Surgical Innovation
1–7

DOI: 10.1177/1553350617728160
journals.sagepub.com/home/sri
SAGE

Comparative Study of 2D and 3D Optical Imaging Systems: Laparoendoscopic Single-Site Surgery in an Ex Vivo Model

Jaime Vilaça, MD[1,3,*], José Pedro Pinto, MD, MSc[2,*], Sandra Fernandes, MD, MSc[3], Patrício Costa, PhD[3,4], Jorge Correia Pinto, MD, PhD[3,4], and Pedro Leão, MD, PhD, FACS[2,3,4]

Abstract

Background. Usually laparoscopy is performed by means of a 2-dimensional (2D) image system and multiport approach. To overcome the lack of depth perception, new 3-dimensional (3D) systems are arising with the added advantage of providing stereoscopic vision. To further reduce surgery-related trauma, there are new minimally invasive surgical techniques being developed, such as LESS (laparoendoscopic single-site) surgery. The aim of this study was to compare 2D and 3D laparoscopic systems in LESS surgical procedures. *Materials and Methods*. All participants were selected from different levels of experience in laparoscopic surgery—10 novices, 7 intermediates, and 10 experts were included. None of the participants had had previous experience in LESS surgery. Participants were chosen randomly to begin their experience with either the 2D or 3D laparoscopic system. The exercise consisted of performing an ex vivo pork cholecystectomy through a SILS port with the assistance of a fixed distance laparoscope. Errors, time, and participants' preference were recorded. Statistical analysis of time and errors between groups was conducted with a Student's *t* test (using independent samples) and the Mann-Whitney test. *Results*. In all 3 groups, the average time with the 2D system was significantly reduced after having used the 3D system ($P < .05$). In the postexercise questionnaire, two thirds of participants showed a preference for using the 3D system. *Conclusion*. This study suggests that the 3D system may improve the learning curve and that learning from the 3D system is transferable to the 2D environment. Additionally, the majority of participants prefer 3D equipment.

Keywords

minimally invasive surgery, laparoscopy, LESS, 3D, single port

Introduction

Since the beginning of the 1990s, laparoscopic surgery has become the preferred approach for many abdominal procedures.[1] The development of these techniques has been increasing rapidly ever since. When compared to classical laparotomic surgery, the minimally invasive laparoscopic approach is associated with numerous advantages, due to the reduction in tissue damage.[2,3] Furthermore, it has been proven that it decreases the pain in the postoperative period, the length of hospital stay, and the time of global recovery for patients.[4-6] Nevertheless, there are some disadvantages for the surgeon, namely, limited surgical field vision, the difficult work axis forced by the most commonly used optical systems, as well as the lack of depth vision.[7]

Laparoscopy is usually performed with a 2-dimensional (2D) optical system.[7] This type of imaging system, despite being an accessible and simple technology, presents a major disadvantage. Monitors and cameras fail to transmit stereoscopic information.[8] Depth perception is very important for good performance in manual tasks.[8] The lack of depth perception in 2D systems is attenuated by the human brain's ability to compare dimensions using light and shadow, motion parallax, and visual memory.[9] Therefore, the 2D imaging system has the following limitations: a long learning curve, errors through misinterpretation, and slow movements.[10]

[1]Hospital da Arrábida, Luz Saúde, Portugal
[2]Hospital de Braga, Braga, Portugal
[3]University of Minho, Braga, Portugal
[4]ICVS/3B's—PT Government Associate Laboratory, Guimarães, Braga, Portugal
*Contributed equally to this work.

