The American Journal of Surgery 194 (2007) 115–121

Laparoscopy

Comparison of learning curves and skill transfer between classical and robotic laparoscopy according to the viewing conditions: implications for training

Adélaïde Blavier, Ph.D.[a,*], Quentin Gaudissart, M.D.[b], Guy-Bernard Cadière, M.D., Ph.D.[b], Anne-Sophie Nyssen, Ph.D.[c]

[a]*National Fund of Scientific Research, Cognitive Ergonomics Laboratory, University of Liège, place du 20-Août, 9à B-4000 Liège, Belgium*
[b]*Department of Gastro-intestinal Surgery, CHU St Pierre, Rue Haute 322, 1000 Brussels, Belgium*
[c]*Cognitive Ergonomics Laboratory, University of Liège, Liège, Belgium*

Manuscript received January 23, 2006; revised manuscript October 16, 2006

Abstract

Background: The purpose of this study was to evaluate the perceptual (2-dimensional [2D] vs. 3-dimensional [3D] view) and instrumental (classical vs. robotic) impacts of new robotic system on learning curves.
Methods: Forty medical students without any surgical experience were randomized into 4 groups (classical laparoscopy with 3D-direct view or with 2D-indirect view, robotic system in 3D or in 2D) and repeated a laparoscopic task 6 times. After these 6 repetitions, they performed 2 trials with the same technique but in the other viewing condition (perceptive switch). Finally, subjects performed the last 3 trials with the technique they never used (technical switch). Subjects evaluated their performance answering a questionnaire (impressions of mastery, familiarity, satisfaction, self-confidence, and difficulty).
Results: Our study showed better performance and improvement in 3D view than in 2D view whatever the instrumental aspect. Participants reported less mastery, familiarity, and self-confidence and more difficulty in classical laparoscopy with 2D-indirect view than in the other conditions.
Conclusions: Robotic surgery improves surgical performance and learning, particularly by 3D view advantage. However, perceptive and technical switches emphasize the need to adapt and pursue training also with traditional technology to prevent risks in conversion procedure. © 2007 Excerpta Medica Inc. All rights reserved.

Keywords: Robotic surgery; Depth perception; Movement freedom; Learning curves; Laparoscopy; Training

---

The fundamental change, produced by new technology, in how surgeons perform operations has educational implications related to learning curves and patient safety [1]. Traditionally, surgeons have honed their skills in the operating rooms through hands-on experience with veteran mentors [2]. This manner of teaching effectively trains surgeons in traditional open surgical techniques, but it is costly in terms of time, resources, and patient morbidity [3]. Over the past decade, minimally access surgery has revolutionized general surgery, posing new obstacles for surgeons attempting to acquire laparoscopic skills [4]. Indeed, laparoscopic surgery requires specialized training and practice in order to acquire new skills to operate and to manipulate tissues with long instruments, and a new knowledge of anatomy and spatial orientation [5,6]. Moreover, classical laparoscopic surgery is generally a 2-dimensional (2D) surgery. The loss of depth perception and spatial orientation are the main drawbacks for the novice to overcome when facing the television monitor [7]. Advanced complicated laparoscopic surgery requires precise manipulation of the instruments. The success of surgery, the operating time, and the morbidity rate are directly related to the manipulation skills and are responsible for the well-described "learning curve" [1,8,9].

However, minimal invasive surgery was introduced and adopted in a rapid form without precise appreciation of the long learning curve that constitutes the only existing path to overcome all of these difficulties [10]. Furthermore, very few studies have been done regarding the surgical skills

---

* Corresponding author. University of Liege, B32, Boulevard du Rectorat, 5, 40001IEGE, Belgium. Tel.: +32 4 366 31 77; fax: +32 4 366 29 44.

E-mail address: Adelaide.Blavier@ulg.ac.be

doi:10.1016/j.amjsurg.2006.10.014

education and competency testing associated with the use of new and sophisticated technology [11]. To avoid the problems that occurred at the introduction of laparoscopic surgery, several recent studies stressed the need to understand how new technology affects learning curves in order to establish appropriate training and assessment [10,11]. Our objective was to answer this question by evaluating learning curves in a comparative study between classical and robotic laparoscopy. Our study analyzed the perceptual and instrumental impacts of robotic technology on learning surgical performance of novice subjects using a standard and ecologic surgical task developed and validated in several studies (bench models [12,13–14]). We used a new-generation 3-dimensional (3D) system, the da Vinci robotic system. This robotic system allows 3D visualization of the operative field and enhances the degrees of instrument movement freedom lost in classical laparoscopy. The 3D camera system may improve the efficiency, shorten the learning curve, and reduce the operating time [7]. However, the literature shows contradictory results about the benefits brought by 3D vision: some studies show best motor performances with 3D vision [14–19], while others failed to find a difference in performance between 2D and 3D [7,20–22]. To identify precisely the nature of the skills and learning involved with the robotic system, we differentiated and independently studied the influence of the 3D view (afferent component) comparing 2D and 3D view and the influence of movement freedom restoration (efferent component) comparing classical laparoscopy with the robotic system. To our knowledge, this is the first study that compares learning curves between the da Vinci system and classical laparoscopy according to the viewing condition. Moreover, we evaluated also the transfer of acquired skills to the other viewing condition (perceptive switch: 2D vs. 3D) and to the other technique (technical switch: classical laparoscopy vs. robotic system). These 2 switches allowed us to study how participants adapted their strategy to the change in depth perception (loss or gain of binocular depth perception) and to the change in technique. Evaluating performance after a technical switch is highly relevant to understanding the risk associated with a change in procedure (e.g., a conversion procedure when the surgeon has to revert to a classical method) and to determine what constitutes adequate surgical training with the different technologies.

