Mixed-Methods Analysis of a Validated Arthroscopic Knot-Tying Simulator With New Indirect Visualization Condition

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Background: Simulation provides low-risk opportunities for surgical trainees to learn and practice fundamental skills. One simulation tool for orthopaedics is the Arthroscopic Knot (ArK) Trainer, which has been validated as an effective simulation tool across multiple methodologies. Previous studies have investigated the ArK Trainer in its basic form using clear plexiglass, which allows direct visualization of tissue anchors.

Purpose: Using a mixed-methods approach, we assessed and compared junior and senior trainees' Seoul Medical Center (SMC) knot–tying performance under direct and indirect visualization.

Study Design: Cross-sectional study.

Methods: Fourteen orthopaedic surgery postgraduate trainees at a single medical school were recruited to participate. Trainees tied SMC knots using the Ark Trainer under direct and indirect visualization. A mixed-methods approach was used to evaluate knot-tying proficiency and characterize participants' approach to knot-tying. Knot-tying proficiency was evaluated using validated tools: a task-specific checklist (TSC), a global rating scale (GRS), and a proficiency scale (PS). Participants' approach to knot-tying was characterized using Likert-type questionnaires and semistructured interviews. An α level of .10 was set a priori owing to the small pool of trainees.

Results: The 14 participants included 7 junior residents (postgraduate years [PGYs] 1 and 2) and 7 senior residents (PGY $\geq$3), of whom 3 were fellows (PGY 6). Senior trainees outperformed junior trainees on both versions of the ArK Trainer: clear (GRS, $P = .055$; PS, $P = .075$) and covered (TSC, $P = .05$). Overall, participants performed better under direct visualization conditions (GRS, $P = .05$). In semistructured interviews, significantly more senior trainees discussed relying on haptic cues while tying knots under direct visualization ($P = .021$). The majority of trainees agreed that both versions of the ArK Trainer were realistic and appropriate practice formats for their level of training.

Conclusion: Senior trainees were significantly more experienced than were junior trainees in arthroscopic skill and outperformed them on both configurations: direct (PS and GRS) and indirect (TSC) visualization. Experienced trainees were significantly more likely to report using tactile cues to aid knot-tying under indirect visualization. It is likely that inexperienced trainees rely more heavily on direct visualization and that the use of tactile cues may be an indicator of knot-tying proficiency. Trainees recommended progression from direct to indirect visualization configurations for inexperienced learners.

Keywords: arthroscopy; simulation training; orthopaedics; sports medicine; medical education

Simulation has become an essential tool in medical education.[4,6,19,20] This is particularly true because the volume of cases has declined in residency and educators are looking for more consistent learning opportunities.[18,23] While simulation is unlikely to ever completely replace the traditional apprenticeship model,[1,20] arthroscopic simulators have permitted residents to have more opportunity for hands-on skill development and progression[6,11] in a structured, low-risk, learner-centered environment.[2,20,22,24]

Medical education literature has focused on defining the theoretical basis for simulated learning. There is general agreement that learning includes progression from anatomy to observation and cadaveric and simulator practice before guided learning in the operating room.[6,11,14,20] However, the optimal timing at which fundamental skills of arthroscopy, such as hand-eye coordination, triangulation, and indirect arthroscopic visualization, should be taught in the learning curve is still not fully understood.[11]

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To date, few studies have focused on the acquisition of skills for knot-tying under indirect visualization.[6] Arthroscopic knot-tying requires the surgeon to not only operate the camera for optimal views but also interpret 2-dimensional data on the screen to manipulate tissues and sutures using instrumentation. While the literature has postulated that indirect visualization would provide additional challenges to a learner as compared with direct visualization, no studies have shown this to date.[3,6,16]

Arthroscopic knot-tying simulators have been described extensively in the literature.[4,13] The Arthroscopic Knot (ArK) Trainer, developed by the senior author (I.W.), has been validated as an effective simulation tool across multiple methodologies.[23,24] However, the ArK Trainer has been tested in only its most basic configuration. In the previously tested configuration, the ArK Trainer allowed participants to see directly through the clear plexiglass to visually guide their knot-tying. A covered (opaque) configuration is possible, which requires users to indirectly visualize their knots using a camera system, similar to true arthroscopic setups.

