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2D Versus 3D Visualization: Impact on Laparoscopic Proficiency Using the Fundamentals of Laparoscopic Surgery Skill Set

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Abstract

Introduction: We compared the impact of two-dimensional (2D) versus three-dimensional (3D) visualization on both objective and subjective measures of laparoscopic performance using the validated Fundamentals of Laparoscopic Surgery (FLS) skill set.
Subjects and Methods: Thirty-three individuals with varying laparoscopic experience completed three essential drills from the FLS skill set (peg transfer, pattern cutting, and suturing/knot tying) in both 2D and 3D. Participants were randomized to begin all tasks in either 2D or 3D. Time to completion and number of attempts required to achieve proficiency were measured for each task. Errors were also noted. Participants completed questionnaires evaluating their experiences with both visual modalities.
Results: Across all tasks, greater speed was achieved in 3D versus 2D: peg transfer, 183.4 versus 245.6 seconds ($P<.0001$); pattern cutting, 167.7 versus 209.3 seconds ($P=.004$); and suturing/knot tying, 255.2 versus 329.5 seconds ($P=.031$). Fewer errors were committed in the peg transfer task in 3D versus 2D ($P=.008$). Fourteen participants required multiple attempts to achieve proficiency in one or more tasks in 2D, compared with 7 in 3D. Subjective measures of efficiency and accuracy also favored 3D visualization. The advantage of 3D vision persisted independent of participants' level of technical expertise (novice versus intermediate/expert). There were no differences in reported side effects between the two visual modalities. Overall, 87.9% of participants preferred 3D visualization.
Conclusions: Three-dimensional vision appears to greatly enhance laparoscopic proficiency based on objective and subjective measures. In our experience, 3D visualization produced no more eye strain, headaches, or other side effects than 2D visualization. Participants overwhelmingly preferred 3D visualization.

Introduction

TECHNICAL NOVELTIES HAVE OFTEN driven major advances in laparoscopic surgery. Basic improvements in instrumentation, including lightweight video cameras and powerful light sources, undoubtedly gave impetus to the explosive growth of laparoscopic applications in surgery.[1] With continued technological progress, the complexity of laparoscopic interventions is only expected to increase.

Traditionally, laparoscopy has relied upon two-dimensional (2D) images displayed on a monitor, thus requiring the surgeon to use auxiliary visual cues to judge instrument position and depth. This limitation can pose a considerable challenge, especially with regard to maneuvers requiring precision and dexterity. Recent advances in three-dimensional (3D) visualization technology for laparoscopy, however, stand poised to eliminate this hurdle. The anticipated advantages for the surgeon are greater accuracy and speed in manual skills, translating to decreased operative time, a reduced learning curve, and enhanced safety.

Nevertheless, studies to date examining the potential advantages and disadvantages of 3D systems have produced contradictory results. Although some have reported that 3D imaging significantly improves performance,[2–10] others have claimed equivalency in task performance between 2D and 3D vision.[1,11,12] It is important that considerable technical advances have been made in the design of high-definition stereoscopic 3D visualization systems since the publication of these earlier studies.[2,13,14] Indeed, newer 3D systems provide superior depth perception and resolution relative to the more

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rudimentary systems previously evaluated. Furthermore, comparisons of 3D versus 2D visualization in these preliminary studies are limited by the lack of a standardized and validated method for defining and assessing technical proficiency in laparoscopic surgery.[1,12]

Nearly a decade ago, the Society of American Gastrointestinal Endoscopic Surgeons (SAGES) designed a comprehensive didactic and manual skills training curriculum useful for both the development and assessment of basic laparoscopic skills.[15–17] Branded as the "Fundamentals of Laparoscopic Surgery" (FLS) program, this curriculum has been validated by multiple studies across surgical specialities as a laparoscopic surgical skill assessment and training tool.[15,16,18–21] We, therefore, sought to compare the impact of 2D versus 3D visualization on laparoscopic performance using components of the validated FLS skill set.