Finally, we studied the impact of the use of technology on the subject's self-confidence, satisfaction, and facility during the learning process, as these factors influence performance, motivation, and new technology acceptance in the operating room [23,24]. To avoid any bias from earlier laparoscopic experience in our comparison between classical and robotic laparoscopic techniques, we only selected medical students without any experience in open, minimally invasive, or robotically assisted surgery.

Methods

Materials

The da Vinci system consists of 2 primary components: the surgeon's viewing and control console and, a moveable cart with 3 articulated robot arms. The surgeon is seated in front of the console, looking at an enlarged 3D binocular display on the operative field while manipulating handles that are similar to "joysticks." Manipulation of the handles transmits the electronic signals to the computer that transfers the exact same motions to the robotic arms. The computer interface has the capacity to control and modify the movements of the instrument tips by downscaling deflections at the handles (by a factor between 5:1 to 2:1). It can eliminate physiologic tremor, and can adjust grip strength applied to the tools. The computer-generated electrical impulses are transmitted by a 10-m long cable and command the 3 articulated "robot" arms. Disposable laparoscopic articulated instruments are attached to the distal part of 2 of these arms. The third arm carries an endoscope with dual optical channels, one for each of the surgeon's eyes. As the 3D visualization can be changed to 2D, we used 3D and 2D options.

We used a pelvitrainer for the classical laparoscopic condition (from Ethicon, Brussels, Belgium). The optical system consists of the laparoscope, camera, light source and video monitor (Storz endoscope, Brussels, Belgium). The camera was always controlled by the same observer.

Subjects

This study was approved by the ethical committee at the University Hospital Centre of Bruxelles. Informed consent was obtained from each participant. Forty medical students (22 women and 18 men, mean age 24.23 ± 2.56 years) without any prior surgical experience were selected. All subjects underwent standard acuity examination (with Ergovision and Visuotest from Essilor, Brussels, Belgium) and only those with either normal or corrected-to-normal vision were included. As shown in Table 1, the subjects were randomly divided into 4 groups: the first using classical laparoscopy with indirect view (2D screen), the second using classical laparoscopy with direct view, the third using the robotic system in 3D, and the fourth using the robotic system in 2D. Subjects were unaware of the existence of 2D and 3D options of the robotic system, and then unaware of the advantages or difficulties related to their experimental condition.

Our 4 experimental conditions allowed us to differentiate 2 dimensions (see Table 1): one we called the "perceptive," afferent component, where the type of vision (binocular vs. monocular) was the main within-technique difference (between 2D and 3D viewing conditions with the same technique) and another we called the "instrumental," efferent component, where the freedom degree for instrument movement was the main between-technique difference (between the robotic system and classical laparoscopy). This experimental plan allowed us to study more precisely the influence of new technology on learning curves and particularly to

Table 1
Number of subjects in each condition according to both dimensions

Perceptive dimension	Instrumental dimension	
	Classical laparoscopy	Robotic system
2D	10 subjects	10 subjects
3D	10 subjects	10 subjects

answer the question: is the impact of this robotic system explained by the benefit of 3D view (in this case, we should observe the predominant effect of perceptive dimension and thus the difference between 2D and 3D) or by the recovery of movement freedom (in this case, we should observe a predominant effect of instrumental dimension and thus the difference between the classical and robotic system)?

Procedure

The experiment consisted of 3 successive phases: (1) learning curves—subjects repeated 6 times the task in 1 of the 4 experimental conditions; (2) perceptive switch—subjects performed 2 trials with the same technique as in the first phase but in the other viewing condition (2D vs. 3D); and (3) technical switch—subjects performed 3 trials with the other technique (classical vs. robotic system).

Task

The task involved passing in succession a needle, with a thread attached, through rings placed at different heights and depths. This task required depth perception and wrist articulation skills [12]. It also developed skills at needle transfer and thus 2-handed coordination and ambidexterity. The rings' routes required a lot of useful and usual fine movements required in minimal invasive surgery (grasping needle, curving and introducing it, etc.), and notably reproduced all of the complexity of the suture gesture (except the knot). With all of these aspects, this task seemed to be a very efficient and accurate way to evaluate minimal invasive systems.

