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CHAPTER 5

FORCE MEASUREMENT PLATFORM FOR TRAINING AND ASSESSMENT OF LAPAROSCOPIC SKILLS
ABSTRACT

Background

To improve endoscopic surgical skills, an increasing number of surgical residents practice on box or Virtual-Reality (VR) trainers. Current training is mainly focused on hand-eye coordination. Training methods that focus on applying the right amount of force are not yet available.

Methods

The aim of this project is to develop a system to measure forces and torques during laparoscopic training tasks as well as the development of force parameters that assess tissue manipulation tasks. The force and torque measurement range of the developed force platform is 0-4 N, and 1 Nm (torque), respectively. To show the construct validity of the developed force platform, a study was conducted in which 11 surgeons experienced in intracorporeal suturing and 21 Novices performed a suture task on artificial tissue in a box trainer. The tissue was mounted on the Force platform that was used to measure the force applied on the tissue in three directions. We evaluated the potential of 16 different performance parameters, related to the magnitude, direction and variability of applied forces.

Results

A force measurement was developed which has a mean accuracy for measuring forces and torques of 0.1 N (SD 0.073) and 0.02 Nm (SD 0.016), respectively. In the validation study nine of the parameters showed significant differences between Experts and Novices. In general the force exerted by the Experts was significantly lower than the force exerted by Novices.

Conclusions

The designed platform is easy to build, affordable, and accurate and sensitive enough to reflect the most important differences in e.g. maximal force, mean force, and standard deviation. Furthermore, the compact design makes it possible to use the force platform in most box trainers. Force measurements in a box trainer can be used to classify the level of performance of trainees and can contribute to objective assessment of suturing skills.
INTRODUCTION

The use of minimally invasive techniques is rapidly increasing and offers the patient many advantages compared to conventional surgery. Because of the increasing complexity of minimally invasive procedures, effective and affordable training tools are required to improve the endoscopic skills of surgical trainees. New training tools such as box-trainers equipped with motion detection\cite{1,2} or virtual reality trainers\cite{3,4} have been developed to enable trainees to practice outside the operation room and to objectively assess their skills. Current assessment focuses mainly on the efficiency of instrument movements and task (completion) time in basic grasping and positioning tasks. However, there is also a need for objective assessment of performance in delicate tasks such as tissue handling and suturing.\cite{5,6} During these tasks high forces can cause serious tissue damage, therefore monitoring other parameters (i.e. the interaction force between tools and tissue) is essential for proper assessment of endoscopic skills. When box trainers are equipped with force sensing technology, information about interaction force and torque can be used to train delicate tasks that require adequate force control. If trainees use these training tasks and assessment methods to train tissue handling skills in laboratory setting before operating on a patient, the risks of tissue damage can be reduced. To this extend a simple and low-cost force platform system that measures force and torque applied on tissue with standard laparoscopic tools to place inside a standard box trainer was developed by T. Horeman, Delft University of technology. This chapter in short describes the development of the force measurement platform and the clinical validation.

DEVELOPMENT OF THE FORCE MEASUREMENT PLATFORM

The design of a platform that measures forces and moments generated between instruments and tissue, should meet the following requirements:

1. Measurement of forces in 3 directions (X,Y,Z)
2. Measurement of moments around the X, Y, and Z axis
3. Device fits in different standard box-trainers with minimal modifications of the training setup
4. Multiple training tasks can be trained with the device
5. Plug and play and compatible with all standard computer operating systems
6. Low cost, robust, and easy to assemble
7. Accuracy 10 % of range
8. Able to measure frequencies up to 20 Hz
9. Force and torque range should be adjustable for different trainings tasks
10. The platform must be able to measure forces and torques up to 12N and 0,7Nm

Based on these requirements, a prototype was made that makes use of a commercially available 6D mouse (Space Navigator, 3Dconnexion GmbH, Seefeld, Germany). This mouse is typically used to move objects in a three-dimensional virtual environment. The potential of the prototype for performance evaluation in laparoscopic tasks was investigated in a pilot study.

**Opto-electronic 6D mouse**

The Space Navigator is a USB device that can be read with standard communication protocols as used by Windows®. In Figure 1 a schematic exploded view of the Space Navigator itself is presented. Relative movements and position of the table are determined by optoelectronic components installed inside the Space Navigator. Basically, 3 bundles of infra-red light are created with 3 pairs of LED’s mounted on a Printed Circuit Board (PCB) (1). With a triangular plastic block (2) with slit diagraph (3), placed over the LED’s (4), the 3 bundles are reshaped into 3 x 2 light paths. The light paths are detected by 3 light detecting components (8), installed on a second PCB (5). Both PCB’s are connected by small springs (6) that allow independent movement in all directions.

