

A computerized assessment to compare the impact of standard, stereoscopic, and high-definition laparoscopic monitor displays on surgical technique

Chuan Feng · Jerzy W. Rozenblit · Allan J. Hamilton

Received: 21 July 2009/Accepted: 11 March 2010/Published online: 2 April 2010
© Springer Science+Business Media, LLC 2010

Abstract

Background Surgeons performing laparoscopic surgery have strong biases regarding the quality and nature of the laparoscopic video monitor display. In a comparative study, we used a unique computerized sensing and analysis system to evaluate the various types of monitors employed in laparoscopic surgery.

Methods We compared the impact of different types of monitor displays on an individual's performance of a laparoscopic training task which required the subject to move the instrument to a set of targets. Participants (varying from no laparoscopic experience to board-certified surgeons) were asked to perform the assigned task while using all three display systems, which were randomly assigned: a conventional laparoscopic monitor system (2D), a high-definition monitor system (HD), and a stereoscopic display (3D). The effects of monitor system on various performance parameters (total time consumed to finish the task, average speed, and movement economy) were analyzed by computer. Each of the subjects filled out a subjective questionnaire at the end of their training session.

Results A total of 27 participants completed our study. Performance with the HD monitor was significantly slower than with either the 3D or 2D monitor ($p < 0.0001$). Movement economy with the HD monitor was significantly reduced compared with the 3D ($p < 0.0004$) or 2D

($p < 0.0001$) monitor. In terms of average time required to complete the task, performance with the 3D monitor was significantly faster than with the HD ($p < 0.0001$) or 2D ($p < 0.0086$) monitor. However, the HD system was the overwhelming favorite according to subjective evaluation. **Conclusion** Computerized sensing and analysis is capable of quantitatively assessing the seemingly minor effect of monitor display on surgical training performance. The study demonstrates that, while users expressed a decided preference for HD systems, actual quantitative analysis indicates that HD monitors offer no statistically significant advantage and may even worsen performance compared with standard 2D or 3D laparoscopic monitors.

Keywords Minimally invasive surgery · Surgical training · Computerized analysis · High-definition · Stereoscopy · Laparoscopic monitor

Minimally invasive surgery (MIS) is increasingly popular because of its clinical advantages for patients [1]. Unfortunately, MIS can be considerably more challenging than conventional open surgery because there is no direct line-of-sight capability and the surgeon is dependent upon monitor display systems (MDS) to visualize the anatomy. Furthermore, the majority of MDS currently employed lack true stereoscopic capability [2].

To optimize the benefits of MIS, it is important to minimize the dangers of its requisite technology. The display of images on MDS can result in projective distortion and inability to acquire stereoscopic depth perception. Therefore, hand-eye coordination is a serious challenge for inexperienced MIS surgeons [3]. Increasingly sophisticated, computer-guided training of surgeons can make MIS safer [4].

C. Feng (✉) · J. W. Rozenblit · A. J. Hamilton
Department of Electrical and Computer Engineering and
Arizona Simulation Technology and Education Center
(ASTEC), University of Arizona, Tucson, AZ 85721, USA
e-mail: fengc@ece.arizona.edu

J. W. Rozenblit · A. J. Hamilton
Department of Surgery, University of Arizona,
Tucson, AZ 85721, USA

As the field of MIS developed, three-dimensional (3D) cameras with special display systems were developed to provide stereoscopic visualization of the operative field. Head-mounted display [2] and monitors that need spectral eyeglasses [5–7] are the two typical solutions. While such systems were theorized to give surgeons more precise visual input about depth perception, studies showed that such 3D systems could be bulky, intrusive, and uncomfortable. The results of such studies often yield contradictory results, with some 3D systems showing enhanced performance when compared with 2D [2] while other studies did not agree [5].

High-definition (HD) systems have recently become popular because of their high fidelity. A typical HD system for MIS includes a conventional endoscope, a HD digital camera providing a 1080p HD image, and a HD monitor with 1080p image quality [8].

