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Effect of training on endoscopic intracorporeal knot tying

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Training in endoscopic, intracorporeal knot tying, was evaluated in 29 obstetrics and gynaecology trainees who performed 100 consecutive intracorporeal, two turn, flat, square knots. An obvious learning curve was observed. With training the quality of the knots increased, whereas the mean duration to tie a knot decreased from 277 ± 114 to 67 ± 27 s for the first 10 and the last 10 knots respectively. The initial and final duration of knot tying were lower in more experienced trainees, as estimated by the year of training or the Royal College of Obstetrics and Gynaecology (RCOG) level of experience. More specifically, duration of knot tying was shorter when more diagnostic laparoscopies, laparoscopic sterilizations or adnexectomies had been performed. This effect of previous experience was however limited compared with the overall effect of training. Previous passive experience, however, as determined by the number of assisted or observed surgical interventions, did not affect the learning curves. Speed of knot tying was slightly higher in trainees who spent more of their leisure time performing handicrafts than in trainees who were more interested in reading, but although significant, these differences were only marginal. In conclusion, the data show an important effect of training on the speed and quality of intracorporeal knot tying and confirm that learning curves improve with previous training.

Key words: endoscopy/endoscopic surgery/intracorporeal knots/learning curve/training

Introduction

Minimal access surgery represents a rapidly increasing component of gynaecological surgery. The introduction of this new area in gynaecological surgery, however, has been poorly controlled and audited (Society of Obstetrics and Gynaecologists of Canada, 1992; Cushieri, 1992, 1993; RCS, 1993; RACOG, 1993; Jakimowicz, 1994; RCOG, 1994a, b; AAGL, 1995; Shaw, 1995; Sutton and Lower, 1996). This has been associated with significant under-reporting of complications and deaths following laparoscopic surgery (RCS, 1993). However, following publication of dramatic complications, concerns have been expressed that without proper training, credentials and monitoring, clinical results will be poor and complication rates high (RCOG, 1994a; Shaw, 1995). Similar problems were seen, for example, in New York State during the changeover to laparoscopic cholecystectomy techniques in the period August 1990 to March 1992: increasing instances of operative complications, particularly bile duct injuries, were reported and were greater than for open cholecystectomy (Airan, 1990; Green, 1991; Altman, 1992a,b; State of New York, 1992).

Laparoscopic surgery requires specific skills in hand–eye co-ordination and due to the lack of manual contact with the tissue and the restricted instrument mobility, the need for specific training was obvious (Cushieri, 1990, 1992, 1993; RCS, 1993; RCOG, 1994a; Sutton and Lower, 1996). It has been shown that complication rates decrease sharply as more laparoscopic procedures are performed (i.e. more experience is gained) (Capelouto and Kavoussi, 1993; Christ and Gadacz, 1993; See *et al.*, 1993, 1994; Royston *et al.*, 1994; McMahon *et al.*, 1995; Moore and Bennett, 1995; Bittner *et al.*, 1996; Watson *et al.*, 1996). Similarly the operation time is longer during the learning phase and decreases with experience (Hunter and McCartney, 1993; Cushieri, 1993; Cagir *et al.*, 1994; Yeko *et al.*, 1994; Munro and Deprest, 1995). The high complication rate and high operation times during the 'learning curve' highlighted the need for structured training to help clinicians along the learning curve quickly and safely (Cushieri, 1993; RCOG, 1994; Royston *et al.*, 1994). With this in mind guidelines for training have been produced by several authorities. These guidelines have established different basic principles for training (Society of Obstetrics and Gynaecologists of Canada, 1992; RACOG, 1993; RCS, 1993; Jakimowicz, 1994; RCOG, 1994a, b; AAGL, 1995). Formal training courses using graded exercises on pelvic simulators and exercises on animal models have been offered. This allows the basic skills required for laparoscopic surgery to be acquired before using them in a clinical set-up and so provides an avenue whereby the learning curve may be partially circumvented (Steele *et al.*, 1994). This kind of training is accepted as useful and even necessary (Wolfe *et al.*, 1993; Clayden, 1994; Nduka and Darzi, 1994; Scot-Conner *et al.*, 1994; AAGL 1995), although the effect of training has rarely been quantified (Hunter *et al.*, 1994; Pier *et al.*, 1994; Champion *et al.*, 1996; Shapiro *et al.*, 1996). One survey documented a link between formal training and complications in minimal access surgery (Chin and Newton, 1996). No data are available on the optimal content of training programmes. Neither is it clear whether training needs to be adapted to the individual's requirements and skill development potential.

