Acquiring minimally invasive surgical skills

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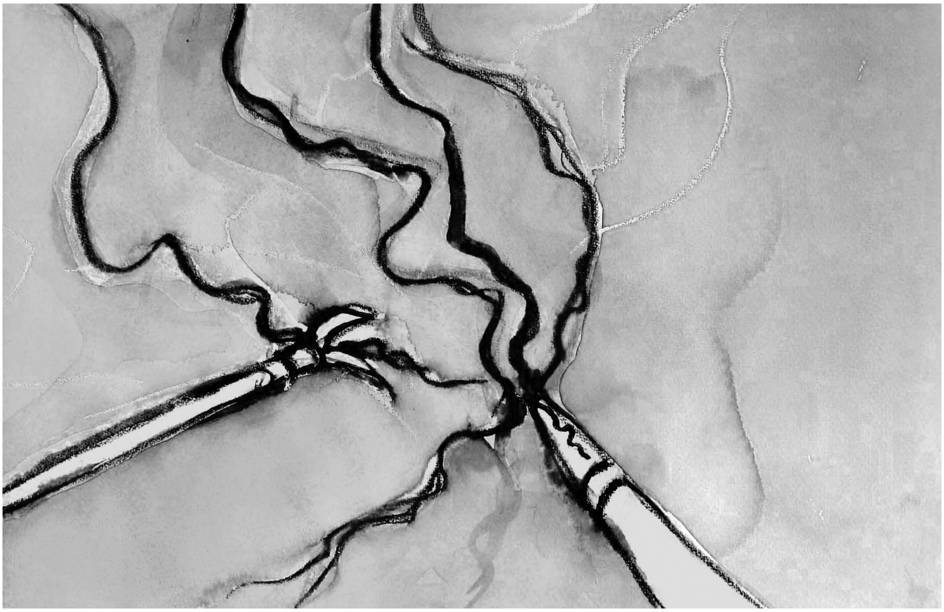
CHAPTER 5
INTRACORPOREAL SUTURING: ECONOMY OF MOVEMENTS IN A BOX TRAINER MODEL



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INTRODUCTION

Training outside the operating room (OR) prior to patient exposure is important to progress along the first part of the learning curve in order to enhance patient safety. Preclinical practice using inanimate models improves psychomotor skills and translates into improved performance in the OR.[Grantcharov et al., 2004; Scott et al., 2000; Seymour et al., 2002] Among the laparoscopic exercises that can be learned using a simulator, intracorporeal suturing is unique, because it is directly applicable in clinical practice. Moreover, all basic laparoscopic skills are incorporated in this task, i.e. ambidexterity, judging depths, handling materials, manipulating instruments, and using fluid movements.[Rosser et al., 1997] Additionally, being proficient in suturing, inclusively being able to tie an intracorporeal knot, is a prerequisite to perform advanced laparoscopic surgical procedures.[Aggarwal et al., 2006] Suturing skills are needed if a complication occurs (e.g. a bleeding, a lesion in the urinary bladder or the intestine), or in case of a dysfunction of suturing devices.

Intracorporeal suturing can be practiced on two categories of simulators: computerized virtual reality (VR) trainers and physical box trainers, which are also called video trainers. The latter trainers have been criticized for the lack of objective assessment of movements, and for the low fidelity of most exercises with regard to real laparoscopic procedures.[Aggarwal et al., 2004] However, Grober et al. revealed that low-fidelity models can be as efficient as high-fidelity training models for technical skills acquisition.[Grober et al., 2004b] In fact, the advantage of box trainers over VR trainers is that real laparoscopic instruments, camera and monitor can be used, which result in natural haptic feedback and perceptions of depths. Regarding suturing, the use of a needle holder and the various suturing threads and needles can be practiced. Furthermore, the absence of instant feedback on economy of instrument movements in box trainers recently has been overcome by the development of tracking devices.[Chmarra et al., 2006] By consequence, objective assessment of economy of movements is facilitated during intracorporeal suturing in box trainers.

Objectifying a subject's level of performance during laparoscopic tasks is worthwhile for skills acquisition to allow a continuous refinement, as well as for credentialing or certification purposes. However, prior to the implementation of a tracking device for assessment purposes for a specific task, the construct validity (i.e. the ability to discriminate between clinicians of a different skills level) of the economy of movement parameters needs to be established, and benchmark criteria need to be set. Two studies have been performed to validate economy of movement parameters during a suturing task in a box trainer.[Aggarwal et al., 2006; Van Sickle et al., 2005] Aggarwal et al. used a tracking device that needs to be applied on the dorsum of a surgeons hand to obtain dexterity data[Aggarwal et al., 2006], and is relatively time consuming. Van Sickle et al. studied a needle driving task, but did not focus on the knot tying.[Van Sickle et al., 2005] A suture, however, does not function without a proper knot.

