

Stereoscopic vision provides a significant advantage for precision robotic laparoscopy

I. C. Jourdan, E. Dutson, A. Garcia, T. Vleugels, J. Leroy, D. Mutter and J. Marescaux

European Institute of Telesurgery, Hôpitaux Universitaires, Strasbourg 67 000, France

Correspondence to: Professor J. Marescaux (e-mail: Jacques.Marescaux@ircad.u-strasbg.fr)

Background: Current surgical robots provide no sense of touch and rely solely upon vision. This study evaluated the effect of new stereoscopic technology on the performance of robotic precision laparoscopy.

Methods: Eight experienced laparoscopists with no experience in robotics performed five tasks of increasing complexity using a laparoscopic robot. The tasks were as follows: rope pass, paper cut, needle capping, knot tying and needle threading. Each test was performed ten times under both stereoscopic and monoscopic conditions. Performance times and errors were recorded.

Results: Mean(s.e.m.) final performance times were calculated from the final five trial times for each test, and were as follows for monoscopic and stereoscopic conditions respectively: rope pass 112.8(4.2) and 97.0(3.7) s ($P = 0.013$), paper cut 117.1(6.0) and 98.4(9.8) s ($P = 0.020$), needle capping 144.5(12.7) and 99.7(6.8) s ($P = 0.008$), knot tying 138.7(14.3) and 70.3(6.0) s ($P = 0.002$), and needle threading 210.8(28.2) and 92.3(4.1) s ($P = 0.002$). The mean(s.e.m.) number of errors per candidate was 60.6(7.8) and 20.8(3.9) under monoscopic and stereoscopic conditions respectively ($P = 0.004$).

Conclusion: Stereoscopic vision provided a significant advantage during robotic laparoscopy in situations that required a precise understanding of structural orientation.

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Introduction

Traditional laparoscopic systems provide the operator with indirect monocular views of the operative field. This means that the operator is denied the binocular depth cues that provide a sense of stereopsis¹. Studies on stereoscopic vision in standard laparoscopy have provided a mixed picture; several studies have demonstrated statistical advantages^{2–8} whereas others have shown no advantage^{9–14}. In some cases, where an advantage has been demonstrated, this appears to be negated by poor operator tolerance to the projection technology¹⁵. Current stereoscopic laparoscopes utilize a dual lens system that mimics the human eyes¹⁶. The two lenses of the stereoscope are separated by 6 mm and have a focal length of around 10 cm, producing useful stereopsis over this distance¹⁷.

The technology for projecting stereoscopic images is evolving and a number of systems currently exist. To produce stereoscopic vision, the view from each laparoscopic lens must be sent separately to each of the operator's eyes. Different image delivery systems have been developed. Dual display systems generate two completely separate images that are then transmitted independently to each eye. They rely on a constant positional relationship between the operator's eyes and the image, and so employ head-mounted or microscope-style projection systems. Single display systems take the images produced by the two lens systems and project them on to the same screen but with a high alternating frequency (100 Hz). The operator is required to wear filtering glasses that allow only one image to be perceived by each eye.

Currently available laparoscopic robotic systems have no sense of haptic feedback. In an attempt to compensate for this, robotic systems have been designed that optimize visual conditions with stereoscopic displays¹⁸. The aim of this study was to determine the effect of a stereoscopic

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system on the performance of tasks of increasing complexity by skilled laparoscopic surgeons.

Methods

Eight experienced laparoscopists who had no previous training in robotic surgery participated in the study. Four of the surgeons were randomly allocated to performing tests with a standard monoscopic view and then with the stereoscopic system, whereas the other four surgeons performed the tests in the reverse order.