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Therefore the current training programmes need to be assessed to ascertain their efficacy and establish their optimal content. The skill development of trainees also needs to be monitored. This particular experiment prospectively investigated the effect of training on the speed and quality of endoscopic knot tying in 29 trainees in obstetrics and gynaecology and studied inter- and intra-operator differences according to previous laparoscopic experience and according to several personal characteristics. The data were assessed with a view to evaluating and adapting the currently used training programme at the Centre for Surgical Technologies (CST) in Leuven.

Materials and methods

The effect of training on endoscopic knot tying was prospectively investigated in 29 obstetrics and gynaecology trainees. All trainees participated on a voluntary basis. During the observation period they performed 100 identical intracorporeal knots in 3–4 training sessions of 2 h over a period of four weeks. During this period they were not exposed to any other additional training in endoscopic surgery, except clinical activities. The study was carried out at the CST in Leuven. Using an endotrainer (Ethicon, Cincinnati, USA) with a fixed camera, a 5 mm needleholder (Storz AG, Tüttlingen, Germany), and 5 mm forceps (Ethicon), a series of 10 knots were performed with Dexon® threads, 13 cm in length, which had been fixed to a flat 10×10 red rubber surface. Prior to the study a video was shown demonstrating the technique of tying the intracorporeal, two-turn, flat, square knot. During the study trainees were allowed to rewatch the video demonstration, and an instructor (C.V.) was present during all training sessions in order to give advice if required.

For each knot the duration of knot tying was noted and the knot was scored for quality. Score 1 was defined as an inefficient knot, score 2 as a tight knot but with insufficient fixation to the underlying tissue and score 3 as a perfect, tight knot well fixed to the underlying tissue. For each trainee data were collected by questionnaire in order to assess their previous laparoscopic experience and personal characteristics. Their year of training, and the number of laparoscopic procedures previously performed as a surgeon, first or second assistant and the number of hours of laparoscopic training on simulator and animal models were ascertained. According to the scoring system for experience designed by the RCOG Working Party (RCOG, 1994a), 18 trainees were recorded as level 0 (no experience), no trainees as level 1 (diagnostic laparoscopy), six trainees as level 2 (minor laparoscopic procedures), five trainees as level 3 (more extensive procedures requiring additional training) and no trainees as level 4 (extensive endoscopic procedures requiring subspecialist or advanced/tertiary level endoscopic skills). In addition personal characteristics such as sex (male, female), leisure activities (sport, needlework, handicrafts, literature, cultural activities), eye dysfunction (none, myopia, presbyopia, astigmatism), eye correction (glasses, lenses, laser treatment), dominant hand (right, left) and personality characteristics (do-it-yourself personality, perseverance, ability to concentrate, ambition, patience) were recorded and scored on a linear analogue scale from 1–10.

Data analysis was performed using the SAS program (SAS Institute, 1985) and Graphpool Prism program (San Diego, CA, USA). To estimate learning curves the decrease in duration of knot tying was fitted as a one (Y = span *exp(-k**n*) + plateau1) or two exponential decay model (Y = span1 *exp(-k1**n*) + span2 *exp(-k2**n*) + plateau2). These curves start at span + plateau (INIT1) or span1 + span2 + plateau2 (INIT2) and decay with rate constants K or K1 and K2 to plateau1 or plateau2 respectively; *n* is the number of knots. Consequently the half lives are expressed by 0.69/K1 and 0.69/K2 respectively.