The current study is conducted to establish the construct validity of time and three economy of instrument movement parameters for the entire suturing task recorded by an easy applicable tracking device, the TrEndo.[Chmarra et al., 2006] Additionally, the improvement of the movement parameters is compared to the improvement in time to complete the task during the three trials. Subsequently, an expert standard is set.

MATERIALS AND METHODS

Measurements were performed in the skills laboratory of the Leiden University Medical Center (LUMC) in the Netherlands.

Participants

For this study, novices, intermediates and experts were recruited. The novices were medical students in the preclinical phase of their study, and consequently without prior operative experience. They were recruited by means of advertisement in the medical library of the LUMC. Intermediates were residents in Obstetrics and Gynaecology in all 6 post-graduate years (PGYs). For their recruitment, an email was sent to all residents who attended the Obstetrics and Gynaecology specialty training at the LUMC. All are being trained in performing laparoscopic surgery, and are two-monthly scheduled to train their basic laparoscopic skills in a laboratory setting. Experts were experienced surgeons in minimally invasive surgery (MIS) who met the following three preconditions:

» Their experience exceeded 200 laparoscopic procedures.
» Their surgical palette contained advanced procedures. Herein, the advanced gynaecological procedures are defined in the ESGE standard of laparoscopy.[ESGE 2009] For general surgery, we choose to set herniorrhaphy, fundoplication, colectomy, adrenalectomy, and splenectomy as examples of advanced procedures.
» Intracorporeal suturing was practiced in the clinical situation.

They were recruited at the department of surgery and of gynaecology at the LUMC, and during a nationwide assembly among gynaecologists who are involved in minimally invasive surgery.

Box trainer

The trainer consisted of a box, measuring 45 x 30 x 25 cm, with a non-transparent cover, and was designed and fabricated at the LUMC.[Kolkman et al., 2008] The image of a 0 degree scope was displayed on a monitor.

Task

The task involved the placement of a simple suture followed by tying an intracorporeal knot. The exercise started with the needle positioned in the needle holder. A thread length of 12 cm of 2/0 Vicryl was used, Ethicon, Johnson and Johnson. A proper bite had to be taken of the suturing pad in a pre-marked area. A 3-throw square knot had to be tied, after the needle and a substantial part of the suture material had been driven through. The knot tying technique was standardized. The suture had to be wrapped twice around the left hand needle holder, and the short end of the thread had to be pulled through the loops. Next, the dread had to be wrapped once around the right hand needle holder and the short end had to be pulled through this loop. Finally, the dread had to be wrapped around the left hand needle holder again and the short end of the thread had to be pulled through this final loop (Figure 1). Prior to performing the task, a demonstration video was shown, followed by the step-by-step graphical explanation (Figure 1). Next, the video was demonstrated a second time. All participants had to perform the suturing task three consecutively times. No practicing was permitted before, or in between, the suturing trials. If necessary, the researcher (EH) coached a participant to perform the correct next step, in order to keep every trial in the study, and to ensure that every knot was of good quality (no slippage was allowed) and was performed in a standardized way.

Motion analysis, four parameters

The movements of the laparoscopic instruments were recorded with the TrEndo tracking device in four degrees of freedom (DOFs): an up-down translation (1^{st} DOF), a forward-backward (2^{nd} DOF), and a left-right (3^{rd} DOF) rotation around the incision point, and the rotation of the instruments around its longitudinal axis (4^{th} DOF).[Chmarra et al., 2006] The recorded data were the **time** (s), defined as the total time taken to perform the task, and additionally the following three economy of movement parameters[Chmarra et al., 2006]:

» **Path length** (m): defined as the average path length of the right and the left instrument tip during the task;

» **Motion in depth** (m): defined as the average of the distance travelled by right and left instrument along its axis;

» **Motion smoothness** (m/s^3): a motion analysis parameter based on the third time derivate of position, which represents the change in acceleration. The motion smoothness was calculated by averaging this parameter for the right and the left instrument. A low-pass Butterworth filter was used to filter the raw data.

