

Orthopaedic Resident Arthroscopic Knot-Tying Skills Are Improved Using a Training Program and Knot-Tying Workstation



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Purpose: To quantify an orthopaedic trainee's ability to tie arthroscopic knots before and after a short cadaveric-based arthroscopy training period using a commercially available knot-tying workstation. **Methods:** During a weeklong cadaveric arthroscopic training camp, 15 third- and fourth-year orthopaedic residents were evaluated using a commercially available benchtop knot-tying workstation. At the beginning of the week (baseline), each participant was asked to tie 3 knots of his or her choice backed up by 3 half-hitches using nonabsorbable suture. Successful knots fit the sizer and elongated less than 3 mm after application of a 15-lb load. Afterward, residents watched a video demonstrating a sample knot and were encouraged to practice over the ensuing days. At the end of the week (post-training), residents were asked to tie 3 knots. The time to completion and success of each knot were recorded. To compare baseline and post-training knot success, *t* tests and χ^2 analysis were performed. **Results:** During baseline testing, residents successfully tied 26.7% of their knots (12 of 45 knots) in 352 ± 116 seconds (mean \pm standard deviation). During post-training testing, residents successfully tied 66.7% of knots (30 of 45 knots, $P = .00014$) in 294 ± 63 seconds ($P = .023$), showing significant improvement in the time and ability to tie arthroscopic knots. **Conclusions:** With a short cadaveric-based training period, orthopaedic trainees showed a significant improvement in their ability to tie arthroscopic knots on a commercially available benchtop knot-tying workstation. Given the initial low percentage of successfully tied knots and the limited opportunities for trainees to improve, trainees should be encouraged to practice and improve their skills. **Clinical Relevance:** With training, residents can improve arthroscopic knot-tying abilities, which may allow them to successfully perform this critical task in the operating room.

Arthroscopic knot tying is an essential skill for arthroscopic surgeons to master. Despite the importance of this task, previous research has shown that even expert arthroscopists fail to tie successful knots every time.^{1,2} In addition, increasing surgeon

experience has been associated with lower retear rates after arthroscopic rotator cuff repair, further highlighting the importance of training.³ During residency, in vivo opportunities to perform shoulder arthroscopy and practice arthroscopic knot tying are limited but opportunities for surgical simulation training are increasing.⁴ Cadaveric and other arthroscopic simulation training has proved helpful in improving a trainee's skill.^{5,6} The Fundamentals of Arthroscopic Surgery Training (FAST) Program and its FAST workstation (Sawbones, Vashon Island, WA) were created by the Arthroscopy Association of North America, American Academy of Orthopaedic Surgeons, and American Board of Orthopaedic Surgery to aid in arthroscopic surgery education.

The FAST workstation knot-tying module provides a way to practice knot-tying skills, and the knot tester offers a standardized way to measure success in developing these skills. Previous research has shown that giving residents access to the FAST knot tester does increase the rate of successfully tied knots when the focus

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is knot tying alone,² but it has not been used as a tool to monitor progress in knot-tying skill development. The purpose of this investigation was to quantify an orthopaedic trainee's ability to tie arthroscopic knots before and after a short cadaveric-based arthroscopy training period using a commercially available knot-tying workstation. We hypothesized that a group of trainees would show improvement in knot-tying proficiency with instruction, time, and practice using a commercially available benchtop knot-tying workstation.

Methods

Background

Our institution holds an annual arthroscopy "boot camp" with third- and fourth-year residents from 2 orthopaedic surgery training programs: a university-based academic program and a neighboring community-based program. The weeklong training session involves sharing a cadaveric extremity at a dedicated arthroscopy workstation with another resident. Generally, a third-year resident is paired with a fourth-year resident. Each day, a fresh-frozen cadaveric knee or shoulder is made available at each workstation and residents perform common arthroscopic tasks, including diagnostic arthroscopy, anterior cruciate ligament reconstruction, rotator cuff repair, and shoulder labral repair. In addition, 2 FAST workstations are available to serve as "dry laboratory" stations. The first 2 days of the work week are dedicated to knee arthroscopy, and the final 3 days are dedicated to the shoulder. There is a daily 30-minute morning and afternoon didactic component to prepare the residents for activity that day as the curriculum builds throughout the week. Faculty members are available to walk residents through procedures and provide tips at approximately a 2:1 resident-to-faculty member ratio. In all, 40 hours of focused arthroscopic training is completed.