Subjects and Methods

This study was approved by the Institutional Review Board of Washington University (St. Louis, MO). Practicing urology clinicians, fellows, residents, and medical students, as well as premedical or non-medical volunteers, participated in this study after informed consent. Thirty-three individuals with varying laparoscopic experience completed three essential drills from the FLS skill set (peg transfer, pattern cutting, and suturing/knot tying) in both 2D and 3D. Three-dimensional visualization was achieved using the Viking 3DHD Laparoscopic Vision System (Viking Systems, Inc., Westborough, MA). All tasks were performed inside a standard laparoscopic trainer. To control for the learning curve effect, participants were randomized to begin all tasks in either 2D or 3D. Time to completion and number of attempts required to achieve proficiency within the allotted time limit for each task were measured. Participants were allowed up to five attempts per task to achieve proficiency. Participants completed questionnaires evaluating their experiences with both visual modalities.

FLS tasks tested

Task 1: peg transfer (time limit, 5 minutes). Six plastic rings were picked up in turn by a grasping forceps from a peg-board on the participant's left, transferred in space to a grasper in the right hand, and then placed around a post on the corresponding right-sided peg-board. The process was then reversed, requiring ring transfer from the right to left hand. Dropping of the peg during transfer was noted. This task tests visual-spatial/depth perception, eye-hand coordination, and ambidexterity.

Task 2: pattern cutting (time limit, 5 minutes). A 4-×4-inch gauze was suspended by alligator clips. Participants were required to cut a precise circular pattern from the gauze along a premarked template. Gross deviation of the cut from the circular pattern was marked as a failed attempt. This task assesses cutting precision and complementary hand utilization to provide traction/countertraction.

Task 3: suturing/knot tying (time limit, 10 minutes). Participants were required to pick up a 2-0 silk suture on a V-20 needle, place a stitch through precise target points on either side of a slit Penrose drain, throw three square knots, and cut the suture. Gross deviation from the marks and strangulation or avulsion of the Penrose drain resulted in a failed attempt. This exercise evaluates participants' suturing and knot-tying abilities.

3D vision technology

The Viking 3DHD Laparoscopic Vision System consists of a dual optic channel stereo digital scope attached to a 3D data processing unit. Two separate image signals are captured and simultaneously transmitted to a high-definition video monitor. The surgeon wears passive, lightweight, polarized eyewear that allows him or her to perceive a 3D image portrayed on a 3D, high-definition video-monitor using micropolarization technology.

Statistical analysis

Continuous variables were compared using the paired t test, whereas categorical variables were compared using Fisher's exact test. Statistical analysis was performed using MedCalc version 11.6 and SPSS version 19 software. $P<.05$ (two-tailed) defined statistical significance.

Results

Of the 33 study participants, 23 (69.7%) described their laparoscopic skill level as novice, 5 (15.2%) as intermediate, and 3 (9.1%) as expert; 2 (6.1%) were unsure. Thirteen (39.4%) participants labeled themselves as premedical or non-medical, 4 (12.1%) as medical students, 6 (18.2%) as residents, 2 (6.1%) as fellows, and 8 (24.2%) as attendings. Eighteen participants (54.5%) were randomized to begin with 2D tasks first, whereas 15 (45.5%) were randomized to begin with 3D.

Across all tasks, 3D visualization was associated with a shorter time to completion, averaging each participant's cumulative attempts for a particular task: peg transfer, 183.4 seconds (SD = 62.3) versus 245.6 seconds (SD = 71.5) ($P<.0001$); pattern cutting, 167.7 seconds (SD = 73.7) versus 209.3 seconds (SD = 87.2) ($P=.004$); and suturing/knot tying, 255.2 seconds (SD = 139.2) versus 329.5 seconds (SD = 155.6) ($P=.031$). 3D visualization was also associated with improved task precision. In the peg transfer task, the mean number of times the ring was dropped during transfer was 1.2 (SD = 1.3) in 3D, compared with 2.5 (SD = 2.5) in 2D ($P=.008$). Fourteen participants (42.4%) required multiple attempts to achieve proficiency in one or more tasks in 2D, compared with just 7 (21.2%) in 3D. A grand total of 127 attempts were made by all 33 participants to achieve proficiency in the three designated 2D tasks; 3 participants (9.1%) failed to achieve suturing/knot tying proficiency within the maximum five attempts allowed per task. In contrast, only 108 attempts were required by participants to achieve proficiency in all 3D tasks, and none failed to achieve proficiency in any of the tasks attempted (although 1 participant who failed to achieve proficiency in 2D suturing/knot tying declined to attempt this task in 3D). Participants' subjective rating of technical efficiency and accuracy/ease overwhelmingly favored 3D visualization. The advantage of 3D vision persisted notwithstanding participants' level of technical expertise in laparoscopic surgery (novice versus intermediate/expert) (Table 1).