Figure 1. Schematic exploded view of the SpaceNavigator (adapted from Patent EP1850210).
Software

Software was written in C++ to record rotation and translation vectors at a rate of 60 Hz. The data was saved in arbitrary units together with a time vector. To compute the force in Newton and torque in Newton per mm for further analysis, the relationship between the measurements and the applied forces was determined by calibrating the force platform.

Mechanical components

To use the Space Navigator as a 6D force platform in box trainers, the allowable range of forces needs to be increased. Increased stiffness in all directions is required to measure forces over 2 N without limiting the movement of the cap. This is accomplished by adding 3 springs around the Space Navigator (Figure 2). On one side the springs are connected to the table (i.e. the upper plate) that is mounted on the cap of the Space Navigator. On the other side, the springs are connected to a base plate fixed on the housing of the Space Navigator. Small adjustments in the position and orientation of all individual springs, with respect to the base plate and table, is possible by repositioning of the spring holders with the three star screws at the top and 3 Allen screws at the base plate. If springs with a stiffness of 14 N/mm are used, a force range of 12 N is easily reached. For the first needle driving tests a lower force range of 6 N is sufficient. Therefore, springs with 4N/mm stiffness are used to maximize the resolution.

Figure 2. Left: force platform built from mechanical components. Right: modified SpaceNavigator that is fixed between base plate and table.
Calibration and accuracy

The calibration and accuracy are described in more detail in the publication by Horeman. The developed force platform has a mean accuracy for measuring forces of 0.1 N (SD 0.073) and 0.02 Nm (SD 0.016) for measuring torques.

Pilot study - Needle driving task

A pilot study in which subjects performed a needle driving task was undertaken to investigate the potential of the force platform. The task was conducted inside a training box (Figure 3, right) equipped with two 5-mm and one 11-mm trocars (Endopath XCEL, Johnson & Johnson), 2 needle drivers (B Braun) and one laparoscopic camera. Artificial tissue, imitating the skin and fat layers (Professional Skin Pad, Mk 2, Limbs & Things, Bristol, United Kingdom), was fixed on the force platform. On top of the artificial tissue, the point of insertion and direction were marked by two lines (Figure 3, Left). The line thickness was 2 mm and the distance between the two lines was 9 mm. The test group (n=10) consisted of five surgeons who had performed at least 50 laparoscopic sutures during surgery and five Novices without hands on experience in laparoscopic surgery or training. All subjects were asked to pick up a needle (Vicryl 3-0 SH plus 26 mm, Ethicon, Johnson & Johnson) with the needle driver and to insert it at the right line on the tissue. Secondly, the subjects were asked to drive the needle, in the desired direction, through the tissue and to remove it completely at the location of the left line. If a subject was not able to insert the needle at the right line or to remove it at the left line, the measurement was removed from the database and the subject was asked to try it again. All subjects were asked to complete the needle driving task two times. During the test, no feedback was given to the subjects. For each subject we determined the maximum absolute force and the mean absolute nonzero force. We defined the mean absolute nonzero force as the force averaged across all samples during which force was exerted so that the resulting measure is based only on the periods of time were interaction took place. To determine whether the results obtained for the experienced surgeons differed from the data from the Novices we performed Students t-tests (SPSS 17.0) to compare the group means. Also, striking differences in force signatures were further investigated. In addition, we asked one Novice and one Expert to perform the needle driving task four times instead of two. This was done to see if learning effects occur within a small amount of repetitions.
Results Pilot study - Needle driving task

It took the surgeons 17.8 s (SD 2.1 s) and the Novice 29.4 s (SD 3.7 s) to complete the task. Before the surgeon and Novices inserted the needle into the artificial tissue, a clear difference between orientation and position of the needle inside the needle driver was visible. After inserting the needle-tip, both subjects used different strategies to drive the needle through the tissue. The surgeon used mostly rotation (R) of the needle around an imaginary rotation point (Figure 4A) whereas the Novice used rotation (R) as well as translation (X,Y) (Figure 4B).