Study Protocol

Fifteen residents participated in the study. There were 8 third-year and 7 fourth-year residents. Institutional review board approval was obtained prior to beginning the study. We included all third- and fourth-year residents who attended the entire boot camp. We excluded 1 resident, an author of this study (P.T.O.), because he aided in developing the study protocol. In September 2017, eligible residents participating in the boot camp were enrolled. On the first day of boot camp or just prior to its start, residents met with a research assistant. Using No. 2 FiberWire (Arthrex, Naples, FL), residents were instructed to tie 3 consecutive arthroscopic knots on the FAST knot-tying module with the knowledge that each knot would be tested once all were complete. The FAST knot-tying module is one of several modules that is inserted into the FAST workstation. The knot-tying

module provides a mandrel around which knots are tied, and the opaque dome of the workstation allows for an arthroscope to be mounted in a hands-free fashion. For each knot, the research assistant loaded the suture over the mandrel and pulled both limbs out of the arthroscopic cannula placed in the portal. Residents were provided a curved hemostat and arthroscopic knot pusher and were instructed to tie an arthroscopic knot of their choice and back it up with 3 half-hitches on alternating posts.⁷ They were also given verbal and written descriptions of a basic sliding-locking arthroscopic knot. Residents had 2 minutes to familiarize themselves with the module and 10 minutes to complete the knots, with the timer stopping between each knot. They did not receive additional coaching from the research assistant during the exercise.

Knots were then tested on the knot tester in the order in which they were tied using the following, previously described method.² The knot tester is a stand-alone implement that includes 2 tines in close proximity that can be pulled apart using the attached long-handled lever. The handle is connected to a calibrated spring, and a force gauge allows for selecting the amount of tension applied to the knot. The knot tester also includes a conical loop sizer with successive markings, each representing 1 mm of loop lengthening. First, the knot was manually placed on the loop sizer to determine its starting size and whether there was loop security. It was then challenged on the FAST knot tester by pulling 15 lb of tension across the knot for 15 seconds. Finally, it was returned to the loop sizer to determine the degree of lengthening and whether there was knot security. Loop security is defined as the ability to maintain a tight loop as the knot is tied, whereas knot security is the ability to resist loop elongation as a load is applied.⁸ The starting and ending positions of each knot on the sizer were recorded. Loops that did not expand 3 mm or more from the size of the mandrel on which they were tied were considered successful.⁸ The time to completion of each knot was recorded. Residents witnessed their knots being tested by the research assistant once they completed the tying exercise.

At the beginning of the second day of boot camp, the residents were shown a video of a successfully tied sliding-locking knot backed up by 3 half-hitches, with a voiceover describing the technique. Residents were told they would be retested at the workstation at the end of the week, and they were encouraged to practice their knot-tying skills with the FAST knot-tying module and knot tester and during cadaveric rotator cuff and labral repair during the final 3 days of the week. The FAST workstations remained available for residents to practice on. On the fifth, and final, day of boot camp, residents were once again asked to tie 3 knots and had them tested using the protocol described earlier.

Table 1. Knot-Tying Time, Number of Successful Knots, and Reason for Failure

	Baseline	After Training	Difference	<i>P</i> Value
Time to completion, mean \pm SD, seconds	352 \pm 116	294 \pm 63	58	.023
Successful knots, n (%)	12 (26.7)	30 (66.7)	18 (40)	.00014
Reason for knot failure, n (%)				
Lack of loop security	16 (35.6)	5 (11.1)	11 (24.4)	.0005
Lack of knot security	17 (37.8)	10 (22.2)	7 (15.6)	.00051

SD, standard deviation.

An a priori power analysis was performed using G*Power (version 3.1.9.7 [available at <http://www.gpower.hhu.de>]; Heinrich-Heine-University of Dusseldorf, Dusseldorf, Germany).⁹ By use of previously published knot-tying data, an effect size of 0.955 was calculated.² With an α of .05 and power ($1 - \beta$) of 0.8, a target sample size of 15 was calculated. Baseline and post-training means and standard deviations were determined with Microsoft Excel (Microsoft, Redmond, WA). Paired Student *t* tests were used to compare baseline and post-training times; χ^2 analysis was used to compare the rate of successfully tied knots before and after the intervention. Statistical significance was considered at $P < .05$.

Results

Baseline Results

During baseline testing, 45 knots were tied. The mean time to complete all 3 knots was 5 minutes 52 seconds (352 \pm 116 seconds; range, 190-590 seconds) (Table 1); and the mean time to tie each knot ranged from 106.3 to 130.3 seconds and did not vary significantly ($P = .28$). Twelve knots (26.7%) were successful (Table 1). Pre-load failure occurred in 16 knots (35.6%), showing a lack of loop security. An additional 17 knots (37.8%) failed after the load was applied, showing a lack of knot

security. One resident tied all 3 knots successfully, six residents tied 1 or 2 knots successfully, and eight residents failed to tie a single successful knot (Fig 1). No significant difference was noted when comparing the success rates of each of the 3 knots individually ($P = .71$). To compare the average starting and ending positions on the knot sizer, knots that expanded greater than 5 mm when placed on the sizer were excluded because it was no longer possible to measure the degree of lengthening. Ten knots expanded beyond 5 mm prior to supplying a load. For the 35 remaining knots, the average starting position on the conical sizer showed 1.5 mm of loop expansion from the original mandrel around which it was tied. After the load was applied, 18 of 35 knots continued to fit the sizer, with a mean end position showing 2.9 mm of expansion (Table 2).

