

# The rabbit nephrectomy model for training in laparoscopic surgery

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**BACKGROUND:** Laparoscopic surgical training is generally done with the teacher–student model using complex exercises. This study was performed to evaluate a new training model that emphasizes the repetition of simple procedures. **METHODS:** Laparoscopic surgery was performed in rabbits ( $n = 200$ ) using conventional instruments. Gynaecologists ( $n = 10$ ) and medical students ( $n = 10$ ) performed a series of exercises during 20 full days training. Nephrectomy was chosen to evaluate and score laparoscopic skills, i.e. duration of surgery and complication rate, since it mimics the surgical challenge and involves dissection of major vessels. Each surgeon performed 20 nephrectomies, alternating left and right sides. **RESULTS:** Duration of surgery and complications decreased with training. For duration of surgery, a two-phase exponential decay learning curve, with different decays for gynaecologists and students, was observed. Gynaecologists achieved shorter operating times than students for real and calculated times in the first procedure ( $P < 0.0001$  and  $P < 0.0001$ ) and for calculated time in the last procedure ( $P = 0.001$ ). Severe complications were more frequent in students than in gynaecologists ( $P = 0.0003$ ). **CONCLUSION:** The rabbit nephrectomy model is suitable for training in laparoscopic surgery. Since it implies the repetition of short and well-defined exercises, progression is easier to monitor and the necessity for continuous supervision is less, making training less expensive.

*Key words:* dissection/laparoscopy/learning curve/rabbits/training

## Introduction

Laparoscopic surgery is rapidly replacing open surgery in both general and gynaecological procedures because it is associated with lower morbidity, better cosmetic results, shorter hospitalization times, reduced post-operative pain and faster return to normal activities. In addition, laparoscopic surgery permits new approaches to surgery.

Although visualization of anatomy is often improved by laparoscopy, tactile information is diminished as instruments are limited by the diameter of the trocars and the fixed position. Laparoscopic surgery requires the ability to appreciate depth from a two-dimensional screen image using subtle visual clues. In addition, specific hand–eye coordination and fine motor skills, distinct from skills used in open surgery, are required. The acquisition of these skills is essential for minimal access surgery to become a real minimally invasive and atraumatic surgery.

Laparoscopic skills are known to be acquired over time, and learning curves are well documented for different procedures such as tubal ligation (Fox *et al.*, 1994), ovarian masses (Yuen and Rogers, 1994), ectopic pregnancies (Yeko *et al.*, 1994),

cholecystectomy (Schlumpf *et al.*, 1994; Wishner *et al.*, 1995), hysterectomy (Harkki-Siren and Sjoberg, 1995), colorectal surgery (Reissman *et al.*, 1996; De Chaisemartin *et al.*, 2003), fundoplication (Watson *et al.*, 1996) and cancer surgery (Melendez *et al.*, 1997). The challenge is to optimize training in order to make learning curves of surgery in humans as short as possible. Training in surgery today, however, tends to be done predominantly using the teacher–student model. What is lacking are structured and validated global training programmes such as are attempted for most skills learning programmes such as music schools, dance schools and many sports.

The best we have today for training outside the operating theatre are a variety of training models, comprising *in vitro* programmes and training in animals. *In vitro* models have the advantage of being relatively inexpensive. They provide a reliable and reproducible method for learning and refining laparoscopic skills, as was shown for cutting, clipping, suturing, and intracorporeal and extracorporeal knot tying (Shapiro *et al.*, 1996; Rosser *et al.*, 1997; Chung and Sackier, 1998; Mori *et al.*, 1998; Fried *et al.*, 1999). In addition to the classic training simulators that have been used for many years,

