we concurrently compared performance in virtual reality (dVSS) and inanimate (FIRST) simulation environments with surgical performance during robot-assisted prostatectomy (RARP) using a set of rigorously validated, standardized metrics. We sought to answer the question: does robotic performance in a simulator correlate to real-world clinical performance?

Materials and Methods

Participants

After we had obtained institutional review board approval, 21 participants consisting of urology residents, fellows and attending physicians were enrolled in the study. The study design is shown in Fig. 2. After enrolment, a standardized questionnaire was used to capture the demographics and surgical experience of the participants. Data on age, gender, training classification, previous robotic or laparoscopic courses, previous minimally invasive fellowship training, previous robotic simulator experience, and previous surgical (laparoscopic and robotic) experience were obtained. For trainees, Accreditation Council for Graduate Medical Education (ACGME) case logs were queried to confirm surgical experience.

Task Completion

For the simulator tasks, participants first completed a brief warm-up and then watched instructional videos for all exercises. They then completed the same eight dVSS tasks and four FIRST exercises in succession and in the same predetermined order: Peg Board 1; Peg Board 2; Ring and Rail 2; Ring Walk 3; Match Board 3; Suture Sponge 3; Tubes; and Energy Switcher, followed by Horizontal Mattress; Clover Pattern Cut; 3-D Dome and Peg; and Circular Needle Target. Performance on FIRST was scored by a trained observer using a modified Fundamentals of Laparoscopic Surgery (FLS) metric based on accuracy and efficiency to generate a normalized score for each exercise [1,11]. Performance scores on dVSS tasks were computer-generated based on 11 performance metrics, as previously described, generating an overall percentage score for each of the tasks [8]. The composite score for each training platform was the sum of the scores generated for each of the individual tasks, respectively.

Clinical robotic performance was concurrently assessed for all participants during the endopelvic fascia dissection portion of an RARP. Trainees were evaluated using the GEARS assessment tool following the case by the attending surgeon. Each intra-operative performance was also video recorded, including audio, and meticulously post-processed for de-identification. An independent, blinded observer (A.C.G.) then scored all trainee and expert performances using GEARS. RARP was selected as the clinical correlate, given that it is the most commonly performed robot-assisted urological procedure. The endopelvic fascia dissection was specifically selected to permit all levels of training to participate in the study, particularly novices with minimal prior robotic experience.

Statistical Analysis

Demographic data were recorded as median (range) or frequency (percent). To highlight the range of participant experience levels, demographic data were stratified into expert and trainee groups and the data compared across groups using the Mann–Whitney *U*-test for categorical data and the chi-squared/Fisher's exact test for nominal data. To remain consistent with previous studies, experts were defined as participants with >30 robotic cases as primary surgeon [10,12,13]. Experience level stratification was not statistically necessary for the primary outcomes of the study, but was carried out to allow contemporary comparison.

To evaluate the relationship between simulator performance and clinical performance, composite dVSS and FIRST scores were plotted against GEARS performance scores to generate a scatterplot for each training method. Associations between simulator scores and GEARS scores were then quantified with Spearman's rank correlation for composite scores as well as individual task scores. To evaluate inter-observer reliability, non-blinded trainee performance scores were compared with their blinded GEARS scores using Spearman's rank correlation.

Finally, composite and individual task scores were compared with the individual domains of the GEARS scores in the same fashion, with the goal of evaluating whether any given training method or task was associated with or measured a specific robotic skill. All statistical analyses were performed using SPSS for Mac Version 22 (IBM Corporation, Armonk, NY, USA) and R statistical program package, version 3.0.3

Fig. 1 Global Evaluative Assessment of Robotic Skills (GEARS).

Date:__________ Evaluator Code: __________

Operator Code:__________ Attending Code: __________

Global Evaluative Assessment of Robotic Skills

Depth perception

1	2	3	4	5
Constantly overshoots target, wide swings, slow to correct		Some overshooting or missing of target, but quick to correct		Accurately directs instruments in the correct plane to target

Bimanual dexterity

1	2	3	4	5
Uses only one hand, ignores nondominant hand, poor coordination		Uses both hands, but does not optimize interaction between hands		Expertly uses both hands in a complementary way to provide best exposure

Efficiency

1	2	3	4	5
Inefficient efforts; many uncertain movements; constantly changing focus or persisting without progress		Slow, but planned movements are reasonably organized		Confident, efficient and safe conduct, maintains focus on task, fluid progression

Force sensitivity

1	2	3	4	5
Rough moves, tears tissue, injures nearby structures, poor control, frequent suture breakage		Handles tissues reasonably well, minor trauma to adjacent tissue, rare suture breakage		Applies appropriate tension, negligible injury to adjacent structures, no suture breakage

