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A comparison of two-dimensional laparoscopic, three-dimensional laparoscopic and robotic suturing performance among operators with different levels of experience

술자의 복강경 수술 경험에 따른 2차원적 복강경, 3차원적 복강경 및 로봇 시스템을 이용한 봉합 술기 시행의 비교 연구

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Abstract

A comparison of two-dimensional laparoscopic, three-dimensional laparoscopic and robotic suturing performance among operators with different levels of experience

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Introduction: High-quality three-dimensional (3D) vision systems are now available for laparoscopic surgery and may improve surgical performance relative to two-dimensional (2D) laparoscopy. It is unclear whether 3D laparoscopy is superior to 3D robotic systems. The effect of surgeon experience on surgical performance with different instruments also remains unclear. This study compared the ability of experienced and inexperienced surgeons to perform a suturing task with 2D laparoscopy, 3D laparoscopy, and a 3D robot.

Methods: The 20 recruited surgeons consisted of experts (≥100 laparoscopic cases, n=9), surgeons with intermediate experience (20–99 cases, n=7), and novices (<20 cases; n=4). All performed a suturing task three times with each instrument. Task failure rates and completion times were measured.

Results: All novices failed to complete the task with 2D or 3D laparoscopy but all completed the task with the robot. The intermediate group failed the task with 2D laparoscopy (23.8% failure rate) more often than with 3D laparoscopy (4.8%) or the robot (0%; p=0.04). Expert failure rates were low for all instruments. Intermediate group task completion times were similar with 2D laparoscopy (median, 312s; range, 229–495s), 3D laparoscopy (324s; 170–443s), and the robot (319s; 213–433s) (*P*=0.237). The expert times differed significantly (*P*=0.01); post-hoc analyses showed that their total completion time with 3D laparoscopy (177s; 126–217s) was significantly shorter than with 2D laparoscopy (244s; 155–270s; *P*=0.004). It also tended to be shorter than with the robot (233s; 187–461s; *P*=0.027).

Conclusions: Novices benefited particularly from the robot. The intermediate group completed the task equally well and equally quickly with 3D laparoscopy and the robot. The experts completed the task equally well regardless of instrument but their times were much faster with 3D laparoscopy. Thus, well-trained laparoscopic surgeons may not really benefit from 3D robot systems if 3D laparoscopy is available.

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Keywords: Three-Dimensional Imaging, Laparoscopy, Robotic Surgery, Suturing

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Introduction

In the past 10 years, open surgery has been substituted by laparoscopic surgery in most fields of general surgery. However, several technical limitations continue to make complex laparoscopic procedures challenging, thereby causing the learning curves of surgeons to have long flat initial periods. The most significant technical difficulties in laparoscopic procedures relate to limited freedom of movement of rigid instruments, camera instability, and the fact that the vision is two-dimensional (2D) due to the use of a conventional monitor (1). The latter is considered to be a particularly major disadvantage when compared to open surgery (2, 3). This limitation means that to judge instrument position and depth, the laparoscopic surgeon must use auxiliary visual cues such as the motion of the laparoscope, the size of anatomic structures, and changes in shading and texture.

To overcome these limitations in conventional laparoscopy, surgical robots were introduced into clinical practice in the late 1990s. The robot system provides a three-dimensional (3D) image that eliminates the mirror effect; they also offer tremor filtering and the instrument wrists are articulated, thereby yielding three additional degrees of freedom (4). However, despite these technical advantages, the clinical benefits of robotic surgery remain unclear (5-7). Moreover, robot surgery associates with high fixed costs (8), and it is now possible to perform laparoscopic procedures with high-quality 3D vision systems. Since the development of these 3D displays, several studies have shown that they yield better laparoscopic performances than 2D vision systems (9-12). The current 3D display technology also appears to make 3D laparoscopy as tolerable as its robotic equivalent.