The robotic system used was the Zeus™ robot (Computer Motion™, Santa Barbara, California, USA) which has three mechanical arms, one to hold the laparoscope and two effector arms (*Fig. 1*). The monoscopic laparoscope was an autoclavable 10-mm 0° instrument (Stryker™, Kalamazoo, Michigan, USA) with a three-chip camera system (Stryker™ 888i). The image was viewed on a 21-inch medical monitor (Sony™, Tokyo, Japan). The stereoscopic laparoscope (Precision Optics™, Gardner, Massachusetts, USA) was a 12-mm scope that housed the lens and light systems of two 5-mm laparoscopes. The focal axes of the two lens systems were separated by 6 mm. The attached camera system housed two three-chip light transducers that relayed two separate visual signals (100-Hz refresh rate). The two video signals were

synchronized and sent to a CrystalEyes™ projection system (Stereographics®, San Francisco, California, USA). This captured frames from the two cameras and displayed images alternately from each on a high-definition monitor. An electronically controlled polarizing filter (Stereographics Z-screen™) was placed in front of the monitor. This was synchronized to the alternating video image so that light from the right camera image was polarized vertically and that from the left was polarized horizontally. The operator wore simple polarizing glasses with the two lenses set at right angles to each other. In this way only the right camera image was sent to the right eye and left image to the left eye with an effective frame rate of 50 Hz.

Five previously validated^{19–21} standardized laparoscopic tasks were used in this study (*Fig. 2*). The rope-pass test involved passing a silastic vascular sling between two articulated graspers. The sling was 30 cm long and marked at intervals of 3 cm with two 3-mm black stripes separated by 2 mm. These were the only points at which the sling could be correctly grasped. Grasping outside of these marks constituted an error. The task was completed when the band had been passed between graspers from end to end in both directions. For the paper cut test, a 30-cm strip of paper (width 1 cm) was marked with 18 equally spaced 1-mm black stripes. The operator was provided with an



Fig. 1 Zeus™ robot set up for the knot-tying test. Effector arms are shown in the foreground with surgeon and actuator controls in the background