The purpose of this study was to apply a mixed-methods approach to assess and compare the Seoul Medical Center (SMC) knot–typing performance of junior and senior trainees under direct visualization using the clear ArK Trainer and indirect visualization using the covered ArK Trainer. Our objectives were as follows:

1. To compare SMC knot–tying performance between senior and junior trainees using validated scoring techniques
2. To understand trainees' perceptions of each ArK Trainer configuration as a testing tool

Our hypothesis was that senior trainees would outperform junior trainees in knot-tying on both configurations of the ArK Trainer.

METHODS

This study was designed as a mixed-methods prospective cohort study including orthopaedic surgery residents and fellows (postgraduate years [PGYs] 1-6) at the Queen Elizabeth II Hospital. This study was approved by a regional ethics committee.

Participant Selection

Participants were surgical trainees in orthopaedics who would ordinarily train on a surgical simulator to practice arthroscopy skills. This sample was composed of junior residents (PGYs 1-2), senior residents (PGYs 3-5), and fellows (PGY 6). A total of 14 participants were recruited, and there were no exclusion criteria. After consent was obtained, each participant completed an intake form, providing year of postgraduate training, arthroscopic exposure, and exposure to the ArK Trainer.

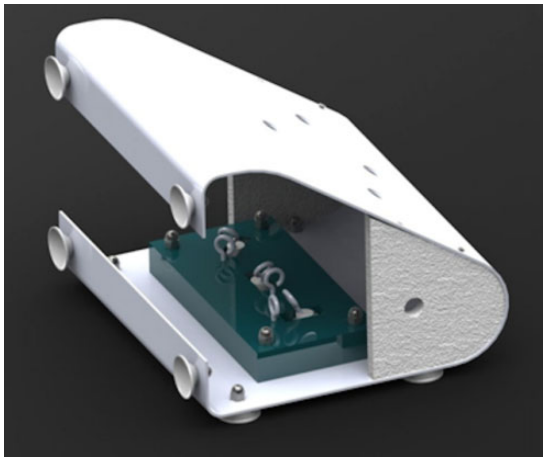

Figure 1. The basic configuration of the Arthroscopic Knot Trainer. The original models had clear plexiglass, which allowed direct visualization of the suture anchors.

ArK Trainer

The ArK Trainer is a validated surgical knot-tying simulator.[24] The original, clear ArK Trainer has internal posts for knot-tying enclosed in a transparent plexiglass cover with portals for cannula and instrument insertion. The clear ArK Trainer allows users to directly visualize the knot and instruments during knot-tying. To tie a knot using the ArK Trainer, trainees must compress 2 spring-loaded hooks using 40 N of force to simulate tissue tensioning and approximation.

The modified (covered) ArK Trainer features an opaque plexiglass cover, which prevents the user from directly visualizing the knot and instruments (Figure 1). Indirect visualization was achieved using tablets (iPads; Apple Inc) with front-facing cameras and overhead cameras attached to tall stands (Figure 2). Footage from these cameras was used in evaluating participants' performance. Both video recordings featured the knots as well as the participants' hand movement during knot-tying.

Research Plan

Study participants completed a 30-minute simulation session. Participants initially viewed an instructional video describing

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Ethical approval for this study was obtained from Nova Scotia Health Authority Research Ethics Board (ROMEO No. 1021351).