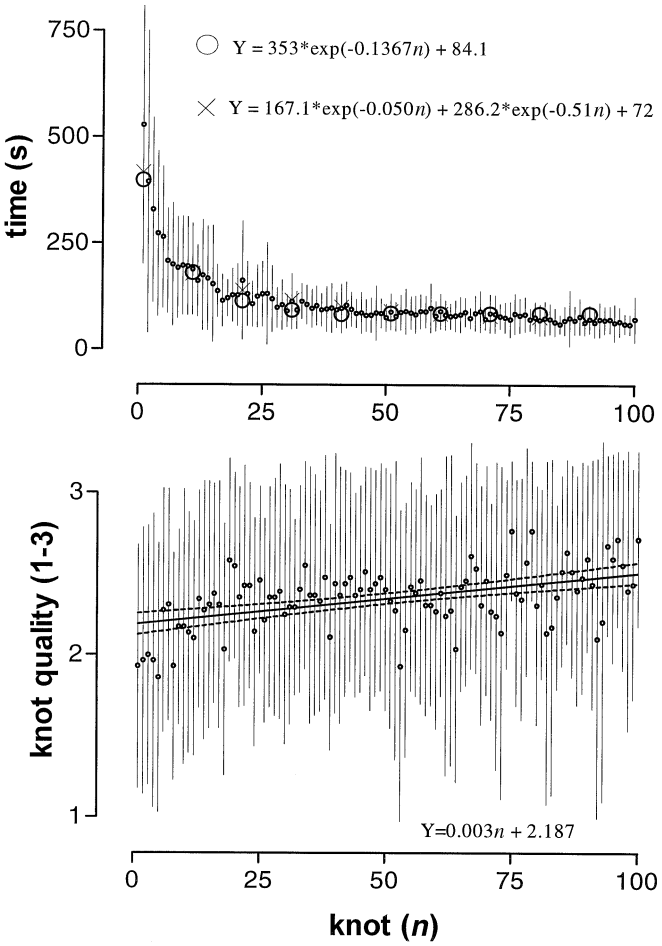

Figure 1. Learning curve of the duration of endoscopic knot tying and the quality of the knots. The means and SD are indicated. For the duration of knot tying the calculated duration using a mono-exponential (○) or bi-exponential decay model (×) are indicated. For the knot quality the regression line and 95% confidence limits are indicated.

These calculated initial tie times (Init1 and Init2), the decay constants (K, K1, K2) and the final tie times (plateau1, plateau2) together with the mean duration (mtim) and the mean knot scores (mscore) of the first 10 and last 10 knots were used to correlate (Spearman) the learning curves with the previous laparoscopic experience and personal characteristics. The calculated tie times have the advantage of integrating the variability of individual tie times but they have the inherent disadvantage of the mathematical model used. Therefore the same correlations were performed with the mean value of the first and last series of knots, for which a number of 10 knots was arbitrarily chosen.

Results

Regarding the duration of knot tying, an obvious learning curve was obtained. The mean time required to tie a knot decreased (Figure 1) from 277 ± 114 s to 147 ± 62, 120 ± 50, 100 ± 32, 87 ± 29, 87 ± 30, 82 ± 22, 79 ± 28, 70 ± 23, and 67 ± 27 s for the first 10 to the last 10 knots respectively. This learning curve can be described as a mono- or bi-exponential decay