Corresponding Author:
Pedro Leão, General Surgery, Hospital of Braga, 4701-965, Braga, Apartado 2242, Portugal.
Email: pedroleao@med.uminho.pt

In the early 1990s the first prototypes of 3-dimensional (3D) systems were used in laparoscopic surgery. The main advantage was stereoscopic vision.[11] However, these rudimentary optical systems, besides providing low image quality, also originated multiple unpleasant symptoms including eyestrain, high adaptation time, and physical discomfort (headache, nausea).[11] With the technological evolution came new 3D systems allowing for the use of 2 separate optical channels and creating 2 separate images for the right and the left eye resulting in stereoscopic vision.[12] Another improvement in technology has resulted in the reduction of unpleasant symptoms and improved resolution of image quality.[8]

In addition to the technological development of imaging systems, an evolution has occurred in terms of enabling laparoscopic tools for use in even less invasive procedures.[13] LESS (laparoendoscopic single-site) surgery is performed through a single port obtained through a small incision in the skin.[13] With the decrease in the number of ports this minimally invasive technique reduces tissue trauma and improves aesthetic results.[14] However, it has limitations that relate to added difficulty of optimal instrument triangulation, contrary to what happens in classical laparoscopy with multiple ports, thus creating a space conflict.[15]

The use of 3D optical systems could improve the depth of field and keep away the optical in LESS surgery, reducing the conflict of instruments. Until the present, there has not been a 2D versus 3D comparative study conducted in LESS surgery in the literature.

The goal of our study was to compare the performance and preference of participants with different levels of expertise in classical laparoscopic surgery using the 2D versus 3D in LESS surgery.

Materials and Methods

To achieve the proposed objectives, we carried out experimental sessions in the Surgical Sciences Domain of the Institute for Research in Life Sciences and Health (ICVS), School of Medicine, University of Minho, Braga, Portugal, with surgeons, residents, and medical students who agreed to participate in the study.

Materials

Study Population. Three different groups participated in the study (n = 27): a novice group (without any experience in laparoscopic surgery), an intermediate group (from 1 to 50 laparoscopic surgeries), and an experienced group (over 50 laparoscopic surgeries performed). From the information gathered in the questionnaires of the 27 participants, 10 belonged to the novice group, another 10 belonged to the experienced group, and 7 to the intermediate group. Previous experience is related to multiport laparoscopy. None had past experience in LESS surgery.

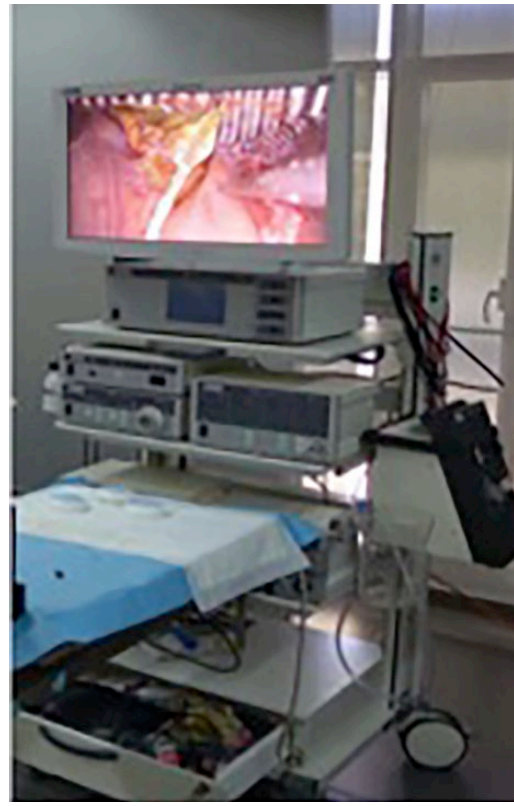

Figure 1. Two-dimensional laparoscopic simulator system.

Instruments. To perform the laparoscopic tasks, the laparoscopic instruments used by participants were 3-mm Karl Storz curved forceps, dissecting scissors, a grasper, and a 5-mm Ultracision harmonic scalpel (Ethicon, Johnson and Johnson, Somerville, NJ). A SILS port (Medtronic, Minneapolis, MN) was used as a single-port device to introduce instruments.

Imaging Systems. This study used 2 types of imaging systems: 2D and 3D, developed by Karl Storz (Tuttlingen, Germany).

The 2D imaging system (Figure 1) consists of a tower, which is connected to a high-definition video monitor, through a camera with a 10-mm lens 0°.

Regarding the 3D imaging system (Figure 2), it is composed of a 3D camera that is connected to a high-definition monitor, and the image is displayed through the use of special polarized light eyeglasses that are part of the Karl Storz equipment.

