

# Utility of Modern Arthroscopic Simulator Training Models

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**Purpose:** The purpose of this study was to review the published literature on modern arthroscopic simulator training models to (1) determine the ability to transfer skills learned on the model to the operating room and (2) determine the learning curve required to translate such skills. **Methods:** A systematic review of all studies using PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines was performed. Two independent reviewers then analyzed studies deemed appropriate for inclusion. Study data collected included participant demographic characteristics, simulator model, type and number of tasks, method of analysis, and results of training, when available. Given the different methods used in each study, descriptive analysis was performed. **Results:** Nineteen studies met the inclusion criteria (9 shoulder, 9 knee, and 1 hip). A total of 465 participants with a mean age of 30 years were evaluated. Twelve studies (63%) compared task performance among participants of different experience levels, with 100% reporting a positive correlation between experience level and simulator performance. Eight studies (42%) evaluated task performance before and after simulator training, with 6 studies showing improvement after training; 1 study noted no difference in performance after 1 hour of training. One study commented on improved operating room performance after simulator training. No studies commented on the number of training sessions needed to translate skills learned on the models to the operating room. **Conclusions:** This review suggests that practice on arthroscopic simulators improves performance on arthroscopic simulators. We cannot, however, definitively comment on whether simulator training correlates to an improved skill set in the operating room. Further work is needed to determine the type and number of training sessions needed to translate arthroscopic skills learned on the models to the operating room. **Level of Evidence:** Level IV, systematic review of studies with Level I through IV evidence.

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Residency training in the field of orthopaedic surgery is undergoing a tremendous paradigm shift. With increasing restrictions on work hours, the development of advanced arthroscopic skills and techniques may be adversely affected. In 2003 new regulations concerning resident duty hours were established by the Accreditation Council for Graduate Medical Education (ACGME). These changes included, among other rules, the implementation of the 80-hour work week. A growing concern over resident fatigue and

potential compromise of patient care was instrumental in establishing these new regulations. Eight years later, in 2011, the ACGME again instituted new regulations, including limiting interns to no more than 16 continuous hours per duty period with a mandatory rest period of 8 hours (10 hours recommended) between duty periods, as well as mandating the presence of direct supervision. Other rules included requiring intermediate-level residents to have at least 14 hours free of duty after 24 hours of in-house call and limiting "night float" residents to a maximum of 6 consecutive nights before requiring a mandatory duty-free period.<sup>1</sup>

The perception of a potentially declining resident operative experience caused, at least in part, by work-hour restrictions has been discussed in several recent survey-based studies.<sup>2-7</sup> On the basis of the results from a national survey conducted by Immerman et al.,<sup>7</sup> after the 2003 changes, both junior and senior residents believed that the new rules did not increase operative time or improve operative experience. Program directors responded similarly to the residents with regard to the impact of work-hour rules on resident operative experience. Comparable results were noted in a different

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*The authors report that they have no conflicts of interest in the authorship and publication of this article.*

*Received August 30, 2013; accepted September 26, 2013.*

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0749-8063/13632/\$36.00

<http://dx.doi.org/10.1016/j.arthro.2013.09.084>

survey conducted by Zuckerman et al.,<sup>6</sup> with most faculty members and residents responding that the work-hour changes negatively impacted the operative experience.

On the basis of the available evidence, residents continue to express concern over the impact of work hours on operative time and experience. It can be logically assumed that these perceptions may lead to decreased confidence with surgical skills and that performance in the operating room may ultimately suffer. The hand-eye coordination and dexterity skills required to perform safe, effective, and efficient arthroscopic operations are demanding, typically requiring hours of experience in the operating room. Alternative methods for obtaining these vital skills are necessary, and simulator-based training models have seen increasing popularity. Recently, an exponential increase has been seen in the number of studies describing the outcomes of modern arthroscopic simulator training being published.<sup>8-10</sup> Arthroscopic models exist for nearly every joint, yet the actual clinical applicability of arthroscopic training models remains unclear. Interestingly, the correlation between training on a simulator and improved performance in the operating room has been established in the general surgery literature.<sup>11-15</sup> In 2013, for example, Gallagher et al.<sup>11</sup> performed a randomized clinical trial comparing the performance of both novices and experienced laparoscopic surgeons either with or without virtual-reality laparoscopic simulation. In both groups, despite experience level, subjects in the simulation group performed significantly better than the control subjects.

The purpose of this study was to systematically review the published literature on modern arthroscopic simulator training models to determine their ability to transfer skills learned on the model to the operating room. We hypothesized that subjects who undergo arthroscopic simulator training would show objective improvement in simulator and operating room technical skills compared with those who do not undergo training.