Hypothesis

The four motion analysis parameters (i.e. time, path length, motion in depth and motion smoothness) are able to distinguish surgeons of a different skills level. Especially, the parameters can discriminate between novices and experts during an intracorporeal suturing task.

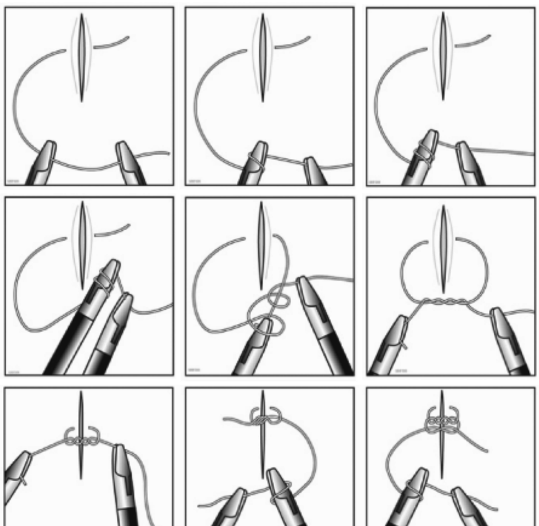

Figure 1. Standardized way to tie an intracorporeal knot.

Statistics

The data were analysed using the SPSS 16.0 software package (SPSS, Chicago, IL, USA). In order to test whether the motion-analysis parameters can discriminate between novices, intermediates and experts, non-parametric Kruskal-Wallis tests were used for each parameter. In case the groups differed significantly, pair-wise comparisons were performed to test the difference between each group using Mann Whitney. Additionally, the Bonferroni correction for multiple testing was used with respect to the differences between novices and experts, and therefore to test the primary research hypothesis. Finally, to test whether improvement within each group was present a Wilcoxon's signed rank-test was used, comparing the first and the third trial. Probability below .05 was considered statistically significant.

RESULTS

In total, 19 novices, 12 intermediates, and 11 expert laparoscopic surgeons participated in the study. All 19 novices who had responded to the advertisement denied previous surgical experience and completed the entire study protocol of 3 trials. Of the 22 residents who received an e-mail, 12 agreed to participate in the study: four in PGY1, two in PGY2, three in PGY3, two in PGY 4, and one in PGY 5. All completed the entire study protocol. Of the 11 participating laparoscopic experts, four were consultants in surgery, and seven were consultants in gynaecology. All met the inclusion criteria of the study definition of an ''expert.'' Eight experts completed the entire protocol of 3 consecutive suturing tasks. Two experts (one surgeon and one gynaecologist) did not perform the third trial, and one expert surgeon performed only the first trial. Time constraints were given as a reason to not complete the entire study protocol.

Examples of the typical trajectory of the right needle holder tip as used by a novice and an expert, both right-handed, are presented graphically in figure 2.

Performance of novices, intermediates, and experts throughout the three trials are displayed graphically in Figure 3 for the four motion-analysis parameters. Differences were observed between the three groups of participants ($p < .001$ during all trials for all four parameters). A Bonferroni correction for multiple testing revealed that performance of novices significantly differed from that of experts in all trials ($p < .01$ for time, path length, motion in depth, and motion smoothness). The difference between each combination of groups, calculated using the Mann-Whitney test, are shown for all parameters during the four trials (Figure 3).

The lower and upper bounds of the boxes represent the 25th and 75th percentiles, respectively, and the black line in the boxes indicate the median. *$p < .05$, **$p < .01$, and ***$p < .001$, all Mann-Whitney test.

Performance of novices and intermediates improved significantly for all four parameters (Table 1). However, no significant improvement was observed in performance of the experts. For novices, initial time improved, on average, by 42%, and path length, motion in depth, and motion smoothness improved by 26%, 25%, and 8%, respectively, of the initial score.

To set an expert standard for the 3-throw knot, the median scores of the 4 motion-analysis parameters of the experts during the second trial were used (Table 2).