Autonomy

1	2	3	4	5
Unable to complete entire task, even with verbal guidance		Able to complete task safely with moderate guidance		Able to complete task independently without prompting

Robotic control

1	2	3	4	5
Consistently does not optimize view, hand position, or repeated collisions even with guidance		View is sometimes not optimal. Occasionally needs to relocate arms. Occasional collisions and obstruction of assistant.		Controls camera and hand position optimally and independently. Minimal collisions or obstruction of assistant

Case Difficulty

1	2	3	4	5
Ideal anatomy		Moderate difficulty		Very challenging, unusual anatomy

Total score: __________

Fig. 2 Study design.

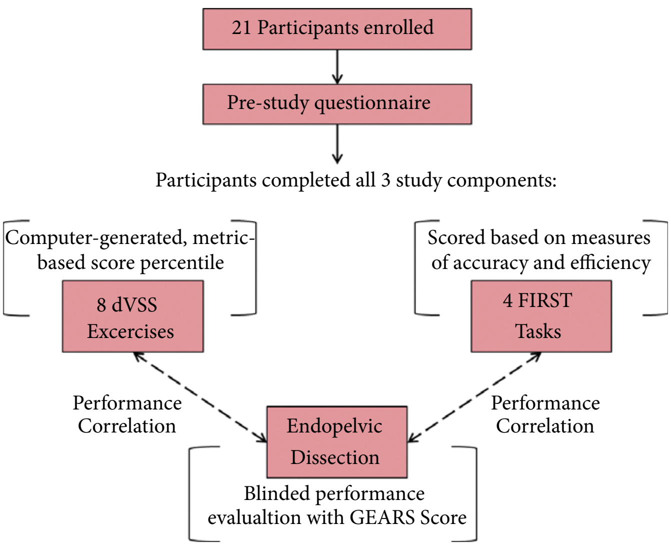


Table 1 Participant demographics.

	All	Trainees	Experts
n	21	17	4
Age*, years	29 (26–48)	29 (26–34)	37 (33–48)
Female, %	2 (10)	2 (12)	0
Classification, %			
Residents	17 (81)	17 (100)	0
Fellows	0	0	1 (25)
In practice	0	0	3 (75)
MIS fellowship*	2 (10)	0	2 (50)
Robotic experience			
Case number (range)			
Surgeon*	2 (0–600)	0 (0–55)	117 (58–600)
Assistant	6 (0–84)	4 (0–84)	14.5 (0–30)
Self-rated skill level†	1 (1–5)	1 (1–4)	4.5 (3–5)
Previous robotic course*	2 (10)	0	2 (50)
Simulator experience, h	0 (0–50)	0 (0–5)	1 (0–50)
Laparoscopic experience			
Case number			
Surgeon*	6 (0–100)	2 (0–41)	81 (43–100)
Assistant*	7 (0–50)	5 (0–33)	28 (20–50)
Self-rated skill level†	1 (1–4)	1 (1–4)	4 (3–4)
Previous laparoscopic course*	2 (10)	0 (0)	2 (50)

*Data are presented as median (range) or counts (percent). *P <0.05 between groups; †Scale of 1–5, with 5 being expert.*

(R Foundation for Statistical Computing, Vienna, Austria) with a P value <0.05 on two-tailed analysis taken to indicate statistical significance.

Results

The demographics of the 21 surgeons are shown in Table 1. The trainee group comprised postgraduate year (PGY)-1 (n = 4), PGY-2 (n = 4), PGY-3 (n = 4), PGY-4 (n = 3) and PGY-5 (n = 2) residents, median (range) age 29 (26–33) years, with a median of 0 (0–55) robotic cases as surgeon. The expert group comprised three attending physicians and a minimally invasive fellow, median (range) age 37 (33–48) years, with a median of 117 (58–600) robotic cases as primary surgeon. Two participants (both experts) had previously completed laparoscopic and/or robotic courses.

Scatterplots correlating simulator performance to clinical GEARS performance score are shown in Fig. 3, with corresponding Spearman's rho and P values. Inanimate and virtual reality simulated robotic performance was strongly positive correlated to robotic clinical performance (ρ = 0.833, P < 0.001 and ρ = 0.805, P < 0.001, respectively). Correlation coefficients for each simulated task to intra-operative performance are shown in Table 2. All inanimate tasks scores strongly correlated with clinical performance; the horizontal mattress exercise showed the strongest relationship (ρ = 0.854, P < 0.001). Similarly, the majority of virtual reality exercises also correlated positively with clinical performance; the strongest of which was Suture Sponge 3 (ρ = 0.784, P < 0.001). One exercise (Energy Switching) did not show a significant correlation to clinical performance (ρ = 0.412, P = 0.063). Both blinded and non-blinded trainee GEARS scores showed statistically significant inter-observer reliability (ρ = 0.775, P <0.001).