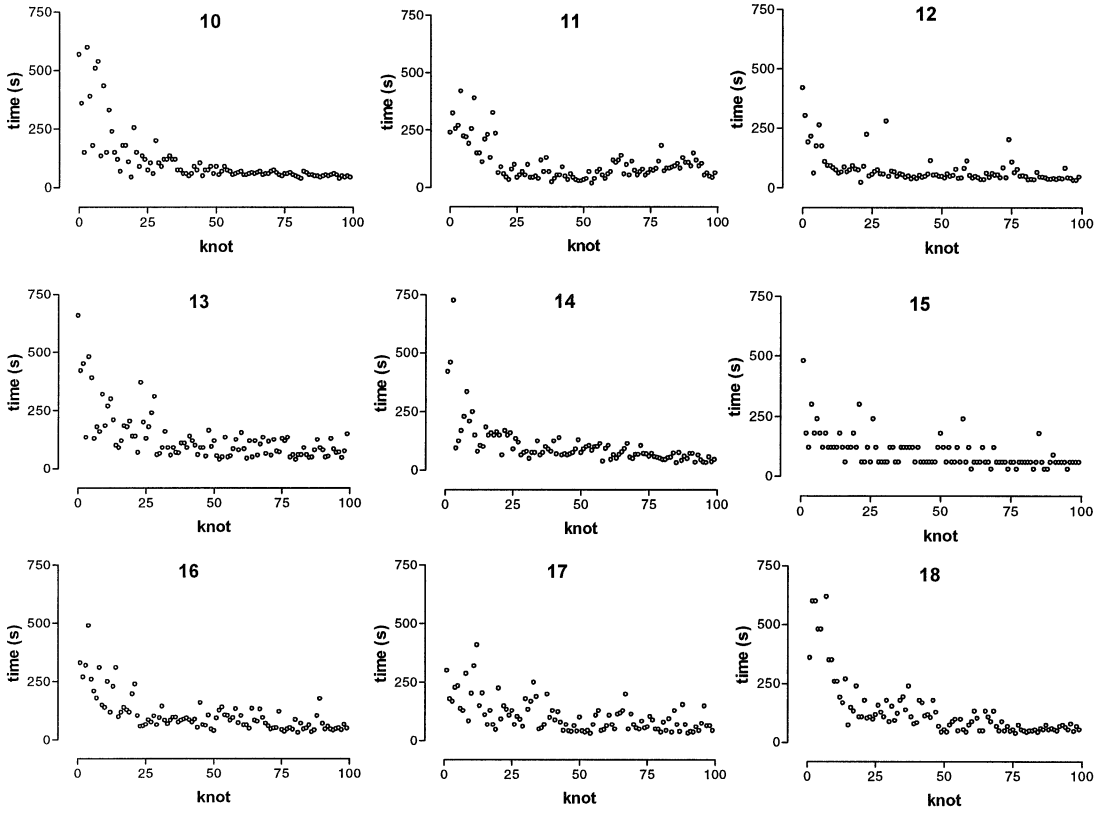

Figure 2. Duration of endoscopic knot tying in nine consecutive individual trainees (10–18), demonstrating individual variability of learning curves.

model, the latter fitting the experimental points only marginally better. In the bi-exponential model the calculated initial duration was slightly higher, the calculated last duration was slightly lower, and the time to tie a knot continued to decrease slowly. Using these models, the calculated time of the first knot was 398 (95% confidence limits 371–425) and 417 (375–454) s, and the calculated time of the last knot was 84 (79–89) and 75 (69–77) s respectively. When individual learning curves were analysed (Figure 2), 16 trainees reached a plateau, one continued to have a slight improvement of tie time and two did not show an obvious learning curve. The experience gained in the previous training session was entirely retained as shown by smooth individual learning curves.