It is unclear whether the introduction of HD systems actually improves surgeons' hand–eye coordination. No study, to our knowledge, has compared all the MDS (2D, HD, and 3D) against each other in a controlled setting. To carry out an objective assessment of MDS, we introduced a computer-assisted surgical trainer (CAST) capable of sensing and analyzing surgical task performance with standardized laparoscopic instruments while collecting data on multiple performance parameters [9].

Materials and methods

Study design

CAST consists of a 3D operative space defined by an electromagnetic sensing device (the microBIRD [10]). We modified standard laparoscopic instruments (Karl Storz Endoscopy, Culver City, CA) to include small (1.3 mm in diameter) sensors embedded in the tip of the instruments (the microBIRD sensing system produced by Ascension Technology, Burlington, VT). During the course of a surgical training task, we recorded the movement of those instruments. The measurement rate is 68.3 Hz with linear accuracy of ± 1.4 mm and rotational accuracy of $\pm 0.5^\circ$ [10].

The system hardware setup is shown in Fig. 1. A standard box trainer is used to simulate the surgical working space. The access ports for introduction of the laparoscope and instruments were fixed. For the standard laparoscopic 2D system, we used a Karl Storz Endoscopy 0° telescope, a charge-coupled device (CCD) camera, a light source, and a 15-inch cathode-ray tube (CRT) monitor. For the HD system, we used a Karl Storz Endoscopy HD camera, and replaced the CRT monitor with a 1080p HD liquid-crystal display (LCD) monitor [8]. For the 3D system, we used a



Fig. 1 Hand–eye coordination experiment system setup

stereovision camera (Welch Allyn Inc., Skaneateles Falls, NY), a ViewSonic 17-inch CRT monitor, and a pair of 3D goggles. We aligned all the monitors to the same height, and adjusted the endoscopes and cameras so that study participants saw the same scenes on the different monitors [10]. The box trainer was placed on a mobile station which was moved each time in order to bring it in front of each monitor used. Therefore, the setup did not affect the performance of the laparoscopic tasks on different displays.

For the surgical tasks, we used a standard set of targets of various heights (from 0 to 10 cm) to introduce depth perception change. The sequence of targets marked was always the same (Figs. 2, 3). We labeled five targets as start, 0, 1, 2, 3, and 4. Study participants were asked to touch the targets as fast as they could, using the instrument tip, in the sequence: start point \rightarrow 0 \rightarrow 1 \rightarrow 0 \rightarrow 2 \rightarrow 0 \rightarrow 3 \rightarrow 0 \rightarrow 4. When a participant successfully moved the instrument from one target to the next one within the required time frame (10 s), this was considered an accurate movement. All of our human subjects research was done under the supervision of, and in compliance with the regulations of, the University of Arizona's Institutional Review Board.

Metrics

During our study, we recorded data on the position of the instrument in 3D space, the time stamp, and the desired target. In addition, we derived these parameters from the data:

1. *Time consumed* By integrating the study participant's transit times between adjacent sample points, we measured the time consumed between targets as well as the total time consumed from the start point to the final target. Participants had to move the instrument quickly and accurately, because a time constraint was

Fig. 2 Screenshot of the basic hand–eye coordination training program. Study participants were asked to touch the tip of the targets in sequence