Correlation of Simulator Scores to GEARS Domains

Correlation of individual simulator task scores to each GEARS domain is shown in Fig. 4. Overall, scores for individual virtual reality and inanimate tasks were most strongly correlated with the domain of autonomy for nine of 13 exercises. The remaining domains were correlated to identify potential areas for focused skills training.

For inanimate exercises, the suture and knot-tying tasks (Horizontal Mattress and Circular Needle Target) were found to correlate strongest with bimanual dexterity (ρ = 0.842, P < 0.001 and ρ = 0.792, P < 0.001, respectively), the dissection exercise (Clover Pattern Cut) correlated most strongly with depth perception (ρ = 0.628, P = 0.002), and the placement task (3-D Dome and Peg) with robotic control (ρ = 0.661, P = 0.001).

For virtual reality exercises, suturing exercises (Suture Sponge 3 and Tubes) similarly correlated best with bimanual dexterity (ρ = 0.763, P < 0.001 and ρ = 0.716, P = 0.001, respectively). Pick and Placement exercises (Peg Board 1, Peg Board 2 and Match Board 3) correlated closely with depth perception (ρ = 0.810, P < 0.001; ρ = 0.675, P = 0.003; ρ = 0.675, P = 0.003, respectively). For exercises requiring movement of objects in space, Ring and Rail 2 correlated strongest with bimanual dexterity (ρ = 0.721, P < 0.001) and Ring Walk 3 correlated best with depth perception (ρ = 0.704, P = 0.002). The energy utilization exercise (Energy Switcher 1) only weakly correlated with Autonomy

Fig. 3 Correlation of simulator performance (fundamental inanimate robotic skills tasks [FIRST]; dVSS, da Vinci Skills Simulator [dVSS]) to clinical performance (Global Evaluative Assessment of Robotic Skills [GEARS]) for each participant with line of best fit and Spearman's rank correlation. Participant postgraduate year level is marked within each data point (E denotes expert).

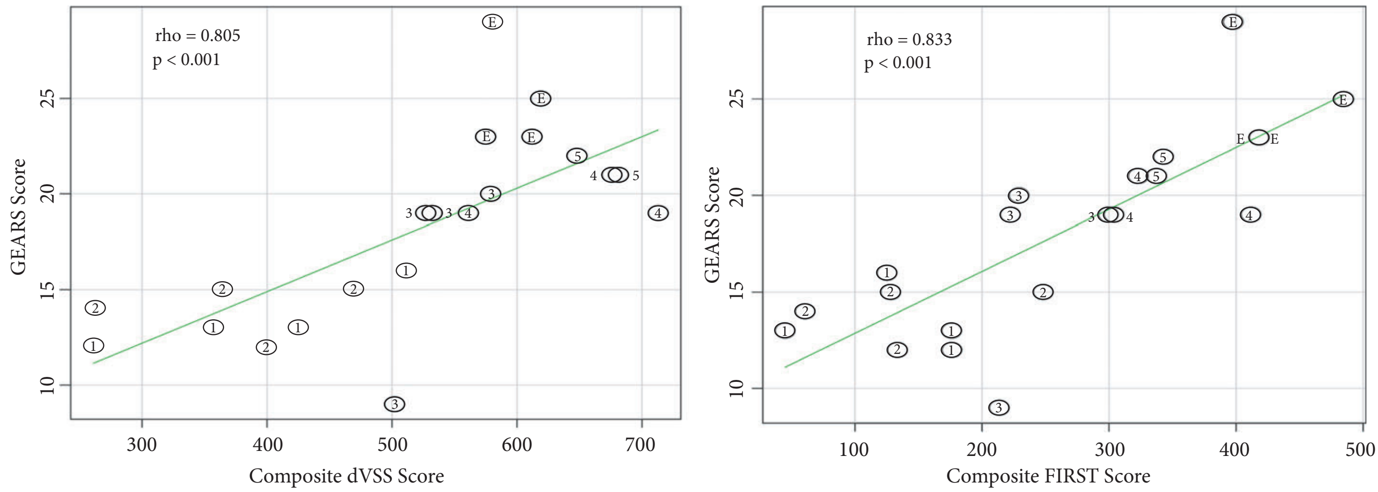


Table 2 Correlation between performance on individual virtual reality and inanimate tasks to Global Evaluative Assessment of Robotic Skills (GEARS) clinical performance scores.