Table 2 compares potential side effects of 2D versus 3D visualization. Participants were questioned regarding any

Table 1. Comparison of the Impact of Two-Dimensional Versus Three-Dimensional Vision on Both Objective and Subjective Measures of Laparoscopic Proficiency in Three Fundamentals of Laparoscopic Surgery Tasks

Task	*2D*	*3D*	P *value*
Peg transfer			
Entire cohort			
Mean task completion time (seconds)	245.6 (71.5)	183.4 (62.3)	<.0001[a]
Number of times peg dropped	2.5 (2.5)	1.2 (1.3)	.008[a]
Ease	4.0 (1.0)	5.0 (1.3)	<.0001[a]
Efficiency	3.8 (1.3)	4.9 (1.6)	<.0001[a]
Novice only			
Mean task completion time (seconds)	263.4 (71.5)	200.5 (62.5)	.003[a]
Number of times peg dropped	2.6 (2.1)	1.5 (1.4)	.063
Ease	3.8 (0.9)	4.7 (1.2)	<.0001[a]
Efficiency	3.5 (1.2)	4.6 (1.6)	.001[a]
Intermediate/expert only			
Mean task completion time (seconds)	191.9 (54.2)	131.1 (33.4)	.006[a]
Number of times peg dropped	2.8 (3.6)	0.4 (0.5)	.084
Ease	4.6 (1.1)	5.5 (1.5)	.006[a]
Efficiency	4.6 (1.4)	5.5 (1.8)	.155
Pattern cutting			
Entire cohort			
Mean task completion time (seconds)	209.3 (87.2)	167.7 (73.7)	.004[a]
Ease	3.5 (1.1)	4.4 (1.2)	<.0001[a]
Efficiency	3.4 (1.2)	4.3 (1.4)	<.0001[a]
Novice only			
Mean task completion time (seconds)	239.2 (85.2)	193.2 (71.7)	.025[a]
Ease	3.2 (1.1)	4.1 (1.2)	<.0001[a]
Efficiency	3.2 (1.2)	4.0 (1.3)	.013[a]
Intermediate/expert only			
Mean task completion time (seconds)	147.6 (44.4)	111.9 (38.3)	.023[a]
Ease	4.0 (1.1)	5.4 (0.7)	.004[a]
Efficiency	4.0 (1.2)	5.3 (1.4)	.028[a]
Suturing/knot tying			
Entire cohort			
Mean task completion time (seconds)	329.5 (155.6)	255.2 (139.2)	.031[a]
Ease	3.4 (1.3)	4.6 (0.9)	<.0001[a]
Efficiency	3.4 (1.3)	4.5 (1.2)	<.0001[a]
Novice only			
Mean task completion time (seconds)	389.1 (138.0)	301.6 (146.6)	.073
Ease	3.0 (1.4)	4.4 (0.9)	<.0001[a]
Efficiency	3.1 (1.2)	4.3 (1.2)	.003[a]
Intermediate/expert only			
Mean task completion time (seconds)	219.1 (121.0)	154.8 (37.0)	.148
Ease	4.5 (0.5)	5.4 (0.5)	.021[a]
Efficiency	4.1 (1.2)	5.4 (0.7)	.028[a]

Data are mean (standard deviation) values. Ease was graded on a scale of 1 = difficult to 7 = easy. Efficiency was graded on a scale of 1 = inefficient to 7 = very efficient. Assessment of mean task completion time was based on an averaging of all attempts at a given task in a given visual modality for individual participants.

[a]Significant difference.

2D, two-dimensional; 3D, three-dimensional.

experience of eyestrain, headache, dizziness, disorientation, discomfort, or poor visualization in each of the three tested tasks, in both 2D and 3D. No statistically significant differences between the two visual modalities were experienced in any of those parameters.