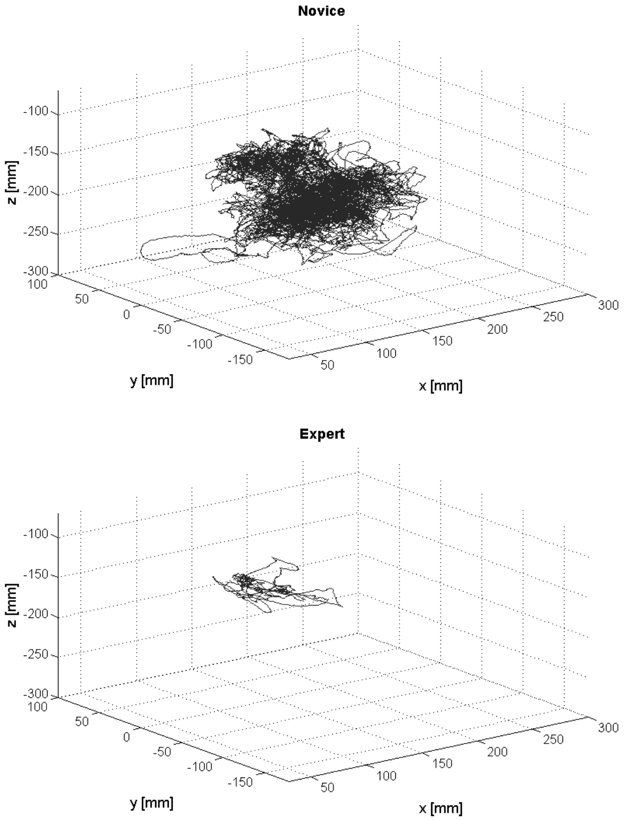

Figure 2. Typical trajectory (in millimetres) of the right-hand instrument during intracorporeal suturing by a novice (A) and an expert (B).

Table 1. Improvement in 4 parameters during 3 trials.

	Parameter	p Value trial 1 - 3
Novice	Time	<001
	Path Length	<01
	Motion in Depth	<01
	Smoothness	<01
Intermediate	Time	<01
	Path Length	<01
	Motion in Depth	<01
	Smoothness	<01
Expert	Time	NS
	Path Length	NS
	Motion in Depth	NS
	Smoothness	NS

Wilcoxon signed rank test was used to compare first and third trials.

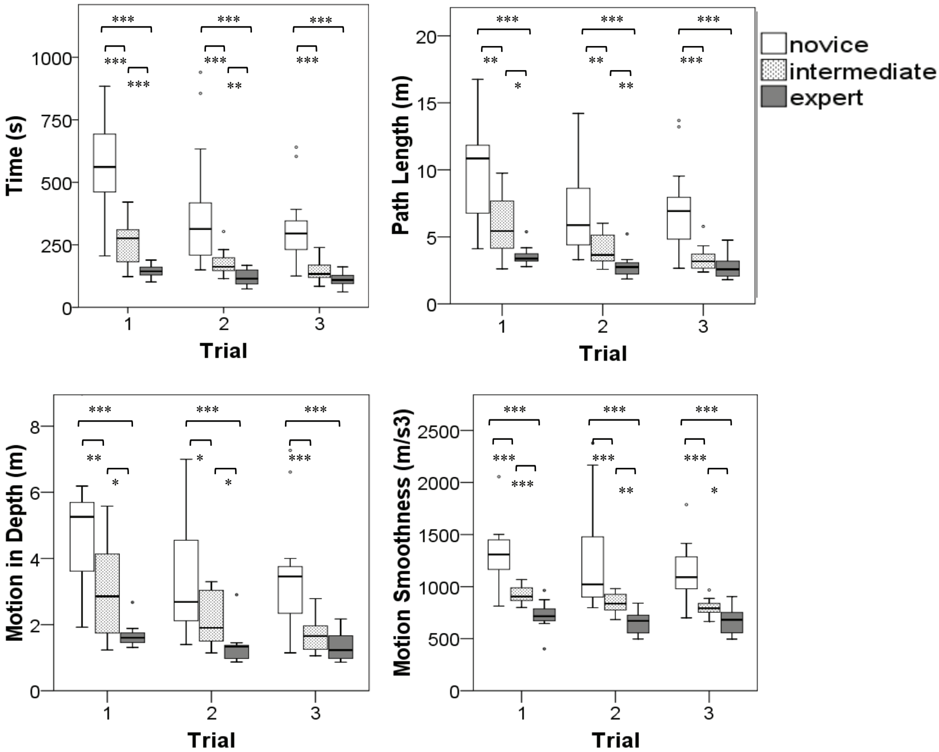

Figure 3. suturing task scores for novices, intermediates and experts.

Table 2. Expert standard, established during second trial.