For each trial, we calculated a performance score based on the number of rings in which the subjects went through with the needle in 4 minutes. All procedures were video-recorded and accuracy was evaluated by 3 independent observers. For each trial, an error score was constituted by the total of failures (failure to grasp needle in 1 attempt, dropping the needle, missing the ring) and an ambidexterity score corresponded to the total number of alternative uses of left and right instruments.

Questionnaires

After determined trials (1, 2, 6, 7, and 9), participants evaluated their performance and answered a questionnaire about their feelings of mastery and familiarity with the technique and their feeling of performance satisfaction, self-confidence, and difficulty on a 4-point Likert scale.

After the technical switch, subjects were asked to compare the 2 techniques (robotic vs. classical laparoscopic system) on a 4-point Likert scale regarding their general performance, speed of execution of the task, gesture accuracy, gesture quality, image quality, site view, instrument utilization, spatial orientation, comfort, action visibility, difficulty, concentration, feedback quality, and anticipation.

Statistical analysis

Learning curves for performance score, error score, and ambidexterity score and answers to the questionnaire were analyzed by repeated-measures analysis of variance (Statistica 6.1; StatSoft, Tulsa, OK). We used the Newman-Keuls test for post hoc comparisons. Student *t* test was used to analyze answers to the final questionnaire comparing classical laparoscopy and the robotic system. Significance was defined as a P value less than .05.

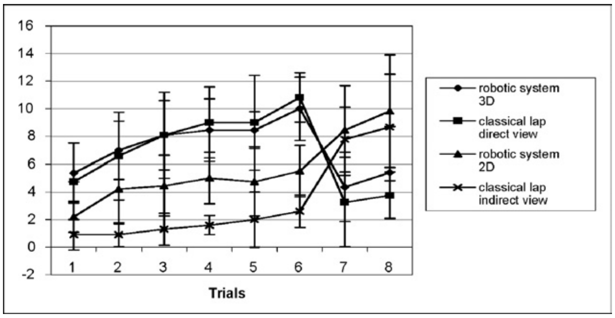

Fig. 1. Learning curves for performance scores in the first 6 trials and in the perceptive switch (trials 7 and 8).

Results

Learning curves

Performance of all subjects improved from their first to sixth trial (F(5,180) = 25.52, $P < .000$), but learning curves were significantly different among the 4 conditions (F(15,180) = 2.12, $P < .005$, Fig. 1): the 3D view (classical and robotic laparoscopy) allowed a great and fast improvement, whereas the improvement was very weak for classical laparoscopy with 2D-indirect view. From the first trial, post hoc comparisons showed that performances with the robotic system in 3D (5.36 ± .56) and in classical laparoscopy with 3D-direct view (4.75 ± .52) were significantly better than with the robotic system in 2D (2.2 ± .58, $P < .005$ and $P < .01$, respectively) and the worst performance was obtained for classical laparoscopy with 2D-indirect view (.9 ± .58, $P < .0005$ and $P < .001$, respectively). As shown in Fig. 1, these differences persisted and increased trial after trial with a better performance with the 3D view (robotic or classical laparoscopy) than with the robotic system in 2D ($P < .005$ in the first trial, $P < .0005$ in the sixth trial) and with classical laparoscopy with 2D-indirect view ($P < .0005$ in the first trial, $P < .0001$ in the sixth trial). The difference between the robotic system in 2D and classical laparoscopy with 2D-indirect view also persisted but decreased trial after trial ($P < .005$ in the first trial, $P < .05$ in the sixth trial).

Concerning the performance quality (Table 2), from the first trial, error score was significantly higher in 2D-view conditions (laparoscopic and robotic) than in 3D-view conditions (F(3,36) = 15.83, $P < .00005$) and did not evolve during the trials (F(5,180) = .53, $P = .75$). In the first trial, ambidexterity score was significantly higher for classical laparoscopy with direct view than for the robotic system in 3D ($P < .05$) and higher in 3D-view conditions than in 2D-view conditions ($P < .0005$, F(3,36) = 16.06, $P < .00001$). From the second trial, difference of ambidexterity score was only between 2D- and 3D-view conditions, independently of the instrument aspect, and significantly evolved in all conditions until the sixth trial (F(5,180) = 9.73, $P < .0000$, Table 2). We observed no significant interaction

Table 2
Error scores and ambidexterity scores in trials 1, 2, 6, 7, and 9 (interobserver reliability, Cronbach's alpha = 0.86)

