Orthopaedic Residents Improve Confidence and Knot-Tying Speed With a Skills Course

Brian B. Gilmer, M.D., Dolores M. Guerrero, M.S., Nathan W. Coleman, M.D., Aaron M. Chamberlain, M.D., and Winston J. Warme, M.D.

Purpose: To determine the effect of a knot-tying module, within an arthroscopic training course, on resident speed, resident confidence, and biomechanical quality of arthroscopically tied knots. **Methods:** Sixty-four participants (8 postgraduate year [PGY]−3 and 8 PGY-4 orthopaedic residents annually for 4 years) were enrolled in a 5-day training course, which included a daily knot-tying module. Self-assessed confidence was obtained by pre-course (day 1) and post-course (day 5) questionnaire. Each participant tied 5 sequential knots using an arthroscopic knot-tying station. Time per knot was recorded in seconds. Knots were later preloaded, cycled, and tested for peak load to failure and displacement change. Mean peak load to failure, displacement change, speed, and confidence were compared before and after training. **Results:** The mean time to complete 5 knots was significantly faster after training (12.8 minutes before the course [day 1] *v* 9.39 minutes after the course [day 5]) ($P < .0001$). Confidence improved from pre-course (mean, 3.3) to post-course (mean, 7.8) questionnaires ($P < .0001$). No statistically significant difference was found between peak force for pre-course (mean, 136 N) and post-course (mean, 138 N) knots ($P = .076$). No statistically significant difference was detected in mean displacement change (mean, 3.51 mm before the course *v* 3.57 mm after the course) ($P = .61$). Comparison of PGY-3 and PGY-4 residents was significant only for a higher pre-course confidence in PGY-4 residents ($P = .02$). **Conclusions:** Participation in an arthroscopic knot-tying module improves resident speed and confidence in tying arthroscopic knots. Our data did not show a significant change in peak load to failure or loop security with training. These findings suggest that participation in a knot-tying module improves efficiency regarding arthroscopic knot tying by residents. **Clinical Relevance:** Residents who practice arthroscopic knot tying 5 days per year as part of an arthroscopic training course may be more efficient in the operating room.

Developing adequate arthroscopic skills in the era of resident training hour restrictions is challenging. Resident work hour restrictions and a growing emphasis on efficiency and cost reduction in the operating room have limited the surgical experience of orthopaedic residents trained under the traditional apprenticeship model.[1-5] Therefore interest in skills courses and simulation training as a mechanism for teaching and acquiring arthroscopic skills has increased.[6-14]

The American Academy of Orthopaedic Surgeons has recently developed and released a 3-day course based on a combination of didactic instruction, demonstration, and hands-on laboratory participation in response to the growing demand for training outside of the traditional postgraduate training model. Our institution designed and implemented a similar course of 5 days' duration beginning in 2007. Currently, the effectiveness of these courses in improving resident performance in the operating room relative to the investment of time and capital involved in implementing such courses is incompletely understood.

The purpose of this study was to determine the effect of a knot-tying module, within an arthroscopic training course, on resident speed, resident confidence, and biomechanical quality of arthroscopically tied knots. We hypothesized that focused instruction would lead to improvement in confidence, speed, and strength of residents' arthroscopically tied knots.

From the Department of Orthopaedics and Sports Medicine, University of Washington (B.B.G., N.W.C., A.M.C., W.J.W.), Seattle, Washington; and the Department of Biomedical Research, Mammoth Orthopedic Institute (D.M.G.), Mammoth Lakes, California, U.S.A.

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Address correspondence to Brian B. Gilmer, M.D., Mammoth Orthopedic Institute, 85 Sierra Park Rd, PO Box 660, Mammoth Lakes, CA 93546, U.S.A. E-mail: bbgilmer@gmail.com

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Methods

Study Group

Residents were prospectively enrolled, and the research protocol was examined by an institutional review board and given an exemption. Each resident was issued a unique identifier that he or she used to submit questionnaires and knots. Both the research team and instructors were blinded to each resident's identity.