At present, surgical trainees are generally exposed primarily to laparoscopic systems and rarely have a chance to perform robotic surgery. We speculated that since most practicing general surgeons are already well trained in laparoscopic procedures, they may not actually need robot assistance during laparoscopic procedures if they can obtain the same quality of 3D display. However, the effect of different levels of laparoscopic experience on surgical performance with different instruments remains to be explored. The present study was performed to assess whether the high-quality 3D display that is employed by a robotic system improves the performance of a suturing task during laparoscopy. To assess the influence of differing degrees of laparoscopic experience, surgeons who were experts, novices, or had an intermediate level of experience in laparoscopy were asked to perform the suturing task with 2D laparoscopy, 3D laparoscopy, and a 3D robot.

Materials and methods

Participants and tasks

Twenty individuals with normal or corrected-to-normal vision were asked to perform a suturing task with 2D laparoscopy, 3D laparoscopy, and a 3D robot. None had any previous experience with robots. Of the 20 individuals, nine were experts (≥100 cases of laparoscopic surgical procedures such as laparoscopic appendectomy or cholecystectomy), seven had an intermediate level of laparoscopic experience (20–99 cases), and four were novices (<20 cases).

For each instrument, the participants had three chances to perform the suturing task. The order of the methods was randomized. Moreover, the three instrument trials of each individual were separated by at least 2 days to reduce bias caused by learning. All participants were given verbal instructions and shown a video demonstration of the suturing task before their first attempts.

The suturing task consisted of three consecutive steps (Fig. 1). The first step consisted placing the first stitch, tying one surgeon’s knot, and then placing two square ties. The second step consisted of five running suture stitches. The third step consisted of tying three square knots. This suturing task imitated the procedure that is used to close a common entry hole that is made after bowel anastomosis by using linear staplers. The suturing task was performed on a synthetic tissue model of 4 layer bowel (SINIX™, SINI co., Seoul, Korea) with 20 cm of 3-0 monofilament glyconate absorbable suture and an HR 26 round needle (Monosyn®, B. Braun Melsungen AG, Melsungen, Germany).

The total time to completion was recorded along with the time spent on each step of the task. Task failure was defined as the inability to accomplish one of the three steps within 5 minutes. The task failure rate and task completion time after each of the three trials for each instrument were calculated. To ensure good quality in the suturing task, the participants were repeatedly cautioned during the first and second attempts about possible strangulation or loosening. During the third attempt with each instrument, these cautions were not given. The time it took to complete the third attempt served as an objective measure of the performance of the participant.

Imaging systems

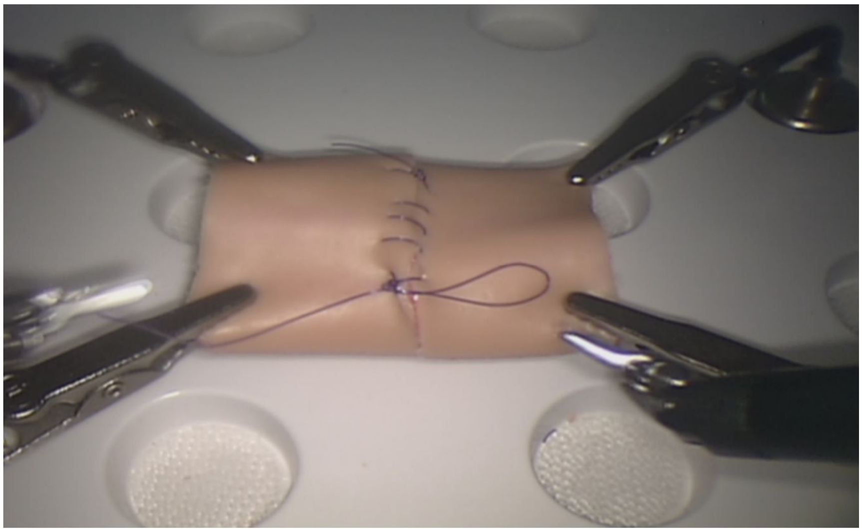
The 2D imaging system (ENDOEYE FLEX System, Olympus, Pennsylvania, USA) consisted of a high resolution camera with a flexible 10-mm diameter laparoscope and a dual CCD digital system attached to a 23-inch HD (1080i) flat screen video monitor. The ENDOEYE FLEX 3D System (Olympus, Pennsylvania, USA) was used for 3D laparoscopy. This system transmits the 3D image line by line with the right and left images being arranged in alternating order while the surgeon views these images with light polarizing 3D glasses. The 3D laparoscopic system thus consisted of a dual lens camera with a flexible 10-mm diameter laparoscope, two video systems creating left and right signals, and a 3D visualization unit that integrated the left and right images and put the 3D signal into a 23-inch 3D HD (1080i) monitor. For both 2D and 3D laparoscopy, the laparoscope was fixed in a static camera holder (Laparostat, CIVCO, Iowa, USA) to capture a constant view during the performance of the task. To ensure that the view generated by these instruments was the same as the view obtained by the robotic system, the 2D and 3D flexible laparoscopes were not articulated.

