

Systematic instruction of arthroscopic knot tying with the ArK Trainer: an objective evaluation tool

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Abstract

Purpose A Proficiency Formula was introduced as an objective self-evaluation method for evaluating basic arthroscopic knot tying in a laboratory setting. The correlation between the Proficiency Formula and gold standard pass/fail dichotomy was demonstrated, as well as with other popular evaluation tools—task-specific checklist (TSC) and global rating scale (GRS).

Method A step-by-step video tutorial was used to instruct 35 medical students on how to tie an arthroscopic Samsung Medical Center (SMC) knot secured by three half hitches. Participants were video recorded performing arthroscopic knot tying and assessed on their success tying an SMC knot, pass or fail, and through three outcome tools: the Proficiency Formula, GRS and the TSC. Independent samples *t* test was used to compare the GRS, TSC and Proficiency Formula scores, between those who were passed or failed by the evaluators. Correlation between the measurement scales was tested using Spearman's rho correlation coefficient.

Results Participants received a mean proficiency score of 195 (140–249). The mean Proficiency score for those that passed was 323 (95 % CI 272–374), for those that failed,

87 (95 % CI 26–148, $p < 0.001$). We found strong linear correlation between the Proficiency Formula and GRS and TSE (0.83 and 0.78, respectively).

Conclusion The Proficiency Formula has high correlation with gold standard GRS and TSC measurements when used to assess arthroscopic knot tying skills on a model. It has the added advantage of being able to be self-assessed.

Level of evidence II.

Keywords Simulation · Knot tying · Arthroscopy · Self-evaluation · Proficiency

Introduction

Instruction, evaluation and feedback are composite roles of the academic surgeon. We have previously demonstrated the construct validity of the Arthroscopic Knot (ArK) Trainer through three sources of evidence: content, relationship to other variable and internal structure evidence [20]. This study further demonstrated the ArK was easy to use and had the capacity to distinguish between groups with differing skill levels [20]. In the present study, an objective evaluation tool was introduced for assessing arthroscopic knot tying on a simulator.

Simulation-based assessment is a new paradigm in surgical education [3, 14, 17, 18]. Technical competency is essential for all surgeons and is expected by patients as a standard of care [11]. Although the operating room remains the most widely used forum for teaching surgical skills [11], the variability in acquisition of these skills makes it difficult to ensure that all residents are exposed to the same core procedures, and difficult to assess residents' technical abilities [3, 7, 13, 14, 18]. Review of several teaching and evaluation techniques [1–3, 7, 8, 13, 19], however, there is

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little precedent for developing an objective self-evaluation tool. Derossis et al. [6] developed and validated a formulaic model for evaluating laparoscopic knot tying skills. The inherent similarities between laparoscopy and arthroscopy allow for the adaptation of the formula towards developing an objective evaluation model for arthroscopic knot tying.

Subjective faculty assessment represents the mainstay of surgical learner evaluation [11, 13]. Although many experienced surgeons believe they are capable of judging technical performance, without specific criteria, even experienced senior surgeons have a high degree of disagreement while rating the skills of a trainee [13, 16]. More importantly, as traditional instructor-centred teaching yields to a learner-centred model placing learners in control of their own learning, it becomes necessary to investigate methods of evaluation that allow learners to objectively measure their own skill to progress [1, 3, 10, 18].

The purpose of this study was to introduce our adaptation of Derossis et al. [6] Proficiency Formula as an objective self-evaluation model for evaluating basic arthroscopic knot tying in a laboratory setting. The correlation between the adapted Proficiency Formula and gold standard pass/fail dichotomy, as well as other popular evaluation tools—task-specific checklist (TSC) and global rating scale (GRS)—was assessed. The study also aimed to propose an educationally meaningful cut-off value for each of the rating tools above in discriminating learners who “pass” Samsung Medical Center (SMC) knot tying from those who do not.

Methods and materials

This study was approved by the McMaster University Institutional Review Board (#10-483). A sample of 35 medical students from the surgical interest group was recruited to participate in this study. After informed consent was obtained, the participants completed an intake survey reporting age, gender, handedness, clerkship year, surgical and non-surgical experience, as well as career interest information.