The duration of the first knot varied with the previous laparoscopic experience (Figure 3). The duration of the first knot was lower in more experienced trainees expressed as year of training (Spearman; $P = 0.02$ for the mean of the first 10 knots, $P = 0.01$ for the calculated duration using a mono-exponentional decay model and $P = 0.0002$ for the calculated duration using a bi-exponentional decay model respectively), RCOG level of experience ($P = 0.014$, $P = 0.02$, $P = 0.004$ respectively), total number of laparoscopies performed ($P = 0.04$, $P = 0.06$, $P = 0.008$ respectively), number of diagnostic laparoscopies ($P = 0.05$, $P = 0.07$, $P = 0.006$ respectively), number of laparoscopic sterilizations ($P = 0.04$, $P = 0.06$, $P = 0.004$ respectively), number of laparoscopic adnexectomies (NS, $P = 0.03$, $P = 0.015$ respectively), total hours of training in the CST ($P = 0.02$, $P = 0.04$, $P = 0.02$ respectively), either pelvic simulator (NS, NS, $P = 0.03$ respectively) or animal models (NS, NS, $P = 0.02$ respectively). By stepwise logistic regression analysis either the year of training ($P = 0.01$) or the RCOG level of experience ($P = 0.03$) was included in the model, but not simultaneously. Both contained similar information about previous training as evidenced by their strong correlation (Pearson; R = 0.91, $P = 0.0001$). The number of laparoscopies and the hours of in-vitro training were not entered in the model, suggesting that they did not contain any information in addition to the year of training or the RCOG level of experience. Whereas the effect of training on the time required to tie a knot was very pronounced, the absolute effect of the previous experience was rather limited for the RCOG levels of experience, as shown in Figure 3. The tie times were 323 + 112, 370 + 53, 161 + 31, 238 + 38, 187 + 135 and 289 + 93 s for trainees in years 0, 1, 2, 3, 4 and 5 of training respectively.

The duration of the last knots (expressed by the plateau reached in the mono- and bi-exponential decay model) also correlated with previous experience. The duration of the last knots correlated with year of training ($P = 0.01$, $P = 0.05$), RCOG level of experience ($P = 0.007$, $P = 0.05$), total number of laparoscopies ($P = 0.005$, $P = 0.05$), number of diagnostic laparoscopies ($P = 0.02$, $P = 0.02$), number of sterilizations ($P = 0.01$, NS), number of adnexectomies ($P = 0.01$, $P = 0.05$) and ovariectomies (NS, $P = 0.04$) and hours of in-vitro training ($P = 0.02$, NS), both on endotrainer ($P = 0.009$) and on animal models ($P = 0.01$). When the duration

