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Retention of Arthroscopic Shoulder Skills Learned with Use of a Simulator

Demonstration of a Learning Curve and Loss of Performance Level After a Time Delay

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Background: In orthopaedic surgery, arthroscopy is an irreplaceable diagnostic and interventional tool, and its breadth of use is increasing. The aim of this study was to investigate the surgeon’s capacity for retention of an unfamiliar arthroscopic skill.

Methods: Six fellowship-trained lower-limb surgeons were given standardized instruction regarding the performance of an arthroscopic Bankart suture on a laboratory-based simulator. They performed three single Bankart sutures on each of four occasions, one to two weeks apart. Six months later, the same surgeons repeated the study. They received no further instruction or guidance. Their performance was objectively assessed with use of validated motion-analysis equipment to record the total path length of the surgeon’s hands, number of hand movements, and time taken to perform the sutures.

Results: A learning curve showing significant and objective improvement in performance was demonstrated for all outcome parameters in both experiments (p < 0.005). The learning curve at six months was a repeated learning curve showing no significant difference from the initial learning curve.

Conclusions: This study objectively demonstrated a loss of all of the initial improvement in the performance of an arthroscopic Bankart suture following a six-month interval in which the surgeons did not do the procedure.

Clinical Relevance: The results indicate a need for regular repetition of some surgical tasks in order to maintain optimum performance levels and to consolidate the skills needed for newly learned procedures. It is hoped that the development of appropriately validated simulators may provide a useful tool with which trainees and established surgeons alike can acquire and maintain certain surgical skills.

Modern surgical practice is subject to increasing peer and public scrutiny. High-profile cases of adverse clinical events have led to improvements in systems for risk management, incident reporting, and monitoring of clinical practice and of patient outcomes. In some countries, consultant surgeons are now required to obtain recertification to demonstrate their continuing capability to practice. Some studies have demonstrated that surgeons who perform high volumes of a particular procedure achieve better outcomes, and some insurance companies have begun restricting their list of surgeons on the basis of volume of practice. This has raised awareness about the need to maintain appropriate skills, especially for rarely performed procedures.

Trainee surgeons in Europe face reductions in training time and the implementation of working-hour restrictions. This is leading to the development of methods of surgical skills training outside of the operating theater. The role of simulation in medical education has become well established in general surgery and is being increasingly recognized across other specialties.

In orthopaedics, arthroscopy is an irreplaceable diagnostic and interventional tool. Its breadth of use is increasing.

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and many advanced procedures have now been developed. Arthroscopic laboratory simulators have been used in training courses worldwide, and some studies have recently demonstrated validity, objective improvement in performance with training, and transferability of these learned skills to the operating theater.\(^\text{15,16}\)

The aim of this study was to investigate the ability of experienced orthopaedic surgeons to acquire the appropriate skills to perform an unfamiliar arthroscopic procedure learned in a simulated environment and to assess their capacity to retain these learned skills.

**Materials and Methods**

**Subjects**

Six consultant orthopaedic surgeons with a subspecialty interest in lower-limb surgery were recruited from a single university teaching hospital. To be included, an individual had to currently be a consultant orthopaedic surgeon in a United Kingdom hospital, have had fellowship training in lower-limb surgery, be familiar with and regularly perform basic lower-limb arthroscopic procedures, and have had standard training in orthopaedic surgery including exposure to shoulder arthroscopy as a trainee. Exclusion criteria were any fellowship training involving shoulder surgery, a consultant practice involving shoulder surgery, any previous operative experience with arthroscopic Bankart repair, and regular performance of meniscal repair.