Overall, 27 participants (81.8%) indicated that the addition of 3D visualization facilitated the performance of the required tasks, 3 (9.1%) felt it did not, and 3 (9.1%) were unsure. Twenty-nine participants (87.9%) indicated a preference for 3D visualization over 2D, whereas 3 (9.1%) preferred 2D vision; the remaining participant (3.0%) had no preference.

Discussion

Technical training and dissemination of operative technique are persistent challenges of complex reconstructive and ablative laparoscopic surgery. Efforts to facilitate laparoscopic surgery, which have focused on improving operative instrumentation, have produced important additions to the laparoscopist's armamentarium of surgical tools. Similarly, surgeons would be wise to explore recent advances in audiovisual technologies as a means of facilitating and enhancing their laparoscopic surgical technique. In particular, given

Table 2. Comparison of Potential Side Effects, Including Eye Strain, Headache, Dizziness, Disorientation, Physical Discomfort, and Poor Visualization, in Two-Dimensional Versus Three-Dimensional Visualization

Number (%) experiencing	*2D*	*3D*	P *value*
Eye strain	5/33 (15.2)	5/33 (15.2)	1.0
Headache	1/33 (3.0)	0/33 (0)	—
Dizziness	1/33 (3.0)	4/33 (12.1)	.121
Disorientation	5/33 (15.2)	5/33 (15.2)	.155
Physical discomfort	6/33 (18.2)	1/33 (3.0)	.182
Poor visualization	6/33 (18.2)	1/33 (3.0)	1.0

2D, two-dimensional; 3D, three-dimensional.

that loss of depth perception and spatial orientation are significant drawbacks of conventional laparoscopic surgery, the role of newly designed high-definition stereoscopic 3D visualization systems in overcoming this barrier is worthy of investigation.

To date, the limited number of studies examining whether 3D systems have significant advantages over conventional 2D systems have failed to produce a consistent answer to this highly relevant question. Birkett et al.[3] examined the efficacy of 3D laparoscopy in 9 participants who had to perform two exercises and concluded that the third visual dimension simplifies complicated procedures in laparoscopy. Wenzl et al.[4] tested the application of 3D laparoscopy in 11 operations and suggested that 3D visualization improved orientation in the abdominal cavity, thereby reducing operative time. In a prospective randomized study, Peitgen et al.[5] demonstrated that 3D imaging significantly improved speed ($P < .0001$) and other measures of performance in two separate tasks, regardless of participants' previous laparoscopic experience.[5] Bhayani et al.[2] demonstrated that among 24 novice laparoscopists, 3D visualization resulted in improved performance in a "bead transfer" task when compared with 2D visualization; the task was performed more rapidly with 3D visualization (108 versus 127 seconds, $P = .05$), and, on subjective evaluation, participants preferred the 3D system to the 2D system by a 2:1 margin. Others have also demonstrated an advantage in laparoscopic proficiency favoring 3D over 2D vision.[6–10] In contrast to the aforementioned studies, Chan et al.,[11] Jones et al.,[12] and Mueller et al.[1] could not demonstrate any superiority of 3D vision over 2D vision in a variety of laparoscopic tasks (Table 3).

It is important that significant technical advances have been made in the design of high-definition stereoscopic 3D visualization systems since the publication of these preliminary studies.[2,13,14] In reference to an earlier 3D system from the mid-1990s, Chan et al.[11] noted that 40% of participants reported a "less clear" and "darker" image associated with 3D visualization. Indeed, they attributed the failure of 3D visualization to demonstrate an advantage over conventional 2D visualization in their study to inferior image resolution and light illumination in the former; they concluded that 3D technology "still needs to be refined before any true benefit can be demonstrated in laparoscopic surgery."[11] To that aim, newer 3D visual systems, including the Viking 3DHD Laparoscopic Vision System used in the current study, can provide considerably superior depth perception and resolution relative to the more rudimentary systems previously evaluated.[1,11,12] Indeed, review of previous comparisons between 2D and 3D vision suggests an increasingly apparent advantage to 3D vision in more recent studies, likely corresponding to the technical evolution of 3D vision systems (Table 3). Furthermore, unlike older 3D systems, which rely on active optic shuttering of alternating high-frequency signals emanating from a 3D screen, the use of passive micropolarization technology in the current system is believed to limit surgeon fatigue.