Furthermore, unlike most surgeons, all Novices pressed the needle driver against the tissue during the task. A force graph and 3D force signature of the best performing surgeon and Novice are presented in Figure 5A, B.

Figure 4. Observed difference in needle driving between Expert (A) and Novice (B). R is rotation around needle centre point, X is translation parallel to X-axis, Y is translation parallel to Y-axis.
The absolute nonzero mean force and maximal force of all subjects, measured during the needle driving task, are presented in Figure 6. The force graphs of a Novice and surgeon that performed the needle driving task four times are presented in Figure 7. The maximum and mean absolute nonzero force used by the Novices was on average 4.7 N (SD 1.3) and 2.1 N (SD 0.6) respectively. For the surgeons, the average maximum force (2.6 N, SD 0.4 N) and the average mean force (0.9 N, SD 0.3) were much lower. The Student t-tests showed that there was a significant difference between the two groups of subjects for both depend variables (Mean nonzero force: \( t=4.3, p<0.005 \), Maximum force: \( t = 3.6, p<0.017 \)).
Figure 7. Force graphs of a Novice and surgeon that performed the needle driving task four times.
VALIDATION

Validation of the force measurement platform was established by determining if significant differences in force application can be found between Experts and Novices during a suturing task, which is performed in a box-trainer.

Participants

31 participants with different levels of experience in laparoscopy participated in the experiment. The participants were divided into two groups, Experts (n=11) and Novices (n=21). The first group consisted of surgeons and gynaecologists that performed over 100 laparoscopic procedures. The Novices in the second group were first and second year medical students with no experience in laparoscopic surgery or laparoscopic training. Each participant was asked to answer a short questionnaire detailing information about prior experience in laparoscopy. All of the participants were right-handed.

Suture Task and protocol

The participants performed a two-handed suturing task inside a box trainer set up with a force measurement platform as described above (Figure 4). A 26 mm Vicryl 3-0 needle from Ethicon (Johnson & Johnson) was used to conduct the suture task. Before the measurements started, a video was shown and a schematic overview was provided to the Novices to explain how to make the suture. Figure 8 shows the type of suture with a three throw knot that is used in this study. In the first phase of a single measurement, the participant was asked to insert a needle at the right line and to guide it through the tissue as close as possible towards the left line using their right hand. The left hand was then used to remove the needle at the left line. If the needle was not inserted correctly, a new measurement was started for the next attempt and all recorded data was deleted. If the participant did not succeed within five attempts the participant was removed from the study. In the second phase the participant made a three throw square knot. If necessary, participants received additional verbal instructions during the knot tying phase until three successful knots were made. Data from Novices that were not able to tie three knots was removed from this study. All participants were asked to repeat the complete sequence three times in a row with a maximum break of 10 minutes in between. For both phases of the task, the participant was not limited in time.

Before every measurement, the needle was positioned inside the needle holder by the experimenter so that the starting conditions were the same across participants and trials.
Since not all participants had previous experience with the type of needle drivers used in this study, each participant had the opportunity to manipulate the buttons and handle for five minutes outside the training box before the start of the first measurement.

**Force parameters and data analysis**

In total 16 different force parameters were chosen to evaluate the application of forces by the participants (Table 1). These parameters are related to the magnitude and direction of applied forces or to the variability thereof. Due to the different task requirements in the needle driving and knot tying phases in a suture task, not all force parameters are suitable performance measures for both phases of the suture task.

For the needle driving phase and knot tying phase, the forces over time for all three directions, Fx, Fy and Fz, were obtained from the recorded data. The X, Y, and Z axis of the force were defined relative to the Force platform. Based on Fx, Fy, and Fz we calculated the mean force parameters (e.g. meanFx, meanFy and meanFz). Furthermore, we calculated the mean absolute force parameter, maximal absolute force parameter and standard deviation (e.g. meanabsforceNZ, maxabsforce and STDabsforce) from the square root of Fx, Fy and Fz.

During the knot tying phase, it is expected that force peaks occur when the threads are stretched to tighten the knot. Figure 9 shows an example of the absolute force in time during needle driving (first phase) and knot tying (second phase) of the task. The highest absolute force peak itself was defined as the period with the highest absolute force between t1 and t2 during the knot tying phase.
The starting time $t_1$ was defined as the point in time the measured absolute force became higher than 0.1 Newton. The stopping time $t_2$ was defined as the first moment after $t_1$ the absolute force became less than 0.1 N again.