The da Vinci™ Robotic Surgical System (Intuitive Surgical Inc., Sunnyvale, CA, USA) served as the 3D robotic system. The system employed two standard 8-mm da Vinci™ needle drivers and a 10-mm 0-degree stereoscope. The robotic camera was also fixed during the performance of the task.

Statistical analysis

The data were analyzed by using SPSS version 21 (IBM, Armonk, New York, USA). For each surgeon group, the three instruments were compared in terms of task failure rates and task completion times by using Fisher's exact test and Friedman test, respectively. Wilcoxon signed rank test was used for post-hoc analysis. *P*-values less than 0.05 were considered to indicate statistical significance. However, to avoid a type I error in post-hoc analysis, *P*-values less than 0.05/3 served as the threshold for statistical significance.

Figure 1. View of the synthetic tissue after the suturing task was performed with the assistance of a three-dimensional robot system



Results

Task failure rate

None of the novices could complete the suturing task with the 2D and 3D laparoscope in any of the three attempts. However, all accomplished the suturing task when the robotic system was used: there were no failures on any of the three attempts (Table 1). The failures in 2D and 3D laparoscopy meant that the task completion time data of the novice group could be analyzed. Of the 24 task failures by the novices with the 2D and 3D laparoscopes, 19 (79.2%) occurred during the first step of the task and five (20.8%) occurred during the second step.

The intermediate group had six task failures: five occurred with the 2D laparoscope and one occurred with the 3D laparoscope. None failed the task when using the robot method (P = 0.04 when the three instruments were compared). The expert group had three task failures: two with the 2D laparoscope and one with the 3D laparoscope. None failed the task when using the robot (P = 0.769 when the three methods were compared). All task failures of the intermediate and expert groups occurred during the first attempt to perform the third task step.

Table 1. Task failure rates of the three surgeon groups with the three instruments

	2D laparoscope (%)	3D laparoscope (%)	3D robot (%)	P-value [a]
Novice (n=4, 12 attempts)	12 (100)	12 (100)	0	< 0.001
Intermediate (n=7, 21 attempts)	5 (23.8)	1 (4.8)	0	0.040
Expert (n=9, 27 attempts)	2 (7.4)	1 (3.7)	0	0.769

2D, two-dimensional; 3D, three-dimensional
[a] Chi-square test

Suturing task completion times

The three instruments were compared in terms of the task completion times at the third attempts of the intermediate and expert groups. The total task completion times of the intermediate group with the three instruments did not differ significantly: the median times when the 2D laparoscope, 3D laparoscope, and robot were used were 312 (range, 229–495) s, 324 (170–443) s, and 319 (213–433) s, respectively (P = 0.237, Table 2). Analysis of the time it took the intermediate group to complete each of the three task steps revealed similar times for each step with the three instruments.