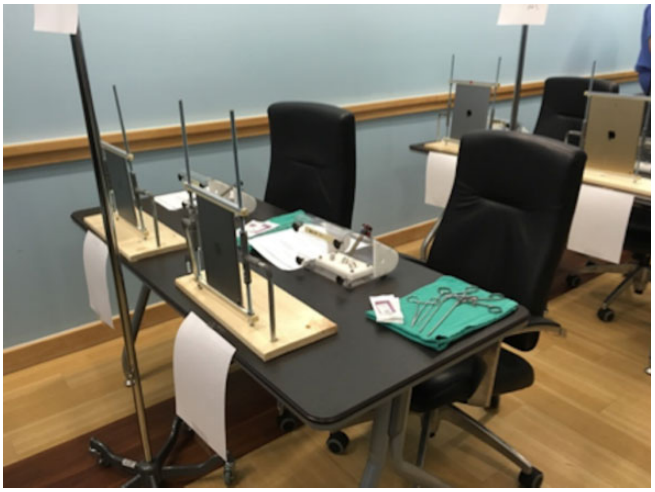

Figure 2. View of the experimental setup for several participants. Visible are the Arthroscopic Knot Trainer, an iPad (Apple Inc) with front-facing camera for indirect visualization (resting on a wooden and metal stand), and instruments. Not visible is the overhead camera, which is positioned at the top of the stand (left).

the instruments, knot-tying technique, and purpose of the session. The video included step-by-step instructions on how to tie an SMC knot backed up using 3 half hitches.

Participants attempted to tie SMC knots first using the clear ArK Trainer and then using the covered version. Indirect visualization was available during both knot-tying attempts. Each attempt was limited to 600 seconds. Video was recorded from 2 sources for performance evaluation: from the iPads for arthroscopy-simulated views and the overhead cameras for extracorporeal views. Participants were provided appropriate tools, such as graspers, suture cutters, cannula, and Ethicon Perma-Hand Silk No. 2-0 braided sutures.

After the completion of the simulation session, participants were interviewed. Interviews were semistructured and conducted by 2 investigators (K.M. and C.R.) familiar with the technique. Participants were prompted to reflect on the value of the ArK Trainer as a testing tool, answering questions modified from a previously validated survey.[24] They were asked 5 structured questions that were scored using a 5-point Likert-type scale. Participants were also asked to discuss their experiences with the ArK Trainer in direct and indirect visualization configurations. They answered 6 open-ended questions, with interviewers asking follow-up or clarification questions as necessary (see Appendix Table A1).

Quantitative Data Analysis

Video recordings from each participant were reviewed by 3 orthopaedic sports medicine fellows experienced in arthroscopy and SMC knot-tying and blinded to the participant experience (A.A., B.R., and E.G.). Reviewers scored the performance of each participant using 3 validated quantitative measures: the global rating scale (GRS), task-specific checklist (TSC), and proficiency scale (PS) (Table 1, Appendix Tables A2-A4).[24] The mean scores for seniors, juniors, and all participants were calculated for the clear and covered ArK Trainer trials. Descriptive statistics and the 1-tailed independent-samples *t* test were used to analyze the mean difference in GRS, TSC, and PS scores. Interrater reliability was calculated using the Fleiss κ owing to the categorical nature of the rating scales. Kappa values were interpreted as follows: <0, poor agreement; 0.0-0.20, slight agreement; 0.21-0.40, fair agreement; 0.41-0.60, moderate agreement; 0.61-0.80, substantial agreement; 0.81-1.0, almost perfect agreement. Intrarater reliability was not calculated. Data were analyzed using SPSS Version 24 (IBM Corp). An α level of .10 was set a priori owing to the small pool of participants.

TABLE 1
Measures for Evaluation of Performance

Global rating scale	Evaluates 7 criteria pertaining to tissue and instrument handling and ability to tie the knot efficiently and independently. One domain (use of assistant) was not applicable to the Arthroscopic Knot Trainer, so the maximum 5 points were awarded to all participants.[24] The maximum total score is 35; a passing score is subjectively rated.
Task-specific checklist	Tallies the number of tasks completed on a checklist for arthroscopic knot tying. The maximum score is 21.
Proficiency scale	Based on knot-tying speed and precision of performance. A passing score is 321.[24]

Qualitative Data Analysis

Semistructured interviews were audio recorded and transcribed verbatim. Data were analyzed using conventional content analysis methodology.[1] Data were coded into "meaning units," which were organized into groups and subgroups based on theme. The number of data points in each meaning unit was quantified to determine trends among participants. Responses and themes were pooled across skill levels to draw conclusions about participants' impressions of the appropriateness of direct and indirect visualization configurations of the ArK Trainer for their skill level. The chi-square test was performed to assess for significant trends in responses. Coding and analysis of data were done using NVivo (QSR International).

