The Influence of 3D in Single-port Laparoscopy Surgery: An Experimental Study

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Abstract: The aim of this experimental study was to analyze the effect of 3-dimensional (3D) imaging in laparoendoscopic single-site surgery. End points were time, errors, and preference. Twenty-six participants were enrolled in the study, and these were divided into Beginners and Experts, in exercises either with a 2-dimensional or a 3D system. The 4 phantom exercises were chosen from the E-BLUS—European Training in Basic Laparoscopic Urological Skills from the American Fundamentals of Laparoscopic Surgery (FLS) system. A postexercise questionnaire was delivered. Statistical analyses using SPSS 22.0 for Windows yielded a 1-way analysis of variance. There was a significant positive impact of 3D imaging on experts' performance: faster exercise completion with fewer errors. The majority reported improved performance with the 3D system (86%, Beginners; 100%, Experts). 3D systems for laparoscopy would likely increase experts' performance for laparoendoscopic single-site surgery and improve comfort during difficult procedures.

Key Words: LESS, SILS, 3D, 2D, laparoscopy, performance

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Since the appearance of laparoscopy, the viewpoint needed to perform surgery is not dependent on the surgeon's eyes only. In fact, video equipment has determinant of the result even if the surgeon has got a highly developed skills set.

The standard imaging for laparoscopy has been 2-dimensional (2D), resulting in lack of depth perception. This limitation has been offset by several means such as parallax movements and image recall. However, misperception is a common cause for injury. Learning curves are long, and even experts in laparoscopy experience fatigue and difficulty in prolonged and delicate procedures.[1]

Efforts to create 3-dimensional (3D) laparoscopes began in the early 1990s. This first-generation equipment did not overcome the 2D counterpart, because images were of lower definition, light was poorer, costs were higher, and side effects were limiting. More recently, new proposals of 3D systems have arrived, providing better images, lower costs, and added comfort.[2,3]

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Several publications in the past years comparing these 2 different technologies have given new strength to this old question of laparoscopic surgery. In fact, there have been studies showing some advantages associated with 3D systems: a shorter learning curve, faster and more accurate movements, surgeons' preference, and reported greater convenience. It seems, nowadays, that 3D technology will likely have more impact on novices, shortening their learning curves, and on experts, raising their accuracy and performance for complex procedures.[4–9]

Another issue that dragged new proposals forward was the aim of lesser invasiveness in laparoscopy. Approaches like minilaparoscopy, laparoendoscopic single-site surgery (LESS), and natural orifice transendoscopic surgery, increased technical demand. When performing LESS interventions, instruments move in a tight space. Conflict of these tools arise as a consequence.

Therefore, we hypothesize that 3D technology could enhance depth perception, and the performance of LESS surgery could be improved when fixing the scope at a set distance.

To our knowledge, there are no studies comparing 3D and 2D systems in the context of LESS surgery, making this the first study aiming toward this proposal.

MATERIALS AND METHODS

These experiments were conducted at the Life and Health Sciences Research Institute (ICVS), School of Health Sciences, University of Minho, Braga, Portugal. Professionals with varying levels of experience in laparoscopic surgery agreed to participate.

Population of the Study

Twenty-six subjects participated in the study. A pre-experiment inquiry included data from the participants, such as age, sex, use of eyeglasses, dominant hand, number of previous laparoscopic surgeries performed as a surgeon, and previous experience in LESS and in laparoscopy with 3D systems. This allowed a division of the subjects into 2 groups according to their experience in laparoscopic surgery: A, <50 procedures performed; B, > 50 procedures performed. Group A was called the novice group (14 subjects) and group B was called the expert group (12 subjects).

Of 14 novice participants, only 4 had performed > 10 laparoscopic surgeries. None had previous experience, whether in LESS or with 3D systems. Half of the experts had previous experience in LESS, and 3 had performed laparoscopic surgery with a 3D imaging system. Forty-six percent of all participants wear eyeglasses.

Laparoscopic Tasks

Four phantom exercises were chosen from the E-BLUS—European Training in Basic Laparoscopic Urological Skills, which is derived from the Fundamentals of Laparoscopic Surgery American system:

(1) Peg transfer: grasping 6 rubber rings, one at a time, transferring them from 1 side of the board to the other. While transferring the rings, subjects change the rings from 1 grasper to the other. After moving all 6 rings from the left side to the right, subjects repeat the procedure from the right side to the left. An error is recorded in the data each time the ring is either dropped or when it is not exchanged from 1 grasper to the other.