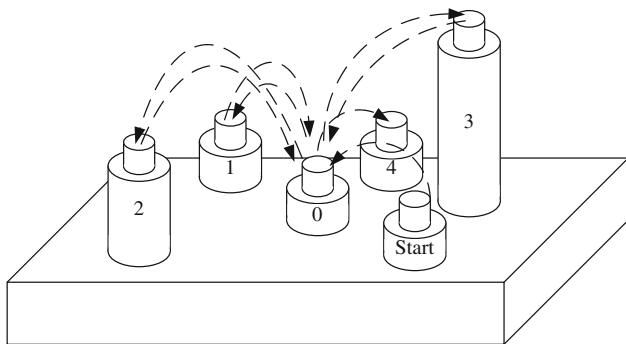
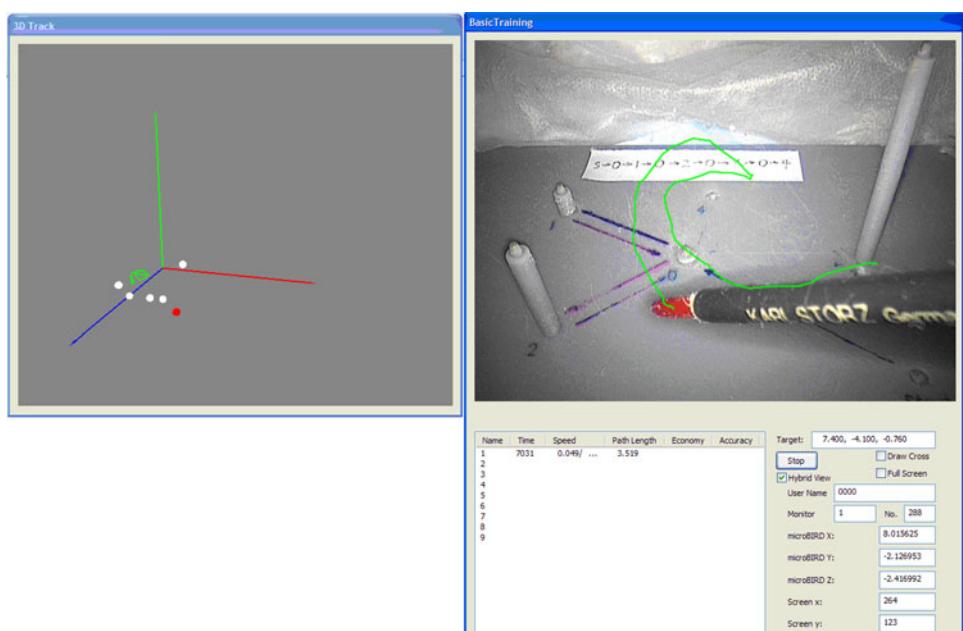


Fig. 3 Hand–eye coordination training scenario

imposed. If they could not touch the correct target within the required time period, they would fail and the destination was changed to the next target.

2. *Average speed* The average speed was the result of overall transit distance divided by the total time consumed from the start point to the final target.
3. *Movement economy* We used this movement economy ratio:

$$r = \sum_{i=1}^n I_i / \sum_{i=1}^n R_i \quad (1)$$

where r is the movement economy ratio, n is the total movement segmentation number, $i = 1, 2, \dots, n$ is the serial number of each movement segmentation, R_i is the real path length of movement segment i , and I_i is the ideal path length of movement segment i . The movement economy is a metric which evaluates the accuracy of instrument motion; only a movement close to the ideal path can get higher accuracy score.

In surgical performance, both time and accuracy are important. A time threshold should be set, so that no performance should last longer than this threshold. When a participant can meet this requirement, analysis should focus on the accuracy of the performance.

For our training scenario, the ideal path was the straight-line segment between two target points. In theory, if a participant made an ideal straight-line movement, his or her movement economy would be perfect, i.e., 100%.

Participants

This study was performed under the supervision of the Institutional Review Board of the University of Arizona and in compliance with its regulations and requirements. All participants volunteered to participate after completion of a standardized informed consent form.

Because the goal of this study is to evaluate the impact of the monitor display system (MDS) on surgical hand–eye coordination, the steep learning curve of the simulation trainer could influence the result. Furthermore, the HD system was a prototype technology at the time the study was undertaken, so that a group with significant experience on a regular resolution display (2D) could also be a biased.

To reduce the learning curve effect, study participants did not use our CAST before actual test data were collected. Before the experiment, we gave participants a short introduction about how to touch the target and the path. They were randomly assigned to four groups to switch among the three MDS in different sequences.

Each participant was required to finish five training iterations. Each of the training iterations consisted of three

Table 1 Switch sequence

Group	Switch sequence
1	HD–3D–2D
2	HD–2D–3D
3	3D–HD–2D
4	3D–2D–HD

trials. For example, a participant in group 1 did the first trial via the HD system, then switched to the 2D system for the second trial, and then finished the third trial via the 3D system. He or she needed to repeat the HD–2D–3D sequence five times. Table 1 details the MDS randomization sequence.