increasingly sophisticated computerized models are being created in an effort to enhance the learning experience. These virtual training models, although still expensive and not universally available, offer objective and precise evaluation, and in most cases emphasize the repetition of short and well-defined exercises with different levels of difficulty (Hyltander *et al.*, 2002; Schijven and Jakimowicz, 2002; Gor *et al.*, 2003; Grantcharov *et al.*, 2003). Animal models, especially pigs and sheep, are used to mimic the human situation, and training is similar to that in theatre, i.e. performing surgical interventions under supervision (Kirwan *et al.*, 1991; Wolfe *et al.*, 1993; Ocelli *et al.*, 2000; Traxer *et al.*, 2001). These animal models, however, are not yet being used widely for several reasons, such as legal prohibition and cost to set up and maintain a training centre. Moreover, they merely provide the opportunity for trainees to be exposed for a few days to endoscopic surgery and are not used for real training over longer periods.

Although a series of programmes has been developed in order to assess and score laparoscopic skills objectively (Fraser *et al.*, 2003; Gor *et al.*, 2003; Shime *et al.*, 2003), the results achieved by most training courses, e.g. the hours of training and number of procedures required to reach a certain skill level, are insufficiently documented. In addition, their efficacy in reducing learning curves or accidents for human surgery remains unproven, and the number of procedures required to reach proficiency in laparoscopic surgery has not been defined clearly (Dagash *et al.*, 2003).

Our aim was to develop a training model for endoscopic surgery, comprising knot tying (Vossen *et al.*, 1997), stitching (unpublished data) and dissection. The key difference from traditional training programmes is that the exercises are kept simple, and are of short duration, permitting them to be repeated until a certain measurable skill level is obtained. This has the advantage that the individual progression in skill can be monitored easily in comparison with traditional more complex training programmes. In the present study, a training model for dissection, i.e. the rabbit nephrectomy model, is described, together with the learning curves for duration of surgery and complication rates of two groups of surgeons with different levels of experience in laparoscopic surgery.

## Materials and methods

### *Animals and anaesthesia*

The study was performed in 200 adult, female, New Zealand, white rabbits weighting 2.5–3.0 kg. The animals were kept under standard laboratory conditions (temperature of 18°C, relative humidity of 40–70%, 14 h light and 10 h dark) at the animal facilities of the Katholieke Universiteit Leuven (KUL). They were fed with a standard laboratory diet (Hope Farms, Woerden, The Netherlands) with free access to food and water. Anaesthesia was induced with i.m. ketamine (50 mg/kg) and xylazine (6 mg/kg) and maintained with inhalational halothane (2%) and oxygen mixed with room air (1.5 l/min) using a vaporizer (Drägerwerk, Lubeck, Germany). The study was approved by the Institutional Review Animal Care Committee.

### *Surgical procedures and experimental design*

The abdomen was shaved and the animal was secured to the table in the supine position. A 10 mm midline incision was performed caudal to the xyphoides and a 10 mm trocar was introduced into the abdominal cavity by open laparoscopy. To avoid gas leakage, the incision was closed gas-tight around the trocar with 2/0 polyglactine suture.

The CO<sub>2</sub> pneumoperitoneum was created with a Thermoflator (Karl Storz, Tuttlingen, Germany), and the insufflation pressure was established at 8 mmHg. A 10 mm 0° endoscope (Karl Storz), connected to a video camera (Karl Storz) and light source (Karl Storz), was introduced, and a secondary 10 mm trocar was placed at the level of the umbilicus under laparoscopic view.

Following pilot studies to evaluate training models useful for surgical tasks needed in humans, two groups of trainees were evaluated prospectively in two series. The first series was performed by right-handed gynaecologists from different countries ( $n = 10$ ) who had finished their training in obstetrics and gynaecology and who had a specific interest but little experience in endoscopic surgery, i.e. <30 diagnostic procedures and no operative procedure. They came to the Centre for Surgical Technologies (CST) of the KUL to undergo training in laparoscopic surgery. The second series was performed by right-handed final-year medical students ( $n = 10$ ) without any experience in diagnostic or operative laparoscopy. Within each series, five two-person teams were created and maintained during the whole training period, one person being alternatively surgeon and cameraman for consecutive surgeries. All participants were trained during 20 working days, each day performing a series of exercises over 8 h. During the initial days of training, only the first exercises could be performed. As skill increased, progressively more exercises were performed in 8 h. None of the trainees performed any other surgical procedure in addition to those of the 8 h/day training programme during the 20 day training period.