The inclusion criteria for our study were all postgraduate year (PGY)−3 and PGY-4 residents at an academic Accreditation Council for Graduate Medical Education−accredited training institution. The exclusion criteria were participants who were unable to complete the course and participants who were unable to return to the course the following year. No residents were excluded by these criteria. Thus in total 64 residents were enrolled: 32 PGY-3 and 32 PGY-4 residents.

Arthroscopic Knot-Tying Module

Sixty-four residents (8 PGY-3 and 8 PGY-4 residents annually for 4 years) participated in a 5-day comprehensive, intensive arthroscopic skills course that included a module teaching arthroscopic knot-tying technique. Residents who completed the course as PGY-3 participants repeated the course as PGY-4 participants. The course curriculum was unchanged from year to year and was developed to provide a broad exposure to the fundamentals of knee and shoulder arthroscopy including instruction on patient positioning, portal placement, triangulation exercises, diagnostic arthroscopy, and specific procedures including subacromial decompression, biceps tenotomy, labral repair, rotator cuff repair, meniscal debridement and repair, and anterior cruciate ligament reconstruction. A full syllabus is available for review as additional material (Appendix 1, available at www.arthroscopyjournal.org). Each year, the same 8 residents who completed the course as PGY-3 participants repeated the course the following year as PGY-4 participants.

Regarding the arthroscopic knot-tying module, the senior author (W.J.W.) demonstrated the SMC knot each morning for each day of the course (day 1 through 5).[15] With the assistance of board-certified attending surgeons with fellowship training in sports medicine or shoulder and elbow surgery, residents viewed step-by-step demonstrations and underwent supervised knot-tying practice sessions as individuals and in small groups for 30 minutes each day. In addition to scheduled instruction, residents were provided unlimited access to arthroscopic knot-tying stations, arthroscopic cannulas, a standard ring-type arthroscopic knot pusher, and high-strength polyblend arthroscopic suture material (FiberWire; Arthrex, Naples, FL).

Assessment of Outcomes

Before beginning the course, all participants were provided pre-course (day 1) surveys consisting of a single question that assessed their confidence independently tying arthroscopic knots for clinical use. Values were assessed on a 10-point Likert scale ranging from 0 (not at all comfortable) to 10 (extremely comfortable) and recorded for later analysis.

As a result of their clinical postgraduate training, residents had familiarity with the SMC knot.[15] Residents were given the instruction to tie this base knot to the best of their ability and finish the knot with 3 reversed half-hitches on alternating posts (RHAPs).

Before the first module (day 1), participants sequentially tied 5 knots on an arthroscopic tying simulator through a standard 8-mm arthroscopic cannula using a ring knot pusher and high-strength polyblend suture material (FiberWire) around a wooden dowel of a fixed diameter (24 mm) (Fig 1). Each test was timed from the beginning of tying the first knot through completion of the fifth knot and therefore included the time to reload the new suture onto the knot pusher between knots. Pre-course knots were collected, and time values were recorded in minutes and seconds.

The same testing protocol was then repeated after completion of the knot-tying module (day 5) with suture from the same lot and batch, and post-course knots were collected and time values recorded in minutes and seconds. After completion of the course, residents repeated the same survey assessing their confidence independently tying arthroscopic knots for clinical use.

Mechanical Testing Protocol

Knots were tested and analyzed annually after completion of the course with a materials testing machine (ElectroForce 3400; Bose, Eden Prairie, MN) using a 500-N load cell as described by Lo et al.[16,17] Suture tails of the tied loops of all knots were cut using the same suture cutter to leave a standardized 3-mm tail. Each knot was preloaded to 5 N. Loop diameter was then measured with digital calipers and recorded in millimeters. Each knot was cycled under a 5-N load to precondition it for 20 cycles. The knot was then tested to failure in displacement mode with values recorded for peak force (in Newtons) obtained during testing and displacement change (in millimeters) before failure. Because knots were tied by trainees, we elected to report change in displacement rather than loop diameter as initially described by Lo et al.[16,17] to avoid the assumption that all knots were initially tied to the same loop diameter, which could introduce measurement error, and to simplify reporting of results.

