Does Arthroscopic Simulation Training Improve Triangulation and Probing Skills? A Randomized Controlled Trial☆

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OBJECTIVE: To determine the effectiveness of simulator training on basic arthroscopic skills utilizing a novel, low-cost arthroscopic triangulation training system.

DESIGN: A randomized controlled trial of subjects without prior arthroscopy training was conducted, with participants randomized to receive either a fixed protocol of simulation training on a triangulation simulation model (30 minutes of training for 4 consecutive days), or no training. On Days 1 and 5, all participants were evaluated on 3 simulated arthroscopic tasks by an independent observer. Variables analyzed included how many times portals were changed, the time it took to complete the tasks, and the task completion rate.

SETTING: Arthrex Inc., Naples, FL.

PARTICIPANTS: Thirty-six participants (92% male, average 28 ± 5 years) with no prior arthroscopy training were randomized into 2 groups, with 17 in the training group (T) and 19 in the no-training group (NT).

RESULTS: On Day 1, there was no difference in rate of task completion between the T group and NT groups (41% versus 53%, p = 0.52). On Day 5, significantly more participants in the T group completed all tasks compared to the NT group (100% versus 63%, p = 0.008). Participants in the T group had significantly improved task completion times on Day 5 versus Day 1 ($p < 0.05$). Participants in the NT group had a significantly improved task completion time for Task 1 on Day 5 versus Day 1 (p = 0.037); no differences were found for Tasks 2 or 3. On Day 5, participants in the T group required significantly fewer portal changes compared to the NT group (2.35 ± 2.29 versus 6.95 ± 8.55, p = 0.039).

CONCLUSIONS: Simulation training on a simple, low-cost arthroscopic triangulation training system resulted in an overall improvement in arthroscopic probing and triangulation skills within 1 week of training, with significantly decreased task completion times and increased efficiency of movement. (J Surg Ed 76:1131−1138. © 2019 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

KEY WORDS: Arthroscopy, Simulation, Arthroscopic Surgery, Orthopaedic Surgery, Residency Triangulation, Surgical Simulation

COMPETENCIES: Patient Care, Interpersonal and Communication Skills, Practice-Based Learning and Improvement

ABBREVIATIONS: T, Training Group; NT, No-training Group

INTRODUCTION

The dexterity skills required for performing safe, effective, and efficient arthroscopic operations are demanding. Among a variety of factors, resident work-hour restrictions have forced residents to utilize alternative strategies to develop surgical skills. One such strategy involves the use of surgical simulation training models, with available models replicating a variety of open and arthroscopic surgical techniques. The development of arthroscopic simulation models, in particular, has evolved from first-generation dry models to virtual-reality models with haptic feedback capabilities.[1-38] Several of the higher-end, virtual models have become available

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for resident use at arthroscopic skills courses around the country, but remain cost-prohibitive for incorporation into the vast majority of orthopaedic training programs. Thus, trainees may only be exposed to such simulator models while at these courses, with no ability to incorporate them into their regular training routines at their residency programs. Several lower-cost "make-it-yourself" arthroscopic training models have been described in the literature,[39-42] but these rely on the program's willingness to purchase the equipment necessary to construct the model, and further, require one to physically assemble the model, which may allow for inconsistency between different users, and certainly, adds additional time to the training regimen. A low-cost, portable arthroscopic training model may provide residents with an ability to learn and practice basic arthroscopic skills without being over-burdening or prohibitively costly.

Therefore, the purpose of this pilot study was to determine the effectiveness of arthroscopic simulator training on basic arthroscopic triangulation and probing skills utilizing a novel, low-cost arthroscopic triangulation training system. The authors hypothesized that subjects undergoing a standardized simulator training program would perform better at triangulation and probing skills compared to subjects not undergoing a standardized simulator training program.

MATERIALS AND METHODS

A randomized controlled trial of 36 subjects without prior arthroscopic skills training was conducted. This study was conducted as a proof-of-concept pilot study as the first step in assessing the utility of the arthroscopic triangulation training system. At the onset of the study, all participants completed a pre-study survey, which included questions on demographic information, hand dominance, prior or current sports participation, and prior or current video game participation. All participants received a demonstration of how to use the arthroscopic triangulation training system (ArthroBox, Arthrex Inc., Naples, FL), (Fig. 1). This system is an arthroscopic triangulation training system that includes a fully integrated arthroscopy video camera, scope and LED light source that plug into a laptop as a monitor with a modular, enclosed fixture to practice arthroscopic surgical skills and techniques.