Since there is variability in the adaptation time for stereoscopic vision person to person, procedures started only after this process occurred.[16]

Figure 2. Three-dimensional laparoscopic simulator system.

Two-dimensional and 3D monitors were placed at eye level of the participants and the distance between the monitors and the eye was fixed at 175 cm, respecting the recommended distance (3 times the monitor's diagonal size). The input distance between the optics and the endo-trainer was also set at 12.4 cm.

Models. The organic model used to conduct this study was pork liver with the gallbladder and intact biliary tract, and 2 livers were available to each participant, making for a total of 54 livers used at the end of all experiments.

For abdomen simulation a Karl Storz endo-trainer was used, and a wooden support was placed inside to allow for placement of the liver in anatomical position.

The procedure conducted was a cholecystectomy in the organic model.

Methods

Randomization. Before performing any laparoscopic task, each participant performed a depth perception test. Only participants with stereoscopic vision and without strabismus were included in the study.[9] Then, each participant completed a prequestionnaire in order to be included in 1 of the 3 categories of experience/level of expertise.

All participants underwent laparoscopic warmup tasks. These exercises were preceded by reading a memorandum of the technique as well as watching a step-by-step video of the procedure. The order of working with the different imaging equipment was determined by random distribution as 3D → 2D or 2D → 3D.

The tasks were performed using the Karl Storz endo-trainer in which laparoscopic instruments were introduced through a single-port SILS (Medtronic). The 2 holders used were always placed in the same manner within the endo-trainer for all participants.

As warmup exercises, each participant performed 2 tasks: cutting between 2 circles removing the center circle using tweezers/grasper and scissors; passing objects on one side of a support to the other transferring from grasper to tweezer or vice versa, without dropping.

A minimum time of 5 minutes to perform the 2 tasks and a maximum time of 15 minutes was set. No data as to the performance of the participants in these 2 tasks were recorded, as the goal was becoming accustomed to the instruments and imaging systems. Both initial tasks were performed on each of the imaging systems (2D and 3D) before the cholecystectomy.

Performance Evaluation: Error and Time. At the end of warmup exercises, each participant was provided with a memorandum summarizing the steps of the surgical procedure to be performed in each of the imaging systems: a single-port laparoscopic cholecystectomy in liver pig model.

Each participant was allowed up to 2 times to read the memo prior to each surgery. Participants then watched a video showing the procedure. Laparoscopic cholecystectomy by single port was divided into 3 main steps: isolation of the gallbladder hilum (Step 1), ligation and transection of the cystic duct (Step 2), and resection of the gallbladder from its bed (Step 3). Detected errors that were recorded were as follows: Step 1, laceration of the cystic duct, nonisolation of the cystic duct in 360°, and perforation of the gallbladder; Step 2, cystic duct partial clamping, sealing/section more than once and dehiscence after sealing; Step 3, perforation of the bladder and perforation of the liver parenchyma. During surgery, times for each of the steps and as well as total imaging system time, in addition to errors associated with each step, were recorded. Tasks using the 3D system were performed in a room with the lights off to allow for better image display.

Evaluation of Preference. After completing the experiment, each participant answered a questionnaire regarding the imaging system. The purpose of this step was to obtain the participant's views as to the possible advantages of 3D versus 2D imaging systems and also determine their preference for the 2 imaging systems.

Table 1. Descriptive Statistics (Mean, Standard Deviation, Sample Size) for the Groups in 4-Way ANOVA (Dependent Variable: LOGTIME).