The exercises in the rabbit comprised a standardized nephrectomy, followed by hysterectomy, enterolysis, a model for salpingostomy and neosalpingostomy, a model for cystectomy, and aorta and vena cava dissection. In addition to these dissection exercises, stitching and knot tying were practised in an endotrainer for 60 and 30 min, respectively. The instruments used were scissors, forceps, clip-applier, clips, suction-irrigation probe, needle-holder, knot-pusher, bipolar coagulation forceps, and monopolar coagulation attached to the scissors. For all surgical procedures, except for nephrectomies, the surgeon stood at the right side of the table, the animal was placed in the 45° Trendelenburg position and two 5 mm trocars were introduced in the right and left flanks for the working instruments.

For this study, nephrectomy was used as the end point to evaluate learning curves of duration of surgery and complications, i.e. bleeding, because it is a simple procedure of short duration, but with large vessels mimicking the surgical challenge of not being too prudent and too slow, and not being too rapid and having bleeding and accidents. The aim was to be as fast as possible, but in a safe and controlled way. Each surgeon performed alternatively the nephrectomy of one side in the first animal and of the other side in the next animal for a total of 20 nephrectomies. For the left nephrectomy, the surgeon stood at the right side of the table and the animal was placed in the right lateral position. For the right nephrectomy, the surgeon stood at the left side of the table and the animal was placed in the left lateral position. In addition to the 10 mm secondary trocar introduced at the level of the umbilicus, a 5 mm trocar was introduced through the left lateral abdominal wall perpendicular to the kidney's hilus for the left nephrectomy. A similar procedure was performed on the right side for the right nephrectomy. Surgery was always performed using the following standard protocol. First, the renal artery and vein were dissected from the hilus up to the aorta, skeletonized, clipped separately and cut. Secondly, the ureter

was dissected from the hilus up to its intersection with the ovarian vessels (~5 cm), which is an obvious anatomical landmark. Finally, the kidney was dissected free of surrounding fat and removed from the renal fossa.

Right and left nephrectomies were performed alternatively in a random order and individually scored for duration of surgery and for complications by both surgeon and cameraman. Duration of surgery was measured from the moment that the two working instruments were ready to start the dissection until the complete isolation of the kidney from the renal fossa. The occurrence of bleeding during the procedure was also scored (0, none; 1, mild; 2, heavy; 3, mortal). Since in pilot studies different levels of difficulty were observed for left and right nephrectomies, both were considered as one surgery using the mean score of both sides for evaluation. To evaluate differences between both sides, the scores of each side were evaluated separately.

The other exercises were performed subsequently, alternating the surgeon every 30–45 min, as follows and in this order.

**Hysterectomy.** Each surgeon performed the exercise in one uterine horn. First, the ovarian vessels were identified and dissected from the ovary up to the aorta, coagulated and cut. Secondly, the meso of the ovary, fallopian tube and uterine horn was exposed, the vessels were coagulated and the meso was cut as close as possible to the organ. Thirdly, the hypogastric and uterine vessels were dissected, coagulated and cut. Finally, the paracolpos was cut including the utero-sacro ligament.

**Enterolysis.** A bowel segment with large vessels was exposed. All vessels of the mesentery were dissected individually, coagulated and cut, dissecting some 10 cm of the bowel. Since the mesentery with the vessels is similar to peritoneal adhesions, this exercise is a model for adhesiolysis.

**Model for salpingostomy.** First, a loop of some 6 cm of the small bowel was exposed. Secondly, the mesentery was perforated at both ends and two surrounding knots were placed in order to limit the working area in the bowel. Finally, a longitudinal incision was performed in the antimesenteric border and the intestinal contents were removed with forceps and a suction-irrigation probe.