**Simulator Training**

An Alex Shoulder Professor benchtop simulator (Sawbones Europe, Malmö, Sweden) was set up in a designated skills laboratory (Fig. 1). A standard 30° arthroscope, arthroscopic camera, and display system (Smith and Nephew Endoscopy, Huntingdon, United Kingdom) were used in all cases. Immediately prior to his first session with the simulator, each surgeon viewed a standardized instructional videotape produced specifically for the study without pauses or rewinding. This videotape demonstrated the technique of performing an arthroscopic Bankart repair suture with use of the simulator. The surgeons were then allowed up to five minutes to familiarize themselves with and practice arthroscopic knot tying on a benchtop suturing model, but they were not allowed any practice sessions on the simulator. They received no additional training during this period.

Each surgeon then performed three separate simulated arthroscopic Bankart sutures on four occasions one to two weeks apart (twelve procedures in total). The number of procedures that the surgeons would perform was determined on the basis of pilot data suggesting that the initial learning curve began to plateau at twelve procedures. The surgeons received no prompting or guidance while they carried out the procedure. The adequacy of each suture was graded as “pass” or “fail” by one of the supervising authors (S.A. or G.C.H.), who used a fixed-diameter arthroscopic hook to ensure that there was no gapping between the labrum and the glenoid and that the knot was tight.

After a period of six months, the surgeons then returned to the laboratory and repeated the process, again performing the procedure twelve times spread over four sessions. During this period, they continued with their routine lower-limb practice and did not infringe on any of the exclusion criteria. They were not shown the instructional videotape again or...
given any instruction or reminders about how to perform the task. They were not allowed to practice on the simulator, but again they were permitted to practice arthroscopic knots on a suturing model.

**Motion Analysis**

During the simulator sessions, a three-dimensional electromagnetic motion tracking system (PATRIOT; Polhemus, Colchester, Vermont) was used to assess surgical performance objectively. This tracking technology has been used previously, and its feasibility, reliability, and validity have been extensively assessed during laparoscopic and open general surgical procedures. We recently showed it to also be valid as a means of objective assessment of arthroscopic psychomotor skills. The system consists of two small sensors placed in fixed positions on the dorsum of the subject's hands and an emitter that is fixed to the simulator. The output consists of the three-dimensional position (x, y, and z coordinates) of each sensor relative to the emitter as a function of time. A standardized simulator environment was maintained at all times. It was kept free from all metal objects other than the arthroscope and arthroscopic instruments. The simulator environment was checked with calibration objects while those metal objects were in situ and was found to provide a reliable output. This output was recorded by a personal computer and processed by custom software (MATLAB, version 6.5; The MathWorks, Natick, Massachusetts). Table 1 presents the results for total path length, number of hand movements, and time taken in both experiments. Figures 2, 3, and 4 show the changes in the three studied parameters during subsequent training episodes with the simulated arthroscopic Bankart suture. The top and bottom of the I bars represent the maximum and minimum values, respectively; the top and bottom of the bars themselves represent the upper and lower quartiles, respectively; and the solid lines within the bars represent the median.
Massachusetts) to produce three outputs: the total path length of the surgeon’s hands, total number of hand movements, and time taken to perform the sutures. Surgeons with greater technical ability and experience perform tasks with greater efficiency and economy of movements. Validation studies have shown this assessment tool and its outcome parameters to be capable of sensitive differentiation between surgeons of differing abilities, and those with greater technical skill perform procedures in less time, requiring fewer hand movements and a shorter total path length. These outputs have been used successfully by others.

Statistical Analysis

Statistical guidance was provided by the Medical Statistics Department of our university. The primary outcome measure was the difference in the performance on the simulator between the initial study and the repeat study after the six-month interval. The data were not normally distributed, and therefore nonparametric tests were used.

The Mann-Whitney U test was used to compare the motion analysis parameters (total path length, number of hand movements, and time taken) during the first three attempts in each study with those parameters during the last three attempts in each study in order to identify any differences in performance on the simulator between these initial and final attempts. The Mann-Whitney U test was also used to compare the motion analysis parameters between the initial and repeat studies in order to demonstrate any improvement in performance, and hence learning achieved, with repetition of the task—i.e., to demonstrate a learning curve.
Source of Funding  
There was no external funding for this study.