				Time Step 1		Time Step 2		Time Step 3	
Video	Group	Order	N	Mean	SD	Mean	SD	Mean	SD
2D	Expert	2D → 3D	6	14.255	7.833	0.962	0.388	18.50	12.232
		3D → 2D	4	11.078	4.446	1.100	0.708	28.49	21.566
	Intermedium	2D → 3D	3	21.773	17.687	1.620	0.726	26.97	9.991
		3D → 2D	4	9.320	3.759	1.300	0.810	22.36	20.627
	Naive	2D → 3D	4	56.038	25.061	4.798	2.610	36.40	22.124
		3D → 2D	6	24.402	14.332	4.993	3.657	29.46	10.103
3D	Expert	2D → 3D	6	8.963	5.885	1.265	1.110	12.61	3.888
		3D → 2D	4	15.000	6.785	2.605	3.103	34.31	25.398
	Intermedium	2D → 3D	3	17.500	15.668	1.077	1.085	18.06	15.773
		3D → 2D	4	17.977	4.489	0.900	0.536	21.59	5.925
	Naive	2D → 3D	4	24.448	16.396	3.183	2.600	25.75	6.329
		3D → 2D	6	36.212	10.499	3.923	2.228	49.56	31.952

Statistical Analysis

For the statistical analysis we used IBM SPSS Statistics 22.0 for Windows.

After checking for normality, data were processed comparing end-points (time and errors). Three mixed design factorial ANOVAs (one for each of the 3 tasks) were performed with 2 between-subjects factors: experience and video order, and the time to perform the task according to 2D or 3D vision as the within-subject factor.

A P value of <.05 was regarded as statistically significant.

Results

Normality Assumption

The Kolmogorov-Smirnov ($P > .05$) and the visual analysis of the histograms, QQ standard plots, and box plots show the normal principle achieved for most of the variables. Despite the normality assumptions being violated for experienced participants categories 2D (1.170 asymmetry and kurtosis 0.084) and 3D (asymmetric 3.494 and kurtosis 1.896), participant through 3D (asymmetry 4.335 and kurtosis −1.882), 3D display and execution order 3D monitor first (asymmetry 0.780 and kurtosis 0.386) and total number of errors in 2D monitor (1 error—asymmetry 1.526 and kurtosis 2.203), we continued the study performing the parametric tests using one-way ANOVA and mixed design factorial ANOVA.

Descriptive Statistics (Table 1)

Time. The beginning of the experiment using the 3D imaging system (order 3D → 2D) helped, overall, develop better performance in the participants when undergoing the experience with the 2D imaging system, namely, in Step 1 (from 24.40 to 56.04 minutes) and Step 3 (29.46 to 36.40 minutes) for the novice group; in Step 1 (from 9.32 to 21.77 minutes), Step 2 (1.30 to 1.62 minutes), and Step 3 (of 22.36 to 26.97 minutes) for the intermediate group; and in Step 1 (11.08 to 14.26 minutes) for the experienced group.

In comparison, regarding the experiment performed in the 3D imaging system, all participants performed better when they began the experiments in order 2D → 3D, regardless of the step to be executed and to which group they belonged, except in Step 2 performed for 3 of the 7 participants of the intermediate group (from 1.08 to 0.9 minutes).

Errors. When the tests were made starting by using the 3D imaging system (order 3D → 2D), the performance of the participants improved in terms of total number of errors, regardless of the imaging system or group, except in the case of tests in the 2D imaging system with the intermediate group (from 1.75 to 1.67 errors).

ANOVA Tests (Figure 3)

Results for the 3 different tasks performed were the following.

Regarding task 1, a significant vision * order interaction effect was obtained, $F(1, 21) = 11.9$, $P = .002$, η^2 $P = .363$. Those who started with 2D vision tended to perform better when using 3D vision (mainly in the Novice group). Additionally, a significant group main effect, $F(2, 21) = 16.7$, $P < .001$, η^2 $P = .614$, was detected, with the time spent performing the task decreasing significantly with medical experience.

