Original Article

Resident Performance on the Fundamentals of Arthroscopic Surgery Training (FAST) Workstation Does Not Predictably Improve With Postgraduate Year

Michael Chapek, B.A., Peters T. Otlans, M.D., M.P.H., Taylor Buuck, M.D., Joseph T. Nguyen, M.P.H., Jaron P. Sullivan, M.D., Brian M. Grawe, M.D., Gregg T. Nicandri, M.D., and Jacqueline M. Brady, M.D.

Purpose: To identify differences in performance on the Fundamentals of Arthroscopic Surgery Training (FAST) workstation between residents across different postgraduate years and training sites. **Methods:** During the 2018-2019 academic year, 102 orthopaedic surgery residents from 4 training sites completed 6 FAST modules. Failure was defined as either completion time exceeding benchmark time or commission of task-specific errors. With the exception of knot tying, each module was completed by participants twice—once with each hand serving as the camera hand. Time to completion (except for knot tying) and errors were recorded for each of the modules. Completion times and failure rates were compared between postgraduate years, seniority groups, and training sites. **Results:** In all modules for which time was recorded, except for the suture-passage module, there was no significant difference in time to completion based on seniority ($P < .01$ for suture passage and $P > .05$ for all others). Significant differences in completion time were observed between sites for all modules except for the suture-passage module ($P = .957$ for suture passage and $P < .05$ for all others). Site predicted failure by at least 1 measure (time or technical error) for all modules ($P < .05$) except for number probing and suture passage. Failure rate across training years varied for each module. **Conclusions:** Time to completion and rate of failure did not predictably decrease with level of training. Training site proved to be a significant predictor of performance. Factors such as hand dominance and familiarity with the equipment proved to be important considerations for some modules. **Clinical Relevance:** Objective assessment of arthroscopic skills among orthopaedic trainees is difficult. Using reproducible methodology to assess trainees on specific skills at all postgraduate years and at multiple training sites may provide important information about orthopaedic training.

From the Kaiser Permanente Bernard J. Tyson School of Medicine, Pasadena, California, U.S.A. (M.C.); Department of Orthopaedics and Rehabilitation, Oregon Health and Science University, Portland, Oregon, U.S.A. (P.T.O., J.M.B.); Department of Orthopedic Surgery, Beaumont Health System, Royal Oak, Michigan, U.S.A. (T.B.); Epidemiology and Biostatistics Core Facility, Hospital for Special Surgery, New York, New York, U.S.A. (J.T.N.); Department of Orthopaedic Surgery, Vanderbilt University Medical Center, Nashville, Tennessee, U.S.A. (J.P.S.); Department of Orthopaedic Surgery, University of Cincinnati College of Medicine, Cincinnati, Ohio, U.S.A. (B.M.G.); and Department of Orthopaedics, University of Rochester Medical Center, Penfield, New York, U.S.A. (G.T.N.).

The authors report the following potential conflicts of interest or sources of funding: J.T.N. reports that, with grant support provided to his institution, he was supported in part by funds from the Clinical Translational Science Center (CTSC), National Center for Advancing Translational Sciences (NCATS) (grant No. UL1-RR024996). In addition, J.T.N. is on the editorial board of American Journal of Sports Medicine *and* Journal of Women's Sports Medicine. *B.M.G. receives consulting fees from Mitek. G.T.N. reports grant support from the Agency for Healthcare Research and Quality (grant No. S03812-01: Integration Next Generation Simulator Training and Operating Room Performance Assessment Into Orthopedic Residency Programs); receives consulting fees, unrelated to this work, from Knowtex; and has a leadership or fiduciary role in AANA Learning Center Committee and AANA FAST Committee. J.M.B. receives fees for talks and laboratory instruction from Miach Orthopaedics and is Membership Chair of The Forum (group of women in orthopaedic sports surgery). Full ICMJE author disclosure forms are available for this article online, as supplementary material.*

Received May 18, 2023; accepted December 14, 2023.

Address correspondence to Jacqueline M. Brady, M.D., Department of Orthopaedics and Rehabilitation, Oregon Health and Science University, 3181 SW Sam Jackson Park Rd, Mail Code OP 31, Portland, OR 97239, U.S.A. E-mail: Munch@OHSU.edu

2666-061X/23634

https://doi.org/10.1016/j.asmr.2023.100866

Orthopaedic surgical training has evolved, but despite standardization efforts, variability in training experiences persists.[1,2] Assessing surgical performance is inherently challenging and subjective, making it difficult to determine when a trainee is ready to operate safely and efficiently.[3] Benchtop arthroscopic simulators have allowed for the creation of standardized surgical experiences that aid in the development of skills while offering a means to objectively assess trainees.[4-9]

Bench models, being more affordable than virtual reality simulators, have been used in general surgery training to promising effect.[10,11] In orthopaedics, the Fundamentals of Arthroscopic Surgery Training (FAST) program was created by the Arthroscopy Association of North America (AANA), American Academy of Orthopaedic Surgeons, and American Board of Orthopaedic Surgery to provide a curriculum for training in arthroscopic surgery. The FAST workstation (Sawbones, Vashon Island, WA) was designed with the FAST program in mind.

