The impact of aptitude on the learning curve for laparoscopic suturing


National Surgical Training Centre, Royal College of Surgeons in Ireland, 121 St Stephens Green, Dublin 2, Ireland

KEYWORDS:
Learning curve; Aptitude; Laparoscopic suturing; Simulation; Proficiency-based training

Abstract

BACKGROUND: Within surgery, several specialties demand advanced technical skills, specifically in the minimally invasive environment.

METHODS: Two groups of 10 medical students were recruited on the basis of their aptitude (visual-spatial ability, depth perception, and psychomotor ability). All subjects were tested consecutively using the ProMIS III simulator until they reached proficiency performing laparoscopic suturing. Simulator metrics, critical error scores, observed structured assessment of technical skills scores, and Fundamentals of Laparoscopic Surgery scores were recorded.

RESULTS: Group A (high aptitude) achieved proficiency after a mean of 7 attempts (range, 4–10). In group B (low aptitude), 30% achieved proficiency after a mean of 14 attempts (range, 10–16). In group B, 40% demonstrated improvement but did not attain proficiency, and 30% failed to progress.

CONCLUSIONS: Distinct learning curves for laparoscopic suturing can be mapped on the basis of fundamental ability. High aptitude is directly related to earlier completion of the learning curve. A proportion of subjects with low aptitude are unable to reach proficiency despite repeated attempts.

Previous studies have shown that increasing the complexity of a procedure is associated with a progressively steeper learning curve. In particular, a protracted learning curve has been demonstrated in laparoscopic suturing. When the learning curve for laparoscopic suturing was examined by Botden et al., the number of repetitions required to reach the top of the performance curve was 8. We planned to establish if this learning curve differs depending on a subject’s aptitude.

Several studies have examined the relationships between specific areas of aptitude, such as visual-spatial and perceptual abilities, and laparoscopic technical skill performance. These studies have concluded that superior laparoscopic performance is demonstrated among novice surgical trainees who possess such attributes.
We have previously shown that aptitude can predict the rate at which a surgical novice achieves proficiency in a basic laparoscopic task, such as laparoscopic appendicectomy. It is intuitive that the more complex the laparoscopic procedure, the greater effect that fundamental ability will have on achieving proficiency.

We aimed to compare the rate at which 2 groups of surgical novices became proficient in laparoscopic suturing and intracorporeal knot tying. These 2 groups were at opposite ends of the aptitude spectrum.

**Methods**

**Setting and study participants**

Participants were recruited to take part in this study on a voluntary basis. Sixty-two medical students with no prior surgical experience were tested in 3 different dimensions of aptitude, described below. All participants were asked to sign a consent form allowing the data collected to be used for research purposes. It was made clear to all the subjects that the data were stored and presented in an anonymous format. Ethical approval was granted by the Research Ethics Committee of the Royal College of Surgeons in Ireland.

On the basis of the results of aptitude testing, 2 groups of 10 participants were selected from opposite ends of the aptitude spectrum. Participants in the first group (group A) were considered to have high aptitude, with scores 1 standard deviation higher than the mean score of the study population. Participants in the second group (group B) were considered to have low aptitude, as their scores were 1 standard deviation lower than the mean score of the study population. Five experienced laparoscopic surgeons were also recruited to set benchmark proficiency levels on the ProMIS III simulator (CAE Healthcare, Sarasota, FL). Each of these surgeons had performed >100 complex laparoscopic procedures.

**Simulator and materials**

The ProMIS III simulator was used for assessment. It facilitates the use of physical models, which ensures tactile feedback, and by tracking the instruments, it provides measurements of performance. Upon completion of a procedure, the simulator generates an immediate profile summary of objective measurements. These include time,
path length, and economy of movement. Numerous studies have provided construct validity for this hybrid simulator.11–14

A 10 × 12 cm piece of synthetic suturing skin (The Chamberlain Group, Great Barrington, MA) was placed in the simulator tray. The laparoscopic suturing task was performed according to Fundamentals of Laparoscopic Surgery (FLS) principles (Table 1) using 3/0 silk sutures and 2 laparoscopic needle holders. Three knots were thrown to complete the task.

**Aptitude testing**

Visual-spatial aptitude is the ability to generate, transform, and retain structured visual images. It represents one’s ability to mentally manipulate 2-dimensional and 3-dimensional figures. Four visual-spatial paper-based tests were selected from the kit of factor-referenced cognitive tests (developed in 1976), which have been previously validated.15 These include the card rotation test, cube comparison test, map planning test, and surface development test.