Statistical Analysis

Statistical analysis was performed using a linear mixed-effects model (R programming language

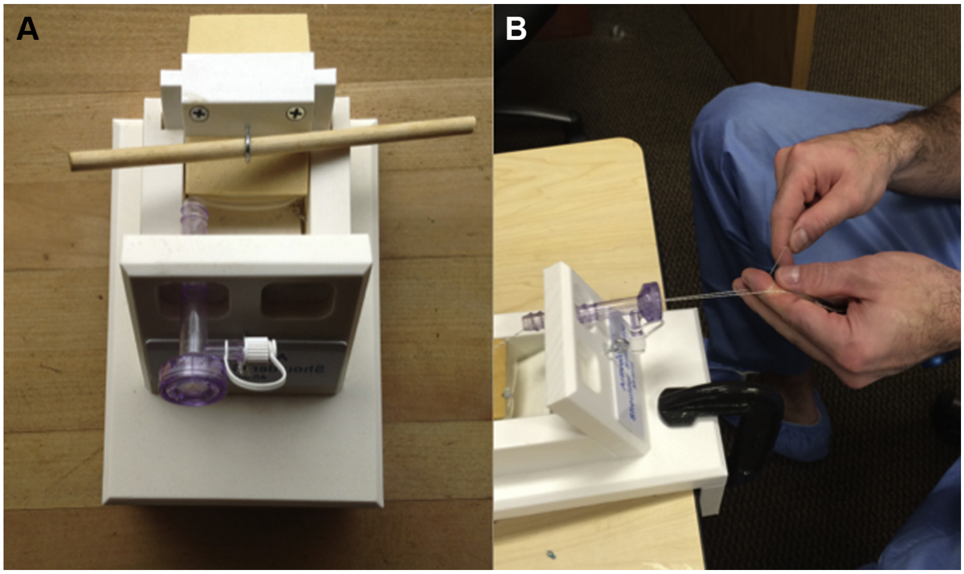

Fig 1. (A) Example of arthroscopic knot-tying station used for pre-course and post-course testing, as well as during instruction and individual practice. The station consists of a wooden dowel of fixed diameter and an 8-mm arthroscopic cannula. Not shown are the high-strength polyblend suture and standard ring knot pusher. (B) Example of a resident tying an SMC knot using the practice station.

[version R 3.0.2], nlme: Linear and Nonlinear Mixed Effects Models, and R package [version 3.1-109]; R Core Team, Vienna, Austria) to compare pre-course and post-course values for all variables: peak force (in Newtons), displacement change (in millimeters), and speed (in minutes). On the basis of preliminary analysis of the first-year participants' data, we assumed a large effect size regarding the primary outcome measure (speed). With a large effect size (Cohen $d = 0.9$), significance established as 5% ($\alpha = .05$), and power of 80%, 58 participants were needed for enrollment. Sixty-four residents were ultimately selected for inclusion in the study. Post hoc power analysis was performed and confirmed the sample size. Secondary analysis was performed to detect interaction between first-year (PGY-3) and second-year (PGY-4) participants because, presumably, previous course participation could alter results.

Results

Time to Complete 5 Knots

The mean pre-course time to complete 5 knots was 12.8 minutes, and the median pre-course time was 11.3 minutes (interquartile range, 9.8 to 15.3 minutes). The mean post-course time to complete 5 knots was 9.4 minutes, and the median post-course time was 8.9 minutes (interquartile range, 7.7 to 10.7 minutes). The improvement in the time between the mean pre-course and post-course values reached statistical significance ($P < .0001$) (Fig 2).

Confidence

The mean pre-course confidence rating was 3.3, and the median pre-course confidence rating was 2.9 (interquartile range, 1 to 5). The mean post-course confidence rating was 7.83, and the median post-course confidence rating was 8 (interquartile range, 7 to 9). The higher mean post-course confidence values were statistically significant ($P < .0001$) (Fig 3).