**Model for neosalpingostomy.** The exercise is performed in the appendix, which is very big and long in rabbits. Because of its size and consistency, the rabbit appendix is similar to a human hydrosalpinx, with its tip simulating the closed fimbria. First, some 6 cm of the appendix including its tip was exposed and a surrounding knot was placed in the 'isthmic part' in order to limit the working area. Secondly, three radial incisions were performed in the appendix's tip and bleeding vessels were coagulated without damaging the mucosa. Thirdly, contents of the appendix were suctioned and rinsed extensively. Finally, the serosa was coagulated with bipolar current using a low power in order to evert and 'flower' the mucosa.

**Model for cystectomy.** The bladder was filled with water, if it was empty, and the sero-muscular layer was gently separated from the mucosa ('cyst capsule').

**Aorta and vena cava dissection.** This exercise was performed at the end of the training day because it is very difficult and can cause massive and mortal bleeding. First, the aorta and the vena cava were individualized and dissected from the level of the ovarian vessels until their bifurcation. The plane of cleavage between the vena cava and aorta was identified and both vessels were skeletonized, coagulating

the small perforating branches. Secondly, the right and left common iliac vessels were identified and dissected from their origin up to their bifurcation, and skeletonized. Finally, the external and internal iliac vessels were dissected over some 2 cm. All lymph nodes over the entire length of the aorta and vena cava, common iliac vessels and external and internal iliac vessels were dissected and removed.

**Stitching and knot tying.** In addition to all these dissection exercises, the trainees performed 60 min of stitching and 30 min of knot-tying exercises *in vitro*. Furthermore, stitching and knot tying were also practised in the rabbit (live or dead) to give the feel of the tissue.

### Statistics

Statistical analyses were performed with the SAS System (SAS Institute, Cary, NC) and GraphPad Prism (GraphPad Software Inc, San Diego, CA). To estimate learning curves, the decrease in duration of surgery was fitted as a two-phase exponential decay model ( $y = \text{span1} \times \exp(-K1 \times n) + \text{span2} \times \exp(-K2 \times n) + \text{plateau}$ ). These curves start at  $\text{span1} + \text{span2} + \text{plateau}$  and decay with rate constants  $K1$  and  $K2$  to plateau. The calculated initial times, the decay constants and the calculated final times together with the real initial and final times were used to compare the learning curve of both groups of trainees. The calculated times have the advantage of integrating the variability of the individual nephrectomies. Paired and unpaired *t*-test were used for individual comparisons of parametric variables, and Fisher's exact test for comparisons of frequencies. All data are presented as means  $\pm$  SD.