The time it took the expert group to complete the total task differed significantly depending on whether they used the 2D laparoscope (median time 244 s; range, 155–270 s), the 3D laparoscope (177 s; 126–217 s), or the 3D robot (233 s; 187–461 s)(P = 0.01, Table 3). Post-hoc analysis then revealed that the expert group completed the task significantly faster if they used the 3D laparoscope than if they used the 2D laparoscope (P = 0.004). They also tended to complete the task faster with the 3D laparoscope than with the robot (P = 0.027). Analysis of the time it took to complete each step revealed that the experts completed the first stitch and tying significantly faster with the 3D laparoscope than with the 2D laparoscope (P = 0.008) or the robot (P = 0.016). They also completed the running suture significantly faster when they used the 3D laparoscope rather than the robot (P = 0.004). However, the instrument did not affect the time it took the experts to complete the final tying step (P = 0.107).

Table 2. Time taken by the intermediate group to complete the whole task and each task step

	2D laparoscope	3D laparoscope	3D robot	P-value [a]
Total completion time	312 (229, 495)	324 (170, 443)	319 (213, 433)	0.237
1st stitch and tying	112 (54, 238)	138 (44, 199)	88 (53, 96)	0.486
Running suture	134 (100, 178)	127 (80, 152)	149 (94, 205)	0.620
Final tying	83 (21, 125)	86 (46, 96)	60 (38, 151)	0.928

2D, two-dimensional; 3D, three-dimensional
The values are expressed as medians and ranges
[a] Friedman test

Table 3. Time taken by the expert group to complete the whole task and each task step

	2D laparoscope	3D laparoscope	3D robot	*P*-value [a]	Post-hoc analysis [b]		
					2D L. vs. 3D L.	3D L. vs. 3D R.	3D R. vs. 2D L.
Total completion time	244 (155, 270)	177 (126, 217)	233 (187, 461)	0.010	0.004	0.027	0.570
1st stitch and tying	82 (52, 116)	60 (36, 91)	86 (51, 139)	0.016	0.008	0.016	0.999
Running suture	83 (50, 100)	68 (75, 244)	120 (75, 244)	0.001	0.055	0.004	0.020
Final tying	64 (47, 104)	42 (27, 108)	33 (24, 112)	0.107			

2D L., two-dimensional laparoscope; 3D L., three-dimensional laparoscope; 3D R., three-dimensional robot
Values are expressed as medians and ranges
[a] Friedman test
[b] Wilcoxon signed rank test

Discussion

Three-dimensional vision technology has developed markedly over the past few years and several studies have been performed to assess the advantages of these visual systems (9-15). These studies compare 2D laparoscopy with 3D laparoscopy (9-12) or a 3D robotic system (13-15) in terms of surgical performance. These studies showed that the high-definition stereoscopic 3D visualization system in 3D laparoscopy clearly confers significant advantages relative to conventional 2D laparoscopy. However, it is unclear whether the 3D robotic system is superior to 2D laparoscopy because the previous studies did not control for the additional benefits of the robot system (*e.g.*, freedom of the wrist joints and tremor filtering). In addition, whether the 3D robot system is superior to the current 3D laparoscopic system has not yet been examined exactly, and the effect of previous laparoscopic experience on the relative advantages of the three instruments (2D laparoscopy, 3D laparoscopy, and a 3D robot) has also not yet been assessed in detail.

When Wagner *et al*. (3) examined how well surgeons performed surgical tasks with a robot system and a laparoscope, both with either 2D or 3D vision, they concluded the tasks tended to be completed faster if a robot system was used, regardless of whether 2D or 3D vision was employed. However, they did not assess the effect of surgeon experience on these outcomes. In our results, none of the novices (defined as having had <20 laparoscopic experiences) could finish the suturing task with laparoscopy and this is the reason why we could not recruit more novices. However, all novices did complete the task when they used the 3D robotic system. This result supports the observation of Wagner *et al.* However, the intermediate group (20–99 laparoscopic experiences) showed similarly low task failure rates with the 3D robot and the 3D laparoscope (0% and 4.8%, respectively). In addition, the expert group (≥100 laparoscopic experiences) completed the task with similar efficiency regardless of the instrument (task failure rates ranging from 7.4% to 0%). Furthermore, the expert group did complete the task faster when they used the 3D laparoscope than when they used the 3D robot or the 2D laparoscope, while this was not observed with the intermediate group. Thus, the more laparoscopic experience a surgeon has, the less advantageous the robotic system is for suturing, even though it also employs 3D vision.