The FAST workstation provides modules for trainees to practice and objectively assess arthroscopic skills by measuring time to completion and specific errors. Previous investigations using bench models showed that senior surgical trainees typically outperformed juniors.[5-7,12-15] However, the modules, protocols, and assessment metrics used in these studies varied greatly, and trainees were enrolled from single sites. Little is known about how trainees with various levels of experience perform on standardized tasks across multiple sites. Normative benchmark values should be defined for these tasks.[16]

The purpose of this study was to identify differences in performance on the FAST workstation between residents across different postgraduate years (PGYs) and training sites. We hypothesized that more senior residents would perform standardized arthroscopic tasks more quickly and with fewer errors than junior residents.

Methods

In this prospective, multicenter study, residents at 4 academic orthopaedic institutions were evaluated on their performance on 6 modules of the FAST workstation: ring transfer, number probe, maze navigation, biting, suture passage, and knot tying. The study design was agreed on by attending surgeons at each training site, and institutional review board approval was obtained at each center. Participants were enrolled during the 2018-2019 academic year.

Study Protocol

A standardized protocol was developed by all sites via conference call, and the protocol was shared via slideshows and sample videos. Each site was required to have a standard arthroscopy tower with 30° arthroscope, a full complement of FAST workstation modules, and standardized arthroscopic instruments and sutures (Appendix Table 1 provides a full description of required items). At each center, a research assistant completed the series of modules with the subject in a one-on-one setting, taking approximately 2 hours.

To anonymize results, at the time of testing, each subject was assigned a participant identification number that had been generated by a random number generator.[17] For each participant, the order of module completion was predetermined by a random number generator. With the exception of knot tying, each module was attempted with both the right hand and the left hand serving as the hand holding the tool used to complete the task to emphasize the ambidextrous nature of arthroscopic skills. The starting hand was also determined randomly on a module-by-module basis.

At the beginning of participant enrollment, the research assistant read a script to the participant outlining a general overview of the study. Modules were then set up in a standard fashion and completed in the assigned order. Prior to each module, an additional script was read to the participant describing the objective of the individual module and the errors that would be recorded. An optional 2-minute practice period was provided, although practice that was irreversible (i.e., tying a knot or using the biter on the template) was prohibited. During module completion, the research assistant was not permitted to coach the participant but could answer basic questions, and the script remained available for review.

Modules and Scoring

Time to completion and errors were recorded for each module. With the exception of knot tying, each module was completed twice—once with each hand—with the module being reset between attempts. First attempt, second attempt, and any attempt were recorded and analyzed as predictor variables. Appendix 1 provides a complete description of the modules. All benchmarks were determined based on the mean performance of a cohort of AANA faculty at the AANA Fundamentals in Arthroscopic Surgery Courses (written and oral communication with G.T. Niccandri, MD, January 2023). This is similar to the methods used to develop the Fundamentals of Laparoscopic Surgery benchmarks, which were derived from the mean performance of 2 expert laparoscopists.[18]

Number Probe. For the number-probe module, a standard paper cutout template of numbers 1 through 21 is inserted into the module. These numbers line up under smaller holes in the module and are visualized by maneuvering the arthroscope to each hole. The participant uses an arthroscopic probe to punch out an assigned series of 10 random numbers in order. A different set of 10 numbers is used in the second trial. Failure is recorded if the time taken to complete the test is 96 seconds or greater or if the incorrect number was probed at any time during the task. Proficiency is defined as a task completion time of less than 96 seconds.

Vertical Ring Transfer. For the ring-transfer module, the objective is to transfer 8 rings across the module and back using an arthroscopic grasper. A dropped ring is to be left in place and is considered an error. Taking longer than 140 seconds or dropping more than 1 ring is considered a failure.

Biting. For the biting module, a paper insert with 2 semicircles is placed in the module. The goal is to completely bite out the inner semicircle while leaving the outer semicircle intact. Failure is recorded if the time to complete the test is 68 seconds or greater and/or if there is more than 1 area in which the participant fails to bite out the inner line or erroneously bites out the outer line.