Post-training Results

During post-training testing, the mean time to complete all 3 knots was 4 minutes 54 seconds (294 \pm 63 seconds; range, 175-360 seconds); this was significantly faster than the time to complete the baseline knots ($P = .023$) (Table 1). Although the mean time to complete each attempt decreased as the exercise progressed (from 105.2 seconds to 96.7 seconds to 91.7 seconds), this decrease was not statistically significant ($P = .62$). The time to complete post-training knot 2

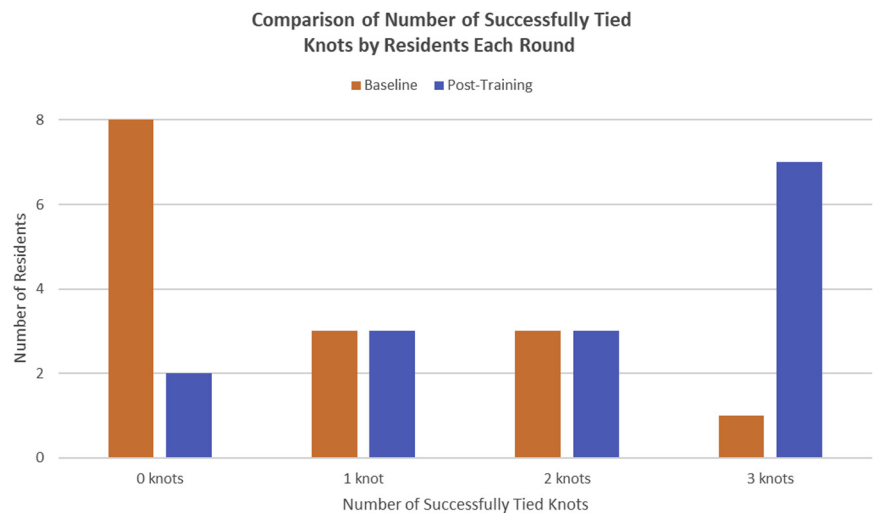


Fig 1. Number of knots successfully tied by residents at baseline and after training.

Table 2. Mean Length of Knot Expansion*

	Baseline	After Training	P Value
Pre-load, mm (n)	1.5 (35)	0.4 (42)	.00051
Post-load, mm (n)	2.9 (18)	1.2 (32)	.000033

n, number tested.

*Measurements were performed on knots continuing to fit the sizer after initial placement (pre-load) and after testing (post-load). The remaining knots had failed by expanding beyond the conical sizer, and no length was able to be measured.

and knot 3 was faster than the time to complete knot 2 during baseline testing ($P = .0080$ and $P = .00069$, respectively), but no other times for a single-knot attempt were found to be significantly different.

Thirty of 45 knots (66.7%) were tied successfully, showing significant improvement in the ability to tie arthroscopic knots ($P = .00014$) (Table 1). Pre-load failure (loop expansion ≥ 3 mm) occurred in 5 knots (11.1%), showing a lack of loop security. An additional 10 knots (22.2%) failed after the load was applied, showing a lack of knot security. Seven residents tied all 3 knots successfully, six tied 1 or 2 knots successfully, and two tied 0 knots successfully (Fig 1). The proportion of successfully tied knots was 66.7% for all attempts. The average starting position on the conical sizer showed 0.4 mm of loop expansion after we excluded knots that expanded greater than 5 mm when placed on the sizer (42 knots included) (Table 2). After the load was applied, 32 knots continued to fit the sizer, with a mean end position showing 1.2 mm of expansion. Both of these positions on the sizer were significantly different from the baseline positions ($P = .00051$ and $P = .000033$, respectively), suggesting that these knots were more secure than the baseline knots.

When we compared residents by postgraduate year, third-year residents tied their baseline knots in 6 minutes 11 seconds (371 seconds) and fourth-year residents took 5 minutes 31 seconds (331 seconds). During post-training testing, third-year residents took 5 minutes 7 seconds (307 seconds) compared with 4 minutes 47 seconds (287 seconds) for fourth-year residents. These differences were not statistically significant ($P = .33$ and $P = .36$, respectively). Third-year residents successfully tied 25% of their baseline knots compared with 28.6% for fourth-year residents. The post-training results showed that 62.5% and 71.4% of knots were successfully tied by third- and fourth-year residents, respectively. These differences were not significant ($P = .79$ and $P = .53$, respectively).