Questionnaire

Participants were required to complete a questionnaire concerning their experience with the different systems after they finished their iterations. We asked the following three questions:

1. Which system gave better depth perception?
2. Which system gave better texture perception?
3. Which system did you find more natural to use?

The participants needed to choose from HD, 3D, or 2D to answer each question.

Results

At total of 27 participants (12 male, 15 female) completed our study. The vast majority (92.6%) were right-handed. Average age was 29.8 years (range 22–65 years). Their surgical skills background is listed in Table 2.

Participants were either nonphysicians or physicians. The nonphysician group ($n = 21$) comprised individuals with no medical experience as well as medical students (with and without laparoscopic training). The physician group ($n = 6$) was comprised of two residents (PGY1 with average 1 laparoscopic case experience), three residents (PGY2 with average 45 laparoscopic cases experience), and one attending faculty surgeon who had completed

Table 2 Surgical background of participants

Background	<i>n</i>
Individual with no medical experience	7
Medical student with no laparoscopic training	9
Medical student with some laparoscopic training	5
Resident	5
Surgeon (residency completed)	1
Total	27

board certification. For the training iterations, we controlled for trial order; our independent variables were training level (nonphysician versus physician), monitor type (2D versus HD versus 3D), and training by monitor interaction indicated in Table 1.

To examine the effect of monitor type on time consumed, average speed, and movement economy, we conducted mixed model analyses on the fifth trial, controlling for trial order; our dependent variables were training level and baseline status before the first trial. A *p* value of less than 0.05 was considered significant. Tables 3 and 4 show our results.

As shown in both Tables 3 and 4, time required for completion of the assigned was significantly longer with the HD monitor than the 3D or 2D monitor ($p < 0.0001$). There were no significant differences in time consumed between the 3D and 2D monitor. Training level did not significantly affect time consumption.

Table 3 Results by monitor type

Monitor	Mean	Std error
Movement economy Scale: 0 (0%) to 1 (100%)		
HD	0.6676	0.0177
3D	0.7511	0.0186
2D	0.7612	0.0187
Average speed (inch/s)		
HD	1.332	0.0747
3D	1.549	0.0749
2D	1.412	0.0748
Time consumed (ms)		
HD	19,205	1,050.03
3D	13,616	1,084.18
2D	14,691	1,075.42

Table 4 Results by training level

Monitor	Training level			
	Nonphysician		Physician	
	Mean	Std error	Mean	Std error
Movement economy Scale: 0 (0%) to 1 (100%)				
HD	0.6865	0.0203	0.6021	0.0384
3D	0.7534	0.0208	0.7503	0.0383
2D	0.7505	0.0212	0.7908	0.0384
Average speed (inch/s)				
HD	1.339	0.0975	1.334	0.2056
3D	1.571	0.0964	1.448	0.2099
2D	1.432	0.0970	1.342	0.2086
Time consumed (ms)				
HD	18,939	1,182.24	20,238	2,251.44
3D	13,506	1,214.34	13,599	2,232.87
2D	15,112	1,220.79	13,521	2,210.73

Table 5 Relationship between average speed and movement economy

Monitor	r	Sig
HD	-0.047	0.514
3D	-0.091	0.265
2D	-0.030	0.679

Table 6 Questionnaire results

Question	HD		3D		2D	
	n	%	n	%	n	%
1	12	44.4	12	44.4	3	11.1
2	24	88.9	1	3.7	2	7.4
3	16	59.3	5	18.5	6	22.2

Average speed with the 3D monitor was significantly faster than with the HD ($p < 0.0001$) or 2D ($p < 0.0086$) monitor. There was no difference in average speed with the HD versus 2D monitor. Training level did not significantly affect average speed.

Movement economy with the HD monitor was significantly reduced when compared with the 3D ($p < 0.0004$) and 2D ($p < 0.0001$) systems. There was no difference in movement economy between the 3D versus 2D monitor. Within each training level (nonphysician versus physician), movement economy was less efficient with the HD monitor than with the 3D or 2D monitor. We noted a trend ($p < 0.06$) toward significance for nonphysicians to be more efficient than physicians with the HD monitor (Table 4).