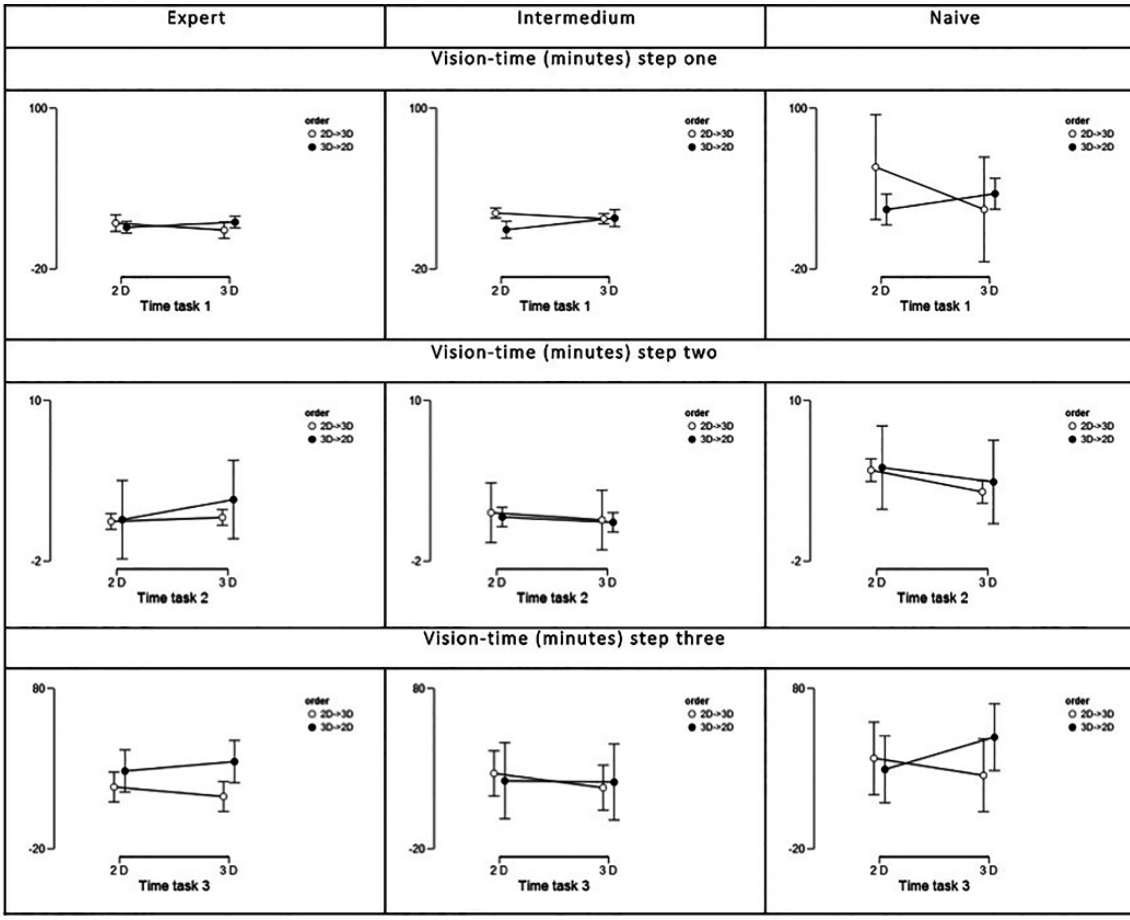

Figure 3. Analyzing the data in terms of time spent by task (or step), taking into account the order by which they are performed: 2D → 3D or 3D → 2D; the results were generally superior when the 3D system was used. We found a statistically significant relationship between the time spent in performing the first step and the order in which the test was performed. The operator's experience proved significantly relevant in carrying out the first and second tasks. Finally, the third task also showed a statistically significant difference in the order in which the test was performed.

Results in task 2 were significant only for group, $F(2, 21) = 8.9$, $P = .002$, η^2 $P = .458$; again, the time spent performing the task decreased significantly with medical experience.

For task 3, similar to task 1, a significant vision * order interaction effect was detected, $F(1, 21) = 4.28$, $P = .039$, η^2 $P = .188$, showing that those who start with 2D vision tend to perform better when using the 3D vision (mainly in the Novice group).

Preference Questionnaire

Compared to 2D view, 11.1% of respondents considered 3D vision much easier, 55.6% easier, 25.9% similar, and 7.4% more difficult. In terms of the advantage that the 3D view provides in some steps of the surgery, 14.8% of the participants considered that it gave advantage only in Step 1 (gallbladder hilum isolation), 3.7% in Step 2 (ligation and transection of the cystic duct), 14.8% in Step 3 (gallbladder removal of its bed), 11.1% in Steps 1 and 3, 7.4% in Steps 2 and 3, and 29.6% considered that there was advantage in all 3 steps. A minority of 18.5% considered that the 3D vision did not confer significant advantage in any of the 3 steps.