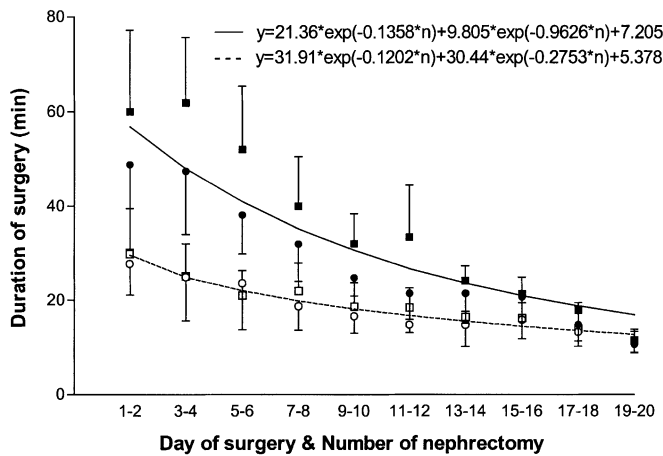
### Results

Duration of surgery decreased with training, assessed by the consecutive number of nephrectomies performed, demonstrating a clear learning curve. The overall time required to perform a surgical procedure decreased from  $44 \pm 18$  to  $11 \pm 2$  min for the first and the last procedure, respectively. This learning curve can be described as a two-phase exponential decay model. Using this model, the calculated times were  $43 \pm 17$  and  $15 \pm 3$  min for the first and the last surgical procedure, respectively. This effect was also observed for both groups of trainees, i.e. gynaecologists and students, analysed separately. For gynaecologists, the real and calculated times were  $30 \pm 9$  and  $30 \pm 9$  min for the first intervention, and  $11 \pm 2$  and  $13 \pm 2$  min for the last intervention, respectively. For students, the real and calculated times were  $58 \pm 14$  and  $57 \pm 11$  min for the first intervention, and  $11 \pm 2$  and  $17 \pm 3$  min for the last intervention, respectively. Gynaecologists achieved shorter operating times than students (unpaired *t*-test) for real and calculated times in the first surgical procedure ( $P < 0.0001$  and  $P < 0.0001$ ) and for calculated time in the last procedure ( $P = 0.001$ ) (Figure 1).

Similar effects were observed for left and right nephrectomies analysed separately. For left nephrectomies, the overall real and calculated times were  $42 \pm 17$  and  $42 \pm 17$  min for the first left nephrectomy, and  $11 \pm 2$  and  $14 \pm 3$  min for the last left nephrectomy, respectively. For gynaecologists, the real and calculated times were  $29 \pm 9$  and  $30 \pm 9$  min for the first left nephrectomy, and  $11 \pm 2$  and  $12 \pm 2$  min for the last left nephrectomy, respectively. For students, the real and calculated times were  $54 \pm 14$  and  $53 \pm 14$  min for the first left nephrectomy, and  $11 \pm 2$  and  $15 \pm 3$  min for the last left

nephrectomy, respectively. In comparison with students, gynaecologists achieved shorter real and calculated times (unpaired *t*-test) in the first left nephrectomy ( $P = 0.0002$  and  $P = 0.0004$ ), but the differences were no longer observed in the last left nephrectomy ( $P = \text{NS}$  and  $P = \text{NS}$ ).

For right nephrectomies, the overall real and calculated times were  $46 \pm 2$  and  $46 \pm 20$  min for the first right nephrectomy, and  $11 \pm 2$  and  $17 \pm 5$  min for the last right nephrectomy, respectively. For gynaecologists, the real and calculated times were  $30 \pm 10$  and  $30 \pm 10$  min for the first right nephrectomy, and  $11 \pm 2$  and  $13 \pm 3$  min for the last right nephrectomy, respectively. For students, the real and calculated times were  $63 \pm 17$  and  $62 \pm 13$  min for the first right nephrectomy, and  $11 \pm 2$  and  $20 \pm 3$  min for the last right nephrectomy, respectively. In comparison with students, gynaecologists achieved shorter real and calculated times (unpaired *t*-test) in the first right nephrectomy ( $P < 0.0001$  and  $P < 0.0001$ ), and the differences were still observed in the last right nephrectomy for the calculated time ( $P < 0.0001$ ).



**Figure 1.** Effect of training upon duration of laparoscopic nephrectomies in rabbits. During a 20 full-day training programme, a daily nephrectomy was performed by gynaecologists (left nephrectomy, open circles; right nephrectomy, open squares) and medical students (left nephrectomy, filled circles; right nephrectomy, filled squares). Means  $\pm$  SD together with calculated times according to a two-phase exponential decay model (gynaecologists, dotted line; students, solid line) are indicated.