Due to the sensor accuracy of 0.1 N sensor outputs less than 0.1 N were neglected for the determination of $t_1$. During the highest absolute force peak, the mean $F_x$, mean $F_y$ and mean $F_z$ components (e.g. forcepeak-mean$F_x$, forcepeak-mean$F_y$, forcepeak-mean$F_z$) should indicate in which direction the threads are pulled at the moment a knot is tightened.

Figure 9. Representation of the absolute force over time during needle-driving and knot-tying phase. The hatched rectangle indicates the area where the highest mean absolute peak force between $t_1$ and $t_2$ is found in the knot tying phase. The height of the dashed rectangle indicates the mean absolute force between $t_1$ and $t_2$. The boxed values represent the mean $F_x$, $F_y$ and $F_z$ during the force peak.

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Figure 10. Phase 1: ellipsoid (transparent) representing the variability in forces in 3D when a needle is pushed from line A to Line B through artificial tissue. Phase 2: ellipsoid (transparent) representing the variability in forces in 3D during the knot tying phase. In both ellipsoids, the thick arrows represent the standard deviations (PC1, PC2, PC3) of the forces along the Principal axes of the ellipsoid.
To determine the main direction of applied forces (that not necessarily coincides with the X, Y, or Z axis), the variability in forces was presented graphically as projections of oriented ellipsoids in 3D (Figure 10). In Figure 11 Fx-local, Fy-local and Fz-local are the three principal axes of the ellipsoid. PC1, PC2 and PC3 are the standard deviations of the force along those principal axes and define the shape of the ellipsoid. The lengths of PC1, PC2 and PC3 and orientations (Fx-local, Fy-local and Fz-local) were determined using Principal Component Analysis (PCA) software (princom.m, Matlab 2008b). PCA is a mathematical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of uncorrelated variables called principal components.14

All analyses were performed for the needle driving phase and knot tying phase, separately. To evaluate whether there were differences between Experts and Novices in the main direction of force application the orientation of the largest principal component (PC1) was determined. This orientation was defined by the parameter Alpha, the rotation in the horizontal plane and parameter Beta, the rotation in the vertical plane.

uniqueness level largest axis: 342 > 5.99 (95% chance @ alfa 0.05)

Figure 11. 3D variability in forces. The dots represent the force in the global coordinate system (Fx,Fy,Fz). The green ellipsoid is fitted on the force data and the orientation of PC1 along Fx-local is defined by Alpha and Beta. PC2 and PC3 are not shown in the figure.
The main direction of force application can only be specified when PC1 is significantly larger than the other components. For instance, when the ellipsoid has the shape of a ball or disk, Alpha and Beta cannot be defined accurately. To evaluate the uniqueness of the principal components, the likelihood criterion of the principal components was determined with:

\[ \chi^2 = -(N-1) \sum \ln l_i + (N-1) r \ln \frac{1}{r} < \chi^2_{\alpha,r} \]

\( \chi^2 \) = Likelihood criterion  
\( \alpha \) = The probability of error = 0.05  
\( r \) = Number of eigenvalues = 2  
\( N \) = Number of simples  
\( l_i \) = The \( r=2 \) eigenvalues being compared for a given covariance matrix (i=1-2 or i=2-3).

The likelihood criterion was calculated for the two largest standard deviations PC1 and PC2 of the ellipsoid (Figure 10). Only ellipsoids with a likelihood criterion higher than 5.99 were taken into account. To get an estimate of the variability in the forces independent from the direction of force we calculated the volume of the ellipsoids. The “volume” parameter was calculated with:

\[ V = \frac{4}{3} \pi (PC1 \cdot PC2 \cdot PC3) \]

\( V \) = volume  
PC1= standard deviation of force along Fx-local  
PC2= standard deviation of force along Fy-local  
PC3= standard deviation of force along Fz-local

Some studies suggest that completion time seems a suitable parameter for discriminating between Experts and Novices. However, since completion time does not provide information about the exerted forces or the quality of the performed task, it is left out of the classification. When compared to force parameters, the performance time can provide useful information for further research and is therefore presented in Table 1.

**Statistical analyses**

A total of 16 force parameters were identified that could be suitable to determine the differences between groups (Table 1). We determined for each of the different parameters whether the group means of the experienced surgeons differed from the group means from the Novices using student T-tests (SPSS 17.0). A probability \( p < 0.05 \) was considered to be statistically significant. The difference between Experts and Novices on the parameters in the coloured fields of Table 1 were not significant.
RESULTS VALIDATION

Each participant performed the needle driving phase and knot tying phase 3 times. The averaged outcome per parameter is used for all calculations. The results for each force parameter including mean value, is listed in Table 1. For parameters that show significant differences, the results from all participants are presented in Figure 12.