dVSS Tasks	ρ	P
Peg Board 1	0.628	0.002
Peg Board 2	0.645	0.002
Ring and Rail 2	0.620	0.003
Ring Walk 3	0.727	<0.001
Match Board 3	0.674	<0.001
Suture Sponge 3	0.784	<0.001
Tubes	0.582	0.006
Energy Switcher	0.412	0.063
FIRST	**ρ**	**P**
Horizontal Mattress	0.854	<0.001
Clover Pattern Cut	0.696	<0.001
3-D Dome and Peg	0.747	<0.001
Circular Needle Target	0.701	<0.001

dVSS, da Vinci Skills Simulator; FIRST, fundamental inanimate robotic skills tasks.

($\rho = 0.484$, $P = 0.049$), but did not show a significant correlation overall.

Discussion

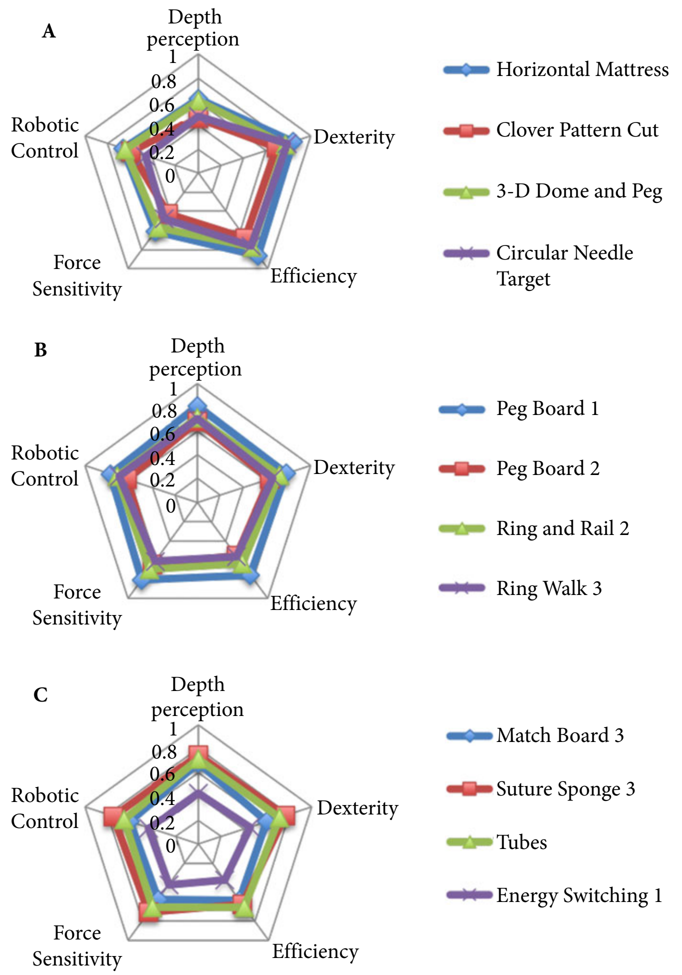
Nearly 15 years after the adoption of robotic surgery, the robotic training landscape contains numerous training platforms that have undergone validation testing. As it currently stands, we know that the available robotic training tools are realistic, are perceived as useful training tools by expert surgeons and can distinguish between users of varying skill levels and also that performance scores on a given simulation platform correlate to performance on a separate simulation platform and training on one simulation platform can yield improvements on another simulated platform.

Despite numerous validation studies of robotic training tasks, a standardized training and/or credentialing process has yet to be widely adopted. The lack of standardized robotic training can be attributed to a fundamental gap in the validity of these training tools: a lack of definitive evidence of a significant relationship between simulator performance and robotic clinical surgical performance, concurrent (concurrent validity) or future (predictive validity). The present study is the first study to show a positive association between robotic simulation-based performance and clinical performance during robotic surgery in two different training environments.

To date, the majority of robotic simulation studies have compared simulation performance to performance outside the operating room (inanimate or animate models) [1,5,9,14–16]. To our knowledge, there is only one previous study (abstract only) comparing virtual reality performance (dVSS) with bladder mobilization during RARP, where the authors were unable to show a significant correlation [17]. The study had several limitations. All participants in the study were relatively experienced with robotic surgery: 78% of participants had previous simulator experience and the median (range) number of previous robotic cases completed was 40 (20–200). The lack of a range of robotic experience in the cohort and significant prior simulation exposure may have confounded the findings.