The overall correlation between average speed and movement economy was not significant for type of monitor system employed (Table 5).

The questionnaire results showed that the HD monitor was the overwhelming favorite in terms of texture perception and naturalness of use. Both the HD and 3D monitors were favored by some participants for depth perception. We found no significant differences in monitor preference by gender or training level (Table 6).

Discussion

Previous studies have attempted to evaluate surgeons' laparoscopic performance with respect to the use of different laparoscopic monitor types. Hagiike et al. [11] claimed that HD monitors improved laparoscopic performance over conventional ones. On the contrary, Otto et al. [12] concluded that HD monitors may not add significant value over current solution.

One reason for these inconsistent results is that these studies did not employ computer-generated quantitative analysis of performance parameters. Most used a stopwatch as the only available measurement [6, 11, 12].

The CAST prototype proved sensitive enough to detect slight differences in performance parameters associated with the use of the three MDS we tested, namely 2D, HD, and 3D. It generated performance parameters including the speed with which the surgical task was successfully completed (time consumption), as well as movement economy, which has been shown to be a significant correlate of surgical proficiency [13]. From the data gathered by the sensors, a trend can be observed for smooth movement to have better economy and higher average speed.

One explanation for our study participants' lower than expected performance with the HD monitor might be the information-to-noise ratio [14]. Since the HD monitor provides much more visual information than a low-resolution monitor (HD, 2 million pixels versus low resolution, 300,000 pixels), human users may consume more resources in processing the HD monitor's image data. A second explanation may relate to magnification and field of view. Users viewing the same scene may have the illusion, when the screen appears relatively larger, that they have more free space or can generate higher speeds than they actually are able to do.

Our study allowed us to compare all the MDS (2D, HD, and 3D) against each other in a controlled setting. In the past, the ergonomics of 3D systems were not attractive to users [6]. Moreover, technical constraints negatively affected 3D picture quality [5]. Thus, 3D systems have not become widely employed in the field of laparoscopic surgery to date. However, putting the ergonomic issues aside, our study found that subjects favored the 3D system for its depth perception capabilities. Participants were also able to perform faster with the 3D monitor than with either the HD or 2D monitor. Several prior studies have attempted to demonstrate the potential beneficial effect of stereoscopic display on acquisition of MIS skills, with inconclusive results. Some studies [2] appear to show a positive effect on training, while others, like our own, were unable to see a beneficial result [7] and found it perhaps to be even detrimental [5]. It would seem, at least, that stereoscopic display does not result in overwhelmingly positive outcomes when assessing MIS training.

Our subjective questionnaire results indicated that most participants preferred the HD monitor, even though objective measurements indicated that HD monitors did not ameliorate performance compared with use of the 3D or standard 2D laparoscopic monitor.

Laparoscopic training has been demonstrated to involve a steep learning curve [15]. Our design attempted to take

this curve into consideration by randomizing the order in which MDS were presented to subjects. One potential disadvantage of the surgical task employed for this study is that the order of target presentation was constant and therefore predictable. Studies have indicated that psychomotor performance is enhanced when target position is known and subjects can anticipate where to direct movement [16]. To overcome this drawback, a second-generation system is under development that will allow multiple targets to be randomly presented. The current study only evaluated dominant-hand performance with a laparoscopic instrument. Hand dominance is known to have a significant effect on hand–eye coordination [17]. The second-generation CAST prototype will collect data from both right and left instruments, either separately or jointly, to evaluate the effect of hand dominance as well as the effect of assigning separate tasks to each hand. Finally, the ability of computerized systems, such as the CAST system employed in this study, raises the possibility of real-time analysis, permitting not only refinement of surgical technique and education but also the development of computer-assisted devices—so-called “smart” instruments—that can analyze the movements of surgical tools in real time to effect path and course correction to reduce technical errors [9].

The goal of the study is to determine the impact of various types of monitors on basic skills of MIS. The training task designed in the study required the participants to maintain smooth, highly efficient movement so that we could evaluate the performance differences quantitatively. The performance impact of the HD and 3D systems on complex surgical tasks such as suturing and cutting is still unclear.