The observation by Wagner *et al.* that tasks were completed faster with a robot system, regardless of whether 2D or 3D vision was employed (3), may be true for novices only; more experienced surgeons seemed to benefit more when a 3D visual system was available in laparoscopy than when a 3D robot system was available. This difference between novices and more experienced surgeons suggests that the novices benefit particularly from the greater freedom of the wrist that is provided by the robot system, whereas the more experienced surgeons benefit particularly from the haptic feedback provided by the laparoscope. Thus, for more experienced surgeons, the advantages of the robotic system tend to be lost when 3D vision is available in laparoscopy.

Our analysis of the time it took for the intermediate and expert groups to perform each of the three steps in the suturing task revealed that the expert group performed the first two steps significantly faster when they used the 3D laparoscope than when they used either of the other two instruments. However, there was no difference in terms of the time taken to perform the final tying step. This reflects the shortening of the thread and the consequent need for greater precision when performing the third step. As a result, the experts took equally long with the 3D laparoscope and the 3D robot to complete the third step. This observation indicates that the meticulous movements of robot instruments (which are due to the greater wrist freedom provided by these instruments) can still be advantageous for experienced surgeons. This finding is partially consistent with that of the study by Chandra *et al*. (13).

Another interesting finding of our study relates to the advantage conferred in laparoscopy by 3D vision. It is generally accepted that experienced laparoscopic surgeons can overcome the loss of depth perception in 2D laparoscopy and that 3D vision is more necessary for inexperienced young surgeons. However, Smith *et al.* (10) found that even experienced surgeons benefit significantly when 3D vision is available because it helps the surgeon to perceive instrument depth more readily. This observation was reproduced by our study. Comparison of the two more experienced surgeon groups in terms of their task completion times when using the 2D and 3D laparoscopes revealed that although the intermediate group did not benefit significantly from the availability of 3D vision, the expert group showed a marked improvement when they used the 3D laparoscope compared to when they used the 2D laparoscope. Thus, while the basic surgical skills of experienced laparoscopic surgeons are better than those of inexperienced surgeons because they can achieve more concise and smoother movements under 2D vision (16, 17), our observation suggests that the surgical performance of even the experts is not fully restored when binocular depth cues are absent. That the intermediate group did not exhibit an improvement in their task completion times when 3D laparoscopy was available may reflect the possibility that their surgical skills were still not sufficiently proficient to benefit from the depth information provided by the 3D display. Thus, the more laparoscopic experience a surgeon has, the more their laparoscopic suturing performance is improved by the availability of 3D vision.

This study has several limitations. The primary limitation is that only the task failure rate and task completion times were measured. Other parameters that could have been measured by using the validated motion-tracking devices were the path length and the average speed of the instruments (10, 13): these analyses would have allowed us to differentiate more clearly between groups as well as three methods. The second limitation involves the quality control of the suturing task. Although we made an effort to maintain a certain level of suturing quality, we did observe differences between the groups in terms of suturing quality. It is possible that more strict control would have indicated more marked differences between the surgeon groups with the three instruments than those shown in our present study. Lastly, we might not have given the participants enough opportunities to adapt to the console of the robot system. The participants repeated the suturing performance three times using each method, however, all of them had no experience of robot surgery. They may have needed more time to adapt to the robot console and they could have shortened the task completion time of 3D robot if they had more chances to exercise the robot suturing.