Mean Peak Force and Displacement Change

Mean peak force for pre-course knots was 136 N, and median peak force was 128 N (interquartile range, 61.8 to 190). Mean peak force for post-course knots was 138 N, and median peak force was 134 N (interquartile

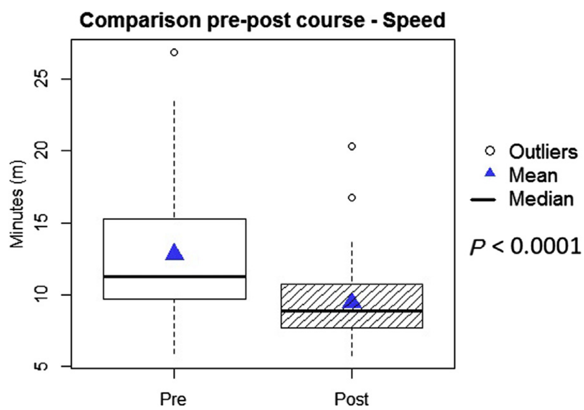

Fig 2. Results of time to complete 5 arthroscopic knots before and after training (in minutes). Boxes represent 25% to 75% interquartile levels, and dashed lines represent ranges. Circles represent outliers whose value lies outside the interquartile range but were still included in the analysis. There is a statistically significant difference between pre-course (mean, 12.8 minutes; median, 11.3 minutes) and post-course (mean, 9.4 minutes; median, 8.9 minutes) values ($P < .0001$), representing mean improvement in time of 3.4 minutes after training.

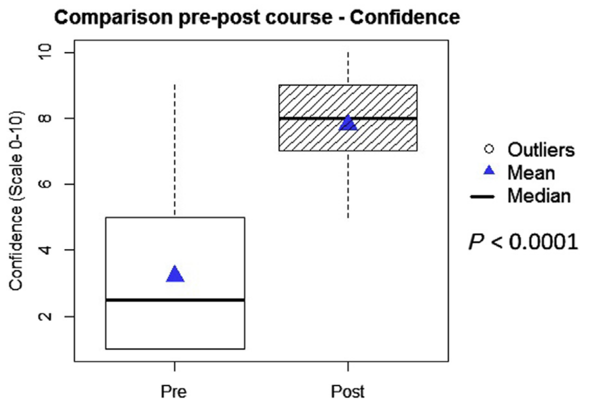

Fig 3. Results of confidence before and after training. Boxes represent 25% to 75% interquartile levels, and dashed lines represent ranges. There is a statistically significant difference between pre-course (mean, 3.3; median, 2.9) and post-course (mean, 7.8; median, 8) values ($P < .0001$), representing mean improvement in confidence of 4.5 units after training.

range, 84.2 to 182). The difference between values was not statistically significant ($P = .076$).

The mean displacement change for pre-course knots was 3.51 mm, and the median displacement change was 3.37 mm (interquartile range, 2.13 to 4.54). The mean displacement change for post-course knots was 3.57 mm, and the median displacement change was 3.21 mm (interquartile range, 2.28 to 4.8). There was no statistically significant difference in mean displacement change values between pre-course and post-course knots ($P = .61$) (Fig 4).

First-Year (PGY-3) Versus Second-Year (PGY-4) Participants

A separate analysis was performed to determine whether there was a difference between first- and second-year participants. There was no statistically significant difference in mean peak force ($P = .64$), mean displacement change ($P = .32$), or mean speed ($P = .25$). A statistically significant mean difference was detected in confidence, with second-year residents (PGY-4) reporting higher pre-course confidence values (mean, 4.1; median, 2) than first-year residents (mean, 2.6; median, 4) ($P = .02$) (Fig 5).

Discussion

Our primary finding is that residents' arthroscopic knot-tying speed increased without a change in knot strength after participation in a 5-day arthroscopic training course that included focused training on arthroscopic knot tying. Our results are similar to those of Henn et al.,[9] who studied arthroscopic skills performance after simulator training in medical students. They found significant improvements in time to complete arthroscopic tasks compared with controls, without changes in subjective scores of task completion.

Pearson et al.[18] compared structured training methods for intracorporeal knot tying and found that all structured programs including live demonstration resulted in improved speed in tying an intracorporeal knot compared with an unstructured program with video demonstration only. In our study, live demonstration with small-group instruction and individual practice resulted in a statistically significant improvement in time to complete 5 arthroscopic knots, without a change in mechanical knot characteristics.