Maze. For the maze module, the participant uses a probe to push a 0.25-inch-sized ball down the track from start to finish. Failure is recorded if the time taken to complete the test is 103 seconds or greater or if the ball is allowed to fall from the platform.

Suture Passage. For the suture-passage module, a foam resection insert containing three 5-mm "target zones" is placed in the module. Each target zone is centered over an eyelet, and a suture is fed through each eyelet, creating 6 equal limbs. The objective is to pass each suture, one by one, through its respective target zone (2 limbs per target zone) using the antegrade suture passer. If the suture unloads from the eyelet, an error is recorded. Time is then stopped, and the research assistant reloads the eyelet, taking care not to disturb previously passed suture limbs. Every suture limb not passed through the eyelet is considered an error, and the sum of distances in millimeters from each limb outside of the target zone is calculated. There is a 15-minute maximum per attempt. Failure is recorded if the time taken to complete the test is 195 seconds or greater with no more than 1 mm of distance from the target area (per target) with no suture unloads.

Knot Tying. The knot-tying module requires the participant to tie 5 arthroscopic knots to demonstrate loop security and knot security on the knot tester. Loop security is the ability of a loop to remain tight as the knot is tied, whereas knot security is the ability to resist loop elongation as the load is applied.[19] The participant uses a curved hemostat and an arthroscopic knot pusher to tie his or her chosen knot, backed with 3 half-hitches on alternating posts. The participant is provided verbal and written descriptions of a basic sliding-locking arthroscopic knot. Time is recorded for each knot, with a 10-minute limit for all 5 knots, followed by knot testing.

Knots are tested in order using a previously described method.[20] Loops that do not expand more than 3 mm from the site of the mandrel on which they are tied are considered successful. Loop security is tested first on a conical loop sizer. Then, the knot is challenged on the FAST knot tester by pulling 15 lb of tension across the knot for 15 seconds. Finally, the knot is returned to the loop sizer to determine the degree of lengthening and whether knot security is present. The starting and ending positions of each knot on the conical sizer are recorded. Failure is recorded for individual efforts if a resident fails to tie a knot (as a result of time elapsing or suture breakage), if the knot starts or ends at the 5-mm mark on the post, or if the change in knot size is more than 3 mm with stress.

Statistical Analysis

Participants were stratified based on seniority. Those in their first, second, and third years of residency were considered junior residents, and those in their fourth and fifth years were considered senior residents. An a priori power analysis was performed using G*Power, version 3.1.9.7.[21] Using previously published data on the FAST workstation, considering an α value of .05 and power ($1 - \beta$) of 0.8, a target sample size of 20 was calculated.[20,22]

All data were recorded and housed in REDCap.[23] Data were analyzed using SAS software (version 9.4; SAS Institute, Cary, NC). For tasks in which time was recorded, the median and interquartile range (IQR) of times for each PGY and for the seniority groups were reported. To assess performance most comprehensively, rates of failure by exceeding the benchmark time and by technical error were compared between groups using the Fisher exact test or χ^2 test, based on appropriate sample size. Although completion time and technical errors are separate concepts, they are both important in determining trainee proficiency. Therefore, as is performed in the Fundamentals of Laparoscopic Surgery curriculum,[18] rate of failure by time or technical error together was also compared between groups. For comparisons of completion times, analysis of variance was used for data with a normal distribution whereas the Kruskal-Wallis test was used to analyze data with a non-normal distribution. When a difference between groups was observed, Wilcoxon rank sum testing was performed to compare various groups and to determine significant differences in completion times. Thus, when comparing median completion times between groups, Wilcoxon rank sum *P* values are provided.

Results

In total, 102 PGY 1 to PGY 5 residents in 4 academic orthopaedic surgery residency programs were tested on the FAST module over the course of 1 academic year. To establish norms for various levels of learners, the completion times for each timed module, according to year of training and group, is reported in Table 1.

Number Probe

For the number-probe module, the median time to completion for junior versus senior residents was 144.50 seconds (IQR, 127.50-180.50 seconds) versus 128.00 seconds (IQR, 104.00-177.00 seconds; $P > .05$) (Table 1). When stratifying by either training year or group (PGY 1-3 vs PGY 4-5), none of the probing variables (i.e., first attempt, second attempt, or average time between the 2 attempts) produced a statistically significant difference in time to completion ($P > .05$ for all). Although time to completion did decrease for the senior resident group as compared with the junior resident group, this was not a significant difference and the time distribution was wider in the senior group (Table 1).