Needle driving phase

The parameters that show significant differences in the needle driving phase are depicted in the first and second row of Figure 12. All Experts (n=11) were able to insert and remove the needle at the desired locations at the first attempt. Of the Novices (n=21), only 32% was able to complete this phase at the first attempt. The other 68% was able to complete the driving phase within the five attempts. Only data of successful attempts was used in the analysis.

Figure 12. Needle driving phase and knot tying phase results. The Experts in group 1 are indicated with a “O” mark (n=11) and the Novices in group 2 are indicated with “X” mark (n=16). Each measurement point represents the averaged value of 3 measurements from one participant. The horizontal lines indicate were the mean value is found. Significant differences are indicated by P values. Time was not used for classification.
The mean maxabsforce and mean meanabsforceNZ found in the Novice group were 4.5 N (STD 1.3) and 1.6 N (STD 0.6) respectively. With a mean maxabsforce of 2.7 N (STD 0.4) and mean meanabsforceNZ of 0.9 N (STD 0.3), the force exerted by the Experts is significantly lower. It took the Experts 21 (STD 6) seconds and the Novices 56 (STD 30) seconds to complete the task.

The mean volume of the ellipsoid, that was computed from the standard deviations along its axes, was considerably higher in the Novice group (1.5 (STD 1.3)) when compared with the Expert group (0.5 (STD 0.4)).

Looking at the orientation of the ellipsoids, a mean value of 224° (STD 39°) for Alpha was found in the Expert group. With a mean value of 176° (STD 57°) for Alpha, the ellipsoids in the Novice group were much further rotated around the Z-axis. A less clear difference was found for the rotation in the vertical plane. A mean value for Beta of 237° (STD 63°) was found for the Expert group and a mean value of 181° (STD 95°) was found for the Novice group. Since all likelihood criteria were higher than 5.99, the orientation was defined reliably for all ellipsoids.

**Knot tying phase**

The parameters that show significant differences in the knot tying phase are depicted in the third row of Figure 12. All Experts (n=11) were able to complete the knot tying phase of the task at the first attempt. Due to time constraints, 5 Novices (n=21) did not finish the complete task and stopped after the needle driving phase. All other participants were able to tie all knots according to the instructions given. The average of 2.7 N (STD 1.2) for the maxabsforce parameter in the Expert group is significantly lower than the average value obtained for the Novice group (4.3 N, STD 0.9). The mean meanabsforceNZ is with 0.4 N (STD 0.1) in the Expert and 0.5 N (STD 0.2) in the Novice group not significantly different between groups. It takes the Experts on average 95 (STD 36) seconds and the Novices 446 (STD 184) seconds to complete this task. The maximal force peak as product of the time and pulling force is with a mean value of 6.7 Ns (STD 7.7) in the Expert group significant lower as in the Novice group (15.4 Ns (STD 10.5)). Looking at the distribution of the pulling force on the threads in the direction of PC3, the averaged standard deviation found in the Expert group is with 0.01 N (STD 0.4) significantly lower as in the Novice group (0.14 N, (STD 0.6)). None of the other pre-defined parameters were significantly different between groups.
A force platform was developed that can measure interaction forces with tissue in a nonclinical setting with a mean accuracy for measuring forces of 0.1 N (SD 0.073) and 0.02 Nm (SD 0.016) for measuring torques.

**Needle driving phase**

In line with the pilot study and the VR suture study of O’Toole\(^8\), we found that the Novice group applied a higher maximum and mean force than the Expert group. These results also matched our observations throughout the experiment. It was clear that most Novices used much more force than required for the needle to cut through the artificial material.
Looking at the distribution of the force inside both groups, the distribution of the mean force required to drive the needle in the desired direction (meanFx) is comparable between groups. Only small forces are expected perpendicular to the direction the needle is pushed. Except for two outliers, the meanFy values found in the Expert group indicate that all Experts behaved similarly and none used excessive force in the Y direction. In the Novice group however, the mean force varied from -2N to +1.8N. The relatively large variation in magnitude of forces in the Y direction in this group may be explained by friction in the training setup. In the X and Z direction, a large part of the movements can be accomplished by rotation of the needle pusher around its pivot point. Movements in the Y direction are mainly accomplished by axial displacement of the needle holder in the trocar. If, for example, the needle is pushed into the artificial tissue and moved excessively in the Y direction before the instrument handle is released, the friction in the trocar and elastic disc prevent the instrument from moving back to its starting position and a “force-offset” is created.