The lack of a validated tool for assessing laparoscopic technical proficiency further limits the comparison of 3D versus 2D visualization in earlier studies.[1,12] We sought to overcome this limitation by basing our assessment of laparoscopic proficiency in the current analysis on components of the standardized FLS curriculum. Developed by SAGES[15] and endorsed by the American College of Surgeons,[18,19] the FLS program has now been validated as a laparoscopic surgical skill assessment and training tool in multiple studies across specialty lines.[16,18,20,21] Fried et al.[15] demonstrated that FLS scores increased progressively with increasing laparoscopic experience among general surgeons ($n = 215$, $P < .0001$) and that surgery residents followed over time increased their FLS scores ($n = 24$, $P < .0001$), thus providing evidence of construct validity. The same study also found that FLS scores correlated with a highly reliable validated intraoperative rating of technical skill during laparoscopic cholecystectomy ($n = 19$, $r = 0.81$, $P < .0004$), evidence of concurrent validity, and, because results in the host institution did not differ from those in five other sites evaluated ($n = 215$), evidence of external validity.[15] Hurr et al.[20] validated the FLS program among gynecology residents, demonstrating a significant difference in FLS pass rates favoring the more senior residents ($P = .007$), as well as a strong correlation between self-reported surgical experience and FLS skills scores ($r = 0.97$, $P = .0048$). Similarly, the use of the FLS skills curriculum for assessing laparoscopic skills among urologists was validated in a study by Sweet et al.[18] In this study, investigators demonstrated that practicing clinical urologists ($n = 81$) outperformed residents and medical students ($n = 35$) in time to completion of the circle cutting exercise ($P < .01$) and that practicing urologists who reported more than three laparoscopic procedures per week were faster at the peg-transfer exercise ($P < .05$) and circle cutting exercise ($P < .01$) than those reporting less than three procedures.[18] Given the demonstrable reliability of the FLS curriculum in assessing laparoscopic surgical proficiency, as evident from the aforementioned studies, this curriculum has become a key skills assessment tool for surgical training programs and is now a prerequisite requirement for eligibility to the qualifying examination of the American Board of Surgery.[18]

Using components of the validated FLS curriculum to assess surgical proficiency, we designed a prospective randomized study comparing the impact of 2D versus 3D visualization on laparoscopic performance among participants with varying surgical experience and skill sets. Our study demonstrates a marked and significant improvement in operative times in 3D for all tasks tested. Furthermore, participants favored a stereoscopic 3D view of the "operative field" over the traditional 2D view in their self-assessment of technical proficiency. Because tasks were performed with identical mechanical instrumentation, the difference can be attributable only to the stereoscopic perception afforded by the 3D system. This technical advantage could prove

Table 3. Studies Comparing Laparoscopic Proficiency Using Two-Dimensional Versus Three-Dimensional Vision