RESULTS

Participant Characteristics

Fourteen surgical trainees were recruited and participated in the study. The participants were divided into 2 groups based on level of training. The junior trainees (n = 7) were junior residents (PGYs 1 and 2), who had some arthroscopic exposure but had not completed dedicated sports or arthroscopy rotations. The senior trainees (n = 7) included

TABLE 2
Participants by Level of Training and Reported Experience[a]

	Previous Experience, %		
	Arthroscopy	SMC Knot Tying	ArK Trainer
Juniors (n = 7)	28.57	14.29	14.29
Seniors (n = 7)	85.71	71.42	71.42
P value	.031[b]	.031[b]	.031[b]

[a]ArK, Arthroscopic Knot; SMC, Seoul Medical Center.
[b]Statistically significant difference at $P < .10$.

senior residents (PGYs 3-5) and 3 fellows (PGY 6), who had completed 1 or more rotations with significant arthroscopic training. Senior trainees reported significantly more experience with arthroscopy ($P = .031$), SMC knot-tying ($P = .031$), and the ArK Trainer ($P = .031$) (Table 2).

Quantitative Results

On attempts to tie knots under direct visualization, senior trainees outperformed junior trainees when evaluated using the PS ($P = .075$) and GRS ($P = .055$). Senior trainees also outperformed junior trainees on the TSC, although this did not reach the level of significance. Under indirect visualization, the senior trainees outperformed junior trainees, although this reached the level of significance on only the TSC ($P = .05$). In terms of overall performance, the mean GRS score was significantly higher for junior and senior trainees using the ArK Trainer under direct visualization ($P = .05$). No significant difference in PS and TSC scores were found between direct and indirect visualization trials (Table 3).

Interrater Reliability

Using the Fleiss κ, interrater reliability across the 3 rating scales was established (Table 4). The PS was calculated using rater agreement of passing or failing scores by evaluators, and there was almost perfect agreement between raters for direct and indirect visualization trials ($\kappa = 0.93$ [direct] and 0.99 [indirect]). The GRS demonstrated substantial or almost perfect agreement ($\kappa = 0.85$ [direct] and 0.90 [indirect]) and was calculated using evaluator agreement of passing or failing scores. The TSC had the lowest κ values of the 3 rating scales, but it also represented the largest number of ratings made by evaluators. Evaluators rated each participant's trial on 20 composite tasks, totaling nearly 500 ratings. However, it still demonstrated a substantial degree of agreement.

Qualitative Results

SMC Knot–Tying Strategies. Participants were asked to reflect on the strategies that they used when tying knots using the ArK Trainer under direct and indirect visualization in a semistructured interview. Our aim was to identify the SMC knot–tying strategies used by junior and senior trainees.

TABLE 3
Participant Performance Under Direct and Indirect Visualization, Stratified by Level of Training

Visualization and Level of Training	Score, Mean ± SD	*P* Value (Senior vs Junior)
Global rating scale		
Direct		.055[a]
Junior	23 ± 5.0	
Senior	28 ± 5.7	
Indirect		.125
Junior	16 ± 11.9	
Senior	23 ± 11.6	
P value (direct vs indirect)	.05[a]	
Task-specific checklist		
Direct		.255
Junior	15 ± 4.8	
Senior	16 ± 4.4	
Indirect		.05[a]
Junior	13 ± 4.7	
Senior	18 ± 3.3	
P value (direct vs indirect)	.455	
Proficiency scale		
Direct		.075[a]
Junior	129 ± 136.7	
Senior	267 ± 192.4	
Indirect		.155
Junior	140 ± 163.8	
Senior	243 ± 196.2	
P value (direct vs indirect)	.355	

[a] Statistically significant difference ($P < .10$, 1-tailed *t* test).

TABLE 4
Interrater Reliability of the 3 Rating Scales[a]

	Fleiss κ (95% CI)	
	Direct Visualization	Indirect Visualization
Global rating scale	0.85 (0.55-0.98)	0.90 (0.56-1.00)
Task-specific checklist	0.65 (0.54-0.76)	0.73 (0.61-0.84)
Proficiency scale	0.93 (0.66-1.00)	0.99 (0.81-1.00)

[a]Interpretation of κ values[8]: <0, poor agreement; 0.0-0.20, slight; 0.21-0.40, fair; 0.41-0.60, moderate; 0.61-0.80, substantial; 0.81-1.0, almost perfect.