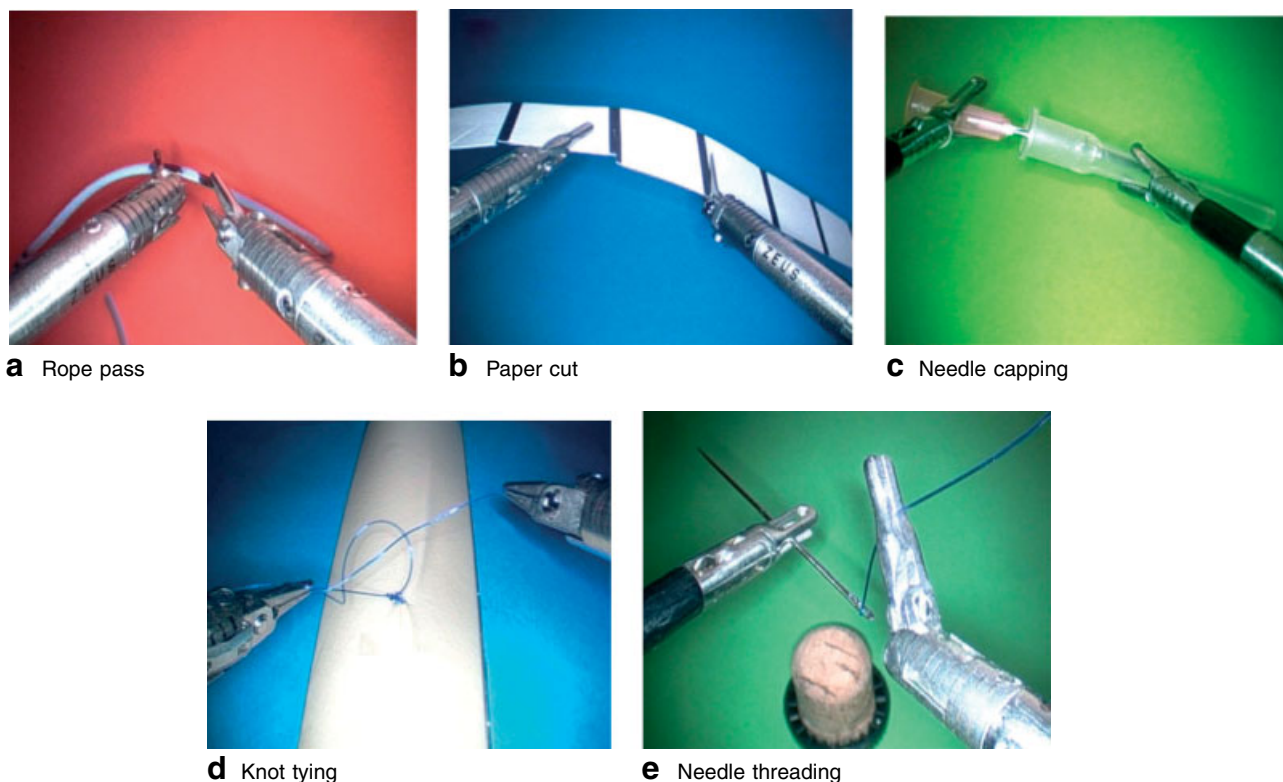


Fig. 2 Skills tests. **a** Rope pass, **b** paper cut, **c** needle capping, **d** knot tying and **e** needle threading

articulated grasper for the left hand and articulated scissors for the right hand. The surgeon was required to make a cut into each stripe equal to the length of the scissor blades. If the cut extended beyond the stripe an error was recorded. The needle-capping test involved uncapping and recapping an 18-G needle from its protective sheath five times. The operator used two unarticulated graspers. Between uncappings the needle and its sheath had to be laid over an air-filled latex roll. If the needle or sheath was dropped an error was recorded. For the knot-tying test, the operator was provided with two articulated graspers. A 10-cm 5/0 polypropylene suture was threaded through a latex roll and five throws of the suture were performed. An error was recorded each time the tail of the suture was misgrasped or if the suture was broken. For the needle-threading test, a non-articulated grasper was provided for the left hand and an articulated grasper for the right hand. A 10-cm length of 3/0 polypropylene was passed through the eye of a standard embroidery needle, first using the articulated grasper to hold the suture and then using the non-articulated grasper. Between threadings, the needle was planted into a cork. While the needle was held by the cork, the suture was pulled through the eye. The task was completed when needle had been threaded successfully with both instruments and the

needle was planted in the cork. An error was recorded if the suture or needle was dropped.

Each candidate was required to perform ten sequential trials of each task. The time to perform each task successfully and the number of errors made were recorded. Following the completion of all trials each candidate completed a questionnaire concerning tolerance and quality of the stereoscopic system.

Results were analysed for the two visual conditions – monoscopic and stereoscopic. A learning gradient for each candidate for each test was measured from a best fit straight line plot of log time against log trial number^{22,23}. Final proficiency was determined by calculating the mean of the last five performance times for each candidate. Normal distribution of these data was confirmed before using a standard *t* test to compare the two groups.

Results

A total of 400 trials were completed successfully by the eight candidates under each visual condition. *Fig. 3* shows the mean performance times under the two visual conditions for sequential trials of each of the five tasks. The first three tasks (rope pass, paper cut and needle capping)