Psychomotor aptitude is the ability to perform motor tasks with precision and coordination. In this study, we measured manual and finger dexterity and hand-eye coordination. This was assessed using a grooved pegboard. It has been previously validated and is a well-recognized assessment tool.16

Depth perception is one’s visual ability to perceive the world in 3 dimensions and to assess the distance of an object. Pictorial surface orientation testing was developed to assess a subject’s perceptual ability in laparoscopic surgery.17

**Performance assessment**

Before performance assessment, each candidate received didactic teaching. Each candidate was sent a stepwise approach detailing how to perform the task and a video link to a live recording of a specific part of a laparoscopic rectopexy before the experiment commenced. When the candidates attended the first session, a simulated laparoscopic suturing demonstration was conducted. They were allocated time to ask questions before they attempted to complete a

---

**Figure 1** Comparison of (A) visual-spatial scores, (B) depth perception scores, and (C) psychomotor scores.
mandatory multiple-choice questionnaire to ensure thorough comprehension of the procedure. Before their first assessments, candidates had the opportunity to familiarize themselves with the testing equipment by completing a basic laparoscopic task.

Participants were asked to perform the suturing task consecutively until they reached the proficiency scores. An interval practice curriculum rather than massed practice was implemented. Candidates were allowed to perform a maximum of 4 tasks per session to avoid fatigue. Sessions

Figure 2  (A) Comparison of path length scores in surgical novices and (B) path length scores for all attempts in those with low aptitude. (C) Comparison of economy of movement scores in surgical novices and (D) economy of movement scores for all attempts in those with low aptitude. (E) Comparison of time scores in surgical novices and (F) time scores for all attempts in those with low aptitude.
were carried out at a maximum interval of 2 weeks. Candi-
dates were supervised by a senior surgeon at all times, and if a
subject needed guidance, instructions were given. The senior
surgeon did not take over the task at any point during the per-
formance assessment. The amount of prompting per case was
not specifically quantified. Upon completion of each proce-
dure, the simulator provided a summary score report, which
was relayed to the candidate as a means of assessing progress
throughout the experiment.

Each performance was recorded and subsequently
assessed by 2 reviewers, blinded to the status of the surgical
novice, using the observed structured assessment of
technical skills (OSATS) scoring system and the FLS rating
scale. The quality of each knot was assessed after task
completion. This information was relayed to the candidate
after each performance.

Data analysis

Statistical analysis was performed using Stata version
12.0 (StataCorp LP, College Station, TX). The aptitude,
metric, and proficiency scores of the 2 groups were
compared using the Mann-Whitney test. P values <.05
were considered statistically significant. Nonparametric
testing was performed, as none of the data were shown
to be normally distributed using the Shapiro-Wilk test.

Interrater reliability was determined using Cronbach’s
α coefficient.

Results

Participant demographics

Of the 20 subjects who participated, 13 were women and
7 were men, and the mean age was 22.3 years (range, 18–36
years). Further demographics are shown in Table 2.

Aptitude scores

The high-aptitude group (group A) achieved signifi-
cantly higher scores than the low-aptitude group (group B)
in all 3 areas of aptitude tested, as illustrated in Fig. 1A–C.
Group A scored 72% for visual-spatial ability compared
with 24% in group B (P < .0001). Depth perception scores
were 93% in group A compared with 50% in group B (P <
.0001), while group A demonstrated improved psychomo-
tor ability by performing the pegboard task in 58 seconds
compared with 73 seconds in group B (P = .03).

Metric scores

The baseline metric scores for both groups are shown in
Table 3; these are the scores from the first attempts of all
candidates. Group A achieved better scores than group B
in all parameters (P < .0001).

Path length scores are illustrated in Fig. 2A. Group A
achieved proficiency faster (P < .0001) than group B. The
learning curve for group A can be seen in Fig. 2B. Within
group B, 30% achieved proficiency after a mean of 14 attempts, 40%
demonstrated improvement but did not attain proficiency despite 16 attempts, and 30%
failed to progress and were unable to progress along the learning
curve (Fig. 2B).