When failures by either time or incorrect probing were analyzed by year, the first attempt approached significance ($P = .05$) and the second attempt achieved significance ($P = .03$). In the analysis of any failure by group, the percentage of failures on the first attempt (95.25% of juniors vs 82.05% of seniors, $P = .041$), on the second attempt (92.06% of juniors vs 74.36% of seniors, $P = .014$), and on any attempt (100.00% of juniors vs 89.4% of seniors, $P = .019$) all achieved significance. Significant differences in overall rate of failure by time were observed between training years ($P = .005$) and groups (100.00% of juniors vs 82.05% of seniors, $P = .001$). No significant difference in rate of failure by error was observed between training years or between groups ($P > .05$ for all). It is interesting to note that significant differences in completion time—but not in rate of failure—existed between sites (Table 2).

Vertical Ring Transfer

For the ring-transfer module, the median completion time was 228.50 seconds (IQR, 159.00-322.50 seconds) for junior residents compared with 196.50 seconds (IQR, 163.00-240.00 seconds; $P > .05$) for seniors (Table 1). No significant difference in failure rate by time (time $\geq$ 140 seconds) was observed between training years or between groups for any ring-transfer variables ($P > .05$ for all). Site was a significant predictor of failure by time for all variables ($P < .05$ for all), including average attempt ($P = .001$).

Rate of failure was high for the ring-transfer task, and all participants had at least 1 failure either by time or by error when using the nondominant hand. Training year and group failed to achieve significance for either attempt ($P > .05$ for all). Failure of any type (i.e., either by time or by error) was found to be significant when examined by training year on the second attempt ($P = .010$). However, this effect lost significance when examined by group ($P = .64$).

Table 1. Median Time to Completion of Arthroscopic Tasks by PGY and by Seniority Group

Module	Median Time (IQR), s	*P* Value
Time to completion by PGY		
Number probe		.344
PGY 1	146.00 (136.50-170.00)	
PGY 2	141.50 (124.25-155.25)	
PGY 3	150.50 (130.50-185.00)	
PGY 4	126.50 (104.00-177.50)	
PGY 5	136.50 (102.50-173.50)	
Ring transfer		.186
PGY 1	238.75 (182.50-322.50)	
PGY 2	172.25 (148.00-279.00)	
PGY 3	249.50 (178.50-338.00)	
PGY 4	179.00 (155.50-240.00)	
PGY 5	203.00 (171.00-266.00)	
Biting		.849
PGY 1	109.00 (77.00-161.50)	
PGY 2	99.00 (76.50-142.25)	
PGY 3	84.00 (80.50-116.00)	
PGY 4	102.00 (81.00-116.50)	
PGY 5	77.00 (76.50-91.50)	
Maze		.259
PGY 1	131.00 (93.00-173.50)	
PGY 2	104.25 (79.25-159.50)	
PGY 3	127.00 (90.00-186.00)	
PGY 4	93.50 (60.50-142.00)	
PGY 5	100.25 (78.00-156.50)	
Suture passage		<.001
PGY 1	890.25 (699.00-900.00)	
PGY 2	749.00 (555.00-900.00)	
PGY 3	577.00 (500.50-851.00)	
PGY 4	397.00 (375.00-519.00)	
PGY 5	418.50 (347.00-516.00)	
Time to completion by seniority group		
Number probe		.062
Junior (PGY 1-3)	144.50 (127.50-180.50)	
Senior (PGY 4-5)	128.00 (104.00-177.00)	
Ring transfer		.174
Junior (PGY 1-3)	228.50 (159.00-322.50)	
Senior (PGY 4-5)	196.50 (163.00-240.00)	
Biting		.705
Junior (PGY 1-3)	97.50 (77.00-148.00)	
Senior (PGY 4-5)	102.00 (78.00-119.00)	
Maze		.087
Junior (PGY 1-3)	126.50 (85.50-175.00)	
Senior (PGY 4-5)	97.00 (74.00-147.50)	
Suture passage		<.001
Junior (PGY 1-3)	736.50 (521.00-900.00)	
Senior (PGY 4-5)	402.00 (366.00-519.00)	

NOTE. Times for the first and second attempts were averaged for each individual, and the median values of the individual averages are displayed.

IQR, interquartile range; PGY, postgraduate year.