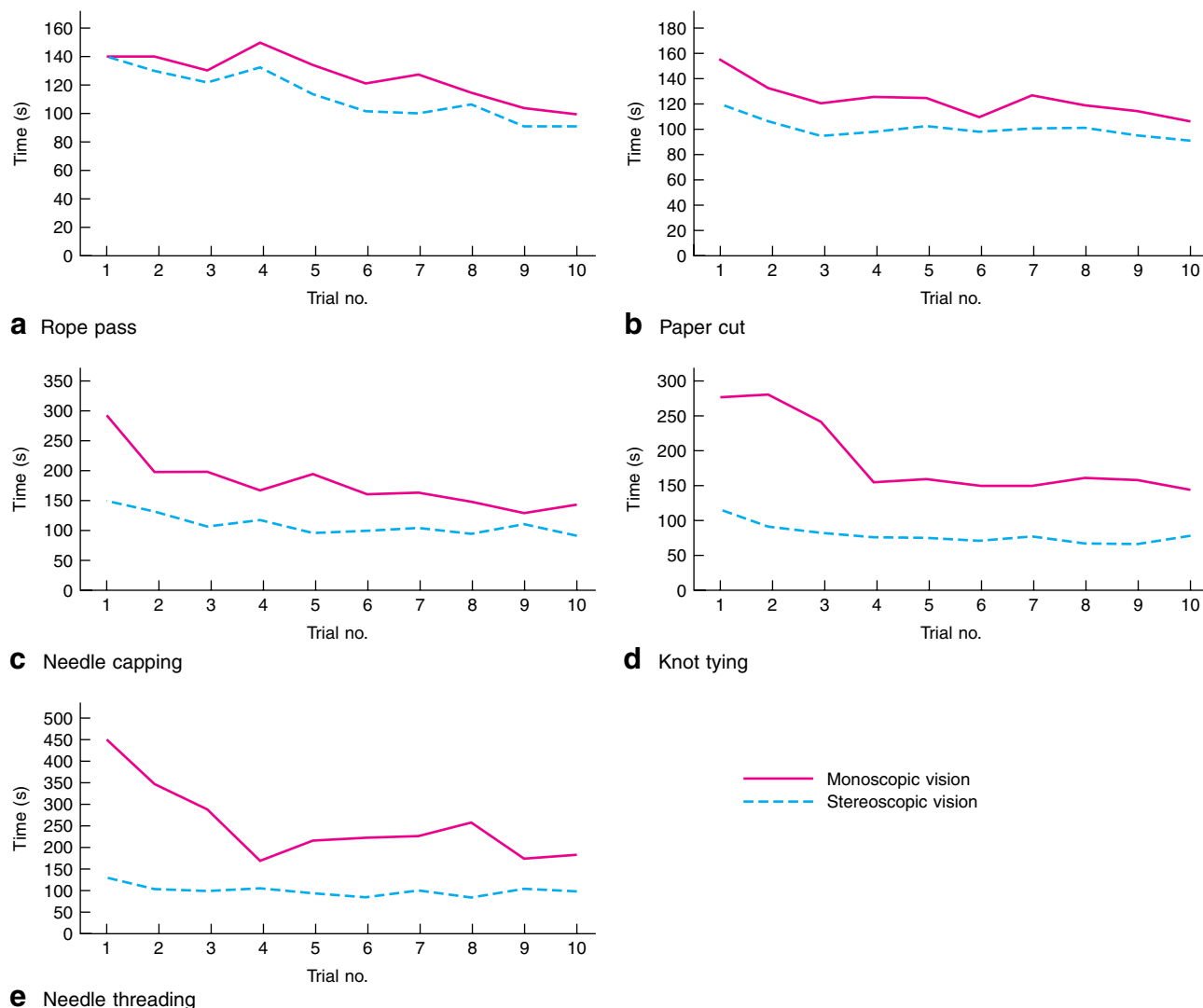


Fig. 3 Mean performance times with respect to trial number for five skills tested under monoscopic and stereoscopic conditions. **a** Rope pass, **b** paper cut, **c** needle capping, **d** knot tying and **e** needle threading

were performed more quickly under stereoscopic vision at all trial numbers and the learning curves were roughly parallel. For knot tying and needle threading, the initial performance times under monoscopic conditions were longer than those for stereoscopic conditions; the learning curves subsequently converged, although performance times remained longer for monoscopic conditions. *Fig. 4* shows box plots of the mean performance times for each candidate for the final five trials under the two visual conditions. Mean(s.e.m.) results for each test are presented in *Table 1*. The mean(s.e.m.) number of errors per candidate

Table 1 Mean performance times for each test under monoscopic and stereoscopic conditions

	Performance time		<i>P</i> *
	Monoscopic	Stereoscopic	
Rope pass	112.8(4.2)	97.0(3.7)	0.013
Paper cut	117.1(6.0)	98.4(9.8)	0.020
Needle capping	144.5(12.7)	99.7(6.8)	0.008
Knot tying	138.7(14.3)	70.3(6.0)	0.002
Threading	210.8(28.2)	92.3(4.1)	0.002

Values are mean(s.e.m.). *Paired *t* test.

