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ORIGINAL ARTICLE

The three-dimensional "insect eye" laparoscopic imaging system-a prospective randomized study

Y. Kaufman · A. Sharon · O. Klein · D. Spiegel · R. Auslander · A. Lissak

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Abstract The VS-1 "insect eye" technology is a new three-dimensional (3D) imaging system used for laparoscopic surgery. It is based on a microscopic array of hundreds of thousands of lenses that form a single apparatus, providing streaming 3D imaging without the side effects of previous 3D systems. This study analyzed the VS-1 system in terms of operative results and surgeon satisfaction compared with the standard two-dimensional (2D) imaging system. Eighty-eight patients undergoing laparoscopic surgery of different difficulty levels, performed by three different surgeons, graded as novice or experienced, were randomly assigned for the VS-1 3D or the standard 2D imaging systems, 44 patients in each group. Results showed that, when using the 3D VS-1 system, surgery duration was reduced for both novice and experienced surgeons. Surgeons reported having good depth perception, anatomic understanding and procedure efficiency, as well as physician confidence and efficiency during complicated maneuvers. No user side effects were reported. The VS-1 "insect eye" 3D imaging system provided improved operative results when compared with the 2D imaging system, with a decrease in surgery duration, along with good surgeon confidence and satisfaction, and without user side effects.

Y. Kaufman (✉) · A. Sharon · O. Klein · R. Auslander · A. Lissak
Department of Obstetrics and Gynecology,
The Lady Davis Carmel Medical Center,
7 Michal St.,
Haifa 34362, Israel
e-mail: mdykaufman@013.net.il

D. Spiegel
Department of Obstetrics and Gynecology,
Bnei Zion Medical Center,
Haifa, Israel

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Introduction

Laparoscopic surgeons may find it frustrating at times that despite profound surgical skills, experience and meticulous surgery, surgical complications during laparoscopic procedures may still occur. It is even more frustrating when the surgeon is unaware that a complication has occurred during surgery. Visual misperceptions are an important cause for surgical accidents. In some cases they arise due to dependence on monocular cues and loss of correcting binocular cues when using two-dimensional visual systems. Monocular depth perception is based on static cues, such as relative size, perspective, shadow and interposition, and on an active cue called motion parallax, which is an effect caused by movement in relation to static objects. Monocular cues usually provide adequate depth perception, but they may be misleading at times, causing optical illusions. Three-dimensional(3D) visual systems were created to overcome these misperceptions, by allowing depth perception to be based primarily on binocular cues rather than monocular cues alone.

Depth perception in humans and many other animals is based on stereovision. A binocular disparity between two separate optical channels, such as two eyes, causes formation of two different two-dimensional (2D) pictures, which are synthesized by the brain to form a (3D) picture.

Most of the previous 3D systems follow this scheme and use two cameras to get two viewpoints. The disadvantages of such a system are that two optical channels require more space than one, and that it is extremely difficult to create exactly identical cameras and, therefore, the two images differ in important characteristics (such as focus, magnification, aberration and distortion). Humans rely on stereovision for accuracy in delicate tasks, and are extremely sensitive to differences between the viewpoints. Inconsistency between the two viewpoints and between other visual cues causes side effects such as headaches, dizziness, nausea, eyestrain and fatigue [1]. Previous 3D systems have not gained popularity, mainly because surgeons had complained about these side effects when using the system.

Some insects, such as the bee, have a different visual system based on hundreds of small optical channels in each eye to get multiple viewpoints, which are synthesized to form 3D vision. The VS-1 "insect eye" system (Visionsense, Petah Tikva, Israel) is a new form of 3D technology based on these principles. It is currently used for minimal invasive surgery. The system is based on a microscopic array of hundreds of thousands of lenses that form a single apparatus. The visual information is processed by a computer that uses intensive algorithms to provide reconstructed streaming 3D imaging without the side effects of previous 3D systems. The present study analyzes the above system in terms of operative results and surgeon satisfaction when compared with a standard 2D imaging system for gynecological laparoscopic procedures.

Materials and methods

The study was approved by the hospital ethical committee and included 88 patients who were admitted for elective laparoscopic gynecological surgery to the Carmel Medical Center Endoscopic Gynecological Surgery Unit from March through September 2004. Patients willing to participate signed an informed consent and were randomly allocated to either the Storz, single chip, 2D imaging system (Tuttlingen, Germany) or to the VS-1 3D system, 44 patients in each group. Three surgeons, including one novice and two experienced surgeons, performed laparoscopic surgery of different difficulty levels. The level of difficulty of the procedures was ranked according to the AAGL credentialing guidelines for operative endoscopy, as proposed by Azziz [2]. The novice surgeon was in his first months of endoscopic training, whereas the experienced surgeons had been practicing laparoscopic surgery for up to 10 years. Operations lasting up to an hour were defined as short procedures, whereas those lasting over an hour were defined as long procedures.