Rosser et al.[19] evaluated the effects of a 2.5-day training program on laparoscopic skills and intracorporeal suturing and shown that, on completion of such a course, residents achieved a comparable level of speed in knot tying to attending surgeons. Their study did not evaluate

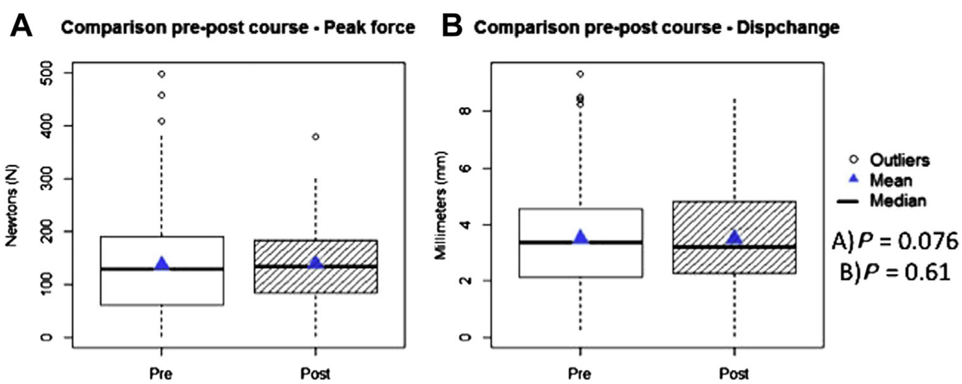

Fig 4. Results of mechanical testing of resident arthroscopic knots before and after training. Boxes represent 25% to 75% interquartile levels, and dashed lines represent ranges. Circles represent outliers whose value lies outside the interquartile range but were still included in the analysis. (A) Comparison between pre-course and post-course peak force in Newtons. There is no statistically significant difference between pre-course (mean, 136 N; median, 128 N) and post-course (mean, 138 N; median, 134 N) values ($P = .076$). (B) Comparison between pre-course and post-course displacement change (Dispchange) in millimeters. There is no statistically significant difference between pre-course (mean, 3.51 mm; median, 3.37 mm) and post-course (mean, 3.57 mm; median, 3.21 mm) values ($P = .61$).

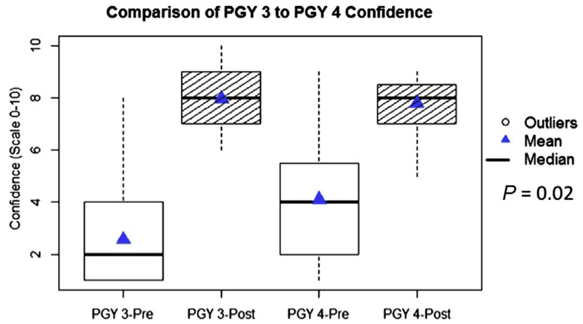

Fig 5. Relation between pre-course and post-course confidence between first-year (postgraduate year [PGY]−3) and second-year (PGY-4) participants. Boxes represent 25% to 75% interquartile levels, and dashed lines represent ranges. There is a statistically significant difference in mean pre-course confidence between first- and second-year residents ($P = .02$), with second-year residents reporting higher pre-course confidence values.

the quality of knots tied. Our study evaluated both speed of knot tying and mechanical properties of residents' arthroscopically tied knots and determined that improvements in speed did not result in statistically significant differences in knot peak force to failure or loop security. Our results support the existing literature that participation in a hands-on skills training program can improve efficiency in arthroscopic knot tying.

The only difference between PGY-3 and PGY-4 participants was increased pre-course confidence in the PGY-4 group. This would be expected because those residents had previously completed the same course as PGY-3 participants. Surprisingly, there was no evidence of a maintained improvement in speed in residents who had previously completed the course 1 year earlier. Our findings are in contrast to those of previous studies showing that a higher level of surgeon experience resulted in improved efficiency in a simulator model.[10,11,19]

Jackson et al.[20] evaluated learning and retaining simulated arthroscopic meniscal repair skills and found no loss of skill despite a 6-month interruption in task performance. This is also in contrast to our findings that improvements in speed were not maintained 1 year after completion of the course. It is possible that residents' acquired improvements are lost somewhere between 6 months and 1 year, assuming that no opportunity is provided to practice during that interval.