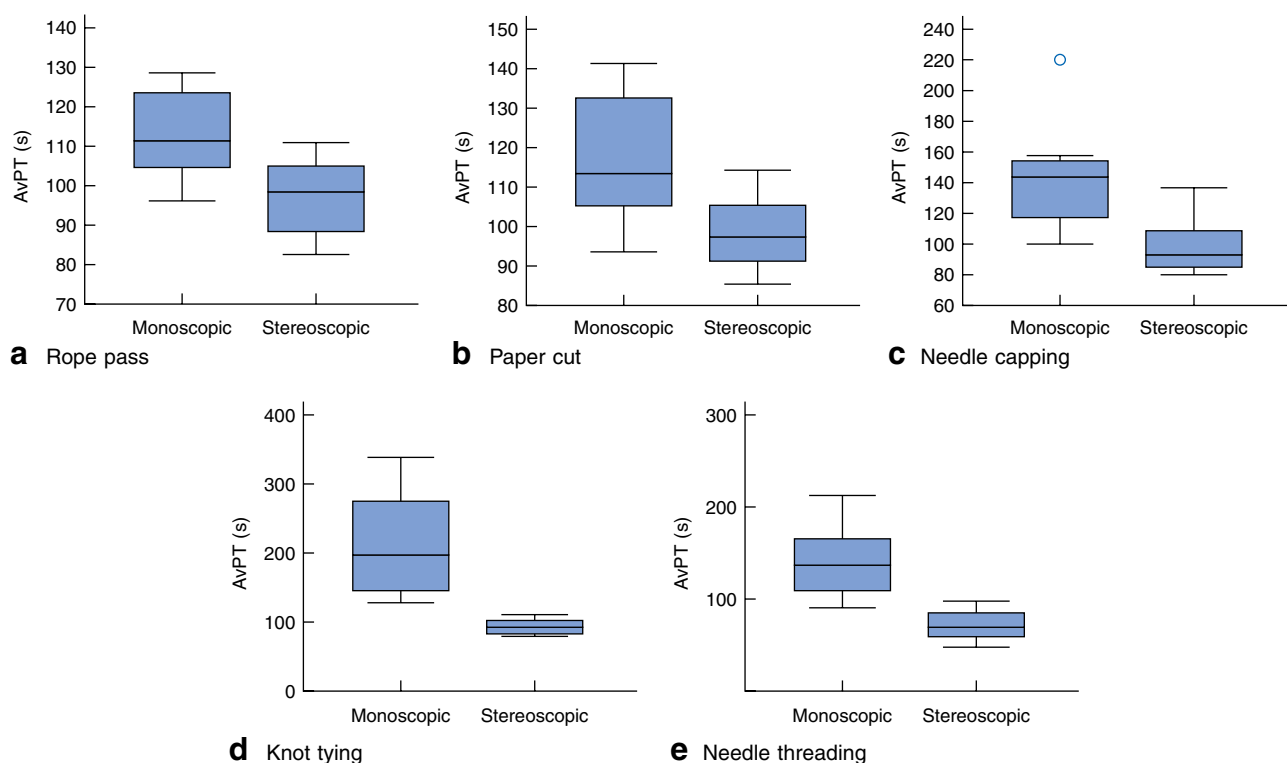


Fig. 4 Box plots showing mean performance times (AvPT) for each candidate for five skills tested under monoscopic and stereoscopic conditions. Horizontal bars denote median time, boxes span the interquartile range, the error bars indicate values within 1.5 box lengths of the interquartile range and a single outlier is shown in **c**. **a** Rope pass, **b** paper cut, **c** needle capping, **d** knot tying and **e** needle threading