All participants were then were randomized to receive either no training or a fixed protocol of simulation training on the simulation model. A computer-generated randomization list was utilized to randomly assign subjects to training group (T) or no-training group (NT). The randomization allocation sequence was concealed from the researchers in sequentially numbered opaque sealed and stapled envelopes, impermeable to intense light. Envelopes were opened sequentially only after participants completed the pre-study survey and demonstration session.

The training protocol consisted of 30 minutes of training for 4 consecutive days. On Day 1 and Day 5, all participants were evaluated on 3 simulated arthroscopic tasks (Fig. 2). Variables analyzed included which hand the camera was held, which portals the participant initially used, how many times portals were changed, the time it took to complete the tasks, and the task completion rate. An independent observer who was blinded to randomization status assessed performance for all participants.

Descriptive statistics were used for demographic variable analysis and for several evaluation scores, when appropriate. Statistical analysis was conducted utilizing Student's t tests, with $p < 0.05$ denoting statistical significance (OriginPro 9 software, Northampton, MA). A blinded statistician performed all statistical analyses.

RESULTS

Thirty-six subjects (92% male) with an average age of 28 $\pm$ 5 years participated in the study. The subjects were randomized into 2 groups with 17 in the T group and 19 in the NT group. On Day 1, 7 of 17 participants (41%) in the T group completed all tasks, while 10 of 19

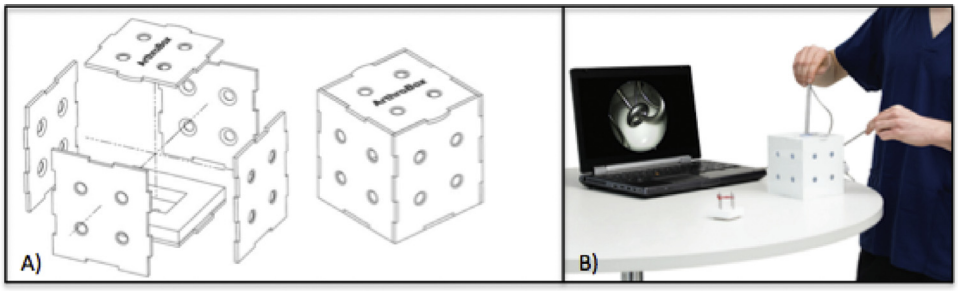

FIGURE 1. (A) Schematic of ArthroBox (Arthrex Inc., Naples, FL) setup; (B) photograph demonstrating complete setup of ArthroBox with scope and LED connected to laptop computer.

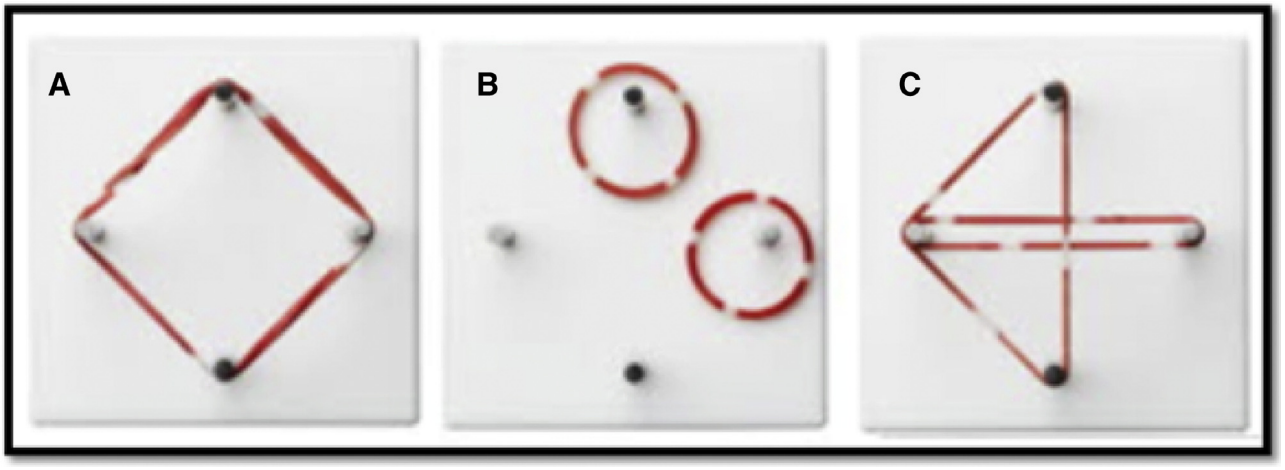

FIGURE 2. Tasks performed on Day 1 and Day 5, including forming a square with a single rubber band (A), removing 2 rubber bands from the jig (B), and constructing an arrow with 2 rubber bands (C).