(2) Cutting a circle: using scissors to cut a circle in a piece of gauze between 2 concentrically drawn circles. An error is recorded in the data whenever participants cut through either of the drawn lines.

(3) Clip and cut: isolating each rubber strip that represents a blood vessel and then putting a rubber tie around them as a reference. Clipping must be performed at 2 points in each of the strips, followed by cutting in the middle of the clips. Errors were recorded because of the following: (i) if a rubber band was detached while isolating it, (ii) if a clip was not placed completely across the vessel, and (iii) if the cut was not made between the clips.

(4) Needle guidance (also called "rings"): guiding a needle through a circuit of 10 metal rings attached to a sponge board. Whenever the needle was dropped or 1 ring was by-passed, an error was recorded.

Materials Used to Perform Laparoscopic Tasks

Exercises were carried out within a trainer box with an SILS Port (Covidiem, Medtronic). One 10 mm 0 degree laparoscope was fixed 11 cm from the end to the surface of the SILS Port. Exercises were carried out using 3 mm instruments from Karl-Storz and a Ligamax Clip Applier (J&J Ethicon).

Two separate Karl-Storz working stations were used. 2D laparoscopy used the latest generation equipment with a HD flat screen video monitor. 3D laparoscopy was conducted in a darkened room with the system attached to a 32″ monitor. Participants wore light-polarized glasses while working with the 3D system.

Participants' Distribution

Subjects were randomly distributed to start the 4-exercise sequence, either with a 3D or 2D system.

For sample size determination, we have considered the interaction between the exercise (peg transfer, cutting a circle, clip and cut, and needle guidance) and video (2D and 3D). A total sample size of 24 required surgeries was calculated on the basis of a medium effect size ($f=0.25$), a type I error of 0.05, and a power (1-β) of 0.80.

Questionnaires

Participants completed 2 separate inquiries: pre-experiment and postexperiment. The pre-experiment is described in the topic "Population of the study"; the postexperiment form was a preference questionnaire comparing 2D versus 3D in accordance with the following topics: preferred system, preferred exercise with 3D, and reported specific advantage of the 3D system.

TABLE 1. Time in 2D Versus 3D Monitors

Descriptive—Time

Group	Exercise	Monitor	Mean	SD	N
E	Circle	2D	341.8	154.172	12
		3D	257.3	69.636	12
	Clip and cut	2D	470.5	207.357	12
		3D	362.4	84.604	12
	Peg transfer	2D	276.3	128.366	12
		3D	221.5	52.152	12
	Rings	2D	582.6	29.557	12
		3D	554.8	111.075	12
N	Circle	2D	266.6	57.872	14
		3D	240.8	85.309	14
	Clip and cut	2D	400.1	142.592	14
		3D	404.1	145.700	14
	Peg transfer	2D	196.6	64.831	14
		3D	191.2	93.729	14
	Rings	2D	600.0	0.000	14
		3D	598.4	6.250	14

Expert group average times for execution of the 4 different exercises were inferior with 3D monitor, regardless of the monitor sequence. Novice group average times were inferior with 3D monitor in all except 1 exercise, "clip and cut."

2D indicates 2-dimensional; 3D, 3-dimensional.

Statistical Analysis

Statistical analysis was performed using the Statistical Package for Social Sciences (SPSS) 22.0 for Windows. A P-value of <0.05 was considered as the threshold for statistical significance.

Comparison between 2D and 3D LESS surgery included performance ratio, measured in time and errors, as well as participants' preference. The former factors were studied using a one-way analysis of variance (ANOVA) while the latter related to preference used the answers of the postexperiment inquiry described as a percentage.

TABLE 2. Errors in 2D Versus 3D Monitors

Descriptive—Error

Group	Exercise	Monitor	Mean	SD	N
E	Circle	2D	0.700	0.949	12
		3D	0.000	0.000	12
	Clip and cut	2D	0.500	0.707	12
		3D	0.000	0.000	12
	Peg transfer	2D	0.500	1.080	12
		3D	0.400	0.699	12
	Rings	2D	3.000	2.000	12
		3D	2.500	2.415	12
N	Circle	2D	1.438	1.263	14
		3D	0.750	1.342	14
	Clip and cut	2D	0.375	0.719	14
		3D	0.063	0.250	14
	Peg transfer	2D	0.625	1.088	14
		3D	0.938	1.063	14
	Rings	2D	4.813	4.385	14
		3D	6.813	3.953	14

For the expert group, fewer errors were committed whenever using the 3D monitor in each exercise. The novice group performed better with the 3D monitor in "clip and cut" and "cutting circle" exercises. In this group, average errors were more frequent with 3D in "peg transfer" and "needle guidance" exercises.