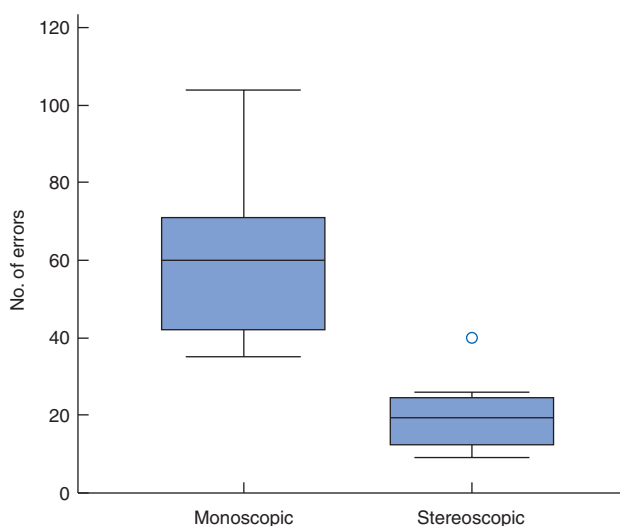


Fig. 5 Box plots showing number of errors made by each candidate for skills tested under monoscopic and stereoscopic conditions. Horizontal bars denote mean number of errors, boxes span the interquartile range, the error bars indicate values within 1.5 box lengths of the interquartile range and a single outlier is shown

was 60.6(7.8) under monoscopic conditions and 20.8(3.9) under stereoscopic conditions ($P = 0.004$) (Fig. 5).

Discussion

In the present study the performance of robotic laparoscopy was significantly enhanced by stereoscopic vision and this advantage persisted beyond the learning curve. As the laparoscopic task became more complex, the advantage of stereoscopic vision was accentuated. For these more complex tasks the learning curve for monoscopic conditions was steeper; final performance times became closer to stereoscopic performance times but remained significantly higher throughout. The fact that the learning curve for procedures performed under stereoscopic vision was much flatter for complex procedures suggests that the operator was able to apply pre-existing skills rather than having to develop new strategies, as appeared to be the case with monoscopic performance. Although performance under monoscopic conditions rapidly improved as these strategies were developed, they did not appear to be able to compensate fully for the loss of stereoscopic cues.

This work helps to clarify some of the issues surrounding stereoscopic technology in standard laparoscopy. Earlier studies of Mueller *et al.*¹³ and Herron *et al.*¹¹ both failed to show any significant advantage for stereopsis. However, these studies involved large numbers of laparoscopic novices, and each candidate performed no more than two repetitions of each test. At such an early point in the learning curve the variation in individual performance is large, making statistical assessment weak. The strength of the present study is that all the surgeons were highly proficient and beyond the learning curve when performance measures were taken. This resulted in differences between individuals being very small relative to the effect of the two visual conditions. In addition, Herron *et al.*¹¹ examined the performance of three basic skills tasks and did not investigate the effect of stereopsis on more complex surgical tasks. As the present study demonstrated, the effect on basic tasks, although significant, is less pronounced than that on complex procedures. Taffinder *et al.*⁶ showed a significant advantage for a dual lens stereoscopic system. Their study benefited from paired data from a large number of candidates, each of whom performed six task repetitions. The effect of this was to bring average results closer to the end of the learning curve and strengthen the statistical analysis. The only randomized clinical study in this field was reported by Hanna *et al.*¹⁰, who investigated the influence of a stereoscopic system on the performance of laparoscopic cholecystectomy. These authors failed to show any advantage in terms of execution time or error rate; however, a first-generation single lens laparoscope was used, which did not project true stereoscopic vision to the operator.

Many reports in this field have commented on the problem of visual tolerance to stereoscopic technology^{3,11,13,15}. Responses to the present questionnaire revealed strong agreement that the system used enhanced stereoscopic vision and that such vision could be advantageous to the surgeon. On the other hand, the continuing problem of poorer image quality than is currently available with standard monoscopic systems would make surgeons reluctant to use the technology for standard laparoscopic procedures. However, image projection systems continue to evolve and a dual-screen projection system has been developed for use with this robot since completion of the present study. This system is better tolerated and it is likely that stereoscopic technology will gain greater acceptance. Stereoscopic systems may be limited initially to areas such as robotic and microsurgery, but may subsequently be used to assist difficult positional manoeuvres, such as knot tying and stent insertion. Once the technology is perfected,

it may eventually replace current monoscopic systems to become standard equipment for general use in laparoscopic surgery.

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