During a single 40-min session in May 2011, participants were instructed using a previously developed video instruction tool on how to tie an SMC knot secured by three half hitches using the previously described ArK Trainer [20]. Students practised knots tying with the video instruction for 30 min with expert faculty feedback. Finally, a 10-min assessment of skill was recorded by video cameras in an overhead position; the scope of each camera was preset to ensure only the students hands, forearms and ArK Trainer were visible in the recording. The time required to tie each knot was measured and recorded to the nearest second.

Proficiency formula

After surveying the literature on arthroscopy and other surgical sub-specialties, we used a previously published evaluation model by Derossis et al. [6], with demonstrated construct validity, as the basis for creating an objective evaluation tool for arthroscopic knot tying (Fig. 1). Performance was scored for both speed (timing score) and precision of performance (penalty score). A *timing score* was calculated by subtracting the time used to complete each knot (seconds) from the overall preset cut-off time of 600 s. This system rewards faster performance with higher scores (Fig. 1). If the time to complete the exercise surpassed the preset cut-off time, a timing score of zero was given, as no negative values were assigned.

The *penalty score* took into account the accuracy and security of the knot and was a sum of three-knot components (approximation, slippage and disruption, Fig. 1). The accuracy of knots was measured giving a one-point penalty for each millimetre of separation greater than two millimetres [6, 20]. Security of the knot was assessed by introducing a pair of scissors under the knot and attempting to pry it open; slippage resulted in a 10-point penalty. In our adaptation of the formula, complete disruption of the knot (i.e. loss of approximation of the rings) resulted in a 60-point penalty, so that a disrupted knot receives a final score of zero. The time required to tie each knot was measured and recorded to the nearest second.

Task-specific checklist

The TSC represents an operation-specific score. As there were no preexisting checklists for tying an arthroscopic SMC knot, a TSC was developed in consultation with five expert arthroscopic surgeons who routinely tie arthroscopic knots to ensure that the instrument captured the salient dimensions of tying an SMC knot. Development of the TSC was also based on previous studies [2, 8, 9] utilizing checklists as evaluation instruments. The TSC measured the steps of knot tying each subject completed up to a maximum of 21 and represented as a percentage. A higher TSC percentage indicates greater performance of knot tying steps (Fig. 2).

Global rating scale

Items on the GRS were developed to be operation independent [16] with each item graded on a five-point scale with the middle and extreme point anchored by explicit descriptions of the necessary requirements to receive the respective point value. Each 5-point item was scored from 0 (poor performance) to 4 (good performance). The final score was determined by summing the marks for the seven

Fig. 1 The Proficiency Formula developed as an objective evaluation tool for arthroscopic knot tying

Proficiency Formula = Timing Score – Penalty Score	
$= [600s - \text{time used (s)}] - (\text{sum of penalties} \times 10)$	
Timing Score	600s – time used (s) to tie one SMC and three half hitches
Penalty Score	Sum of penalties $\times$ 10
1. Approximation	One-point penalty for each millimeter (mm) of separation greater than 2mm • Separation of 3mm would result in an error of three points; a separation of 2mm or less would result in no error
2. Slippage	Introduce a small pair of suture scissors into the knot in an attempt to pry it open • Slippage of the knot tails is a 10-point penalty
3. Disruption	Complete disruption of the knot (ie. loss of approximation of the rings) results in a 60-point penalty, so that a disrupted knot receives a final score of zero

items and dividing by 28 to obtain a percentage. As use of the ArK Trainer did not require an assistant, all participants were awarded the maximum five points for that parameter. Higher scores indicate better technical skill.

Pass/fail

A summative evaluation, made by reviewing the video recording, was used to assess the final product of the knot.

Evaluation

Evaluators were all orthopaedic surgeons and fellows of the Royal College of Surgeons of Canada who were fellowship trained in arthroscopy and have a primarily arthroscopic-based practice. Evaluators were instructed to assess only the first knot tied during the allotted 10-min assessment. The order of the videos was randomly

allocated and two evaluators, blinded to the identity of the participants, independently reviewed a total of 35 10-min videos. Levels of agreement between the evaluators were measured, and disagreements were resolved with consensus.