	Classical laparosc with indirect view	Classical laparosc with direct view	Robotic system in 2D	Robotic system in 3D	*P* value
Error score					
Trial 1	20.12 ± 2.29	9.03 ± 3.14	18.89 ± 5.1	11 ± 4.3	<.0000 (1,2-3,4)
Trial 2	20.87 ± 5.74	10.33 ± 1.53	17.75 ± 6.98	12.67 ± 4.66	<.05 (1,2-3,4)
Trial 6	20.56 ± 5.66	8.67 ± 1.53	17.292 ± 4.15	8.67 ± 4.87	<.0001 (1,2-3,4)
Trial 7	22.67 ± 4.73	11 ± 8.66	22.11 ± 5.28	11.63 ± 7.25	<.01 (1,2-3,4)
Trial 9	30.43 ± 9.55	13.08 ± 4.58	23.67 ± 8	10.5 ± 4.37	<.0005 (1,2-3,4)
Ambidexterity score					
Trial 1	3.02 ± 2.33	15.67 ± 10.21	4.67 ± 3.24	9.38 ± 4.24	<.001 (4-3-1,2)
Trial 2	4.62 ± 2.44	17.54 ± 2.64	6.25 ± 3.49	9.33 ± 3.7	<.0001 (1,2,3-4)
Trial 6	7.06 ± 2.5	23.05 ± 7.23	7.86 ± 4.18	17.56 ± 5.68	<.00001 (1,2-3,4)
Trial 7	9.33 ± 2.08	14.04 ± 7.81	7.11 ± 3.95	11.63 ± 7.25	NS
Trial 9	2.86 ± 2.54	13.07 ± 7.43	5.78 ± 2.77	9.87 ± 4.05	<.005 (1-3,4;2-4)

Trial 1 = classical laparoscopy with indirect view; 2 = robotic system in 2D; 3 = robotic system in 3D; 4 = classical laparoscopy with direct view; Laparoscop = laparoscopy; NS = not significant.

between the conditions and the error score ($F(15,180) = .89$, $P = .57$) or the ambidexterity score ($F(15,180) = 1.61$, $P = .08$).

Concerning answers to the questionnaire, feelings of mastery ($F(2,72) = 11.61$, $P < .00005$), familiarity ($F(2,72) = 19.78$, $P < .0000$), satisfaction ($F(2,72) = 6.55$, $P < .005$), self-confidence ($F(2,72) = 5.54$, $P < .01$), and difficulty ($F(2,72) = 3.34$, $P < .05$) significantly evolved in all conditions during the trials. As shown in Table 3 (trials 1, 2, 6), subjects significantly reported in general less mastery ($F(3,36) = 4.29$, $P < .05$), familiarity ($F(3,36) = 4.39$, $P < .05$), and self-confidence ($F(3,36) = 2.95$, $P < .05$) and more difficulty ($F(3,36) = 3.61$, $P < .05$) in classical laparoscopy with 2D-indirect view than in other conditions. Satis-

Table 3
Feelings scores of mastery, familiarity, satisfaction, self-confidence and difficulty for trials 1, 2, 6, 7, and 9

	Classical laparoscopy with indirect view	Classical laparoscopy with direct view	Robotic system in 2D	Robotic system in 3D	*P* value
Trial 1					
Mastery	1.22 ± .44	1.83 ± .72	1.89 ± .78	2 ± .7	NS
Familiarity	1.33 ± .5	2.25 ± .96	2.11 ± .78	2.33 ± 1	<.05
Satisfaction	1.44 ± .53	2.17 ± 1.03	1.78 ± .83	2.33 ± .87	NS
Self-confidence	1.44 ± .73	2 ± .95	2 ± .87	2.56 ± .73	<.05 (3-1)
Difficulty	3.67 ± .5	3 ± .74	3 ± .74	2.78 ± .67	<.05 (2,3,4-1)
Trial 2					
Mastery	1.44 ± .53	2.25 ± .75	2.33 ± .87	2.56 ± .53	<.01 (2,3,4-1)
Familiarity	1.56 ± .53	2.5 ± .79	2.33 ± .87	2.78 ± .67	<.01 (2,3,4-1)
Satisfaction	1.78 ± .67	2.33 ± .87	2.22 ± .67	2.11 ± .6	NS
Self-confidence	1.67 ± .7	2.25 ± .61	2.44 ± .88	2.56 ± .53	<.05 (2,3-1)
Difficulty	3.67 ± .5	2.83 ± .72	2.78 ± .83	2.67 ± .7	<.05 (2,3,4-1)
Trial 6					
Mastery	1.78 ± .67	2.72 ± .65	2.22 ± .67	2.56 ± .53	<.05 (3,4-1)
Familiarity	2 ± .7	2.9 ± .7	2.33 ± .7	2.78 ± .67	<.05 (1-4)
Satisfaction	2.11 ± .78	2.9 ± 1.04	2.22 ± .67	2.56 ± .53	NS
Self-confidence	1.89 ± .78	2.72 ± .79	2.44 ± 1.13	2.56 ± .53	NS
Difficulty	3.22 ± .83	2.36 ± .92	3.22 ± .44	2.44 ± .88	<.05 (1-3)
Trial 7					
Mastery	1.75 ± .5	2.56 ± .88	1.56 ± .73	2.78 ± .97	<.05 (3,4-1)
Familiarity	1.75 ± .5	2.77 ± .67	1.67 ± .7	3 ± .7	<.005 (3,4-1,2)
Satisfaction	2 ± .82	2.67 ± .5	1.22 ± .44	2.89 ± .78	<.0005 (3,4-1,2;1-2)
Self-confidence	1.75 ± .5	2.67 ± .7	1.56 ± .73	3.11 ± .78	<.0005 (3,4-1,2)
Difficulty	3 ± 1.41	2.67 ± .7	3.33 ± .7	3 ± .7	NS
Trial 9					
Mastery	1 ± 0	1.71 ± 1.11	1.75 ± .46	2.27 ± .79	<.005 (2,3,4-1)
Familiarity	1 ± 0	1.43 ± .53	2.12 ± .64	2.55 ± .93	<.0005 (2,3-1,4)
Satisfaction	1 ± 0	1.43 ± .53	1.87 ± .64	2.18 ± .98	<.005 (2,3-1)
Self-confidence	1 ± 0	1.86 ± .69	1.75 ± .7	2.45 ± .93	<.0005 (2,3,4-1)
Difficulty	3.9 ± .32	3.57 ± .53	2.87 ± .64	2.64 ± .8	<.0005 (2,3-1,4)