When evaluating the unpleasant symptoms in the use of a 2D imaging system, 96.3% of the participants did not report having any unpleasant symptoms and 3.7% reported pain in their hands and wrists. In relation to the 3D imaging system, the vast majority of the participants, 70.4%, did not mention any unpleasant symptom. Four of the 27 participants complained of headache, one of nausea, and one of both.

All participants admitted there is at least one advantage associated with the use of 3D imaging system, of which 59.3% considered it to be the perception of depth, 7.4% pointed out mostly spatial orientation, 3.7% both perception of depth and bimanual ability, 11.1% spatial orientation and perception of depth, and 18.5% reported finding all 3 advantages (bimanual ability, depth perception, and spatial orientation). In terms of current 3D technology development status, 18.5% did not consider it to be developed and 81.5% fairly developed. When asked about their preference, 66.7% of the participants preferred the 3D system compared with the 2D version.

Discussion

Minimally invasive surgery has undeniable advantages despite having several limitations. Technological developments can help improve its use, particularly through the development of new instruments and better image systems.

Limitations of 2D image are well documented. This study evaluated whether the use of a 3D imaging system in a LESS organic model cholecystectomy confers performance advantages.

Participants having different levels of practice in multiport laparoscopy were divided into 3 different groups (novice, intermediate, and experienced), later carrying out the surgical simulation in 2D and 3D.

When comparing the average total experiment time, taking into account the order, there was improved performance in the 3D imaging system when the order of 2D → 3D was followed and the time was better in the 2D display when the order was 3D → 2D, which revealed the existence of a learning curve, as we can see in other studies.[9]

The learning curve is the improved performance resulting from the repetition of the exercise.

The learning curve was more notable when the order was 2D → 3D compared to the inverse sequence, as demonstrated by our work in 2016.[17] This can be explained by increased depth perception afforded by 3D systems after going through the 2D experience.

For the analysis of average time per step and the order of imaging systems, it was found that in the sequence 2D → 3D, the experiment performed in 2D took longer on average in Steps 1 and 3; in the inverse sequence of 3D → 2D, the experiment performed in 2D took less time on average in any of the 3 steps individually. This demonstrates a positive learning effect, taking into account the average time of each step, in contrast to the total of the experiment, when starting the experiment using the 3D imaging system. The analysis of average time per order of groups and imaging systems showed that 2D → 3D order was better in all groups using 3D, and performance decreased in view of the experience of the participants; in the order of 3D → 2D, performance was improved when using the 2D system, and the average highest time occurred in the novice group and the performance of the intermediate group was better than the experienced group. This can demonstrate the benefit of the 3D system in accelerating the learning curve, particularly in subjects with average experience or who were inexperienced.

Comparing times and errors with 2D as the first or second exercise (before or after 3D), it was clear that 3D experience is transferable to 2D in terms of the learning curve.

By analyzing the preference of the participants, it was possible to conclude that most choose the 3D system over the 2D system. This imaging system can possibly benefit during longer surgeries and with those of a higher degree of difficulty.

There were some drawbacks that are important to point out, however. To obtain more consistent results, the study sample could have been greater and it would be interesting to compare another 2 groups—2D after 2D and 3D after 3D—to better determine the effect of 3D systems in the learning curve. To avoid operation errors, all participants should have the same degree of experience with laparoscopic instruments. Although it is not possible to control the size of the liver or bladder, it is important to note that there was variability. Finally, in future studies besides recording the quality of the mistakes, also the number of times each mistake occurred could better distinguish participants' performance.

Conclusions

Taking into account the obtained results it can be concluded that the 3D imaging system may improve the learning curve for the implementation of LESS surgery. The 3D imaging system can accelerate the learning process in individuals without any experience and those with limited previous laparoscopic practice.