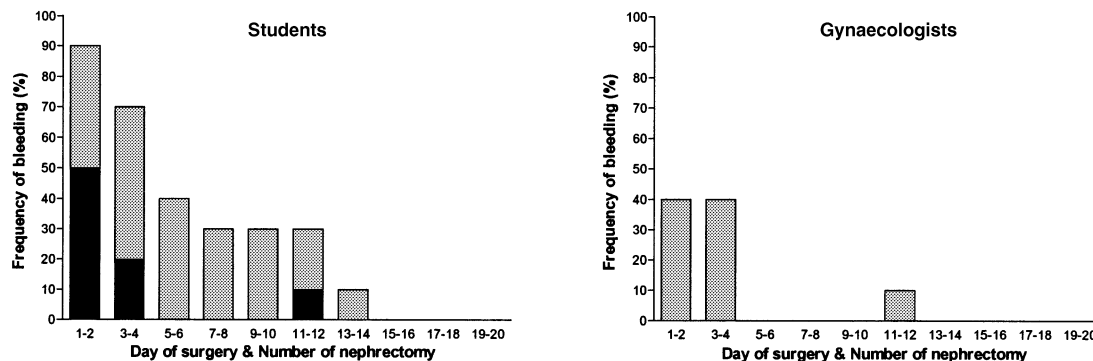
Overall operating times for right nephrectomies were longer than for left nephrectomies (paired *t*-test,  $P < 0.0001$ ). The same effect was observed for both gynaecologists ( $P = 0.01$ ) and students ( $P < 0.0001$ ) analysed separately (Figure 1).

Students had more heavy and mortal bleeds than gynaecologists (Fisher's exact test,  $P = 0.0003$ ). At the beginning of the training, these complications were observed in 90% of the cases in students, i.e. 40% of heavy bleeding and 50% of mortal bleeding, and in 40% of the cases in gynaecologists, i.e. 40% of heavy bleeding and no mortal bleeding. In both groups, the frequency of these serious complications decreased with training and was no longer observed in the last interventions (Figure 2).

### Discussion

For training in endoscopic surgery and for training in surgery in general, the current apprenticeship model, in which trainees start watching and assisting surgery then performing minor interventions and gradually proceeding to more complex and advanced procedures, is logical but is not really validated. It implies long learning curves since it is mainly a 'prevention of complications' model. Specifically in endoscopic surgery, to improve the endoscopic skills, to shorten the learning curve and to reduce complications, two different approaches can be used. One approach emphasizes the repetition of simple procedures up to a certain level of speed and quality, whereas the other emphasizes the performance of a surgical intervention with complex tasks from the beginning. This latter approach is commonly used in the classic 1–3 day courses using endotrainers and/or animal models.

Our aim was to develop a training model for what we judged essential skills required in endoscopic surgery, i.e. knot tying (Vossen *et al.*, 1997), stitching (unpublished data) and dissection. We chose simple exercises for knot tying, stitching and dissection, which were performed repetitively. This has the advantage over more complex procedures that they can be monitored more easily since, by being short and simple, more exercises are available to be evaluated. Another major advantage for a training centre is that the necessity for the continuous presence of a tutor is much less. Indeed, since the trainees always perform the same exercises, after a few days of



**Figure 2.** Frequency of heavy (grey shading) and mortal (black shading) bleeding during laparoscopic nephrectomies in rabbits. During a 20 full-day training programme, a daily nephrectomy was performed by gynaecologists and medical students.

intensive supervision, a few hours of supervision daily is sufficient. We fully acknowledge the necessity to evaluate the effectiveness of this new training model in comparison with the classical 1–3 day training courses, and certainly in performance of human surgery later. Our hypothesis is that repetitive skill training would be useful to have the full benefit of training courses in larger animals, and we hope to show over the years that performance in human surgery can be improved.

For training in dissection, *in vitro* models are poor substitutes for *in vivo* models since pulsating vessels, bleeding and control of bleeding are essential to surgery. We chose the rabbit nephrectomy model because rabbits are relatively cheap and easy to handle with little technical assistance, which is important to reduce costs. Laparoscopic surgery can be performed in a real pneumoperitoneum environment with conventional trocars and instruments despite the rabbit's size and weight. Furthermore, the model not only permits dissection exercises with varying degrees of difficulty, but also practice of several other laparoscopic tasks such as cutting, coagulation, stitching, and intra- and extracorporeal knot tying. Furthermore, the extra difficulty due to the small space seems an additional advantage for trainees to adapt to the very slow controlled movement of instruments necessary in endoscopic surgery.