Motion analysis Parameter	Median	Interquartile Range
Time [s]	114	90 – 150
Path Length [m]	2.75	2.17 – 3.13
Motion in Depth [m]	1.33	0.96 – 1.39
Motion Smoothness [m/s^3]	670	550 – 728

DISCUSSION

This study has confirmed the hypothesis to be true that the four motion-analysis parameters are able to discriminate between groups with different levels of experience during an intracorporeal suturing task in a physical box trainer. This indicates the construct validity of these objective assessment parameters for psychomotor skills for intracorporeal suturing.

Although experts outperformed intermediates during the first and second trial for all parameters, no significant difference was present during the third trial for time, path length and motion in depth. The intermediates were residents in Obstetrics and Gynaecology who had been exposed to one or more laparoscopic skills training sessions during their specialty training. As a result of this training, some of them may approach the expert level after a short rehearsal of two intracorporeal sutures. This might be an essential difference between being proficient (i.e. an expert), and progressing along a proficiency gaining curve (i.e. a resident).

5

The relevance of economy of movement parameters in the in vivo situation was revealed by their ability to discriminate between surgeons of a different level of experience during a laparoscopic cholecystectomy on a porcine model.[Smith et al., 2002] Furthermore, specified feedback on performance can be provided if these parameters are used during simulator training. Unfortunately, most of the currently described tracking devices can only be used in a virtual environment.[Chmarra et al., 2007] Regarding intracorporeal suturing, a recent study revealed no additional value of VR simulation over a box trainer model.[Botden et al., 2008] Unlike box trainers, VR trainers do not offer a natural instrument-tissue interaction, or the possibility to use real laparoscopic instruments and materials (e.g. a needle holder and suturing material). Determining motion-analysis parameters with the TrEndo in a box trainer combines the haptic advantages of box trainers with the objective assessment ability of VR trainers.

Prior studies have used time to completion of a suturing task to establish learning curves.[Kolkman et al., 2008; Munz et al., 2007; Van Sickle et al., 2005; Vossen et al., 1997] However, Smith et al. found that time improved during the first three trials and then stabilized, while the path length continued to improve over 10 trials.[Smith et al., 2002] Therefore, it was concluded that the learning curve for time alone fails to account for the more protracted learning curve for accuracy. We found that the novices' performance in suturing improved significantly for all four motion-analysis parameters across the three trials. However, the observed improvement in time was relatively larger (42%) than the improvement in the three economy of movement parameters (path length, motion in depth and motion smoothness). Since most of the training effect is achieved after tying 20-30 knots[Vossen et al., 1997], achievement of proficiency should not be expected within 3 trials. Additionally, it was revealed that experts still outperform novices after 100 trials to tie a proper knot.[Vossen et al., 1997] Our study is in line with that finding. The relatively small improvement in the economy of movement parameters, compared to the time to completion of the task, suggests that it takes more trials to perform an intracorporeal suture with efficient use of movements than to perform it quickly.

Another objective of this study was to set a performance standard for laparoscopic suturing by using the parameters of the experts' performance. Obviously, the experts did not improve significantly across the trials, since they had already achieved proficiency. Although arbitrary, we choose to set the experts performance at the second trial as the expert standard. The first trial was not chosen in order to correct for possible adaptation to the simulator setup, and the third trial had the disadvantage that it was only performed by 8 out of 11 experts. This performance standard can be used for training purposes, but also for assessment or even certification in order to enhance patient safety. Even though, experts are quite consistent in performance, expressed by small interquartile ranges of their scores, their spread around the median should be taken into account when this standard is implemented.

Intracorporeal suturing incorporates all basic laparoscopic skills[Rosser et al., 1997], and it is a prerequisite for advanced laparoscopic procedures as it is needed to handle possible complications or in case of instrument failure. Acquisition of suturing translates directly to the clinical situation. Concerns have risen whether the suturing skill is too complex to acquire for junior residents. However, the results of our study confirms those of Aggarwal et al. who revealed that residents with little or no previous laparoscopic experience are able to carry out the task competently after a short training course.[Aggarwal et al., 2006] Consequently, in our opinion, intracorporeal suturing training should be incorporated early in the residency curriculum.

5

The construct validity of time, and three economy of movement parameters (i.e. path length, motion in depth, and motion smoothness) has strongly been suggested for the intracorporeal suturing task performed in a box trainer. An expert standard has been set. Economy of movement parameters should be added to assessment package in order to form a framework of specified feedback, and to allow continuous refinement of psychomotor skills during training, and can be used for assessment and for certification purposes.