Furthermore, background experience in multiport laparoscopy is an advantage for LESS surgery.

The preference of the majority for the 3D system demonstrates added comfort afforded by this equipment, and this can mean improved and sustained performance in complex and prolonged surgical procedures.

Author Contributions

Study concept and design: Pedro Leão and Jaime Vilaça
Acquisition of data: Jaime Vilaça, José Pedro Pinto, and Sandra Fernandes
Analysis and interpretation: Jaime Vilaça, Patrício Costa, Jorge Correia Pinto, Pedro Leão, and José Pedro Pinto
Study supervision: Pedro Leão, Jaime Vilaça, and José Pedro Pinto

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

References

1. Mittermair C, Schirnhofer J, Brunner E, et al. Single port laparoscopy in gastroenterology and hepatology: a fine step forward. *World J Gastroenterol*. 2014;20:15599-15607.
2. Himal HS. Minimally invasive (laparoscopic) surgery. *Surg Endosc*. 2002;16:1647-1652.
3. Ahmed I, Paraskeva P. A clinical review of single-incision laparoscopic surgery. *Surgeon*. 2011;9:341-351.
4. Shussman N, Wexner S. Current status of laparoscopy for the treatment of rectal cancer. *World J. Gastroenterol*. 2014;20:15125-15134.
5. Xin H, Zelek J, Carnahan H. Laparoscopic surgery, perceptual limitations and force: a review. Paper presented at: First Canadian Student Conference on Biomedical Computing, Kingston, Ontario, Canada; 2006.
6. Schwenk W, Haase O, Neudecker J, Muller J. Short term benefits for laparoscopic colorectal resection. *Cochrane Database Syst Rev*. 2005;(3):CD003145.
7. Cicione A, Autorine R, Breda A, et al. Three-dimensional versus standard laparoscopy: comparative assessment using a validated program for laparoscopic urologic skills. *Urology*. 2013;82:1444-1450.
8. Wilhelm D, Reiser S, Kohn N, et al. Comparative evaluation of HD 2D/3D laparoscopic monitors and benchmarking to a theoretically ideal 3D pseudodisplay: even well-experienced laparoscopists perform better with 3D. *Surg Endosc*. 2014;28:2387-2397.
9. Storz P, Buess GF, Kunert W, Kirschniak A. 3D HD versus 2D HD: surgical task efficiency in standardized phantom tasks. *Surg Endosc*. 2012;26:1454-1460.
10. Votanopoulos K, Brunicardi FC, Thornby J, Bellows CF. Impact of three-dimensional vision in laparoscopic training. *World J Surg*. 2008;32:110-118.
11. Izquierdo L, Peri L, Cruz E, et al. 3D advances in laparoscopic vision. *Eur Urol Rev*. 2012;7:137-139.
12. Honeck P, Wendt-Nordahl G, Rassweiler J, Knoll T. Three-dimensional laparoscopic imaging improves surgical performance on standardized ex-vivo laparoscopic tasks. *J Endourol*. 2012;26:1085-1088.
13. Lee IO, Yoon JW, Chung D, et al. A comparison of clinical and surgical outcomes between laparo-endoscopic single-site surgery and traditional multiport laparoscopic surgery for adnexal tumors. *Obstet Gynecol Sci*. 2014;57:386-392.
14. Agrusa A, Romano G, Cucinella G, et al. Laparoscopic, three-port and SILS cholecystectomy: a retrospective study. *G Chir*. 2013;34:249-253.
15. Romanelli J, Earle D. Single-port laparoscopic surgery: an overview. *Surg Endosc*. 2009;23:1419-1427.
16. Lambooij M, Fortuin M, Heynderickx I, Ijsselteijn W. Visual discomfort and visual fatigue of stereoscopic displays: a review. *J Imaging Sci Technol*. 2009;53:30201.
17. Leite M, Carvalho AF, Costa P, et al. Assessment of laparoscopic skills performance: 2D versus 3D vision and classic instrument versus new hand-held robotic device for laparoscopy. *Surg Innov*. 2016;23:52-61.