Since the force-offset is a result of the force-equilibrium between Force-platform springs and trocar valve or elastic disk, nothing is felt at the handle. Because Novices use more force to accomplish the task, the risk on a force offset that influences the meanFy parameter is higher. A second explanation is found in limitations in depth perception. Earlier studies indicate that instrument movements in the direction of the optical axis are difficult to estimate.19, 20 Presumably, limitations in depth perception make it difficult for untrained eyes to detect unintentional needle displacements in the Y direction. Since needle displacements result in force, a limitation in depth perception could influence the meanFy parameter.

The ellipsoid volume and standard deviations in exerted forces are possibly related to the participant’s control of movement direction. If the needle is pushed with a constant force in one direction through the material, the standard deviations are near zero and the ellipsoid volume is small. Especially the direction of the largest principal component (PC1) and the size of the ellipsoid volumes indicate that a large part of the Novices used multiple movements to manipulate the needle through the artificial tissue. The needle is locked inside the needle holder with an angle of 90 degrees with respect to the needle holder shaft.

Due to the configuration of the holes and dimensions of the box trainer, the needle describes an angle of 230 degrees with respect to the positive X-axis in the horizontal plane at the moment of insertion (Figure 13). If forces are exerted in the direction of the needle, the ellipsoid’s largest principal component should aim in the same direction.
as the needle tip. With Alpha values close to 230 degrees (mean 224°, STD 39°) in the Expert group, it seems that Experts are able to manipulate the needle more efficiently through the artificial material than Novices (mean 176°, STD 57°). Beta does not depend on the location of the trocar relative to the location of the suture area and an ideal value cannot be determined in advance.

**Knot tying phase**

The maximum force in the Novices group is significantly higher compared with the Expert group. However, the low mean force in X, Y and Z direction in both groups indicates that the high absolute forces only occurred during short periods of time. The significant difference in maximal force peak between groups confirms that Novices not only use more force to secure the knot but also that the force is exerted for a longer period of time.

During the maximal force peak, the mean force in this phase shows in which direction the threads pull on the artificial tissue. The meanFZ-force peak value suggests that Novices tend to pull on the threads in the –Z direction while tightening the knot whereas Experts tend to push in the +Z direction. The meanFX-force peak and meanFY-force peak value’s showed no indication of specific differences between groups.

Compared with the volumes calculated in the needle driving phase, the volumes calculated during knot tying are much smaller. The reason can be that interaction takes place through threads without direct contact between instrument and tissue. A thread
under tension transmits only force in the direction of the thread to the tissue. If the tip pulls on a thread, only the movements in the axial direction of the thread results in a reaction force in the artificial tissue. All other movements of the tip are not counteracted and do not add “volume” to the ellipsoid.

**Force and torque information in training tasks**

In the present study we evaluated performance in a suturing task. However, potentially any training task, used to practice laparoscopic skills, can be mounted on the force platform. Box trainers equipped with the force platform can provide students and instructors with objective information about interaction forces and torques for more effective training and assessment.

With respect to training an important question remains how to present the torque and force data to the student in real-time (Figure 14). When tasks are performed inside a laparoscopic box trainer, the resident’s attention is directed to the monitor. Further, the complexity of the task may make it difficult to detect whether the proper amount of forces is applied. If the platform is used for well-defined simple tasks, it should be possible to find an effective method of providing force feedback during training. One option is to use this same monitor to display torque and force information. Another option is to use sounds to indicate, for example, that the exerted torque or force exceeds a stored maximum value.

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Figure 14. Schematic diagram of a resident during training on box trainer equipped with a force platform.
**CONCLUSION**

A force measurement was developed to measure force and torque in three directions during performance of endoscopic tasks inside box trainers. The validation study indicates construct validity of the force measurement platform. Experience influences the applied interaction forces during the laparoscopic suturing task. The maximal absolute force and time clearly discriminate between the two different levels of experience during both suture phases. The mean force and the force variability (e.g. Ellipsoid volume and direction) discriminate between groups in the needle driving part of the task.

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