2D indicates 2-dimensional; 3D, 3-dimensional.

TABLE 3. Differences Between Group and Monitor Variables

ANOVA—Time

Cases	Sum of Squares	*df*	Mean Square	*F*	*P*	η^2 *P*
Group	22,071	1	22,071	2.141	0.145	0.011
Exercise	3.844e +6	3	1.281e +6	124.330	< 0.001	0.660
Monitor	71,095	1	71,095	6.898	0.009	0.035
Group×exercise	55,015	3	18,338	1.779	0.152	0.027
Group×monitor	46,698	1	46,698	4.531	0.035	0.023
Exercise×monitor	13,509	3	4503	0.437	0.727	0.007
Group×exercise×monitor	12,182	3	4061	0.394	0.757	0.006
Residual	1.979e +6	192	10,307			

A significant difference between group and monitor variables was observed as well as between exercise and monitor.
Type III sum of squares.

RESULTS

Descriptive Statistics

Table 1 summarizes descriptive statistic results on the basis of time. The expert group achieved shorter execution times for all tasks when using the 3D system. The novice group had similar results in 3 of the 4 exercises; only in "clip and cut" did they achieve a shorter time, performing the exercise with the 2D system (400.1 vs. 404.1).

Table 2 summarizes descriptive statistic results for errors. In all exercises, a better result was achieved when using the 3D system for the expert group. The novice group had lower error with 3D system in "circle" (0.750 vs. 1.438) and "clip and cut" (0.063 vs. 0.375), whereas in "peg transfer" (0.625 vs. 0.938) and "needle guidance" (4.813 vs. 6.813) the best results occurred using the 2D system.

1-Way ANOVA

Table 3 summarizes the results of the 1-way ANOVA for the variable *time*. A significant effect of exercise and monitor was found on average time ($P < 0.05$). Average time was significantly different between group/monitor ($P < 0.05$) as well.

Figure 1 shows timelines and the relationship between monitor and group. There was a large difference between novice and expert groups in regard to time required for executing the laparoscopic tasks according to the type of the monitor: less time was required when the 3D monitor was used by the expert group; the novice group did not demonstrate a significant reduction in time when using 3D; in fact, the time taken was very similar with both types of monitors.

Figure 2 shows timelines and the relationship between monitor, group, and exercise. The expert group showed a decrease in execution time for all laparoscopic tasks when the 3D monitor was used; the most dramatic reduction was recorded for "clip and cut." In contrast, the novice group only showed a slight decrease in time with 3D for the "cutting a circle" task.

In Table 4 the error variable results are included using the 1-way ANOVA. A significant effect of group and exercise on the mean error ($P < 0.05$) was reported. The mean error was significantly different between group/exercise ($P < 0.05$) also. The statistically significant effect found in the mean error by group is shown in Figure 3 (the error is lower in the expert group).

Figure 4 shows error lines and the relationship between monitor, group, and exercise. In the expert group, the mean error markedly decreases in the tasks "cutting a circle" and "clip and cut" when a 3D monitor was used; a smaller decrease is observed for the other tasks ("peg transfer" and "needle guidance"). In the novice group 2 completely opposing situations occurred: error reduction in the tasks "cutting a circle" and "clip and cut" with a 3D monitor, as was the case in the expert group; in contrast, there was an increase in the error for 3D monitor in "peg transfer" and "needle guidance."

Preference—Questionnaire

Results of the participant preference postexercise inquiry are presented in Table 5. When compared with 2D vision, one third of experts rated working with 3D equipment as much easier; two thirds found it easier. None of the experts reported 3D to be similar or worse than the 2D counterpart. Novices' opinions were not as favorable in regard to 3D, despite being positive: none found it to be much easier, 12 reported it easier, 1 similar, and 1 reported it more difficult to work with the new technology.

With regard to the technical advantage per exercise, results were quite similar; however, more exercises were found to benefit from the use of 3D vision, in the case of experts. The exercises that benefited most from 3D vision were those with wider depth movements like "cutting a circle" and "needle guidance" (also called "rings").

Finally, the greatest advantage of 3D features reported by participants was "depth perception" for both groups.