1 = classical laparoscopy with indirect view; 2 = robotic system in 2D; 3 = robotic system in 3D; 4 = classical laparoscopy with direct view.

faction was not significantly different among the 4 conditions (F(3,36) = 2.58, $P = .69$).

Perceptive switch

After the perceptive switch (Fig. 1, trial 7), subjects performed significantly better with 3D view (robotic system, 8.44 ± 3.24, and classical laparoscopy, 7.78 ± 2.33) than with 2D view (robotic system, 4.42 ± 2.39, $P < .05$, and classical laparoscopy, 3.25 ± 1.7, $P < .005$, F(3,36) = 7.66, $P < .001$). The gap between the trials 6 and 7 was significant in all conditions (F(3,36) = 35.06, $P < .0000$): performance significantly decreased from 3D to 2D condition in classical ($P < .0005$) and robotic ($P < .0005$) system and significantly increased from 2D to 3D condition in classical ($P < .0005$) and robotic ($P < .005$) system. The performance improvement between trials 7 and 8 was not significant in any condition (F(1,36) = 1.24, $P = .27$).

Similar results were obtained concerning error score with a significantly higher score in 2D-view conditions than in 3D-view conditions (Table 2, F(3,36) = 6.82, $P < .005$). Concerning ambidexterity score, no significant difference was obtained among the 4 conditions (Table 2, F(3,36) = 1.46, $P = .18$).

When we compared subjective evaluation between trials 6 and 7 (Table 3), feelings of familiarity (F(3,36) = 13.96, $P < .00005$), mastery (F(3,36) = 19.96, $P < .00005$), and self-confidence (F(3,36) = 18.04, $P < .000005$) significantly decreased for subjects switching from 3D to 2D with classical (respectively, $P < .005$, $P < .0005$, $P < .001$) and robotic (respectively, $P < .05$, $P < .005$, $P < .01$) system and significantly increased for subjects switching from 2D to 3D only in classical laparoscopy (respectively, $P < .05$, $P < .01$, $P < .05$). Feeling of satisfaction significantly decreased only for subjects switching from 3D to 2D with the robotic system ($P < .01$, (F(3,36) = 10.51, $P < .0001$). No significant difference was obtained in the switch from 2D to 3D with the robotic system and in difficulty evaluation.

Technical switch

After the technical switch (trial 9, see Fig. 2), performance decreased in all conditions, reaching the same score as the first trial (in classical laparoscopy, performance was slightly worse than in the first trial). We obtained a significant difference between all conditions (F(3,36) = 18.21, $P < .000005$) except between classical laparoscopy with 3D-direct view (3.78 ± 1.64) and robotic system in 2D (2.38 ± 1.3); best performance was obtained with the robotic system in 3D (5.55 ± 2.77) and worst performance was in classical laparoscopy with 2D-indirect view (.3 ± .48). The improvement during these last 3 trials was significant only in classical laparoscopy with 3D-direct view ($P < .05$, F(2,36) = 27.92, $P < .001$). In trial 10 (F(3,36) = 7.45, $P < .001$), performance was significantly better in 3D view (robotic system in 3D, 6.56 ± 3.05 and classical laparoscopy with direct view, 5.5 ± 3.25) than in 2D view (robotic system in 2D, 2.67 ± 1.5 and classical laparoscopy with indirect view, 1.37 ± 1.06). In trial 11 (F(3,36) = 23.99, $P < .00005$), performance was significantly different between all conditions except between robotic system in 2D (3.5 ± 2.38) and classical laparoscopy with 2D-indirect view (1 ± 1), with a significantly better performance in classical laparoscopy with 3D-direct view (11.67 ± 2.08) than with robotic system in 3D (7.8 ± 1.09).