Results  
The surgeons within the study were well matched in terms of both general surgical experience and specific experience with shoulder surgery and arthroscopy, and all knots were tied satisfactorily. Motion analysis revealed that the performance of all surgeons objectively improved with repetition during the first study and the repeated study. Learning curves for all three output parameters (total path length, number of hand movements, and time taken) were clearly demonstrated. In the first study, the median path length improved from 1826 mm (interquartile range, 1605 to 2398 mm; standard error, 161 mm) to 1497 mm (interquartile range, 1424 to 1529 mm; standard error, 28.4 mm), the median number of hand movements improved from 238 (interquartile range, 168 to 295; standard error, 25.6) to 131 (interquartile range, 125 to 140; standard error, 3.8), and the time taken improved from 221 seconds (interquartile range, 146 to 245 seconds; standard error, 19.7 seconds) to 104 seconds (interquartile range, 103 to 111 seconds; standard error, 2.3 seconds). In the repeated study, the median path length improved from 2376 mm (interquartile range, 1457 to 2933 mm; standard error, 273 mm) to 1348 mm (interquartile range, 1136 to 1558 mm; standard error, 82.8 mm), the median number of hand movements improved from 261 (interquartile range, 160 to 376; standard error, 39.6) to 114 (interquartile range, eighty-three to 141; standard error, 13.2), and the time taken improved from 220 seconds (interquartile range, 110 to 317 seconds; standard error, 37.9 seconds) to ninety-four seconds (interquartile range, sixty-nine to ninety-nine seconds; standard error, 7.9 seconds). These results are displayed in Table I and graphically in Figures 2, 3, and 4.

All learning curves in both studies showed that the subjects’ performance improved significantly with repetition (p < 0.005). The similarity of the learning-curve shapes for each assessment variable (Figs. 2, and 4) between the first and the repeated study was confirmed by a comparison of the motion analysis performance data between the two studies. With the numbers evaluated, significant differences could not be demonstrated between the curves (Table II). This suggests that there was no significant retention of the improved level of technical skill that had been acquired in the first study and that the surgeons repeated their learning curve six months later. There was a very slight improvement in the time taken at the end of the learning curve in the repeated study, suggesting that the surgeons may have developed a familiarity with the task. However, with the numbers studied, this improvement was not significant and no improvement was seen in the economy-of-movement parameters (path length or number of hand movements).

Discussion  
This study objectively demonstrated an initial learning curve for an unfamiliar arthroscopic technical skill performed in a simulated environment by a group of experienced surgeons. It also showed that, after six months without practice, the previous level of learned skill and performance was lost.

The concept of the learning curve for a surgical procedure has been well described but often only anecdotally discussed. Learning curves for performance of simulated and live surgical procedures have been demonstrated with use of various forms of assessment.

A learning curve for arthroscopic rotator cuff repair in vivo has been acknowledged but is difficult to quantify. To our knowledge, this is the first study to objectively demonstrate a learning curve for an arthroscopic shoulder procedure in a simulated environment.

The role of simulation in medical education is being increasingly well established. There have been a large number of studies across surgical specialties supporting the role of both laboratory and virtual reality simulators for a wide variety of open and minimal access procedures. Importantly, some recent studies have demonstrated transfer validity of simulator-acquired skills to improved performance in the operating theater, answering early criticisms regarding the application of simulation to the clinical situation.