Statistical analysis

Level of agreement between the evaluators was calculated using kappa statistics. Means, with standard deviations (SD), were reported for continuous variables and counts with percentages for categorical variables. Proportion of participants who successfully tied SMC knots was reported as pass or fail. Independent sample t test was used to compare the GRS, TSC and Proficiency scores, between those who were passed or failed by the evaluators. Correlation between the measurement scales was tested by Spearman's rho correlation coefficient. To detect the

Fig. 2 The task-specific checklist tying an arthroscopic SMC knot secured by three half hitches. The task-specific checklist was used in conjunction with the global rating scale

Task Specific Checklist for Arthroscopic SMC Knot Please circle the most appropriate number			Not Done	Done
Step 1: Thread the suture through a pair of eyelets.			0	1
Step 2: Tie the SMC knot by a)			0	1
Thread the knot pusher and snap onto the post strand				
Assume the starting position (separate both strands with the post in the non-left hand, keeping both strands of the suture on top of each index finger)			0	1
Cross the suture over the left index finger			0	1
Bring the suture under 2 limbs			0	1
Bring the suture over 2 limbs			0	1
Bring the suture under 1 limb, by reaching between the two strands			0	1
Bring the suture over 1 limb			0	1
Bring the suture through the triangle from the bottom to top			0	1
Dress the knot pulling on the non-post suture toward the cannula			0	1
Pull the knot into the model by pulling on the post			0	1
Step 3: reduce tissue			0	1
Step 4: Past-point the knot			0	1
Step 5: Tie the first half hitch			0	1
Step 6: Past-point the knot			0	1
Step 7: Tie the second half hitch			0	1
Step 8: Past-point the knot			0	1
Step 9: Tie the third half hitch			0	1
Step 10: Past-point the knot			0	1
Step 11: Cut the suture leaving the 3mm tail			0	1
Total				/21

ability of cut-off values of GRS, TSC and Proficiency to detect successful SMC knot tying, we generated receiver operating characteristic (ROC) curves using the values of calculated GRS, TSC and Proficiency scores against observed successful knot tying (gold standard). The area under the curve with 95 % CIs and *p* value was calculated to demonstrate the probability that the GRS, TSC and Proficiency scores for a randomly chosen pass for arthroscopic knot tying would exceed the GRS, TSC, versus Proficiency scores for a randomly chosen fail SMC knot tying (the probability of discrimination). An area of 1.0 indicates complete discrimination, whereas an area of 0.5 indicates complete absence of discrimination. Using the coordinates of the ROC curve, we decided on the most optimal cut-off values for GRS, TSC and Proficiency scores. An alpha error of 0.05 was considered for statistical significance. SPSS (www.IBMSPSS/software.com) and Minitab (www.minitab.com) were used for analysis.

Results

Thirty-five subjects were tested and consisted of 27 first-, three second- and one-third-year medical student. Four participants did not indicate their year of training. As expected, participants had no self-reported arthroscopic

Table 1 Demographics and non-surgical data of study participants

Demographics			
Number of participants		35	
Age (median)		23 (Range 20–33)	
Gender (male/female)		18/17	
Handedness (right/left)		31/4	
Participants arthroscopic knot tying experience			
Witnessed in operating room		6	
Previously performed		0	
Non-surgical skills	None	Novice	Expert
Play with computer games	12	18	5
Typing skills	0	4	31
Use of chopsticks	6	13	16
Musical instruments	11	9	15
Ability to sew	13	18	4
Experience operating tools	14	13	18

knot tying experience, with only 17 % of participants having observed arthroscopic knot tying in the operating room and were all considered novice learners. The summary of other results, including self-rated proficiency in non-surgical motor tasks, obtained from intake survey is shown in Table 1.