Discussion

After a brief training session, third- and fourth-year residents significantly improved their mean time to tie 3 arthroscopic knots and their percentage of successful knots, confirming our hypothesis. At baseline testing,

third- and fourth-year residents tied a very low percentage of successful knots (26.7%).

Our findings echo the results of previous investigations. Chong et al.¹⁰ showed trainee improvement in knot-tying abilities over a 10-week curriculum, and differences were seen in abilities based on year of training. Gilmer et al.¹¹ reported trainee improvement in knot-tying speed but not peak load to failure or loop security during a weeklong training session. Dedicated time for cadaveric-based training with hands-on instruction allowed for our residents to develop various arthroscopic skills, including knot tying. It is our belief that the knot tester enhanced the resident experience, helping to illustrate that not all arthroscopic knots are equal, because knots were tested immediately in front of the residents. Residents were then permitted to use the dry laboratory workstation throughout the week, and they knew that a post-training test was to occur, which may have served as motivation to improve. The FAST modules provide a means for residents to work on arthroscopic skills in a controlled environment. The knot-tying module allows residents to tie knots in a reproducible fashion, whereas the knot tester subjects the loops to a uniform stress, providing the trainee with objective information. Pedowitz et al.² showed that residents with access to the FAST knot tester were more successful at knot tying than residents who did not use the tester.

After training, Pedowitz et al.² reported an 11% knot failure rate among trainees, which is lower than our rate, but their group contained fourth- and fifth-year residents who received direct feedback and were tested once they felt they were ready to be tested. Our low rate of successful baseline knots may reflect the true rate of how a resident performs. Baseline testing was performed prior to and at the beginning of boot camp, and not all of our residents had recently performed arthroscopic knot tying; therefore, they may have come to testing "cold." We did capture residents going into all fields of orthopaedic surgery, however, so it is possible our low baseline success rate more closely resembles the skills of a general orthopaedic trainee at any given time. Either way, our results provide knowledge for trainees and instructors alike that residents have room for improvement.

Historically, surgical training was performed using an apprenticeship model, in which a resident's experience depended greatly on the instructor, surgical volume, pathology, and degree of direct clinical participation. Determining who had mastered certain surgical skills was often difficult to assess. There has been an increasing focus on surgical simulation training as the technology becomes available, and the American Board of Orthopaedic Surgery and Accreditation Council for Graduate Medical Education have pushed to make it a part of surgical education.¹²⁻¹⁴ The value in this is manifold. Not only does surgical simulation training produce methods to objectively grade trainees and

identify areas for improvement, but it is increasingly necessary in our current environment. New technologies, new surgical techniques, and expanded indications for procedures require surgeons to spend time outside of the operating room honing their skills. In addition, with trainee work-hour restrictions, financial pressure to maximize the value of operating room time, and medicolegal liability, there is an increasing need to produce effective ways to efficiently train residents so that a balance between quality patient care and educational opportunities can be achieved. The cadaveric boot camp and the FAST knot-tying module and knot tester lend themselves well to this goal of providing a standardized way to train surgeons. Including pre- and post-training knot-tying assessment in our boot camp was easy to institute and fit in nicely with our established arthroscopic boot camp curriculum. Given the poor success rate of knot tying in the baseline period, we have shown that this is an important issue to address with trainees and one that can be quickly improved.

Limitations

There are several limitations to our study. First, we did not directly investigate the impact available methods of knot-tying practice had on the development of knot-tying skills. We did not capture the time each resident spent tying knots or using the module and tester, which would have allowed us to better analyze the contribution of the workstation or other methods of training to the observed improvement. We also did not include a control group to test various interventions, such as use of the knot tester. It is likely that arthroscopic knot-tying skills would have improved through time with the cadavers and instructors alone. We had a relatively small sample size of participants and number of knots tied despite having a sufficient number of participants based on the power analysis. Finally, we tested residents during a single week and it remains unclear how progress in their performance relates to achieving surgical proficiency, if their newly acquired skills will carry forth, and how their performance will translate in vivo.

Conclusions

With a short cadaveric-based training period, orthopaedic trainees showed a significant improvement in their ability to tie arthroscopic knots on a commercially available benchtop knot-tying workstation. Given the initial low percentage of successfully tied knots and the limited opportunities for trainees to improve, trainees should be encouraged to practice and improve their skills.

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