Table 2. Median Time to Completion of Arthroscopic Tasks by Training Site

Module	Median Time (IQR), s	*P* Value
Number probe		<.001
Site A	177.00 (150.50-242.50)	
Site B	144.75 (123.75-169.25)	
Site C	132.25 (116.25-165.25)	
Site D	123.50 (99.00-136.50)	
Ring transfer		<.001
Site A	348.00 (302.50-464.50)	
Site B	191.50 (155.75-242.00)	
Site C	220.75 (181.25-260.75)	
Site D	156.00 (137.00-179.00)	
Biting		.001
Site A	116.00 (107.00-159.90)	
Site B	93.75 (82.50-158.25)	
Site C	88.00 (75.25-120.75)	
Site D	80.50 (71.50-98.00)	
Maze		<.001
Site A	175.00 (117.00-222.00)	
Site B	139.75 (115.75-175.75)	
Site C	89.50 (82.25-98.25)	
Site D	70.00 (42.50-134.00)	
Suture passage		.957
Site A	543.50 (424.50-710.00)	
Site B	613.75 (382.50-900.00)	
Site C	578.50 (412.00-792.75)	
Site D	624.00 (439.50-762.00)	

NOTE. Times for the first and second attempts were averaged for each individual, and the median values of the individual averages are displayed.

IQR, interquartile range.

Biting

For the biting module, median time to completion for junior versus senior residents was 97.50 seconds (IQR, 77.00-148.00 seconds) versus 102.00 seconds (IQR, 78.00-119.00 seconds; $P > .05$) (Table 1). None of the biting module variables reached the level of statistical significance for completion time by year or group ($P > .05$ for all). Few trainees failed the biting module by time (time ≥ 68 seconds) or technical failure (>1 area of over- or under-biting). Differences in failure by time were not significant between years or between groups for any attempt ($P > .05$ for all). When rate of technical failure was examined, the first attempt was a significant factor when analyzed by group (34.29% of juniors vs 15.38% of seniors, $P= .032$). No failures reached the level of significance when time and technical error were combined for analysis ($P > .05$ for all). As for analysis by site, there were significant differences in rate of failure by technical error for the second attempt, and differences in the completion times recorded for the first attempt, second attempt, and average of both attempts achieved significance ($P < .05$ for all).

Maze

For the maze module, the median completion time for junior residents was 126.50 seconds (IQR, 85.50-175.50 seconds) compared with 97.00 seconds (IQR, 74.00-147.50 seconds) for senior residents ($P > .05$) (Table 1). When examined by training year and by group, none of the maze module variables reached the level of statistical significance for completion time ($P > .05$ for all). Analysis by site showed that all variables (first attempt, second attempt, and either attempt) achieved significance for time to completion ($P < .001$ for all).

When the failures by time (completion time ≥ 103 seconds) were analyzed by training year, there was no significant difference for either attempt ($P > .05$ for all). Stratifying by group showed a significant difference in failure rate by time for the second attempt ($P = .01$). The first attempt, the second attempt, and either attempt were significantly different in time error failure by site ($P < .001$). When failures by dropping the ball were examined with respect to trainee year and trainee group, no variables achieved significance ($P < .05$ for all). When failures of either sort (time ≥ 103 seconds or dropped ball) were examined together, significance was noted for the first attempt with respect to group and site ($P < .05$ for both).

Suture Passage

For the suture-passage module, the median completion times recorded were significantly different across training years ($P < .01$) and groups (732.50 seconds for juniors vs 402.00 seconds for seniors, $P < .01$) (Table 1). When analyzed by year, all variables (first attempt, second attempt, and any attempt) achieved significance ($P < .001$). These variables were also significant when the residents were separated into seniority groups ($P < .001$ for all). Site was not a significant predictor of time for the suture-passage module ($P > .05$ for all).

Residents showed a learning curve when examined for errors (time ≥ 195 seconds, failing to pass 6 total sutures, unloading the eyelet, or missing the target by > 1 mm); all participants failed by the benchmark time limit, regardless of training year or site. The prescribed time limit was 900 seconds, and the average time taken was 579 seconds. Of 102 participants, 30 ran out of time on their first attempt, whereas 25 of 102 participants ran out of time on their second attempt. When measured against the benchmark of 195 seconds for proficiency with the module, all participants failed regardless of year or site. Because so many participants ran out of time during testing, a univariate model was conducted to evaluate whether the dominant-hand suture time was greater than or equal to the average time taken of 579 seconds. Year of training and group predicted performance in this approach (Table 3).

Regarding technical errors, analysis by training year and group showed that significantly more senior trainees successfully passed 6 total sutures and fewer unloaded the eyelet on both the first and second

Table 3. Univariate Analysis by Training Year and Seniority Group Examining Percentage of Participants With Dominant-Hand Suture Module Time of 579 Seconds or Greater

Trait	% of Participants With Module Time ≥ 579 s	*P* Value
PGY		<.001
1	90.9	
2	70.0	
3	42.9	
4	15.8	
5	15.8	
Seniority group		<.001
PGY 1-3	68.3	
PGY 4-5	15.8	
Training site		.532
A	40.0	
B	50.0	
C	59.3	
D	44.0	

PGY, postgraduate year.