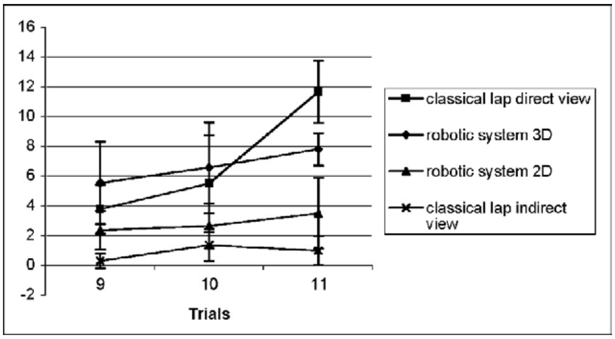

Fig. 2. Learning curves for performance scores after the technical switch.

Table 4
Answers to questionnaire comparing the two techniques (classical and robotic laparoscopy)

	Classical laparoscopy	Robotic system	T and *P* value
General performance	2 ± 1.06	3 ± 1.05	2.83; <.01
Speed of performance	1.94 ± .96	2.89 ± .94	3; <.005
Gesture accuracy	1.82 ± .95	3.42 ± .69	5.81; <.05
Image Quality	1.8 ± .79	2.98 ± .89	3.38; <.05
Site view	2.23 ± 1.15	3.05 ± .78	2.52; <.05
Instrument utilization	1.87 ± .96	3.42 ± .84	5.09; <.00005
Spatial orientation	1.88 ± .78	3.31 ± .88	5.12; <.00005
Comfort	1.53 ± .62	3.53 ± .61	9.68; <.000000
Concentration	2.24 ± .9	2.37 ± 1.12	NS
Feedback quality	2.35 ± 1.17	2.74 ± .87	NS
Action visibility	2.12 ± 1.08	3.11 ± .8	3.05; <.005
Anticipation	2.23 ± .97	2.89 ± .96	2.07; <.05
Complexity	2.98 ± 1.02	1.96 ± 1.01	2.29; <.05
Gesture quality	1.88 ± .78	3.32 ± .58	6.28; <.00000

Error score was significantly higher in classical laparoscopy with 2D-indirect view than in the 3D-view conditions (Table 2, F(3,36) = 16.45, $P < .0005$). This high error score in classical laparoscopy with 2D-indirect view decreased in the following trial to reach a score similar to the 2D robotic system score (20.17 ± 3.54). Ambidexterity score was significantly higher in the 3D-view conditions than in 2D-view conditions (Table 2, F(3,36) = 18.35, $P < .005$).

After the technical switch, subjects in classical laparoscopy with 2D-indirect view significantly reported worse feelings of mastery (F(3,36) = 11.47, $P < .00005$), familiarity (F(3,36) = 6.02, $P < .005$), satisfaction (F(3,36) = 6.05, $P < .005$), self-confidence (F(3,36) = 7.87, $P < .0005$), and difficulty (F(3,36) = 9.03, $P < .0005$, Table 3, trial 9). The same negative evaluations about familiarity and difficulty feelings were reported by subjects in classical laparoscopy with 3D-direct view. Robotic system did not differ between 2D and 3D in any subjective evaluation.

The final questionnaire comparing the 2 techniques showed significant difference for all items except for the concentration and the feedback quality; perhaps these questions were too abstract or not understood by the subjects (Table 4).

Comments

First phase: learning curves

The need to compare learning curves obtained with different technologies and to determine the impact of several factors (depth perception, dexterity, etc.) on surgical training has been pointed out by recent studies [10,11,25]. Indeed, our study showed that learning curves were different according to the technique and the viewing condition. In 3D-view conditions, learning curves of robotic and classical laparoscopy followed a similar pattern, with better performance and greater improvement than robotic system in 2D and classical laparoscopy with indirect view. In 2D-view conditions, we observed an improvement during the first 3 trials with the robotic system, while in classical laparoscopy, the improvement was very small and progressive. Moreover, the gap in performance between 3D-view conditions (robotic system in 3D and classical laparoscopy with direct view) and 2D-view conditions (robotic system in 2D and classical laparoscopy with indirect view) increased trial after trial. This finding of best performance with a 3D view whatever the instrumental aspect (classical or robotic) emphasizes the persistent and increasing impact of perceptive advantage brought by binocular vision that overlaps the instrumental difficulty. In contrast, in 2D-view conditions, performances and improvement were better with the robotic system than in classical laparoscopy. This result suggests that unlike the 3D view, instrumental benefit influences and facilitates performance in 2D view.