With regard to the clear ArK Trainer, the majority of junior and senior trainees discussed the ease of direct visualization in knot-tying (Table 5). As participant 002 explained, "you can see your knot and make sure you're seating your knot in the appropriate position."

When using the covered ArK Trainer, significantly more senior trainees than junior trainees described using tactile or haptic cues ($P = .021$) (Table 5). For example, participant 005 described a period when the knot is in the covered cannula and "you have to go by feel and have a good grasp of the knot . . . You have to depend on your knot and your tactile feel as opposed to actually watching the knot slide down through the clear ArK Trainer, which you don't get to do in a real person."

Realism and Appropriateness of ArK Trainer. Data from the semistructured interviews and Likert-type questionnaires were used to understand learners' perceptions of the realism and appropriateness of each ArK Trainer configuration.

The majority of participants agreed that both versions of the ArK Trainer were realistic. Based on results from the Likert-type questionnaire, 57% of the trainees agreed that the clear version (direct visualization) was a realistic practice format, and 86% agreed that the covered version (indirect visualization) was realistic. Ninety-three percent of trainees agreed that the covered version was more realistic than was the clear version (Figure 3). The data from the Likert-type questions largely agreed with findings of the semistructured interviews, with most trainees (n = 11) finding the configuration with indirect visualization had more real-world fidelity. As participant 008 explained, the covered version is "more realistic of what you would use in the [operating room]. It's more realistic to look at the screen while you are tying the knot." The majority of participants agreed that the clear version of the ArK Trainer was easier to use than was the covered version.

TABLE 5
Participants' Approach to Direct and Indirect Visualization With Corresponding Meaning Units[a]

Theme: Meaning Unit	No. of Trainees Discussing This Meaning Unit				Total No. of Mentions
	Total	Junior	Senior	*P* Value (Junior vs Senior)	
Approach to direct visualization in clear ArK Trainer					
Ability to see knot and posts clearly	10	5	5	≥.99	16
Knot position	3	2	1	.51	6
Tension used to tie knots	3	1	2	.51	6
Approach to indirect visualization in covered ArK Trainer					
Inability to see knot and posts clearly	9	5	4	.58	14
Knot-tying using haptic cues	6	1	5	.021[b]	9

[a]Chi-square analysis was performed to assess significance. ArK, Arthroscopic Knot.
[b]Statistically significant difference ($P < .10$).

The majority of participants agreed that both versions of the ArK Trainer were appropriate practice formats for their levels of training. Based on the Likert-type questionnaire, 79% of the trainees agreed that the clear ArK Trainer was an appropriate practice format for their levels of experience, and 79% agreed that the covered ArK Trainer was an appropriate tool for them. No significant differences were detected between junior and senior trainees' responses (Figure 3). Data from the semistructured interviews supported these findings (Table 6). All 14 participants endorsed the clear version for use by inexperienced learners, and 12 participants endorsed the covered version for use by experienced trainees. Participants' definitions of "experienced" varied but often included those who had completed a sports rotation where residents are trained in arthroscopy. Many of the participants suggested using the clear ArK Trainer as a stepping stone for junior trainees as they progress toward the covered trainer. As participant 002 discussed, "it's better to start with the clear version till you know your steps then you can progress to the covered version."

Participants suggested technical adaptations to the ArK Trainer to improve its utility (Table 6). Suggestions included increasing camera magnification, stabilizing the cannula in the port, stabilizing the ArK Trainer on the table, and providing more time for participants to familiarize themselves with the equipment. Senior trainees were