Table 4. Repeated-Measures Multivariate Logistic Regression Assessing ORs of Knot Failure by PGY (PGY-5 as Referent Value), Seniority Group (Seniors [PGY 4-5] as Referent Value), and Training Site (Site D as Referent Value)

Trait	OR (95% CI)	*P* Value
PGY		
1	2.56 (1.10-5.97)	.029
2	1.39 (0.58-3.33)	.454
3	3.00 (1.27-7.08)	.012
4	2.05 (0.79-5.27)	.139
5	1.00 (referent)	NA
Seniority group		
PGY 1-3	1.56 (0.87-2.81)	.135
PGY 4-5	1.00 (referent)	NA
Training site		
A	0.95 (0.44-2.05)	.895
B	1.66 (0.80-3.45)	.172
C	0.21 (0.09-0.46)	<.001
D	1.00 (referent)	NA

CI, confidence interval; NA, not applicable; OR, odds ratio; PGY, postgraduate year.

attempts ($P < .05$). A similar proportion of juniors and seniors missed the target by more than 1 mm on either attempt ($P > .05$).

Knot Tying

As our focus was on the quality of the knot rather than the speed at which it was tied, we elected to forgo reporting of comparative average times and to focus only on success or failure for the knot-tying module. On the first attempt, 53 of 102 trainees (52%) tied a successful knot. The subsequent efforts showed little improvement: 53 of 102 (52%) were successful on the second attempt, 59 of 102 (58%) were successful on the third attempt, 49 of 102 (48%) were successful on the fourth attempt, and 49 of 102 (48%) were successful on the final attempt. When examined by year or group, more senior residents did have significantly fewer knot failures overall than junior residents ($P < .05$ for both). Site was a significant predictor of knot failure ($P < .001$).

A repeated-measures multivariate logistic regression model was created to assess odds ratios with 95% confidence intervals (CIs) of knot failure between groups (Table 4). When knot failures were assessed by year with PGY 5 as the reference group, PGY 1 residents had 2.56 times the odds of failure compared with PGY 5 residents (95% CI, 1.10-5.97; $P = .03$) and PGY 3 residents had 3.00 times the odds of failure compared with PGY 5 residents (95% CI, 1.27-7.08; $P = .01$). Compared with the senior group, junior residents had 56% higher odds of knot failure, which did not reach the level of statistical significance (95% CI, 0.87-2.81; $P = .1$).

Discussion

The most important finding of this multicenter study was that more senior residents had a more proficient skill set than their junior counterparts, but contrary to our hypothesis, trainees with a more advanced PGY standing did not always perform arthroscopic tasks more quickly and with fewer errors. Training site was an important predictor of performance across many of the modules.

The probing module indicated failure by time as the best performance measure, with significant differences between training years by time, but not by errors. In the ring-transfer module, failures by dropping rings were common, and hand dominance was a significant factor: All participants had a failure while holding the grasper in the nondominant hand. Given such a high rate of failure, this module could not differentiate between training years or groups based on time to completion or rate of failure of any type. Failures were comparatively uncommon for the biting module, and time to completion did not correlate closely with year in training. We suggest that an element of increased difficulty—such as poor visualization representative of a tight posteromedial knee with a meniscal tear—could be added to this module to better differentiate the participants in a clinically relevant way. The maze module also failed to differentiate between training years or groups, but hand dominance and site both had significant effects on completion time for this module.

We observed a notable difference in time and errors between juniors and seniors in the suture-passage module; this was likely influenced by advanced familiarization, especially considering the varied completion times across training years. In the knot-tying module, seniors generally exhibited fewer failures than juniors, with greater failure odds for PGY 1 and PGY 3 residents versus PGY 5 residents. A failure trend in the fourth and fifth knots seemed related to time constraints. It is therefore recommended that no time limit be placed on knot tying to allow for a true evaluation of skill and knot quality.

Other investigations have shown that resident year of training correlates with arthroscopic skill.[5-7,12-15,24] Our findings of variable times and error rates across levels of training likely reflect the multicenter nature of our undertaking. Site was a statistically significant variable in many of the results, indicating that the variability in residency program arthroscopy skills training affects our ability to establish universal benchmarks for FAST performance. Given the inherent variability in time to arthroscopic exposure and arthroscopic case volume at different sites, stratification by case volume—as opposed to PGY—may offer better perspective into the ability of the FAST module to discriminate based on experience level. Previous studies have suggested a relation between arthroscopic case experience and improved performance on simulated arthroscopy models, but this relation is not absolute.[22,24-26] Our study included a combination of academic, university-based training programs, and we hypothesize that an undertaking involving different types of residency programs would find even more variability in its results. Further research is needed to determine whether performance on the FAST training modules correlates with more direct measures of arthroscopic skill and experience, such as arthroscopic case volume or performance in the operating room.