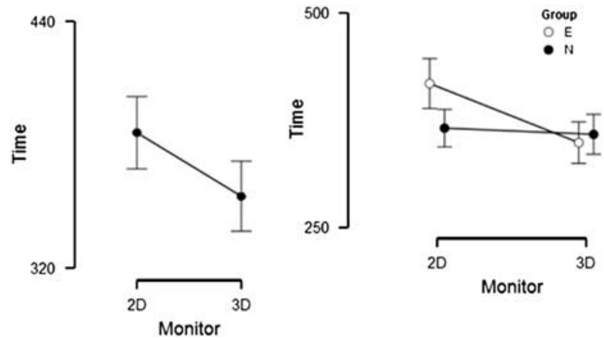

FIGURE 1. Monitor effect on average time. These graphics confirm descriptive and ANOVA statistical analysis. ANOVA indicates analysis of variance; E, expert group; N, novice group.

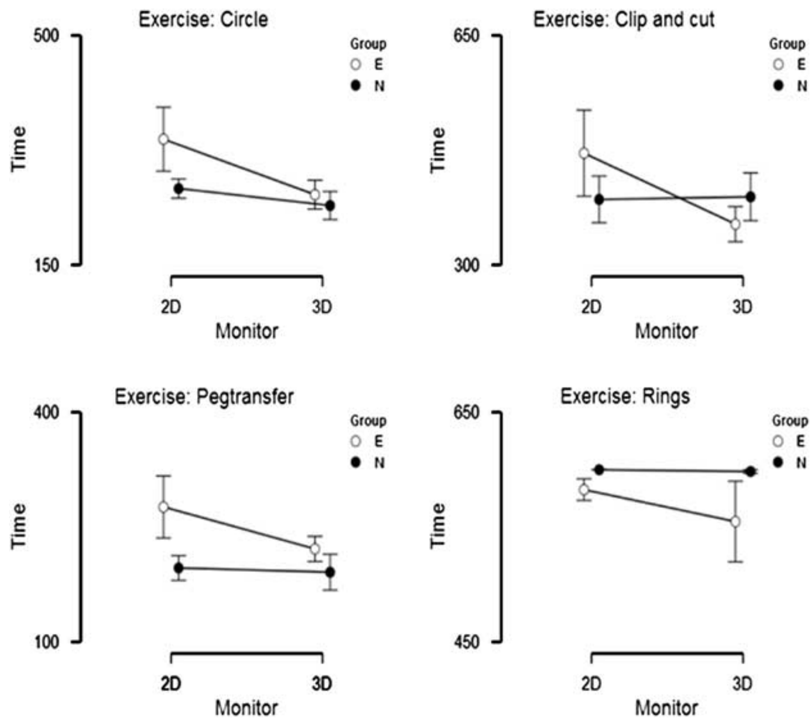

FIGURE 2. Monitor effect on average time per group and exercise. A much more relevant reduction on the average time was recorded in the expert group in each of the 4 exercises. The novice group only demonstrated significantly faster performance in the "circle" exercise. In this group, the "rings" exercise yielded slower performance with 3D technology. 3D indicates 3-dimensional; E, expert group; N, novice group.

DISCUSSION

The authors present an experimental study with validated phantom exercises to identify advantages and preferences in regard to the use of new generation 3D system versus standard 2D HD equipment in the context of LESS surgery. A group of 26 participants was included in the study.

This series reveals that 3D technology for LESS surgery has a better positive impact in terms of time and errors for expert surgeons rather than for novices. A direct relationship with subjective postexperience inquiry results was also observed. Experts felt more comfortable with 3D technology, particularly when performing exercises involving wider depth movements.

Less straightforward results for the novice group were observed in this series, better and worse results mixed together, presenting no apparent pattern. It can be postulated that high-expertise demand techniques like LESS surgery would downplay and obscure possible 3D image performance improvement.

Nevertheless, novices reported feeling better with 3D imaging: 86% reported easier performance with this technology. Both groups revealed the same sensibility for the possible advantages of 3D imaging: enhanced depth perception (58% for novices vs. 53% for experts), better spatial orientation (35% for novices vs. 31% for experts), and 2-handed maneuvre (7% for novices vs. 16% for experts).

TABLE 4. Error Between Group and Exercise

ANOVA—Error

Cases	Sum of Squares	*df*	Mean Square	*F*	*P*	η^2 *P*
Group	51.881	1	51.881	13.586	< 0.001	0.066
Exercise	527.722	3	175.907	46.065	< 0.001	0.419
Monitor	0.183	1	0.183	0.048	0.827	0.000
Group×exercise	71.722	3	23.907	6.261	< 0.001	0.089
Group×monitor	7.452	1	7.452	1.951	0.164	0.010
Exercise×monitor	14.834	3	4.945	1.295	0.277	0.020
Group×exercise×monitor	12.411	3	4.137	1.083	0.357	0.017
Residual	733.188	192	3.819			

Error analysis revealed a statistically significant difference between group and exercise. There was also a significant difference according to group and exercise.