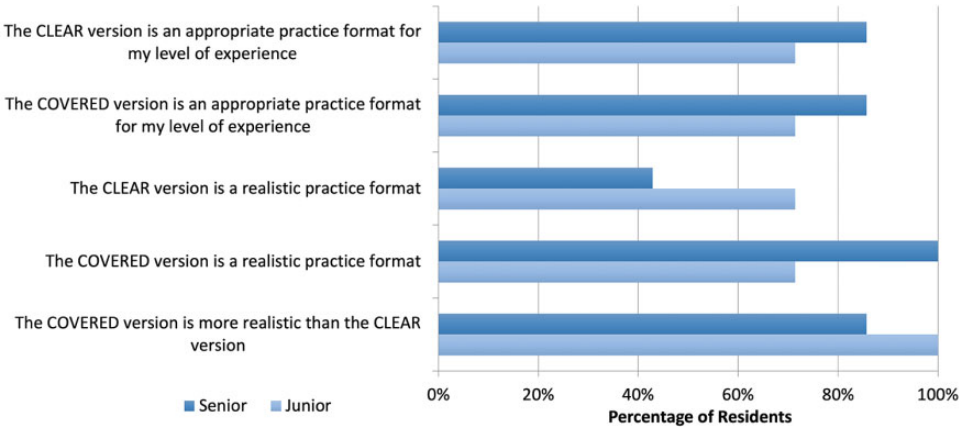

Figure 3. Participant responses to structured questions on a Likert scale, stratified by level of training. No significant differences were detected between junior and senior trainees.

TABLE 6
Participants' Perceptions of the Realism and Appropriateness of the Clear and Covered Versions of the ArK Trainer, With Corresponding Meaning Units[a]

Theme: Meaning Unit	No. of Trainees Discussing This Theme	No. of Mentions
ArK Trainer as a realistic practice model		
Covered version is more realistic	11	24
Clear version is unrealistic	4	6
Covered version is more similar to arthroscopy than the clear version	6	13
ArK Trainer ease of use		
Clear version is easier to use	10	13
Covered version is more challenging to use	9	21
Appropriateness of each version of the ArK Trainer		
Clear version is better for inexperienced learners	14	22
Covered version is better for experienced learners	12	15
Clear trainer as introductory skill building for covered trainer		
Clear version is useful for familiarization with tools or process	5	8
Clear version is useful for practice before using as practice for covered	6	12
Inexperienced learners can progress from the clear to the covered version	6	12
Technical issues with ArK Trainer setup		
Camera magnification was problematic	5	13
Cannula was too mobile	7	13
Provide time for familiarization	3	8
Stabilize attachment of ArK Trainer to table	4	10

[a]ArK, Arthroscopic Knot.

more likely than were junior trainees to comment on the poor view from iPad and camera magnification.

DISCUSSION

Performance

This study applied a mixed-methods approach to assess and compare SMC knot–tying performance between senior and junior residents. According to GRS and PS scores, senior trainees outperformed junior trainees under direct visualization conditions. TSC scores indicated that senior trainees also outperformed junior trainees under indirect visualization conditions. Previous experience with arthroscopy, SMC knot-tying, and using the ArK Trainer may have contributed to senior trainees' higher scores. Existing research supports these data, as Lopez and colleagues[10] found that senior residents performed at a higher level than did junior residents and novice medical students while using a low-cost arthroscopic knot-tying simulator. Research has further demonstrated that knot-tying performance improves with practice.[14] Chong and colleagues[3] found that PGY 1 residents improved the tensile strength of their knots over a 10-week training period.

Perceptions

Data from the semistructured interviews provided insight into trainees' perceptions of the clear and covered versions of the ArK Trainer. Participants discussed knot-tying strategies, skill acquisition, and the use of the ArK Trainer as a learning tool.

The majority of participants agreed that the clear version of the ArK Trainer was easier to use than was the covered version. Participants endorsed the possibility of progression from direct to indirect visualization using the clear and covered versions of the ArK Trainer, respectively. While studies have examined opaque box top simulators, none have compared performances across direct and indirect visualization scenarios.[15] Researchers have also attempted to test whether there are ways to ease the learning curve using visual-spatial training. Despite a variety of approaches and techniques, only limited benefits have been seen.[7,12,21] When learning to translate indirect visualization in 2 dimensions into 3-dimensional space, the learner must likely progress through predictable stages: the cognitive stage, the associative stage, and the autonomous stage.[18,20] The time necessary to progress through these stages may be variable but nevertheless cannot be entirely short-circuited.