## Methods

We conducted a systematic review of publicly available evidence using PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines with a PRISMA checklist.<sup>16,17</sup> Three independent reviewers completed the search. The search was performed on August 5, 2013. The following databases were used: Medline (PubMed), CINAHL (Cumulative Index to Nursing and Allied Health Literature), and Cochrane Central Register of Controlled Trials. The following terms were searched: arthroscopy, arthroscopic, simulation, and simulator. Our Medline (PubMed) search strategy included the following:

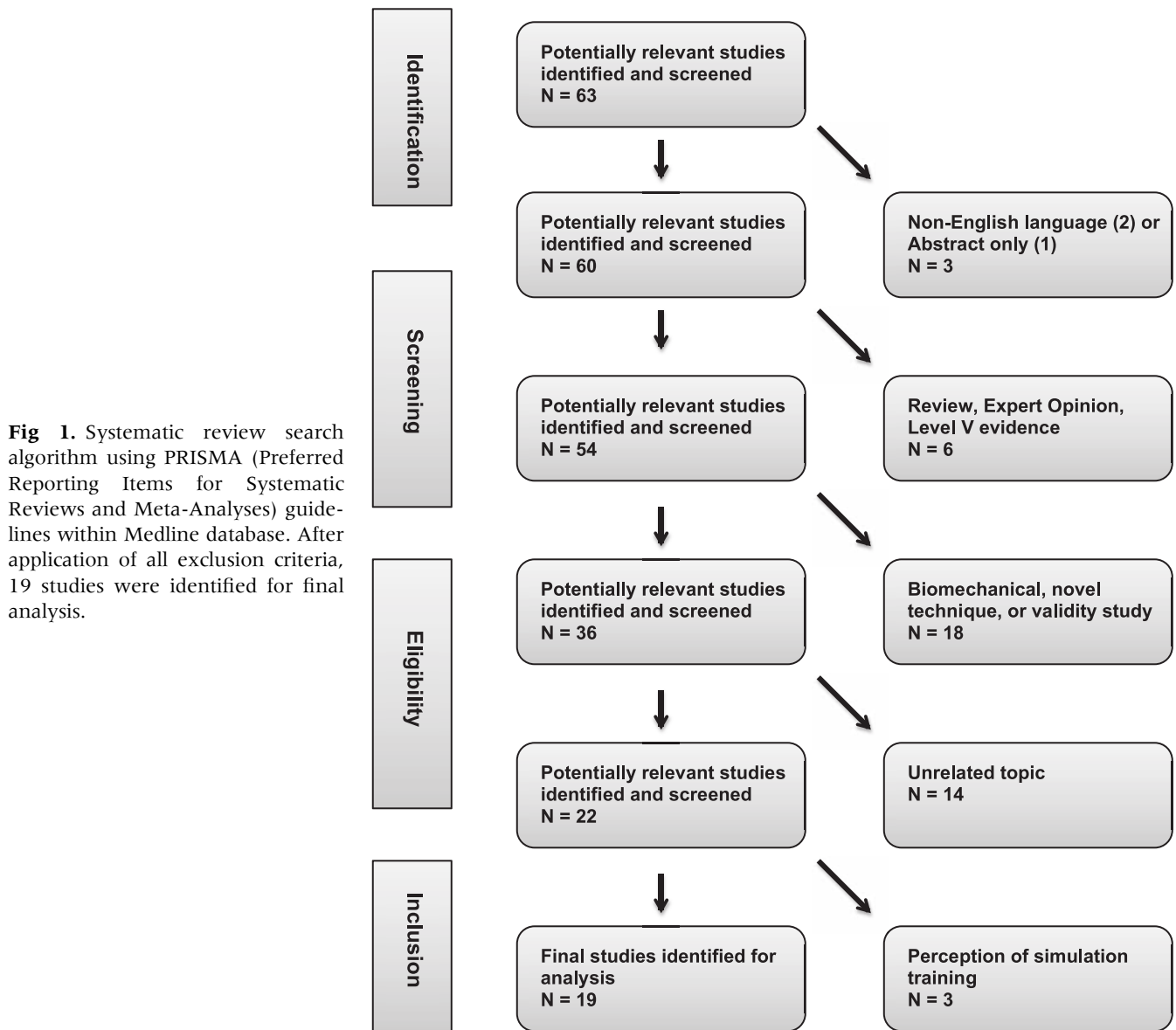
- Search 1: “arthroscopy”[MeSH Terms] OR “arthroscopy”[All Fields] “arthroscopic”[MeSH Terms] OR “arthroscopic”[All Fields]
- Search 2: “simulator”[MeSH Terms] OR “simulator”[All Fields] “simulation”[MeSH Terms] OR “simulation”[All Fields]
- Search 3: search 1 AND search 2

Inclusion criteria were English-language studies incorporating the terms arthroscopy OR arthroscopic AND simulation OR simulator. Exclusion criteria included non-English-language studies, biomechanical studies, novel technique studies, perception-based studies, scientific meeting abstracts/proceedings, and systematic reviews/meta-analyses. Evidence Levels I, II, III, and IV were deemed inclusive (per the Oxford Centre for Evidence-Based Medicine used by the *Journal of Bone and Joint Surgery*<sup>17</sup> and *Arthroscopy*) if published in the English language and articles that were E-published only, articles that were E-published ahead of print, and print journal articles were acceptable. In the event of disagreement on final study inclusion for analysis, the senior author made the final decision. All references within included studies were cross-referenced for potential inclusion if omitted from the initial search. [Figure 1](#) shows the search methods used to generate the final studies for inclusion and analysis.