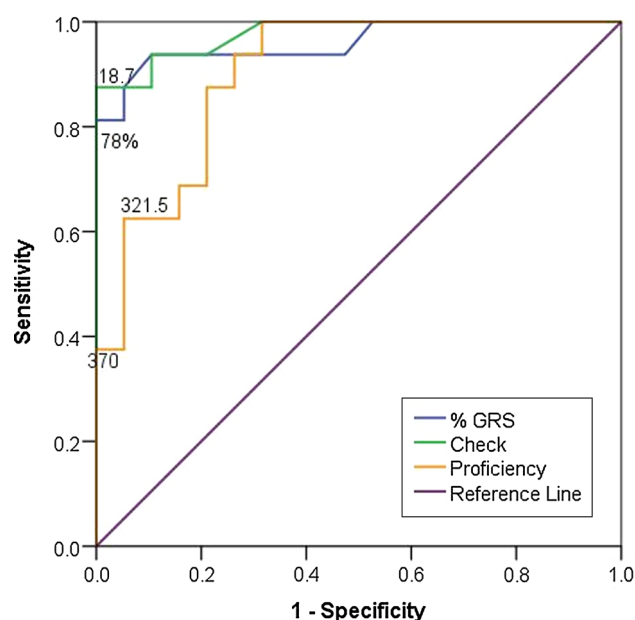


Fig. 3 Receiver operating characteristic (ROC) curve

The level of agreement between the evaluators for all outcome measures was high for all measures: 72 % (95 % CI: 49–95 %) for pass or fail, 86 % (95 % CI: 72–93 %) for GRS and 88 % (95 % CI: 77–94 %) for TSC. Sixteen (46 %) of the 35 participants successfully tied SMC knots at the end of the session. The maximum TSC score of 21 was achieved by nine (25 %) of participants. Only two (6 %) obtained the maximum GRS score of 100 %, though 21 (60 %) received pass grades. Of those who passed, a mean GRS score of 86 % (95 % CI: 80–92 %) and raw TSC score of 20 (95 % CI: 19–21) were obtained; of those that failed, the mean GRS and TSC scores were 62 % (95 % CI: 60–65 %, $p < 0.001$) and 14 (95 % CI: 12–16, $p < 0.001$), respectively. On average, participants in this study received a Proficiency score of 195 (95 % CI: 140–249). The mean Proficiency score for those that passed was 323 (95 % CI: 272–374), for those that failed, 87 (95 % CI: 26–148, $p < 0.001$).

There were strong linear correlations between Proficiency, TSC and GRS scores. The correlation coefficient between Proficiency and GRS (0.83) is higher than the observed correlation between GRS and TSC (0.72). As some of the participants that passed obtained the maximum TSC score of 21, there is an evident ceiling effect. The area under the ROC curve (Fig. 3) was similarly high for % GRS (0.96, 95 % CI: 0.89–1.00), TSC (0.98, 95 % CI: 0.93–1.0) and Proficiency (0.90, (95 % CI: 0.80–1.00). The cut-off value for %GRS for detecting pass SMC knot tying from fail SMC knot tying was 78.0 % with a sensitivity of 81.3 % and a specificity of 100 %. The cut-off value for TSC for discriminating the pass from fail is 18.7 with a sensitivity of 87.5 % and a specificity of 100 %. The cut-

off value for Proficiency for discriminating the pass from fail is 321 with a sensitivity of 62.5 % and a specificity of 95.0 %. For a specificity of 100 %, the cut-off point for proficiency was 370 with a sensitivity of 37.5 %.

Discussion

The most important finding of the study was we were able to show the Proficiency Formula can be used as an objective evaluation tool in assessing arthroscopic knot tying in a laboratory setting using the ArK Trainer. The correlation between the adapted Proficiency Formula [6] and already accepted outcomes, including pass/fail dichotomy, GRS and TSC proficiency scores, was illustrated. These findings are useful in that no other self-assessment measure has been shown to correlate well with expert evaluation of techniques [8].

As the surgical profession continues the evolution from an apprenticeship-based training system to a structured competency-based curricula with milestones, clear, objective goals for technical skills are important [1, 3, 7, 14, 18]. The availability of set criteria against which technical skills can be assessed has increased the objectivity of the assessment process [3, 13]. Measuring competency by setting time and frequency targets is now regarded as crude and unacceptable in most instances, recognizing that a fast who has been present in many operative cases is not necessarily a good surgeon. Instead, instruments such as the TSC and the GRS have been created to better capture the salient dimensions of each surgical skill.