When compared with junior trainees, significantly more senior trainees described using tactile or haptic cues when tying knots using the covered ArK Trainer. It therefore seems that experienced trainees are better able to appreciate and respond to subtle haptic feedback during the task. While more evidence is needed in this area, it suggests that integration of haptic cues is indicative a more advanced skill. This is consistent within the literature, with researchers reporting that proficiency in kinesthetic skills (eg, knot-tying) requires learning of visual and haptic cues. Ernst and Banks[5] demonstrated that humans integrate visual and haptic cues optimally to facilitate kinesthetic tasks. In a study of kinesthetic learning in surgeons, Pinzon and colleagues[16] found that muscle memory—knowledge gained through haptic learning—helps surgeons learn skills where visual feedback is limited.[17] Haptic learning

may therefore aid in the progression from direct to indirect visualization during arthroscopic knot-tying.

Participants endorsed the clear ArK Trainer as a realistic simulation format and described the covered version as the most realistic version. Participants likened using the covered ArK Trainer to arthroscopy, where indirect visualization is necessary. The ArK Trainer is an accessible low-cost simulator that can be modified to suit the needs of learners as they progress.

A few participants believed that the low-fidelity aspects of the ArK Trainer limited testing performance under indirect visualization. While specific concerns can be addressed via low-cost modifications to the ArK Trainer, low-fidelity knot-tying simulators are accessible and reliable tools for learners. In a recent article, Ling et al[9] showed no performance difference between their low-fidelity arthroscopic camera and a commercial version. Furthermore, de Montbrun and MacRae[4] argued that there was no safety or performance advantage in the operating room when comparing trainees who learned using high-end or virtual reality simulators versus low-fidelity knot-tying trainers. Likewise, the majority of participants agreed that both versions of the ArK Trainer were appropriate for their learning. This setup with the ArK Trainer and tablet is an accessible low-fidelity model for learners to practice arthroscopic skills, including indirect visualization.

Limitations

This study was limited in the total enrollment of participants. Because of the low numbers of participants and the pilot nature of the study, the α level was set at .10 a priori. The results also had a large degree of in-group variability. This may have been in part because of the very limited experience of some junior trainees, some of whom actually improved on the second trial.

While the ArK Trainer was useful to discriminate among trainee skill levels, this study was not designed to show whether it would influence skill progression as a training tool. As a consequence, the conclusions that can be drawn about the role of the ArK Trainer as a training tool are limited. This is an area for future work.

CONCLUSION

Senior trainees were significantly more experienced than were junior trainees in arthroscopic skill and outperformed them on both configurations: direct (PS and GRS) and indirect (TSC) visualization. Experienced participants were significantly more likely to report using tactile cues to aid knot-tying under indirect visualization. It is likely that inexperienced trainees rely more heavily on direct visualization and that the use of tactile cues may be an indicator of knot-tying proficiency. Trainees recommended progression from direct to indirect visualization configurations for inexperienced learners.

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APPENDIX

TABLE A1
Questionnaires Used in this Study[a]

Follow-up Questions (Likert Scale)

1. The CLEAR version of the ArK Trainer is an appropriate practice format for my level of experience.
   a. Strongly agree
   b. Agree
   c. Neutral
   d. Disagree
   e. Strongly disagree
2. The COVERED version of the ArK Trainer is an appropriate practice format for my level of experience.
   a. Strongly agree
   b. Agree
   c. Neutral
   d. Disagree
   e. Strongly disagree
3. The CLEAR version of the ArK Trainer is a realistic practice format.
   a. Strongly agree
   b. Agree
   c. Neutral
   d. Disagree
   e. Strongly disagree
4. The COVERED version of the ArK Trainer is a realistic practice format.
   a. Strongly agree
   b. Agree
   c. Neutral
   d. Disagree
   e. Strongly disagree
5. The COVERED version of the ArK Trainer is a more realistic practice format than the CLEAR version.
   a. Strongly agree
   b. Agree
   c. Neutral
   d. Disagree
   e. Strongly disagree

Semistructured Interview Questions

Differences between the covered and uncovered versions
1. Describe your experience using the clear version of the ArK Trainer.
   a. Discuss any challenges associated with using the clear version.
   b. Discuss any benefits associated with using the clear version.
2. Describe your experience using the covered (opaque) version of the ArK Trainer.
   a. Discuss any challenges associated with using the covered (opaque) version.
   b. Discuss any benefits associated with using the covered (opaque) version.
3. Compare and contrast your experience using the covered (opaque) and clear (transparent) version of the ArK Trainer.
   a. How would differences between the two versions impact your learning?