No accuracy progress was observed in any condition during all trials, but ambidexterity score improved in all conditions, particularly in 3D-view conditions, where subjects used both hands with more facility. In parallel, participants generally reported less mastery, familiarity, and self-confidence and more difficulty in classical laparoscopy with 2D-indirect view than in the other conditions. However, these impressions positively evolved in all conditions, indicating an increase in the satisfaction and in the control sensation of the situation.

Second phase: perceptive switch

After the perceptive switch, as expected, subject's performances were affected by the 2D–3D change. In the 2 trials of this phase, the performance and error scores were only differentiated by the perceptive dimension, with better performance in 3D view (classical and robotic system) than in 2D view. Furthermore, performances were stable without any positive or negative evolution during the 2 trials. Perceptive switch also had a strong impact on subjective evaluation: a positive impact on subjects switching from 2D to 3D and a negative impact on subjects switching from 3D to 2D. As in the previous phase, subjects reported more mastery, familiarity, self-confidence, and satisfaction when they used 3D view (classical or robotic system) than when they acted with 2D view. These results again emphasized the role of perceptive dimension (see Table 1), differentiating between 2D and 3D whatever the instrumental dimension.

Third phase: technical switch

In the final phase, after the technical switch, the performances in all conditions decreased to the same score as in the first trial. Moreover, the performances did not much improve in this final phase, participants showing difficulty adapting their movements to the other technique: with the robotic system, subjects kept a conservatory strategy used in classical laparoscopy and showed difficulty moving the camera, and with classical laparoscopy, manipulation of long and rigid instruments seemed to be the most difficult obstacle to overcome, producing a very high error score in classical laparoscopy with 2D-indirect view. However, the improvement and best performance in the last trial in classical laparoscopy with direct view showed that 3D view allowed efficient overlap of instrumental difficulty in classical laparoscopy.

Moreover, a supplementary factor has to be taken into account for the difference between classical laparoscopy with direct and indirect view: in classical laparoscopy with indirect view, the eye–hand orientation axis is deviated because the subject does not look in the same direction as he acts, while in classical laparoscopy with direct view the eye–hand axis is re-established. This modification of the perception–action axis can explain a part of the difference observed between the 2 conditions, but its impact is difficult to estimate exactly. Recent studies have shown that the angle and direction of looking affect the quality of endoscopic surgery [26,27]. The optimal position of the monitor appeared to involve a reasonable angle relative to the operating area (45°), while performance decreased with greater angle (90°) [26]. In our study, the angle in classical laparoscopy with indirect view was 90°. This factor could particularly influence performance during the perceptive switch, where the improvement between classical laparoscopy with indirect and direct view was more significant than between 2D and 3D robotic system.

In conclusion, the findings after a technical switch led to 2 highly relevant observations: the skills acquired with a specific technique were not transferred to another technique, suggesting that skills acquired within each technique were not identical, and moreover, the learning with a specific technique could prevent learning and adequate use of another technique. Previous study suggested that the robotic system could be an ideal training tool for residents and fellows because of the greater impact of the learning curve [25]. However, our study moderates this suggestion, emphasizing the difficulty to transfer skills learned with the robotic system to classical laparoscopy.

General conclusion

In this study, 3D view led to better performance and greater improvement than 2D view whatever the instrumental advantage may be. The difference in learning curves between the different conditions confirms the hypothesis that the learning process in the da Vinci system is shorter than in classical laparoscopy [10], but our study specifies that this shortness is particularly due to the 3D view. All of these findings emphasize the need to adapt the training tasks to the technique used (eg, the weak learning effect in classical laparoscopy with 2D-indirect view suggests we should begin with more simple and basic tasks, as already advocated [28]). Moreover, the difficult skill transfer after the technical switch suggests that the 2 techniques involved or trained less than identical skills, and stresses the necessity to pursue training with the different techniques in order to prevent gaps in performance and thus operating risk if a conversion procedure occurs. In our study, classical laparoscopy with direct view had no clinical relevance but was only used to understand better the cognitive and visual–motor mechanisms involved in the learning of a complex surgical task. Participants were novices and did not achieve an expert level at the end of the trials; it is possible that other cognitive and visual–motor processes are involved in expert practice.

Finally, we showed a benefit of the training in the improvement of the performance but also in the feelings of mastery, familiarity, satisfaction, self-confidence, and facility, which are essential factors of well-being, motivation, accurate performance, and new technology acceptance in the operating room [23,24]. By all of these characteristics, this study encourages the use of bench models in training of surgical skills in parallel with traditional learning techniques.

Acknowledgment

The authors thank all medical students who participated in the study and David Douglas and Olivier Germay for their able technical assistance. This research was funded by a Grant from the National Fund of Scientific Research of Belgium.