Our finding of no change in knot strength or loop security before or after training when tying the SMC knot is interesting. Multiple biomechanical studies have shown that the SMC knot with 3 RHAPs is secure, strong, and comparable with other arthroscopic sliding knots.[17,21-23] Baumgarten and Wright[24] evaluated the ease of tying 10 different knot types by orthopaedic residents of various levels of training. They found the SMC knot to be only moderately easy to learn (6 of 10). We did not specifically evaluate residents' subjective sense of ease tying the SMC knot with RHAPs.

Using a similar testing model, Lo et al.[16,17] found an average load to failure of 96.4 N for the SMC knot with RHAPs tied by an experienced surgeon. Our results were similar; mean load to failure for residents' knots was 136 N before the course and 138 N after the course. These findings may suggest that the SMC knot is a good choice for teaching residents because it has excellent security and strength even in less experienced hands.

Our findings are interesting in light of recent evidence from Hanypsiak et al.[25] showing that, among expert arthroscopists, surgeons were unable to tie 5 consecutive knots of the same type consistently and that, regarding both ultimate load and clinical failure load, surgeons with less than 10 years in practice were able to tie knots more consistently than surgeons with more than 10 years. It is possible that more structured, formal training programs in younger surgeons have led to higher consistency and improved biomechanical properties of arthroscopically tied knots; however, this assumption lies outside the scope of our results.

Limitations

One limitation of our study is that participants were orthopaedic residents who participated in the course in consecutive years. An a priori power analysis was not performed. Analysis was performed to detect differences between first-year (PGY-3) and second-year (PGY-4) residents, and no statistically significant difference was detected for any variable except pre-course confidence; however, this analysis may be limited by a smaller sample size (32 residents in each PGY group). The sample size did not allow further stratification by expressed interest in arthroscopic surgery, resident case load, number of sports medicine rotations, or depth of arthroscopic experience.

The participants were third- and fourth-year orthopaedic residents, and our results may not apply to residents at different levels of training. Because all members of the postgraduate orthopaedic training program participate in the course annually and we did not want to deprive any participants of the presumed benefits of the training course, it was not practical to designate a control group for the study.

Residents were familiar with the SMC knot from their clinical training but did not have it demonstrated before pre-course testing. Thus it is possible that knots tied in pre-course testing were not properly performed SMC knots. Our finding that mean peak force and mean displacement change were not significantly different between pre-course and post-course testing suggests that the knots were likely similar in their technique, but we cannot be certain of this. In addition, we did not assess other knot configurations because the SMC is the preferred clinical knot of the senior author; therefore our findings may not be applicable to other knot types. Finally, it is unclear how performance in an arthroscopic course would correlate to performance in the operating room.

Conclusions

Participation in an arthroscopic skills course improves resident speed and confidence in tying arthroscopic knots. Our data did not show a significant change in peak load to failure or loop security with training. These findings suggest that participation in a 5-day arthroscopic training course improves efficiency regarding arthroscopic knot tying by residents.

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Appendix 1. Arthroscopy Basics Course—Schedule and Curriculum

Monday (day 1)
- 7-8:30 AM
  - Laboratory introduction and history of course
  - Obtain consent forms
  - Pre-course evaluation
  - Pre-course knot testing
- 8:30-9 AM
  - Didactic lecture—**Shoulder Arthroscopy 1: Basics**
    - Patient positioning
    - Portal placement
    - Diagnostic shoulder arthroscopy demonstration
      - Glenohumeral joint
      - Subacromial space
- 9-9:15 AM
  - Live demonstration
- 9:15 AM to noon
  - Hands-on cadaveric skills laboratory
- Noon to 1 PM
  - Lunch
- 1-2 PM
  - Didactic lecture—**Shoulder Arthroscopy 2: Basic Skills**
    - Intra-articular debridement
    - Biceps tenotomy
    - Subacromial decompression
    - Distal clavicle excision
- 2-2:30 PM
  - Live demonstration—subacromial decompression, distal clavicle excision, biceps tenotomy
- 2:30-5 PM
  - Hands-on cadaveric skills laboratory
- 5-6 PM
  - Open session
  - Open dissection
  - Self-directed knot-tying practice
  - Faculty discussion and review
- 6 PM
  - Adjourn