Most simulator studies to date have largely focused on training in and assessment of simple technical skills appropriate for more junior trainees. Simulation has been particularly advocated for use at the initial steep end of a trainee’s learning curve for a new procedure prior to operating on patients. There is the potential for it to perform a similar role for established surgeons learning newly developed procedures or wishing to maintain their level of performance of more complex, infrequently performed procedures. We have shown that a simple laboratory simulator combined with an objective

### TABLE II P Values of the Comparisons Within and Between Studies with Regard to Total Path Length, Number of Hand Movements, and Time Taken

<table>
<thead>
<tr>
<th></th>
<th>First Study: Initial vs. Final Three Attempts</th>
<th>Repeat Study: Initial vs. Final Three Attempts</th>
<th>Initial Three Attempts: First vs. Repeat Study</th>
<th>Final Three Attempts: First vs. Repeat Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Path length</td>
<td>0.0003</td>
<td>0.0046</td>
<td>0.5166</td>
<td>0.2888</td>
</tr>
<tr>
<td>No. of hand movements</td>
<td>&lt;0.0001</td>
<td>0.0003</td>
<td>0.393</td>
<td>0.1799</td>
</tr>
<tr>
<td>Time taken</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.236</td>
<td>0.055</td>
</tr>
</tbody>
</table>
assessment tool can be appropriate for developing initial skills at the steep end of the learning curve for a more technical arthroscopic procedure.

Previous studies have shown that surgical outcomes are improved by surgeons performing a particular procedure with high frequency\(^4\). They have also shown varying degrees of retention of simulator-acquired laparoscopic surgical skills, with the variability due in part to differences in study design. All, however, have provided a snapshot assessment of performance after a time delay, rather than a repetition of the entire learning curve\(^29\).\(^31\). We found no previous studies in which the retention of arthroscopic skills was evaluated with a method similar to ours.

The demonstration in this study of the loss of the level of performance that had been achieved after the initial learning curve for a particular simulated surgical procedure confirms that newly acquired technical skills can be lost, even by experienced surgeons, without continued practice. This study was not conducted to define any level of competence, and it is worth mentioning that all of the surgeons performed adequate Bankart repairs even though they were learning the procedure. However, the study suggests that these newly acquired skills need to be practiced to maintain the best performance. This finding can be related to the well-established Fitts and Posner three-stage theory of motor skill acquisition, applied to surgical skills by Reznick and MacRae\(^6\). The theory describes an initial cognitive stage whereby the surgeon learns to understand the task but performs erratically, a subsequent integrative stage in which knowledge is translated into appropriate behavior, and finally an autonomous stage in which the performance is smooth and the surgeon no longer needs to concentrate on specific aspects of the new skill. Perhaps, when new skills are learned, an integrative stage of motor learning is achieved after completion of an initial learning curve such as the one demonstrated in our study, but if these learned skills are not firmly consolidated by continued practice, and the surgeon does not reach the autonomous stage of learning, then the level of performance is not retained.

Although this study focused on a single simulated arthroscopic shoulder procedure, that procedure was chosen to provide a generic, unfamiliar arthroscopic skill to be learned by an experienced cohort of study subjects. Thus, it seems reasonable that a similar skill-loss effect would be seen for other, similar technical skills. If that is the case, these findings raise the important point that there is a need to ensure continued repetition and practice of acquired surgical skills in order to retain them. Although we have previously shown that skills acquired in a simulated environment can be transferable to the operating theater\(^15\),\(^16\), we cannot conclude from the present study that skills acquired in an operating theater environment would also be lost. However, it is reasonable to suggest that they might. Although they will not be easy to perform, additional studies are required to objectively assess intraoperative performance of trainees and their skill retention over time in the operating theater environment.

A limitation of this study is the small sample size; however, several of the comparisons revealed highly significant values. Furthermore, the surgeons in the study were well matched in terms of general surgical experience and also specific experience with shoulder surgery and arthroscopy. While there is the potential for a type-II error when study periods are compared, the graphical data for each study period demonstrated almost identical learning curves. Further work is focusing on a larger number of surgeons and an evaluation of the frequency of practice required for skill retention.


Good doctors, safer patients; proposals to strengthen the system to assure and improve the performance of doctors and to protect the safety of patients. DOH white paper. London: Department of Health; 2006 July 14.


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