Surgery time distribution (in minutes) was presented using Box-plots and tested using the non-parametric Mann-Whitney test. The median and interquartile range (IR) were used to summarize the distribution. In addition, time was categorized as <60 min or ≥60 min. Baseline binary characteristics as well as binary outcomes (e.g., blood loss >100 cc, surgery time ≥60 min) were compared between study groups using the chi-square test (or Fisher exact test, when appropriate).

Multivariate regression models (linear and logistic, as appropriate) were applied in order to adjust group comparisons to baseline characteristics. In the linear regression model for surgery time, the log-transformed time was used as the dependent variable, in order to normalize time distribution. All tests were two-sided with a significance level of 0.05. Analyses were performed using SPSS (version 11.5) statistical software (SPSS, Chicago, Ill., USA).

Results

During the study period 88 laparoscopic surgeries were performed, including 21 diagnostic laparoscopies, 16 bilateral (BSO) and eight unilateral (USO) salpingo-oopherectomies, 15 ovarian cystectomies, six bilateral tubal ligations (BTL), 18 sub-total hysterectomies (STLH), including ten combined with bilateral salpingo-oopherectomies and four total hysterectomies (TLH), including two bilateral salpingo-oopherectomies. Only one laparoscopy was converted to laparotomy. The patient belonged to the 3D VS-1 system group and conversion was performed due to ovarian malignancy diagnosed during surgery.

The youngest patient was 19 years old and the oldest was 80, with a mean age of 42 for the 2D group and 41 for the 3D group. Data on the patients and procedures are included in Table 1. There was no significant difference between the two groups with regard to experience of the surgeons and the surgical level of difficulty.

In a univariate analysis, surgery duration was shorter, with borderline significance using the 3D system vs the 2D system (median=33 min, IR=20–52 vs median=39 min, IR=27–79, P=0.087). However, when controlling for surgeon experience and surgery level of difficulty in a multivariate analysis, the difference becomes significant statistically, P=0.04 (Table 2, Figs. 1, 2). Similarly, the percent of long procedures (operations lasting longer than 60 minutes) tended to be higher in the 2D group (36% vs

Table 1 Data on the patients, surgeons and procedures

		2D (n=44)	3D (P=44)	P value
Mean age±SD		42±13	41±14	0.65
Surgeon experience (percent performed by each group)	Novice	40.9%	36.4%	0.66
	Experienced	59.1%	63.6%	
Surgical level of difficulty[a]	Level 1	29.5%	31.8%	0.82
	Level 2	70.5%	68.2%	

[a] According to the Azziz criteria [2]

Table 2 Surgery duration and blood loss according to the system in use

		2D	3D	Univariate *P* value	Adjusted *P* value[a]
Surgery duration (min)	Median (IR)	39 (27–79)	33 (20–52)	0.087	0.040
	Operation lasting >60 min	16 (36.4%)	9 (20.5%)	0.098	0.058
Operations with blood loss >100 cc	13 (27.1%)	9 (19.1%)	0.359	0.146	0.146

[a] Multivariate analysis adjusted for surgeon experience and surgery level of difficulty

20%), *P*=0.095 and 0.058 in a univariate analysis and when adjusted for surgeon experience, respectively (Table 2). In all analyses, no interaction was found between the endoscope type and surgeon experience or the difficulty of the procedure. There was no statistical difference between the two groups in the number of cases where blood loss was estimated to be more than 100 cc.

A subjective assessment of surgeon satisfaction with each of the systems was performed. There were more surgeons that reported excellent results in terms of better depth perception, anatomic understanding and procedure efficiency as well as more physician confidence and efficiency during complicated maneuvers, but this was not statistically significant (*P* values=0.520, 0.820, 0.161, 0.338, 0.098, respectively). No user side effects were reported.

Discussion

Laparoscopic minimally invasive surgery is a leading field in gynecological surgery and is considered an excellent option for abdominal surgery. In an effort to increase safety in high risk industries, such as commercial aviation, nuclear energy control and healthcare delivery, the science of “human error” attempts to characterize human performance, anticipate its failure modes and then redesign systems accordingly and retrain personnel. The same can be done within the field of laparoscopic surgery. There are numerous handicaps that impair the surgeon’s ability to perform laparoscopic surgery and may be a source for potential errors and accidents as a result. These include loss of haptic perception, movements restricted to a fixed pivot on the abdominal wall, loss of direct visualization and the use of 2D information in order to perform 3D maneuvers. Way et al. [3] analyzed the reasons for surgical accidents during laparoscopic cholecystectomy using operative radiographs, clinical records and video tapes of the operations. They found that up to 97% of the accidents happened as a result of visual misperceptions. Therefore, it might be wrong to attribute surgical complications solely to faulty decision-making and lack of surgical skills. Reliance on monocular cues alone may cause optical illusions and erroneous maneuvers as a result [4, 5]. In addition, impaired stereoscopic vision may decrease the accuracy of movements, requiring more correctional ballistic sub-movements to perform tasks [6]. Movement on the *x*- and *y*-axes relies mainly on monocular cues, whereas movement on the