In contrast to robotics, the laparoscopic training literature features multiple studies that have shown the relationship between training tasks and clinical performance. Once the positive relationship between training task and intra-operative performance during laparoscopic cholecystectomy was proven [18], subsequent studies were able to show measurable improvements in intra-operative laparoscopic performance

Fig. 4 Correlation (Spearman's rho) between inanimate (**A**) and virtual reality (**B, C**) exercises to each Global Evaluative Assessment of Robotic Skills (GEARS) domain (excluding autonomy).



after structured training interventions [19–22]. This critical, demonstrable relationship between simulator performance and intra-operative clinical performance was crucial in demonstrating the true value of laparoscopic simulator models and supported their subsequent widespread endorsement and adoption. Likewise, in order to prove the value of simulation in robotics, similar studies are required. The present study takes the pivotal first step of demonstrating concurrent validity of simulator tasks and likewise sets the stage for evaluating the effectiveness of robotic simulation-based training (predictive validity).

We show a stronger association between inanimate skills performance and robotic clinical performance compared with virtual reality tasks. These findings are similar to our previous work which showed that FIRST exercises were more strongly correlated ($\rho = 0.8$) to performance on an *in vivo* porcine task than four selected dVSS virtual reality tasks ($\rho = 0.6$) [5]. The data continue to show the limitations remaining in virtual reality robotic simulation and highlight the utility of multiple training environments.

With respect to the performance of GEARS, consistent with previous results [12], the GEARS clinical assessment tool showed high consistency between raters, with excellent inter-observer reliability (0.78, 95% CI 0.42–0.94).

To identify areas for feedback and targeted training, we compared simulation task performance with individual GEARS domains. In both inanimate and virtual environments, suturing/needle-driving exercises were strongly related to domains of dexterity and efficiency. Placement exercises in virtual reality were associated best with depth perception, while the inanimate Dome and Peg task correlated best with efficiency. Exercises requiring movement of objects through space correlated best with dexterity and depth perception. The energy usage exercise did not reach statistical significance for any of the domains and appears to have limited training utility. These findings can be used to drive curricular training and development. For example, weaknesses identified in specific domains can be focused on simulation tasks that have the strongest associations with those technical skills.

Several limitations to this study are worth mentioning. These include the homogenous study population consisting of only urological surgeons. Future studies will need to evaluate the reproducibility of our results within the context of other surgical specialties. Also, intra-operative clinical performance was assessed solely on a basic portion of the overall RARP procedure (the endo-pelvic dissection). Although this task is a relatively simple portion of the operation, it encompasses a range of basic robotic skills, including targeting, sharp and blunt dissection, energy usage, bimanual dexterity, robotic manipulation and autonomy. Admittedly, this task does not represent the complexity of the entire operation; however, this portion of the procedure was a carefully considered part of our study design. When examining the methodology of FLS validation studies [18], dissection of the gallbladder from the liver bed, a similar basic task, was chosen in order to capture a cohort of trainees with a wide range of laparoscopic experience and to support the ability to demonstrate robust concurrent validity. Thus, for the present study, a portion of the overall procedure that was sufficiently complex and could be performed safely by trainees with a broad range of robotic experience, such as the endo-pelvic dissection was selected as our intra-operative clinical correlate. Additionally, the strong correlation we observed between clinical and simulation performance with increasing experience would support that the endo-pelvic dissection task was not oversimplified and maintained construct validity. Further investigation will be needed to determine if performance during simulation correlates with more complex portions of the procedure and even complete operations. Determination of optimum timing of robotic training and assessment remains to be investigated; however, we feel that this will continue to occur earlier in resident training. Finally, this study focused on the relationship between simulation and intra-operative robotic technical skills performance. Whether better simulation-based performance translates to better clinical outcomes remains to be evaluated.

The findings of the present study provide the basis for robotic simulation as a platform for robotic skills assessment and training. We are currently assessing the impact of a standardized training curriculum on clinical robotic surgical performance.

In conclusion, we show a significant positive association between performance on inanimate and virtual reality training tasks and intra-operative robotic performance. Validated simulated training tasks are used for evaluation and training. Further investigation is needed to understand the effect of training to proficiency on robotic skills acquisition.

Conflict of Interest

None declared.

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Abbreviations: FIRST, fundamental inanimate robotic skills tasks; dVSS, da Vinci Skills Simulator; GEARS, Global Evaluative Assessment of Robotic Skills; RARP, robot-assisted radical prostatectomy; FLS, Fundamentals of Laparoscopic Surgery; PGY, postgraduate year.