Type III sum of squares.

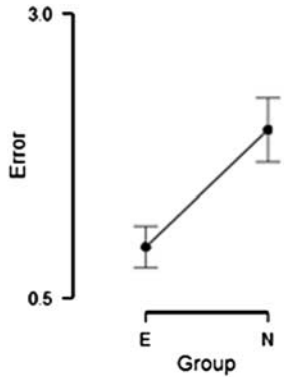

FIGURE 3. ANOVA result for the entire group of participants. ANOVA indicates analysis of variance; E, expert group; N, novice group.

The use of a fixed-distance laparoscope may well also provide further advantages in performance and participant comfort with 3D technology. The sense of depth with 2D imaging worsens as the distance of the scope to the surgical field increases. Only a very active engagement with constant forward and backward motion of the scope can offset the lack of depth perception.

The fixed distance of the laparoscope can enlarge the space of work while allowing for less conflict between instruments. It can also improve image stability and reduce collision between the surgeon and his assistant. In specific situations such as transanal procedures, it is very difficult to assist in a surgeon's performance, because the space between the legs is limited to 2 people.

The Storz study with new generation 3D systems suggested better performance for experts in the context of complex and difficult surgeries.[8] Besides that, the proof that 3D imaging is more comfortable for prolonged procedures than 2D standard imaging will probably be related to better outcomes.

LESS surgery has been gaining renewed interest in the last years, in part because of the adaptation of these approaches to transanal surgery.[10,11] With recent advances in rectal oncology, more conservative and natural orifice transendoscopic surgery techniques tend to increase the use of the transanal route.[11] An enhanced imaging technology that improves depth perception would be of utmost importance in a narrow space.[12] In fact, such a conclusion has already been widely reported in terms of the advantages of 3D robotics view for lower rectal surgery.[13]

Another field of expanding indications for LESS is thoracic surgery. Here, improved image quality can be of paramount importance for tasks such as "clip and cut."[14] In this series, this particular exercise showed better performance not only for experts but also for novices (less errors).

This study reveals several limitations: sample size, homogeneity of groups, and the monitoring of side effects. An increased number of participants would clarify 3D imaging impact on novice performance. The introduction of participants with intermediate experience in the novice group jeopardizes the results of this category even more. Conversely, experts with previous LESS surgery experience probably would be better included in a super-expert group. Finally, the record of side effects would be of interest, despite the subjective preference questionnaire. Undesirable effects such as numbness and headaches were frequently reported with first-generation 3D laparoscopic equipment.

We conclude that 3D systems for laparoscopy would likely increase experts' performance for LESS procedures. Larger experimental and clinical studies are needed to validate this advantage definitively.

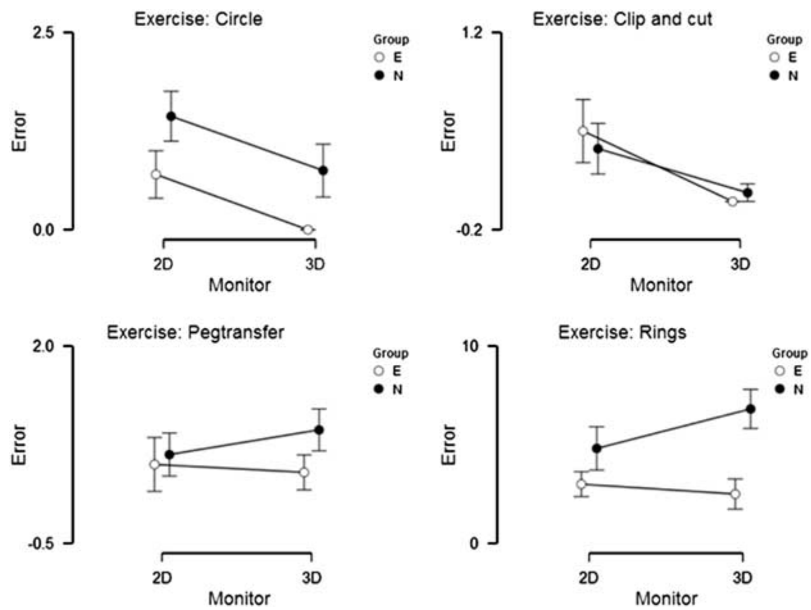

FIGURE 4. ANOVA results for 3 variables: exercise, monitor, and group. Both experts and novices demonstrate a significant reduction in errors while using 3D imaging for "clip and cut" and "cutting circle" exercises. For the expert group, better performance was observed for the "peg transfer" and "needle guidance" also. For these 2 exercises, novices performed better in this series. ANOVA indicates analysis of variance; 3D, 3-dimensional; E, expert group; N, novice group.