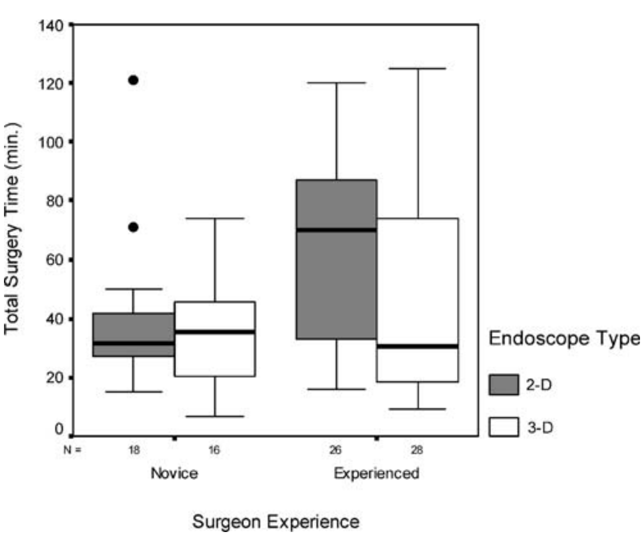

Fig. 1 Surgery duration according to surgeon experience and endoscope type

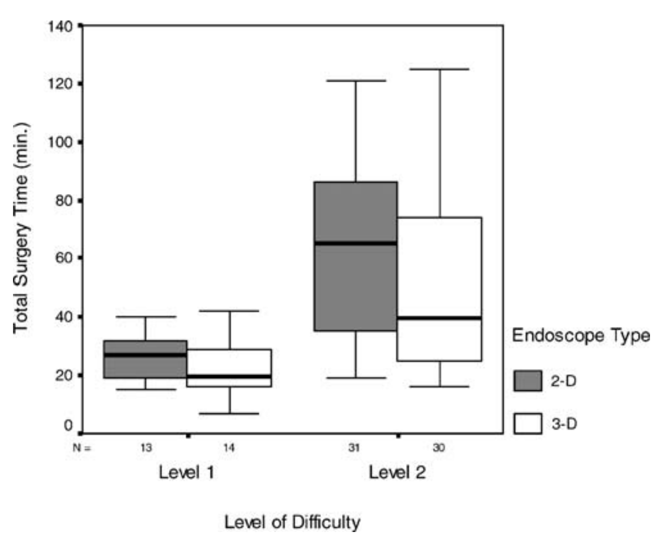

Fig. 2 Surgery duration according to surgery level of difficulty (according to the Azziz criteria [2]) and endoscope type

z-axis requires depth cues based on 3D vision. To compensate on the loss of binocular vision, the surgeon uses what is known as the *z*-lag, which means aligning first on the *x*- and *y*-axes and only then moving in on the *z*-axis. Additional movements and delayed movement on the *z*-axis prolong surgery duration and smear the learning curve of novice surgeons. It has already been proven on a closed box laparoscopic trainer simulator that using a second-generation 3D imaging system reduces the amount of time, movements and distance needed to complete a task by approximately 40–50% when compared with a 2D system [6]. This is true for both novice and expert surgeons. But the second-generation systems, using two video channels or a shutter mechanism, cause significant side effects, thereby decreasing their popularity. The VS-1 "insect eye" 3D imaging system, using a single sensor, overcomes the side effects. None of the surgeons using the system in our study reported any side effects.

Our results show that surgery duration decreases when using the VS-1 3D system compared with the Storz 2D system. We believe there may be more potential advantages to the VS-1 system that have not been statistically significant due to the small number of cases and the large variety of operations that have been examined.

The second phase of the study has recently begun in order to increase the statistical power of the study. In our view, the VS-1 system may improve learning curves of novice surgeons and offer experienced surgeons a better tool for complex surgical procedures. This remains to be studied. Enhanced learning curves may make laparoscopic surgery friendlier and, hence, increase the population of endoscopic surgeons. Cutting-edge developments are aimed at integrating the VS-1 system with other imaging modalities, such as CT and 3D/4D ultrasound, that will offer the surgeon the ability to "see through the tissue" and improve surgical performance.

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