References

[1] Sidhu RS, Tompa D, Jang R, et al. Interpretation of three-dimensional structure from two-dimensional endovascular images: implications for educators in vascular surgery. J Vasc Surg 2004;39:1305–11.
[2] Hamilton EC, Scott DJ, Fleming JB, et al. Comparison of video trainer and virtual reality training systems on acquisition of laparoscopic skills. Surg Endosc 2001;16:406–11.
[3] Bridges M, Diamond DL. The financial impact of teaching surgical residents in the operating room. Am J Surg 1989;210:118–21.
[4] Jones DB, Brewer JD, Soper NJ. The influence of three-dimensional video systems on laparoscopic task performance. Surg Endosc 1996;6:191–7.
[5] Gallagher AG, Ritter EM, Satava RM. Fundamental principles of validation, and reliability: rigorous science for the assessment of surgical education and training. Surg Endosc 2003;17:1525–9.
[6] Cadière GB, Leroy J. Principes généraux de la chirurgie laparoscopique, Encyclopédie Médicale de Chirurgie. Techniques Chirurgicales–Appareil digestif, 40-050. Paris: France; 1999.
[7] Chan ACW, Chung SCS, Yim APC, et al. Comparison of two-dimensional vs three-dimensional camera systems in laparoscopic surgery. Surg Endosc 1997;11:438–40.
[8] Forbes TL, DeRose G, Kribs SW, et al. Cumulative sum failure analysis of the learning curve with endovascular abdominal aortic aneurysm repair. J Vasc Surg 2004;39:102–8.
[9] Smith CD, Farrell TM, McNatt SS, et al. Assessing laparoscopic manipulative skills. Am J Surg 2001;181:547–50.
[10] Hernandez JD, Bann SD, Munz Y, et al. Qualitative and quantitative analysis of the learning curve of a simulated surgical task on the da Vinci system. Surg Endosc 2004;18:372–8.
[11] Prasad SM, Maniar HS, Soper NJ, et al. The effect of robotic assistance on learning curves for basic laparoscopic skills. Am J Surg 2002;183:702–7.
[12] Scott DJ, Bergen PC, Rege RV, et al. Laparoscopic training on bench models: better and more cost effective than operating room experience? J Am Coll Surg 2000;191:272–83.
[13] Derossis AM, Fried GM, Abrahamowicz M, et al. Development of a model for training and evaluation of laparoscopic skills. Am J Surg 1998;175:482–7.
[14] Reznick R, Regehr G, MacRae H, et al. Testing technical skill via an innovative "bench station" examination. Am J Surg 1997;173:226–30.
[15] Taffinder N, Smith SGT, Huber J, et al. The effect of a second-generation 3D endoscope on the laparoscopic precision of novices and experienced surgeons. Surg Endosc 1999;13:1087–92.
[16] Van Bergen P, Kunert W, Bessell J, et al. Comparative study of two-dimensional and three-dimensional vision systems for minimally invasive surgery. Surg Endosc 1998;12:948–54.
[17] Dion YM, Gaillard F. Visual integration data and basic motor skills under laparoscopy: influence of 2-D and 3-D video-camera system. Surg Endosc 1997;11:995–1000.
[18] Peitgen K, Walz MV, Holtmann G, et al. A prospective randomized experimental evaluation of three-dimensional imaging in laparoscopy. Gastrointest Endosc 1996;44:262–7.
[19] Birkett DH, Josephs LG, Este-McDonald J. A new 3-D laparoscope in gastrointestinal surgery. Surg Endosc 1994;8:1448–51.
[20] Hanna GB, Shimi SM, Cuschieri A. Randomised study on influence of two-dimensional versus three-dimensional imaging on performance of laparoscopic cholecystectomy. Lancet 1998;351:248–51.
[21] Crosthwaite G, Chung T, Dunkley P, et al. Comparison of direct vision and electronic two- and three-dimensional display systems on surgical task efficiency in endoscopic surgery. Br J Surg 1995;82:849–51.
[22] Pietrabissa A, Scarcello E, Mosca F. Three-dimensional versus two-dimensional video system for the trained endoscopic surgeon and the beginner. End Surg 1994;2:315–7.
[23] Jones G, Cale A. Goal difficulty, anxiety and performance. Ergonomics 1997;40:319–33.
[24] Marshall RL, Smith JS, Gorman PJ, et al. Use of a human patient simulator in the development of resident trauma management skills. J Trauma 2001;51:17–21.
[25] Yohannes P, Rotariu P, Pinto P, et al. Comparison of robotic versus laparoscopic skills: is there a difference in learning curve? Urology 2002;60:39–45.
[26] Verwey WB, Stroomer S, Lammens R, et al. Comparing endoscopic systems on two simulated tasks. Ergonomics 2005;48:270–87.
[27] Previc FH. The neuropsychology of 3D space. Psychol Bull 1998;124:123–64.
[28] Arnold P, Farrell MJ. Can virtual reality be used to measure and train surgical skills? Ergonomics 2002;45:362–79.