participants (53%) in the NT group completed all tasks ($p = 0.52$). On Day 5, significantly more participants in the T group completed all tasks on Day 5 compared to the NT group (17 of 17 (100%) versus 12 of 19 (63%), $p = 0.008$, Fig. 3). On Day 1, participants in the T group required slightly more time to complete the tasks compared to the NT group, though this was not significant (average 9.8 ± 5.7 versus 7.5 ± 3.1 minutes, $p = 0.3$), whereas on Day 5, participants in the T group required less time to complete the tasks (average 3.6 ± 2.1 versus 5.7 ± 3.6 minutes, $p = 0.053$). Participants in the T group had significantly improved task completion times for all 3 tasks on Day 5 versus Day 1 (Fig. 4, Table 1). Participants in the NT group had a significantly improved task completion time for Task 1 on Day 5 versus Day 1; no differences were found for Tasks 2 and 3 (Table 1). On Day 5, participants in the T group required significantly fewer portal changes compared to the NT group (2.35 ± 2.29 versus 6.95 ± 8.55, $p = 0.039$).

There were no significant correlations between sports participation and/or video game participation and task performance in either group.

DISCUSSION

The principle findings of this pilot study suggest that simulation training on a simple, low-cost arthroscopic

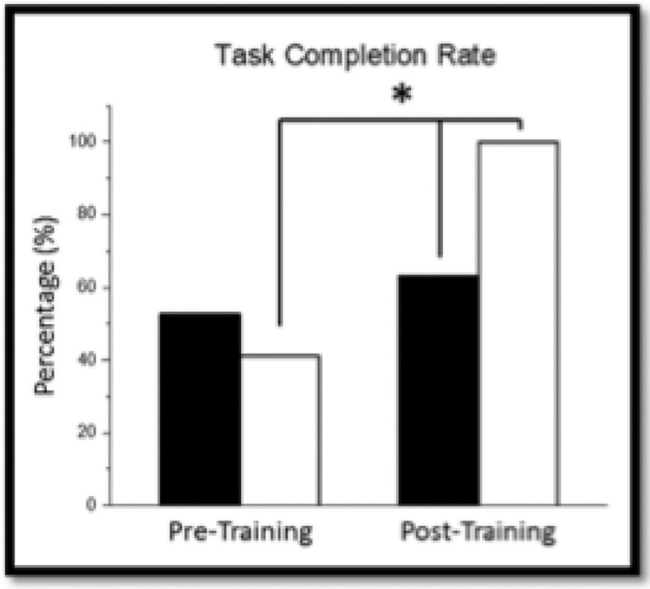

FIGURE 3. Task completion rate for Tasks 1-3. On Day 5, significantly more participants in the T group completed all tasks on Day 5 compared to the NT group (17/17 (100%) versus 12/19 (63%), P=0.008).

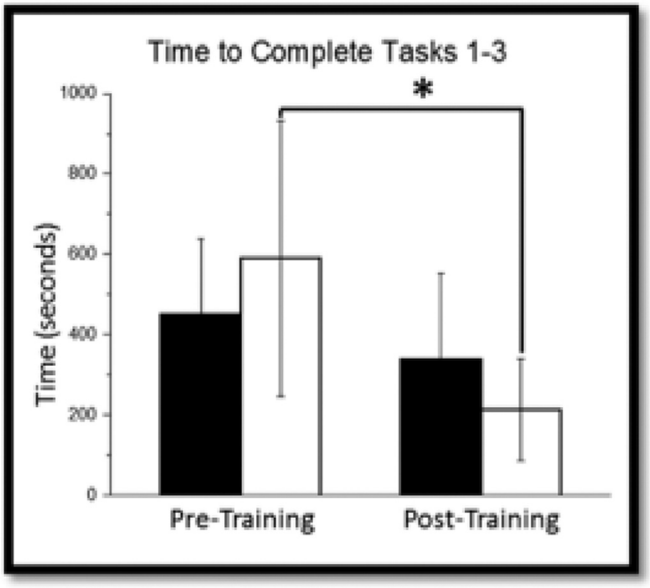

FIGURE 4. Task completion time for Tasks 1 to 3. Participants in the T group had significantly improved task completion times for all 3 tasks on Day 5 versus Day 1.

triangulation training system results in an overall improvement in arthroscopic probing and triangulation skills within 1 week of training, with significantly decreased task completion times and significantly increased efficiency of movement.