Limitations

This study is not without limitations. First, participants did not receive coaching prior to study initiation. This may be the reason many junior residents had difficulty completing certain modules, such as suture passage and knot tying. Previous studies have shown that even brief periods of training lead to immediate improvement in simulated arthroscopic performance.[27-29] Second, the degree of experience with the FAST workstation likely predicts performance, and this variable was not controlled in our analysis. Furthermore, there is considerable variability in arthroscopic experience across training programs,[1,2] and residents may differ individually in their level of arthroscopic experience based on their own professional interest and exposure. Therefore, a more appropriate variable for measuring arthroscopic ability may be case volume—as well as the level of hands-on experience during these cases—instead of PGY. Finally, it is difficult to determine how results on a benchtop model correlate to intraoperative performance, although other studies in the orthopaedic and general surgery literature have suggested that there is a relation.[30-32] Bench performance has also been associated with improved cadaveric diagnostic arthroscopy performance.[33-35]

Conclusions

Time to completion and rate of failure did not predictably decrease with level of training. Training site proved to be a significant predictor of performance. Factors such as hand dominance and familiarity with the equipment proved to be important considerations for some modules.

References

1. Gil JA, Waryasz GR, Owens BD, Daniels AH. Variability of arthroscopy case volume in orthopaedic surgery residency. *Arthroscopy* 2016;32:892-897.
2. Gil JA, Daniels AH, Weiss AP. Variability in surgical case volume of orthopaedic surgery residents: 2007 to 2013. *J Am Acad Orthop Surg* 2016;24:207-212.
3. Carpenter JE, Hurwitz SR, James MA, et al. American Board of Orthopaedic Surgery: Modules for PGY-1 Residents. https://urldefense.com/v3/__https://www.abos.org/residents/residency-skills-modules/abos-surgical-skills-modules-for-pgy-1-residents/__;!!Mi0JBg!MfiaOLxN16kqJn7vxfp_j9DrLxbhNEWL8l28-au9V5XsMuv2ozngLyzXwRkW46QgNY5bXDe4XLSdoYU$. Accessed October 23, 2023.
4. Bliss JP, Hanner-Bailey HS, Scerbo MW. Determining the efficacy of an immersive trainer for arthroscopy skills. *Stud Health Technol Inform* 2005;111:54-56.
5. Gomoll AH, O'Toole RV, Czarnecki J, Warner JJ. Surgical experience correlates with performance on a virtual reality simulator for shoulder arthroscopy. *Am J Sports Med* 2007;35:883-888.
6. Gomoll AH, Pappas G, Forsythe B, Warner JJ. Individual skill progression on a virtual reality simulator for shoulder arthroscopy: A 3-year follow-up study. *Am J Sports Med* 2008;36:1139-1142.
7. Coughlin RP, Pauyo T, Sutton JC III, Coughlin LP, Bergeron SG. A validated orthopaedic surgical simulation model for training and evaluation of basic arthroscopic skills. *J Bone Joint Surg Am* 2015;97:1465-1471.
8. Pedowitz RA, Marsh JL. Motor skills training in orthopaedic surgery: A paradigm shift toward a simulation-based educational curriculum. *J Am Acad Orthop Surg* 2012;20:407-409.
9. Feldman MD, Brand JC, Rossi MJ, Lubowitz JH. Arthroscopic training in the 21st century: A changing paradigm. *Arthroscopy* 2017;33:1913-1915.
10. Bilgic E, Kaneva P, Okrainec A, Ritter EM, Schwaitzberg SD, Vassiliou MC. Trends in the Fundamentals of Laparoscopic Surgery (FLS) certification exam over the past 9 years. *Surg Endosc* 2018;32:2101-2105.
11. Schmiederer IS, Kearse LE, Korndorffer JR Jr, Lee E, Sgroi MD, Lee JT. Validity evidence for vascular skills assessment: The feasibility of fundamentals of vascular surgery in general surgery residency. *J Surg Educ* 2021;78:e201-e209.
12. Dwyer T, Slade Shantz J, Chahal J, et al. Simulation of anterior cruciate ligament reconstruction in a dry model. *Am J Sports Med* 2015;43:2997-3004.
13. Wong IH, Denkers M, Urquhart N, Farrokhyar F. Construct validity testing of the Arthroscopic Knot Trainer (ArK). *Knee Surg Sports Traumatol Arthrosc* 2015;23:906-911.