Tuesday (day 2)
- 7:50-8 AM
  - Review and discussion of day 1
- 8-8:30 AM
  - Knot instruction and practice in dry laboratory
- 8:30-9 AM
  - Didactic lecture—**Shoulder Arthroscopy 3: Bankart Repair**
    - Beach-chair position
    - Lateral decubitus
- 9-9:15 AM
  - Live demonstration—anterior inferior labrum, Bankart repair
- 9:15 AM to noon
  - Hands-on cadaveric skills laboratory
- Noon to 1 PM
  - Lunch
- 1-2 PM
  - Didactic lecture—**Shoulder Arthroscopy 4: Rotator Cuff Repair Basics**
- 2-2:30 PM
  - Live demonstration—single-row rotator cuff repair
- 2:30-5 PM
  - Hands-on cadaveric skills laboratory
- 5-6 PM
  - Open session
    - Open dissection
    - Self-directed knot-tying practice
    - Faculty discussion and review

Appendix 1. (*Continued*)

- 6 PM
  - Adjourn

Wednesday (day 3)
- 7:50-8 AM
  - Review and discussion of day 2
- 8-8:30 AM
  - Knot instruction and practice in dry laboratory
- 8:30-9 AM
  - Didactic lecture—**Shoulder Arthroscopy 5: Advanced Techniques**
- 9-9:15 AM
  - Live demonstration—biceps tenodesis, coracoclavicular reconstruction
- 9:15 AM to noon
  - Hands-on cadaveric skills laboratory
- Noon to 1 PM
  - Lunch
- 1-2 PM
  - Didactic lecture—**Shoulder Arthroscopy 6: Advanced Techniques**
- 2-2:30 PM
  - Live demonstration—double-row rotator cuff repair, SLAP repair, posterior labrum
- 2:30-5 PM
  - Hands-on cadaveric skills laboratory
- 5-6 PM
  - Open session
    - Open dissection
    - Self-directed knot-tying practice
    - Faculty discussion and review
- 6 PM
  - Adjourn

Thursday (day 4)
- 7:50-8 AM
  - Review and discussion of day 3
- 8-8:30 AM
  - Knot instruction and practice in dry laboratory
- 8:30-9 AM
  - Didactic lecture—**Knee Arthroscopy 1: Basics**
    - Patient positioning
    - Portal placement
    - Diagnostic arthroscopy
    - Accessory portals—Gillquist, posteromedial
- 9-9:15 AM
  - Live demonstration—diagnostic arthroscopy
- 9:15 AM to noon
  - Hands-on cadaveric skills laboratory
- Noon to 1 PM
  - Lunch
- 1-2 PM
  - Didactic lecture—**Knee Arthroscopy 2: Meniscus**
- 2-2:30 PM
  - Live demonstration
    - Partial meniscectomy—medial and lateral
    - Meniscal repair—inside out, outside in, all inside
- 2:30-5 PM
  - Hands-on cadaveric skills laboratory
- 5-6 PM
  - Open session
  - Open dissection
  - Self-directed knot-tying practice
  - Faculty discussion and review
- 6 PM
  - Adjourn

Appendix 1. (*Continued*)

Friday (day 5)
- 6:50-7 AM
  - Review and discussion of day 4
- 7-7:30 AM
  - Knot instruction and practice in dry laboratory
- 8:30-9 AM
  - Didactic lecture—**Knee Arthroscopy 3: Anterior Cruciate Ligament**
- 9-9:30 AM
  - Live demonstration
    - Graft harvest—patellar tendon, hamstrings
    - Anterior cruciate ligament reconstruction
- 9:30 AM to noon
  - Hands-on cadaveric skills laboratory
- Noon to 1 PM
  - Lunch
- 1-2 PM
  - Didactic lecture—**Knee Arthroscopy 4: Collateral Ligaments**
- 2-2:30 PM
  - Live demonstration
    - Posterolateral corner dissection
    - Posterolateral corner reconstruction
- 2:30-5 PM
  - Hands-on cadaveric skills laboratory
- 5-5:30 PM
  - Open session
    - Open dissection
- 6-7 PM
  - Closing
  - Post-course surveys
  - Knot-tying post-test
- 7 PM
  - Adjourn