In July of 2013, the Accreditation Council for Graduate Medical Education implemented new training requirements for postgraduate year 1 (PGY-1) orthopaedic surgery residents as mandated by the American Board of Orthopaedic Surgery and Residency Review Committee for orthopaedic surgery.[43] One component of the new training requirements was the introduction of mandatory surgical skills training and education. Since that mandate, the rate of development of different simulation models for surgical skill development has grown exponentially. Similarly, discussion and debate over which simulation models are the most effective has also increased. As mentioned previously, the development of arthroscopic simulation models, in particular, has evolved from first-generation dry models to virtual-reality models with haptic feedback capabilities. Several of the higher-end, virtual models have become available for resident use at arthroscopic skills courses and various conferences around the country, but remain cost-prohibitive for incorporation into the vast majority of orthopaedic training programs. Further, the current lack of concrete data proving the translatability of arthroscopic simulation training models to actual operating-room performance makes it difficult to justify purchasing the models.

When considering the utility of an arthroscopic simulator model, it is critical to evaluate the goals of the trainee, and the ability of the simulator to help the trainee achieve those goals. Several basic skills, such as portal placement and fluid management, are vital to performing an effective arthroscopic procedure, but essentially are never even practiced even on the most advanced arthroscopic simulation models, as portals are pre-established, and fluids are

TABLE 1. Time (seconds) to complete each task

	NT Group (*N* = 19)	T Group (*N* = 17)	p Value
Task 1 Pre	172.66 ± 145.0	147.69 ± 101.25	0.569
Task 1 Post	94.63 ± 58.44†	51.88 ± 36.20*	0.014
Task 2 Pre	324.75 ± 219.11	383.27 ± 267.78	0.571
Task 2 Post	231.36 ± 194.62	106.41 ± 64.00*	0.001
Task 3 Pre	107.9 ± 97.23	257.57 ± 292.25	0.149
Task 3 Post	62.54 ± 43.35	55.88 ± 68.46*	0.762

*Participants in the T group experienced significantly improved testing times following training for Task 1 (p = 0.0009), Task 2 (p = 0.0003), and Task 3 (p = 0.012).

†Participants in the NT group only experienced significantly improved testing times for Task 1 (p = 0.037).

not used or otherwise simulated. Often, the virtual reality arthroscopic simulation models progress to techniques such as shaving the meniscus or labrum, before basic triangulation skills, including probing, are taught. In those models in which triangulation is assessed, such as those that ask the trainee to probe for an object (a star, ring, etc.) and provide haptic feedback, while certainly beneficial, it is likely that the same triangulation skills can be obtained with a simulator system that is a fraction of the cost, and portable.

In 2016, Bouaicha and colleagues conducted a study to validate the ArthroBox.[44] In this nonrandomized study, 46 participants, including 12 novices, 12 intermediates, and 22 experts performed a single task on the simulator (moving a rubber ring around a helix). The authors found that novices were significantly slower compared to intermediates and experts in completing the task, and further, that portal changes were significantly more common in novices and intermediates compared to experts. Thus, the authors concluded that construct validity was established given the ability of the training system to discriminate between participants of different skill levels. The present pilot study differs from the study conducted by Bouaicha et al., as our study population included only novices who were either randomized to either receive or not receive a fixed protocol of simulation training on the simulator model. The results from both studies are helpful, as together the data suggests that simulation training on this low-cost, portable, validated arthroscopic triangulation training system result in an overall improvement in arthroscopic probing and triangulation skills within 1 week of training.