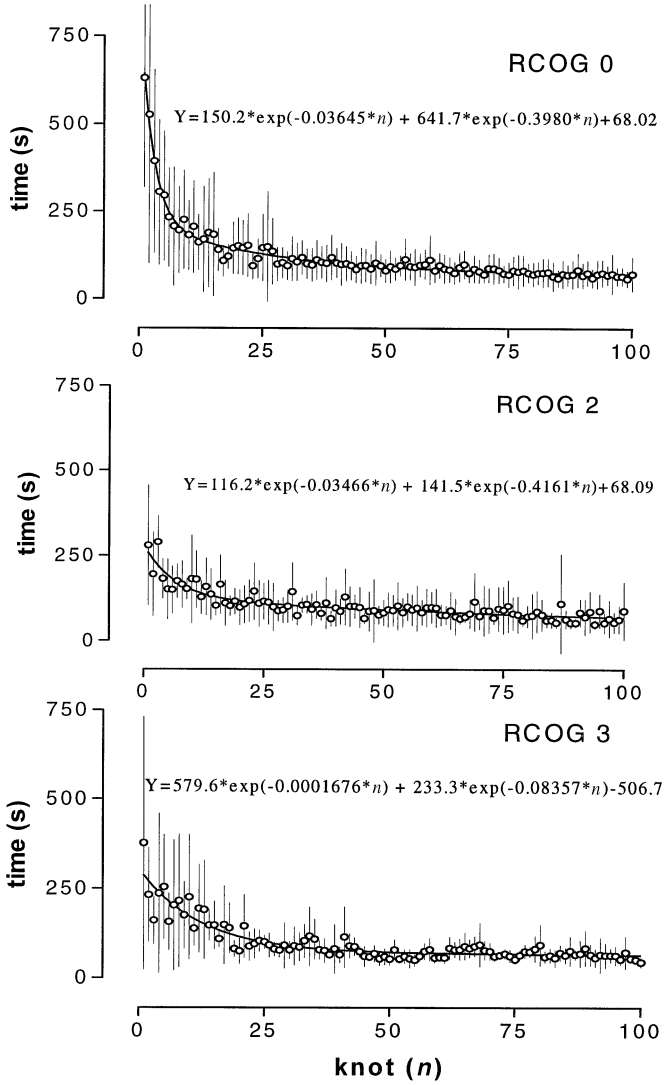

Figure 3. Duration (mean and SD) of tie times according to the Royal College of Obstetrics and Gynaecology (RCOG) level of experience and the calculated bi-exponential decline (solid line).

of the last knots was expressed as the mean time of the last 10 knots, however, none of the parameters reached statistical significance. Although statistically significant, the absolute effect of the previous experience upon the tie times of the last knots was limited.

The rate of improvement of the tie times was slower in more experienced trainees (Figure 3), as expressed by the negative correlation between K (the rate constant of the decay) and year of training ($P = 0.03$) and RCOG level of experience ($P = 0.02$).

The learning curves varied slightly with personal characteristics. The mean duration of the 10 first knots was shorter in trainees who spent more of their leisure time doing handicrafts ($P = 0.04$) and the calculated duration of the first knots using a mono-exponential model was higher in trainees who were more interested in reading ($P = 0.03$). The duration of the last knots (bi-exponential model) was also shorter in trainees performing more of their leisure time in sports or handicrafts ($P = 0.02$). None of the other personal characteristics significantly affected the duration of knot tying, the speed of improvement or the quality of the knots.

For the quality of endoscopic intracorporeal knots, a learning curve was also seen: whereas the tie times decreased, the quality of the knots increased (Figure 1; from 2.0 ± 0.4 for the first 10 knots to 2.2 ± 0.97 SD for the last 10 knots). Final knot scores were higher for more experienced ($P = 0.01$) and more practically orientated trainees, practising handicrafts ($P = 0.05$).

Discussion

This study was undertaken to demonstrate the effect of training on the speed and quality of intracorporeal knot tying. The two turn, flat, square knot was chosen, because during training sessions at the CST this exercise was estimated to be relatively difficult for inexperienced trainees. In order to limit training to one specific skill, the exercise was limited to knot tying without stitching.

Training of intracorporeal knot tying was efficient and the learning curves of all trainees were remarkably similar. The duration of knot tying decreased 3–5 times and the quality of the knots simultaneously improved. The learning process followed an exponential decline, in which most of the training effect was achieved after 20–30 knots, which corresponds to some 2–3 h of training, which is considerably faster than generally accepted. These data are indicative of the minimum necessary time trainees should be provided with to achieve this particular skill. As expected more experienced trainees were clearly characterized by lower initial tie times, as well as slightly lower final tie times. The effect of previous experience was, however, limited compared with the overall effect of the actual training. It was impossible to distinguish between individual training effects of specific previously performed operations, such as sterilizations or adnexectomies, because by step-wise forward logistic regression only the year of training or the RCOG level of experience was retained to express previous experience. This is logical since the year of training determined for each trainee the number of operations they had performed as well as the hours of previous training. We were surprised, however, that previous exposure to surgery either by assisting or by watching laparoscopic interventions did not affect the learning curve, suggesting that the training effect of watching and assisting endoscopic procedures is rather limited, at least for developing specific skills such as knot tying. This is not unexpected if we consider one cannot expect to learn to play the piano by going to concerts.

These data do not allow any firm conclusions to be drawn on fundamental aspects of training in endoscopic surgery, such as specific difficulties with depth of vision on a 2D screen and hand–eye co-ordination, or on long term aspects of training. The observation that more experienced trainees were characterized by lower initial and persistently lower final tie times, whereas their speed of learning was slightly lower suggests other differences between these two groups, such as long term and cumulative effects of training. To explain this, our knowledge of the neurophysiology of learning and memory is not yet sufficient. It is well known, however, that some aspects

of learning take months, rather than hours, as it is common sense that in sports, e.g. tennis, beginners make dramatic improvements in a few days, although it takes much more time and practice to become skilled.