Conclusion

The novice group could only perform the suturing task by using the robot. By contrast, the expert group performed the laparoscopic suturing task faster under 3D vision than under 2D vision; they were also faster with the 3D laparoscope than when they used the 3D robot. The intermediate group did not gain an advantage from 3D vision in laparoscopy relative to either 2D laparoscopy or the 3D robot. Thus, the current robot system may be beneficial for novices in terms of lowering the entry barrier to minimally invasive surgery. However, whether the 3D robot offers experienced surgeons any marked additional benefits when 3D laparoscopy is available remains unclear.

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초 록

서론: 로봇 수술 시스템은 복강경 수술의 단점을 보완하기 위하여 도입되었으나, 아직 복강경 수술에 비하여 우수한 임상적 유용성이 명확히 밝혀진 바 없다. 더구나 고화질의 3 차원 영상 시스템은 이제 로봇 수술뿐만 아니라 복강경 수술에서도 사용 가능하며, 대부분의 외과의들이 복강경 수술에 익숙한 현실에서 로봇 수술 시스템이 반드시 필요한가에 대한 의문이 남는다. 본 연구에서는 외과 기본 술기 중의 하나인 봉합술을 시행하는데 있어서 2 차원 복강경, 3 차원 복강경, 그리고 3 차원 로봇 시스템 사용에 대한 비교를 시행하였으며, 술자를 복강경 외과 수술 경험치에 따라 나누어 분석을 시행하였다.

방법: 총 20 명의 외과의가 모집되었으며 100 례 이상의 복강경 수술 경험을 가진 전문가 그룹이 9 명, 20-99 례의 경험을 가진 중간 그룹이 7 명, 그리고 20 례 미만의 경험을 가진 초보자 그룹이 4 명 선발되었다. 2 차원 복강경, 3 차원 복강경, 3 차원 로봇 시스템을 이용하여 봉합술을 시행하였으며 각 시스템마다 3 번의 기회가 주어졌다. 평가 변수는 봉합술을 제한 시간 내에 끝내지 못하는 실패율과 술기 수행 시간으로 구성되었다.

결과: 모든 초보자 그룹은 2차원 복강경과 3차원 복강경 시스템을 이용하여 봉합술을 시행하는데 실패하였으나, 로봇 시스템을 이용하였을 때에는 모두 성공하였다. 중간 그룹은 2차원 복강경 시스템을 이용하였을 경우 (실패율 23.8%), 3차원 복강경 시스템(4.8%)과 로봇 시스템(0%)을

사용하였을 때보다 실패율이 유의하게 높았다 (P=0.04). 전문가 그룹에서는 모든 시스템에서 유의한 차이 없이 낮은 실패율을 보였다. 중간 그룹의 술기 수행 시간은 2차원 복강경 시스템 (중간값 312초, 범위 229−495초), 3차원 복강경 시스템 (324초, 170−443초), 그리고 로봇 시스템 (319초, 213−433초)을 사용하였을 때 유의한 차이가 없었다 (P=0.237). 전문가 그룹은 세 가지 시스템에서 시간 차이가 유의하였는데 (P=0.01), 사후 분석 결과 3차원 복강경 시스템 (177초, 126−217초)은 2차원 복강경 시스템(244초, 155−270초, P=0.004)보다 유의하게 짧았고, 로봇 시스템(233초, 187−461초, P=0.027)보다 짧은 경향을 보였다.

결론: 봉합술 시행 시, 초보자 그룹은 로봇 시스템으로부터 도움을 받을 수 있다. 중간 그룹은 3 차원 복강경 시스템과 로봇 시스템에서 술기 실패율과 수행 시간 모두 차이를 보이지 않았다. 전문가 그룹에서는 시스템과 상관 없이 모두 같은 수준의 낮은 술기 실패율을 보였으나, 3 차원 복강경 시스템 사용시 가장 빠른 술기 수행 시간을 보였다. 그러므로 3 차원 복강경 영상 시스템이 가능한 상황에서, 복강경 수술에 이미 익숙한 외과의는 로봇 시스템으로부터 실제적인 이득을 얻지 못할 수 있다.

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주요어: 3 차원 영상, 복강경, 로봇 수술, 봉합술

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