Several authors have described other "low cost" arthroscopic simulation systems, with encouraging results.[39,41,42] Colaco et al.[39] presented a study of a novel "low-cost portable" simulator model designed to train basic shoulder arthroscopy skills. The authors describe their model as a homemade box trainer, comprised of a translucent polypropylene box with multiple portals drilled into the box and/or translucent lid and sealed with flexible silicone sealing grommets. Similar to the training system described in our pilot study, their system utilizes a 0-degree scope and requires a laptop connection. The authors found that their system was able to distinguish between novice and experience performance, establishing construct validity. It remains unclear as to how feasible it would be for trainees to reproducibly build and utilize this box model. In 2016, Lopez et al.[41] described another low-cost (average $79) arthroscopic simulator model that requires the assembly of over 12 unique items that can be purchased from a hardware store. While simple in theory to construct, the effort and time needed to reproducibly create the same setup described by the authors, is unclear. The advantage of the triangulation training system utilized in the present study is its low-cost, ease of portability, minimal components, and ease of assembly.

Other critical questions to consider when assessing arthroscopic simulator models include, (1) the potential ceiling effect—will more senior residents or fellows benefit from using the model, (2) the time required to setup and use the model—will residents actually put in the effort to use the model, and (3) the duration of training time needed to make a difference—will residents be able to incorporate simulation training into their already busy schedules. While the present pilot study did not evaluate for the presence of a possible ceiling effect, an ongoing randomized controlled trial is currently evaluating for the possibility of a ceiling effect, as well as assessing the translatability of this triangulation training system on operative performance. Importantly, the setup time for this arthroscopic training model is negligible (less than 20 seconds of setup required), and the system itself is completely portable, making it easy for residents to use when convenient for them.

Of everything to consider when evaluating the utility of arthroscopic training models, perhaps most relevant is the translatability of the model to improving operative performance. In 2014, a systematic review of 19 studies assessed the ability of modern arthroscopic simulators to influence the transfer of arthroscopic skills learned on simulation models to the operating room.[45] The authors found that while trainee participation on the models improved trainee performance on the models, there was no direct correlation to technical performance in the operating room. Since the publication of that systematic review, several dozen additional studies introducing, analyzing, validating, and comparing arthroscopic simulators have been published, with varying results. An updated analysis of all published studies on arthroscopic simulation through 2017 (unpublished data, submitted manuscript), including a meta-analysis of 46 studies incorporating nearly 1300 participants, found similar outcomes—namely that training on arthroscopic simulators improves performance on arthroscopic simulators and that performance on simulators for basic diagnostic arthroscopy correlates with experience level. While the results of this proof-of-concept pilot study demonstrate an improvement in simulator performance among trainees who participated in the simulation training program, the translatability of the triangulation training system assessed here to operative performance remains unknown. Currently, we are assessing the translatability of this triangulation training system on operative performance as part of a larger randomized controlled trial. We suspect that task performance on this simulator model will correlate positively with both subject training level and with subject prior experience, and that subjects who train on the training model will have improved

operative performance, regardless of their training level or prior experience.

Limitations

This study had several limitations. The overall sample size was relatively small, and there were an uneven number of participants in each group. The original study protocol anticipated 40 participants total, with 20 per group; however, 4 subjects were unexpectedly unable to participate, and the distribution of the sealed envelopes, while uneven by subject 36, would have evened out by the time the 40th participant was randomized. No cadaver or real-life patient post-test assessment was performed in this study to determine the translatability, if any, of the simulation system on real-life arthroscopic performance. This is because this pilot study was conducted solely to assess the utility of the ArthroBox in improving basic triangulation skills as a proof-of-concept study. A larger randomized controlled trial utilizing the ArthroBox as the intervention with cadaveric triangulation performance as one of the primary outcomes of interest is currently underway. The ArthroBox utilizes a 0-degree scope, which may not realistically replicate the typical 30-degree scope utilized in clinical practice. Importantly, basic triangulation skills, as well as developing arthroscopic hand-eye coordination, can certainly be accomplished with a 0-degree scope. Finally, the training protocol in the present study was relatively short, with 5 days between the pre- and post-tests. It is unclear as to if longer or shorter training periods would be more or less beneficial, and further, it is unclear if impact of the training program lasts beyond 1 week of training. Certainly, a simulation training model and training program that allows for sustained results over 1 or more years of residency training is ideal.

CONCLUSIONS

Simulation training on a simple, low-cost arthroscopic triangulation training system resulted in an overall improvement in arthroscopic probing and triangulation skills within 1 week of training, with significantly decreased task completion times and increased efficiency of movement.

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