14. Colaco HB, Hughes K, Pearse E, Arnander M, Tennent D. Construct validity, assessment of the learning curve, and experience of using a low-cost arthroscopic surgical simulator. *J Surg Educ* 2017;74:47-54.
15. Phillips L, Cheung JJH, Whelan DB, et al. Validation of a dry model for assessing the performance of arthroscopic hip labral repair. *Am J Sports Med* 2017;45:2125-2130.
16. Lakhani S, Selim OA, Saeed MZ. Arthroscopic simulation: The future of surgical training: A systematic review. *JBJS Rev* 2021;9:e20.00076.
17. Maple Tech International. Random number generator. Calculator. Published 2008, https://www.calculator.net/random-number-generator.html. Accessed September 1, 2017.
18. Scott DJ, Ritter EM. Fundamentals of Laparoscopic Surgery: Technical skills proficiency-based curriculum. https://www.flsprogram.org/wp-content/uploads/2014/02/Proficiency-Based-Curriculum-updated-May-2019-v24-.pdf. Published 2019. Accessed July 5, 2023.
19. Lo IK, Burkhart SS, Chan KC, Athanasiou K. Arthroscopic knots: Determining the optimal balance of loop security and knot security. *Arthroscopy* 2004;20:489-502.
20. Pedowitz RA, Nicandri GT, Angelo RL, Ryu RK, Gallagher AG. Objective assessment of knot-tying proficiency with the Fundamentals of Arthroscopic Surgery Training program workstation and knot tester. *Arthroscopy* 2015;31:1872-1879.
21. Faul F, Erdfelder E, Buchner A, Lang AG. Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behav Res Methods* 2009;41:1149-1160.
22. Goyal S, Radi MA, Ramadan IK, Said HG. Arthroscopic skills assessment and use of box model for training in arthroscopic surgery using Sawbones—"FAST" workstation. *SICOT J* 2016;2:37.
23. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)—A metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform* 2009;42:377-381.
24. Tofte JN, Westerlind BO, Martin KD, et al. Knee, shoulder, and Fundamentals of Arthroscopic Surgery Training: Validation of a virtual arthroscopy simulator. *Arthroscopy* 2017;33:641-646.e3.
25. Vaghela KR, Trockels A, Lee J, Akhtar K. Is the virtual reality Fundamentals of Arthroscopic Surgery Training program a valid platform for resident arthroscopy training? *Clin Orthop Relat Res* 2022;480:807-815.
26. Baxter JA, Bhamber NS, Patel RS, Tennent D. The FAST workstation shows construct validity and participant endorsement. *Arthrosc Sports Med Rehabil* 2021;3:e1133-e1140.
27. Wang KC, Bernardoni ED, Cotter EJ, et al. Impact of simulation training on diagnostic arthroscopy performance: A randomized controlled trial. *Arthrosc Sports Med Rehabil* 2019;1:e47-e57.
28. Rahm S, Wieser K, Bauer DE, et al. Efficacy of standardized training on a virtual reality simulator to advance knee and shoulder arthroscopic motor skills. *BMC Musculoskelet Disord* 2018;19:150.
29. Cychosz CC, Tofte JN, Johnson A, Gao Y, Phisitkul P. Fundamentals of Arthroscopic Surgery Training program improves knee arthroscopy simulator performance in arthroscopic trainees. *Arthroscopy* 2018;34:1543-1549.
30. Howells NR, Gill HS, Carr AJ, Price AJ, Rees JL. Transferring simulated arthroscopic skills to the operating theatre: A randomised blinded study. *J Bone Joint Surg Br* 2008;90:494-499.
31. McCluney AL, Vassiliou MC, Kaneva PA, et al. FLS simulator performance predicts intraoperative laparoscopic skill. *Surg Endosc* 2007;21:1991-1995.
32. Steigerwald SN, Park J, Hardy KM, Gillman LM, Vergis AS. Does laparoscopic simulation predict intraoperative performance? A comparison between the Fundamentals of Laparoscopic Surgery and LapVR evaluation metrics. *Am J Surg* 2015;209:34-39.
33. Martin KD, Belmont PJ, Schoenfeld AJ, Todd M, Cameron KL, Owens BD. Arthroscopic basic task performance in shoulder simulator model correlates with similar task performance in cadavers. *J Bone Joint Surg Am* 2011;93:e1271-e1275.
34. Butler A, Olson T, Koehler R, Nicandri G. Do the skills acquired by novice surgeons using anatomic dry models transfer effectively to the task of diagnostic knee arthroscopy performed on cadaveric specimens? *J Bone Joint Surg Am* 2013;95:e15.
35. Henn RF III, Shah N, Warner JJ, Gomoll AH. Shoulder arthroscopy simulator training improves shoulder arthroscopy performance in a cadaveric model. *Arthroscopy* 2013;29:982-985.