The advantage of the Proficiency Formula for the trainee, once they have developed the basic arthroscopic knot tying technique, is the ability to practise and refine their skills independently and objectively measure this progress. As requirements for clinical care increase and the opportunity to gain experience and feedback in the operating room decreases [2, 3], the need to research the most effective use of limited available time, in and away from the operating room, becomes more urgent. The Proficiency Formula can provide feedback and a method to measure progression of skills. This has a significant advantage for resources, timeliness and scheduling over TSC and GRS evaluations that require the time of expert evaluators in person or through video review. To evaluate the videos in this study, each expert surgeon required more than six hours to review and evaluate the videos. While the Proficiency Formula does not eliminate the need for expert teachers, it does have the ability to reduce demands on time from experts as well as provide timely feedback. As traditional instructor-centred teaching yields to a learner-centred model that puts learners in control of their own learning, systems must evolve to allow assessment of

technical skills in real time, with less reliance on other assessors, and enable learners to objectively measure their own skills [3, 10, 18].

This study attempted to teach novice learners, with no experience, arthroscopic SMC knot tying in a 40-min workshop using video tutorial and expert feedback. When graded for a pass at the level of a competent learner, 46 % of these students would have passed at the end of the session. This shows that even with a short 40-min workshop, novice learners may be able to acquire the skill needed to pass assessment for arthroscopic knot tying. This is encouraging, as early residents (postgraduate year 1–3) range in skill from novice to advanced beginners and would have more opportunity to practise and learn this skill. Further study is needed to determine learning curve and retention of this skill on this population of learners.

Cox et al. [5] define three main purposes of clinical simulators: optimizing the capabilities of all residents by providing motivation and direction for future learning, providing a basis for choosing applicants for advanced training and identifying incompetent residents [5]. The second and third purposes each require instruments of different strengths. If intended as a certification and advancement tool, an instrument with high sensitivity (the percentage of competent surgeons who are correctly identified as having mastered a skill) is best suited. The GRS and TSC, both have high sensitivity, are ideally suited for their use in the Objective Structured Clinical Examination (OSCE) [15] and Objective Structured Assessment of Technical Skills (OSATS) [3, 4, 12]. The Proficiency Formula may be suited for this goal with a cut-off score of 321 that gives a sensitivity of 62.5 %. If, however, our objective is to provide a threshold score for learners to use when self-evaluating, an instrument with higher specificity would be more appropriate (the percentage of non-competent surgeons who are correctly identified as lacking the skill). Thus, one could use a Proficiency score of 370 with a specificity of 100 %. It seems important to note at this point, that we are not suggesting the Proficiency Formula as a substitute for any of the established methods. We maintain that each tool serves a specific and necessary purpose. Rather we are proposing the use of the Proficiency Formula as the first objective measure for self-evaluation in arthroscopic knot tying on an ArK Trainer. With its high correlation to already accepted evaluation tools, the immediacy of feedback, and its ability to be used in the absence of faculty supervision, makes for good evidence in support of its use as an objective self-evaluation tool. Further research is required to obtain to support the validity and reliability of the Proficiency Formula.

Strengths of this study are the prospective design and the first communication, to the best of our knowledge, that introduces a formulaic model for self-evaluation of an

arthroscopic skill outside the operating room. Inherent limitations of this study include the small sample size and the limited generalizability of the conclusions to the entire orthopaedic community—in that all the students came from the same university system, however, as all students were novice learners this weakness may be somewhat mitigated. Orthopaedic residents would vary in experience from novice to competent learners. Thus, we would expect higher success rates of learning after a single 40-min workshop (more than 46 %). The next step would be to apply the Proficiency Formula to a participant group with a larger diversity of arthroscopic experience and skill. A multi-centred study with a wider spectrum of learner experience would be necessary to fully overcome both limitations of sample size and institutional bias. The Proficiency Formula has only been validated for the SMC knot. While it should be possible to evaluate other arthroscopic knots, proper validation would have to be carried out.

Conclusion

The Proficiency Formula can be used to objectively assess arthroscopic knot tying skills on an ArK Trainer. It has sufficiency high correlation with already accepted outcomes using pass/fail, GRS, checklist and Proficiency scores. This is a useful tool to allow orthopaedic residents to perform self-assessment of their arthroscopic knot tying skills and an evaluation tool that allows faculty to quantify and track progress in resident skill acquisition and progress.

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