Conclusions

A computerized data collection and analysis of performance metrics has the capacity to measure the effect of monitor display systems on surgical performance. Using our prototype system, we found that, while the higher resolution provided by HD displays was widely favored by surgeons, it did not yield significant improvements on parameters such as speed and movement economy. HD displays may, in fact, have detrimental effects on such parameters when compared with standard lower-resolution laparoscopic or stereoscopic display systems.

Acknowledgments This work, sponsored by Karl Storz Endoscopy, was completed at the Arizona Simulation Technology and Education Center (ASTEC), University of Arizona, Tucson, AZ, USA.

Disclosure Drs. Chuan Feng, Jerzy W. Rozenblit, and Allan J. Hamilton have no conflicts of interest or financial ties to disclose.

References

- Grimbergen GA, Jaspers JEN, Herder JL, Stassen HG (2001) Development of laparoscopic instruments. *Min Invas Ther Allied Technol* 10(3):145–154
- Bhayani SB, Andriole GL (2005) Three-dimensional (3D) vision: does it improve laparoscopic skills? An assessment of a 3D head-mounted visualization system. *Rev Urol* 7:211–214
- Holden JG, Flach JM (1996) Hand–eye coordination in an endoscopic surgery simulation. In: Proceedings of the 3rd Symposium on Human Interaction with Complex Systems (HICS ‘96), pp 110–115
- Dunkin B, Adrales GL, Apelgren K, Mellinger JD (2007) Surgical simulation: a current review. *Surg Endosc* 21:357–366
- Falk V, Mintz D, Grunenfelder J, Fann JI, Burdon TA (2001) Influence of three-dimensional vision on surgical telemanipulator performance. *Surg Endosc* 15(11):1282–1288
- Van Bergen P, Kunert W, Buess GF (2000) The effect of high-definition imaging on surgical task efficiency in minimally invasive surgery: an experimental comparison between three-dimensional imaging and direct vision through a stereoscopic TEM rectoscope. *Surg Endosc* 14:71–74
- Hanna GB, Cuschieri A (2000) Influence of two-dimensional and three-dimensional imaging on endoscopic bowel suturing. *World J Surg* 24:444–449
- Karl Storz Endoskope (2008) <http://www.karlstorz.com/>. Accessed 8 July 2009
- Feng C, Haniffa H, Rozenblit JW, Peng J, Hamilton AJ, Salkini M (2006) Surgical training and performance assessment using a motion tracking system. In: Proceedings of the 2nd European Modeling and Simulation Symposium. EMSS 2006, pp 647–652
- Ascension Technology Co. (2005) microBIRD Technical Reference Guide. <http://www.ascension-tech.com/>. Accessed 8 July 2009
- Hagiike M, Phillips EH, Berci G (2007) Performance differences in laparoscopic surgical skills between true high-definition and three-chip CCD video system. *Surg Endosc* 21:1849–1854
- Otto KJ, Hapner ER, Baker M, Johns MM III (2006) Blinded evaluation of the effects of high definition and magnification on perceived image quality in laryngeal imaging. *Ann Otol Rhinol Laryngol* 115:110–113
- Grantcharov TP, Kristiansen VB, Bendix J, Bardram L, Rosenberg J, Funch-Jensen P (2004) Randomized clinical trial of virtual reality simulation for laparoscopic skills training. *Br J Surg* 91:146–150
- Cruz M, Cruz RF, Krupinski EA, Lopez AM, McNeely RA, Weinstein RS (2004) Effect of camera resolution and bandwidth on facial affect recognition. *Telemed J e-Health* 10(3):392–402
- Schauer P, Ikramuddin S, Hamad G, Gourash W (2003) The learning curve for laparoscopic Roux-en-Y gastric bypass is 100 cases. *Surg Endosc* 17(2):212–215
- Heuer H (2002) The effects of weak perturbations on rapid finger oscillations. *Hum Mov Sci* 21(2):119–130
- Kaufman AS, Zalma R, Kaufman NL (1978) The relationship of hand dominance to the motor coordination, mental ability, and right-left awareness of young normal children. *Child Dev* 49(3):885–888