Appropriateness for level of learning
4. Which version of the ArK Trainer was the most helpful practice format for you? Why?
   a. Is there another group of learners who would benefit from this version of the ArK Trainer?
   b. Are there any learners who would benefit from using the other version of the ArK Trainer?

Evaluation of the ArK Trainer for follow-up
5. Is there anything about the covered (opaque) version of the ArK Trainer that you would change in order to increase its fidelity to arthroscopic knot tying?
6. Any suggestions to improve the trial? Any difficulties experienced during this study or areas for improvement?

[a]ArK, Arthroscopic Knot.

TABLE A2
Global Rating Scale

Respect for Tissue				
1	*2*	*3*	*4*	*5*
Frequently used unnecessary force or cause damage by inappropriate use of instrument		Carefully handling of tissue but occasionally caused inadvertent damage		Consistently handled tissues appropriately with minimal damage
Time and Motion:				
1	*2*	*3*	*4*	*5*
Many unnecessary moves		Efficient time/motion but some unnecessary moves		Clear economy of movement and maximum efficiency
Instrument Handling:				
1	*2*	*3*	*4*	*5*
Repeatedly makes tentative or awkward moves with instruments by inappropriate use of instruments		Competent use of instruments but occasionally appeared stiff or awkward		Fluid moves with instruments and no awkwardness
Knowledge of Instruments:				
1	*2*	*3*	*4*	*5*
Frequently asked for wrong instrument or used inappropriate instrument		Knew names of most instruments and used appropriate instrument		Obviously familiar with the instruments and their names
Flow of Operation:				
1	*2*	*3*	*4*	*5*
Frequently stopped operating and seemed unsure of next move		Demonstrated some forward planning with reasonable progression of procedure		Obviously planned course of operation with effortless flow from one move to the next
Use of Assistants:				
1	*2*	*3*	*4*	*5*
—	—	—	—	All participants received a score of 5
Use of Assistants:				
1	*2*	*3*	*4*	*5*
Deficient knowledge. Needed specific instruction at most steps		Knew all important steps of operation		Demonstrated familiarity with all aspects of operation
OVERALL ON THIS TASK, SHOULD THE CANDIDATE: **FAIL** **PASS**				
TOTAL SCORE:				

TABLE A3
Task-Specific Checklist[a]

Steps for Arthroscopic SMC Knot	Not Done	Done
Step 1: Thread the suture through a pair of eyelets	0	1
Step 2: Tie the SMC knot by	0	1
2.1 Thread the knot pusher and snap onto the post stand	0	1
2.2 Assume the starting position (separate both strands with the post in the left hand, keeping both strands of the suture on top of each index finger)	0	1
2.3 Cross the suture over the left index finger	0	1
2.4 Bring the suture under 2 limbs	0	1
2.5 Bring the suture over 2 limbs	0	1
2.6 Bring the suture under 1 limb, by reaching between the 2 strands	0	1
2.7 Bring the suture over 1 limb	0	1
2.8 Bring the suture through the triangle from the bottom to top	0	1
2.9 Dress the knot pulling on the nonpost suture toward the cannula	0	1
2.10 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 3 mm tail	0	1

[a]SMC, Seoul Medical Center.

TABLE A4
Proficiency Scale[a]

Proficiency formula = timing score – penalty score
Timing score: 600 s – time used (s) to tie 1 SMC and 3 half hitches
Penalty score: sum of penalties × 10
1. Approximation: 1-point penalty for each millimeter of separation >2 mm
   - Separation of 3 mm results in an error of 3 points; a separation of ≤2 mm results 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

[a]SMC, Seoul Medical Center.