For evaluation of dissection skills, the rabbit nephrectomy was chosen because it is a simple, short and well-defined procedure, permitting an objective evaluation of learning curves and because it involves dissection of major vessels (renal artery and vein are both 5 mm in diameter), exposing the surgeons to the opposing requirements of going fast to reduce time but without having accidents such as a heavy bleed. It is important to stress that the main feature of this *in vivo* training model is the repetition of similar procedures, under the same conditions, during 20 full days of training, which is in contrast to the classic 1–3 day courses, often teaching complex surgical interventions.

This study confirms the expected effect of training for both groups of trainees and the effect of previous surgical experience, indicating the usefulness of this model. Indeed, operating times decreased exponentially with training as expected, with different learning speeds for the two groups of trainees, i.e. gynaecologists and students. Simultaneously, the occurrence of heavy and mortal bleeding decreased with training. We can only speculate whether the accidents observed were a random phenomenon, i.e. a consequence of inexperience, or whether they reflect personal characteristics. In addition, our results confirm the high inter-subject variability at the beginning of the training programme.

Our data demonstrate that right nephrectomies took longer and were more difficult. This was not surprising since, in comparison with left nephrectomy, right nephrectomy has two important anatomical differences, leading to a longer and more dangerous procedure. On the right side, the liver is partially obstructing the working field and the renal vessels are shorter and not parallel, making the working space smaller and dissection closer to the aorta and vena cava. In addition to these anatomical differences, left and right nephrectomies are performed with a different relative position of the hands,

instruments and organs. Indeed, for left nephrectomies, instruments in the second port (umbilicus, horizontal) and third port (lateral abdominal wall, vertical) are handled with the right and the left hand, respectively, and vice versa for right nephrectomies. For left nephrectomies, the scissors were used with the right hand (second port, horizontal) and the forceps with the left hand (third port, vertical). For right nephrectomies, however, the scissors were used with the left hand (second port, horizontal) and the forceps with the right hand (third port, vertical) or vice versa. In the former case, the relative position of the hands/instruments was different from those for left nephrectomies but the relative position of the instruments/organs was similar, whereas in the latter case the relative position of the hands/instruments was the same and that of the instruments/organs was different. These differences in the relative position of hands, instruments and organs could partially explain the differences between right and left nephrectomies. We consider this, in addition, extremely important since the model forces the trainees to use both hands for each instrument.

Another element that should be considered is the effect of the assistant surgeon, i.e. the cameraman. Indeed, the data presented in this study are in fact the result of collaborative and alternative work between surgeon and assistant. This aspect is more important than had been anticipated, especially in the student teams, in which neither the surgeon nor the assistant had had experience in endoscopic surgery before this training programme. It is obvious that even experienced surgeons would not be able to develop all their potential laparoscopic skills if they are assisted by poorly qualified surgeons. We become aware of this problem in some specific trainee teams.

In conclusion, our data show that the rabbit model could be a suitable model for training in laparoscopic surgery, and that nephrectomy, resembling real life conditions closely in terms of occurrence and control of bleeding, is a sensitive exercise to evaluate learning curves and skills. Moreover, the model forces the use of scissors with both hands and is also suitable for training in assisting endoscopic surgery. In addition, this study confirms that training improves the laparoscopic skills, decreasing duration and increasing quality of surgery, which is a desirable goal in terms of minimizing cost and complications associated with prolonged surgeries and/or prolonged pneumoperitoneum. The most important conclusion probably is that some 20 days of training of 8 h per day seems to be required to develop the necessary skills. This is not surprising, but is in sharp contrast to the currently available training models. Obviously, the efficacy of the model will have to be validated in more complex surgery in larger animals and in human surgery.

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