The fundamental issues of training in endoscopy, however, are not speed but quality of surgery and prevention of accidents. Although the latter are beyond the scope of this manuscript, we should realize that two different approaches to training exist. In this experiment we evaluated the training of one task in laparoscopic surgery, i.e. intracorporeal knot tying. The assumption was that the sequential training up to a plateau of all different tasks of endoscopic surgery could be advantageous in comparison with the current apprenticeship model, where trainees start by watching and assisting surgery, then perform minor surgical interventions and gradually proceed to more extensive laparoscopic procedures. In this approach it has been recommended that video monitoring should be used in diagnostic laparoscopies in order to achieve skills in eye–hand co-ordination. If, however, the training effect of watching and assisting surgery is limited, this observation should impact upon training programmes of residents. It might be that video-endoscopy of pure diagnostic procedures only trains depth of vision cues, not eye–hand co-ordination. Future studies will have to show the relative benefits of a gradual step-up approach and of a more global approach where the trainee is instructed to perform a complex operation from the beginning. The former emphasizes hours of training with simple procedures up to a certain speed and quality, whereas the latter emphasizes difficulty by performing multiple tasks from the beginning.

Personal characteristics such as manual dexterity did influence learning curves but the effect was limited compared to the overall effect of training. With all the restrictions imposed by this small study, this observation suggests that great caution should be used before it becomes accepted that some people—estimates range from 10 to 13% (Sutton and Lower, 1996)—might be innately unable to achieve the necessary skills to perform more advanced laparoscopic procedures safely and effectively (RACOG, 1993; RCOG, 1994; Shaw, 1995; Sutton and Lower, 1996). This supports the view of those who feel that aptitude testing for surgeons should be considered with extreme caution (RCOG, 1994a, b; Shaw, 1995; Sutton and Lower, 1996b).

It is assumed that adequate training can minimize the complication rate (Chamberlain, 1987; Wagner *et al.*, 1993; Monson, 1997) because complications were particularly seen during the early part of the learning curve. A survey published in 1996 (Chin and Newton, 1996) confirmed that the attendance of formal training courses supplemented with senior supervision for initial cases (‘proctoring’) are the most important factors to minimize patient morbidity and mortality from minimal access surgery (MAS) (Cushieri, 1993; Chin and Newton, 1996; Monson, 1997). The guidelines for training given by several authorities also brought ‘proctoring’ forward as an important part of an appropriate training schedule (Society of Obstetrics and Gynaecologists of Canada, 1992; RACOG, 1993; RCOG, 1994; AAGL, 1995). Similarly See’s findings indicated that, after attending a formal training course, attachment of trainees to other experienced surgeons during the early part of the learning curve will decrease complication rates. By 12 months after formal training, this impact is obviated by the decreased complication rates associated with additional experience (See *et al.*, 1993, 1994). It has been claimed that laparoscopic procedures could be safely introduced to young inexperienced residents provided they were properly supervised. This would reduce the need for formal ‘hands-on’ courses (Schirmer *et al.*, 1992; Aharoni *et al.*, 1993; Bartsch *et al.*, 1993; Wagner *et al.*, 1993; Tsang *et al.*, 1994; Sefr *et al.*, 1995). This concept is only true if training is considered for the prevention of complications only. Besides the cost in theatre time, inexperience also affects the quality of surgery.

In conclusion, these data demonstrated similar and important learning effects in all trainees in endoscopic knot tying over a period of a few hours and showed that more experienced trainees at the beginning of the training were able to tie better quality knots faster than the inexperienced trainees. Following this learning period the differences between inexperienced and experienced trainees, although small, persist. Surprisingly, assisting and watching surgery did not contribute to the training effect. Specific consecutive training of each aspect of endoscopic surgery may be more appropriate.

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