TABLE 5. Postexercise Inquiry

A. Overall, Compared With 2D Vision, You Feel the 3D Vision is			B. If You Feel That 3D Vision Provides a Significant Advantage in Any Task, Please Mark Them (%)			C. What is (are) the Most Important Advantage(s) of 3D Vision? (%)		
	Novice	Expert		Novice	Expert		Novice	Expert
Much easier	—	4	Peg transfer	43	56	Depth perception	58	53
Easier	12	8	Cutting circle	71	67	2-handed maneuvre	7	16
Similar	1	—	Clip and cut	28	44	Spatial orientation	35	31
More difficult	1	—	Needle guidance	50	78			
Much more difficult	—	—						

Question A—results per number of participants. Better impression among experts. Questions B and C—percentage results. Each question can comprise > 1 answer. Very similar results in terms of advantage distribution per exercise and enhanced feature.

2D indicates 2-dimensional; 3D, 3-dimensional.

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REFERENCES

1. Way LW, Stewart L, Gantert W, et al. Causes and prevention of laparoscopic bile duct injuries: analysis of 252 cases from a human factors and cognitive psychology perspective. *Ann Surg*. 2003;237:460–469.
2. Izquierdo L, Peri L, Garcia-Cruz E, et al. 3D advances in laparoscopic vision. *Eur Urol Rev*. 2012;7:137–139.
3. Ohuchida K. New advances in three-dimensional endoscopic surgery. *J Gastrointest Dig Syst*. 2013;3:1–3.
4. Romero-Loera S, Cárdenas-Lailson LE, de la Concha-Bermejillo F, et al. Skills comparison using a 2D vs. 3D laparoscopic simulator. *Cir Cir*. 2016;84:37–44.
5. Cicione A, Autorino R, Breda A, et al. Three-dimensional vs standard laparoscopy: comparative assessment using a validated program for laparoscopic urologic skills. *Urology*. 2013;82:1444–1450.
6. Bilgen K, Ustün M, Karakahya M, et al. Comparison of 3D imaging and 2D imaging for performance time of laparoscopic cholecystectomy. *Surg Laparosc Endosc Percutan Tech*. 2013;23:180–183.
7. Honeck P, Wendt-Nordahl G, Rassweiler J, et al. Three-dimensional laparoscopic imaging improves surgical performance on standardized *ex-vivo* laparoscopic tasks. *J Endourol*. 2012;26:1085–1088.
8. Storz P, Buess GF, Kunert W, et al. 3D HD versus 2D HD: surgical task efficiency in standardised phantom tasks. *Surg Endosc*. 2012;26:1454–1460.
9. Tanagho YS, Andriole GL, Paradis AG, et al. 2D versus 3D visualization: impact on laparoscopic proficiency using the fundamentals of laparoscopic surgery skill set. *J Laparoendosc Adv Surg Tech A*. 2012;22:865–870.
10. Young DO, Kumar AS. Local excision of rectal cancer. *Surg Clin North Am*. 2017;97:573–585.
11. Veereman G, Vlayen J, Robays J, et al. Systematic review and meta-analysis of local resection or transanal endoscopic microsurgery versus radical resection in stage I rectal cancer: a real standard? *Crit Rev Oncol Hematol*. 2017;114:43–52.
12. Di Marco AN, Jeyakumar J, Pratt PJ, et al. Evaluating a novel 3D stereoscopic visual display for transanal endoscopic surgery: a randomized controlled crossover study. *Ann Surg*. 2016;263:36–42.
13. Byrn JC, Schluender S, Divino CM, et al. Three-dimensional imaging improves surgical performance for both novice and experienced operators using the da Vinci Robot System. *Am J Surg*. 2007;193:519–522.
14. Sandri A, Sihoe ADL, Salati M, et al. Training in uniportal video-assisted thoracic surgery. *Thorac Surg Clin*. 2017;27:417–423.