Study	*Type of study*	*Cohort size*	*3D equipment*	*Number and type of tasks tested*	*Conclusions*
Birkett et al.[3] (1994)	Prospective	9	Unspecified (active eyewear)	2 (passing needle and suture through series of hoops, includes a "simple" and a "complex" task)	3D equivalent to 2D for simple tasks but associated with shorter time to task completion for complex tasks
Chan et al.[11] (1996)	Prospective randomized	32	Baxter, V. Mueller VS7700 (active eyewear)	1 (stringing 10 beads on a suture)	3D equivalent to 2D
Jones et al.[12] (1996)	Prospective randomized	30	American Surgical Technologies Corp. 3DSCOPE model 3000 (active screen, passive eyewear)	5 (1, checkerboard; 2, loop pass; 3. Lapra-Ty; 4, loop ligature; 5, simple suture and instrument tie)	3D equivalent to 2D
Peitgen et al.[5] (1996)	Prospective randomized	60	Laser Optik System, Mainz, Germany (active eyewear)	2 (1, pea transfer; 2, loop test)	3D associated with improved speed and accuracy compared with 2D
Mueller et al.[1] (1998)	Prospective randomized	30	Zeiss, Grimmbach, Germany (active eyewear)	4 (1, transfer peas to matchbox; 2, transfer matches to matchbox; 3, elastic band stretch; 4, elastic band cutting)	3D equivalent to 2D
Taffinder et al.[6] (1999)	Prospective	28	Surgical Vision, Reading, UK (passive eyewear)	6 (a variety of suturing tasks for experienced surgeons and grasping and cutting tasks for novices)	3D associated with improved precision and speed compared with 2D in both the novice and experienced groups
Bhayani et al.[2] (2005)	Prospective randomized	24	Viking Systems, EndoSite 3Di Digital Vision System (active eyewear)	1 (transferring 10 beads from one container to another)	3D associated with shorter time to task completion compared with 2D
Patel et al.[7](2007)	Prospective randomized	17	Viking Systems, EndoSite 3Di Digital Vision System (active eyewear)	5 (1, linear cutting and suturing; 2, curved cutting and suturing; 3, tubular suturing; 4, dorsal vein complex suturing simulation; 5, urethrovesical anastomosis)	3D associated with improved accuracy and speed compared with 2D in the novice group only
Votanopoulos et al.[8] (2008)	Prospective randomized	36	Viking Systems, EndoSite 3Di Digital Vision System (active eyewear)	6 (1, peg drop; 2, ring board exchange; 3, rope passing; 4, duct cannulation; 5, instrument spatial navigation; 6, suturing)	3D associated with improved accuracy and speed compared with 2D in 5 of 6 tasks in the novice group only
Kong et al.[9] (2010)	Prospective	27	Wasol camera system prototype, RAHPACAM 105i (passive eyewear)	2 (1, passage of surgical thread through 6 holes; 2, rubber band manipulation)	3D associated with improved accuracy compared with 2D in the novice group only
Storz et al.[10] (2012)	Prospective randomized	30	Richard Wolf GmbH, Knittlingen Germany (passive eyewear)	5 (1, one-handed shape positioning task #1; 2. one-handed shape positioning task #2; 3, wire bending and threading; 4, bimanual stitching using a straight needle; 5, continuous suturing using a circular needle)	3D associated with improved accuracy and speed compared with 2D in 4 of 5 tasks
Current study	Prospective randomized	33	Viking Systems, 3DHD Laparoscopic Vision System (passive eyewear using micropolarization technology)	3 FLS tasks (1, peg transfer; 2, pattern cutting; 3, suturing/knot tying)	3D associated with shorter time to task completion and fewer errors compared with 2D

2D, two-dimensional; 3D, three-dimensional.

beneficial when laparoscopic radical prostatectomy, laparoscopic pyeloplasty, and other complex urological or nonurological reconstructive techniques are performed. Nevertheless, further investigation is required to determine whether the benefits of 3D vision can ultimately translate into real clinical improvements, specifically in terms of improved operative times, shortened learning curves, greater surgeon comfort, and increased patient safety.

Limitations of this study include the relatively small sample size. Although this study was adequately powered to detect a clear technical advantage favoring 3D visualization over 2D, more subtle differences in side effects between the two modalities may require a larger sample size to elucidate. We take note of a statistical trend ($P = .121$) for increased "dizziness" associated with 3D vision and, conversely, a trend for increased "physical discomfort" associated with the 2D system ($P = .182$). Furthermore, although our cumulative data clearly suggest that the advantage of 3D vision persists independent of participants' prior laparoscopic experience, some loss of statistical power is apparent in this subset analysis, again reflecting our relatively small sample size. Another criticism of the study is that slightly larger numbers of participants (54.5%) were incidentally randomized to begin with 2D, thus imposing a slightly increased "learning curve disadvantage" on the 2D arm of the study.

Despite these limitations, the current analysis demonstrates that 3D visualization appears to greatly enhance the ease and efficiency of basic laparoscopic skills and hasten the development of surgical proficiency. In our experience, 3D vision was not associated with any demonstrable increase in eye strain, headache, or other side effects relative to standard 2D vision. Further investigation is required to determine whether the benefits of 3D vision can ultimately translate into real clinical improvements.

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Disclosure Statement

G.L.A. serves as a Medical Advisor for Viking Systems. B.M.B. serves as a Consultant for Viking Systems. Y.S.T., A.G.P., K.M.M., G.S.S., and J.E.V. declare no competing financial interests.

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