Economy of movement and time scores for both groups
for all attempts are displayed in Fig. 2C, E, respectively. Group A achieved proficiency in a shorter time frame for
these 2 parameters than group B (P < .0001). group B
can be further divided into 3 subgroups for economy of
movement and time scores: 30% attained proficiency, 40%
showed improvement but did not attain proficiency,
and 30% failed to progress, as illustrated in Fig. 2D, F, respectively.

**Attainment of proficiency**

The mean number of attempts to achieve proficiency for group A was 7 (range, 4–10), compared with 14 (range, 10–16) for group B ($P = .01$; Fig. 3). In the low-aptitude group, 30% achieved proficiency after a mean of 14 attempts, 40% demonstrated improvement but did not attain proficiency, and 30% failed to progress and dropped out of the study. They dropped out by personal choice, as they were unable to complete the task after an average of 5 attempts.

![Graphs showing subjective OSATS and FLS scores for surgical novices and those with low aptitude.]

**Figure 4**  (A) Comparison of OSATS scores in surgical novices and (B) OSATS scores for all attempts in those with low aptitude. (C) Comparison of FLS scores in surgical novices and (D) FLS scores for all attempts in those with low aptitude. (E) Comparison of error scores in surgical novices.
Subjective scores

The baseline subjective scores (OSATS, FLS, and error scores) for both groups are shown in Table 3; these are the scores from the first attempts of all candidates. Group A achieved significantly better scores compared with group B in all parameters ($P < .0001$).

OSATS scores for both groups are shown in Fig. 4A, and FLS scores are shown in Fig. 4C. Group A achieved proficiency with fewer attempts ($P < .001$) than group B. The consistent separation in learning curves among group B was again demonstrated with regard to OSATS and FLS scores, as depicted in Fig. 4B, D, respectively. Interrater reliability between the 2 assessors was determined using Cronbach’s $\alpha$ coefficient and was found to be .98 and .95 for FLS and OSATS scores, respectively.

The error scores for both groups are shown in Fig. 4E. The baseline mean error score was 2.2 in group A compared with 4.7 in group B ($P < .001$). Interrater reliability using Cronbach’s $\alpha$ coefficient was .86.

Comments

It is clear that distinct learning curves for laparoscopic suturing can be mapped on the basis of fundamental ability. This study has shown that there is a wide disparity in attaining proficiency in groups with differing levels of aptitude.

Surgical training bodies have many objectives, and one of their most important aims is to ensure that candidates excel in their chosen fields. Several specialties demand advanced technical skills specifically in the minimally invasive environment. On the basis of our study findings, candidates who possess good fundamental ability are more likely to succeed in their training pathways within a given time frame.

The current literature shows that residents with higher visual-spatial scores perform significantly better than those with lower scores.\textsuperscript{23,24} Our study supports these findings, as we have shown that candidates with high aptitude scores have a superior baseline in all parameters and attain proficiency quicker.

Grantcharov et al.\textsuperscript{25} previously identified 4 types of learning curves, which varied on the basis of psychomotor ability. Our data strongly support these findings, and we have specifically defined these learning pathways. We also found that a proportion of students fail to progress or follow any upward learning curve.

Previous work carried out at our institution showed that 25% of candidates with low aptitude were unable to achieve proficiency in laparoscopic appendectomy despite repeated attempts.\textsuperscript{10} This study shows that the proportion is higher when a complex task such as laparoscopic suturing is being attempted. Only 30% of the candidates with low aptitude were able to achieve proficiency in the laparoscopic suturing task, implying that aptitude plays an important role in learning advanced laparoscopic skills.

Limitations

These findings have been demonstrated in a simulated laparoscopic environment. There is conflicting evidence to support the transfer of skills from a simulated environment to the live operating room.\textsuperscript{26} We cannot guarantee that these specific findings would be reproducible in a live setting. Furthermore, we have stated that those with higher aptitude have a faster learning curve and can achieve proficiency at a faster rate, but this is somewhat of an artificial learning curve. The initial part of the learning has been shown to be the period of time when most errors are committed. Although the candidates were penalized if they committed any predefined errors, it was not an environment in which patient safety was an issue, so perhaps it is difficult to truly establish whether candidates overcame the learning curve.

Conclusions

High aptitude predicts a faster learning curve and improved performance in laparoscopic suturing. A significant number of candidates with low innate ability are unable to reach proficiency despite repeated practice. This study supports the concept of using objective selection processes based on aptitude to select suitable trainees who are likely to flourish in the challenging field of surgery if selected.

References