For those studies deemed appropriate for inclusion, study data collected included participant demographic characteristics, simulator model, type and number of tasks, method of analysis, and results of training, when available. Specific information on the participants, including level of training and prior experience performing arthroscopic surgeries, was analyzed. Other factors including study country of origin, author conflict of interest (COI), and single-center versus multicenter study design were assessed. Descriptive statistical analysis was performed for each study and variable analyzed.

## Results

Sixty-two studies were identified with the initial search. One additional study was identified by cross-referencing the references within the studies from the initial search. A total of 44 studies were excluded, including non-English-language articles (n = 2), an abstract-only listing (n = 1, which was also on an unrelated topic), review articles (n = 6), biomechanical studies (n = 12), studies analyzing novel techniques (n = 4), studies analyzing the validity of simulator models (n = 2), studies discussing topics unrelated to orthopaedic/arthroscopic simulator training (n = 14), and studies analyzing subject/examiner perception of simulator training (n = 3). Nineteen studies met the inclusion criteria and underwent further analysis ([Fig 1](#)). Of the studies, 9 (47%) investigated shoulder



models,<sup>18-26</sup> 9 (47%) evaluated knee models,<sup>27-35</sup> and 1 (6%) evaluated a hip model.<sup>36</sup> These studies are described in detail in Tables 1, 2 and 3.

Simulators varied by study and included the Proce-dicus arthroscopy simulator (Mentice, Göteborg, Sweden) in 6 of 9 shoulder studies,<sup>18,19,20,21,25,26</sup> the Alex Shoulder Professor bench-top simulator (Sawbones Europe, Malmö, Sweden) in 1 of 9 shoulder studies,<sup>22</sup> and the Insight Arthro VR (Immersion, San Jose, CA) in 2 of 9 shoulder studies.<sup>23,24</sup> For the knee, the Proce-dicus Virtual Arthroscopy (VA) trainer (Mentice) was used in 2 of 9 studies,<sup>32,34</sup> an arthroscopy knee bench-top simulator (Sawbones Europe) in 3 of 9 studies,<sup>22,29,31</sup> the Sheffield Knee Arthroscopy Training System (SKATS; University of Sheffield, Sheffield, England) in 2 of 9 studies,<sup>30,35</sup> a high-fidelity

physical knee arthroscopy simulator in 1 of 9 studies,<sup>27</sup> and the Virtual Environment Knee Arthroscopy training system (VE-KATS; Castle Hill Hospital, Hull, UK) in 1 of 9 studies.<sup>33</sup> Finally, the hip study used a hip arthroscopy bench-top simulator (Sawbones Europe).<sup>36</sup>

A total of 465 subjects with a mean age of 30 years (range, 21 to 55 years) were evaluated, with various degrees of experience including students, orthopaedic residents, fellows, and attendings. Twelve studies (63%) compared task performance among participants of different experience levels, with 100% reporting a positive correlation between experience level and simulator performance.<sup>19,20,23-27,30,31,33,35,36</sup> Eight studies (42%) evaluated task performance before and after simulator training,<sup>1,18,22,28-30,32,34,36</sup> with 6 of

**Table 1.** Summary of Shoulder Arthroscopy Simulator Studies

Author, Year, Country	LOE	No. of Participants	Participant Details	Simulator Type	Practice Session Given	No. of Tasks	Time Allowed	Tasks Assessed	Attempts Given	Compared Between Different Levels of Training	Outcomes
Smith et al., <sup>25</sup> 1999, United Kingdom	IV	18	5 OS 6 non-OS with MIS experience 6 MS	Procedicus arthroscopy simulator	No	4	Unlimited	Identify anatomic structures Find targets	1	Yes	OS could locate anatomic structures more quickly, but the path they took was not necessarily more direct, and they had the same number of collisions as the novices
Pedowitz et al., <sup>26</sup> 2002, United States	IV	78	35 MS interviewing for ortho 22 OR interviewing for sports 21 OS	Procedicus arthroscopy simulator	Yes, 5 min	11	NA	Time Path ratio Collisions Injuries	1	Yes	Overall performance significantly better in OS No difference in probe collisions between groups
Srivastava et al., <sup>19</sup> 2004, United States	IV	35	Group 1: novices Group 2: 1-50 previous arthroscopies Group 3: >50 previous arthroscopies	Procedicus arthroscopy simulator	Yes, unlimited time	3	Task 1: unlimited Task 2: unlimited Task 3: 5 min	Hook manipulation Anatomic identification Arthroscopic navigation	1	Yes	No difference in identification Group 3 was best at hook manipulation (group 2 was better than group 1) Each group had improved times Group 3 was best at arthroscopic navigation (no difference between groups 2 and 1)
Gomoll et al., <sup>20</sup> 2007, United States	IV	43	8 novices 11 junior OR 14 senior OR 10 fellows/attendings	Procedicus arthroscopy simulator	NA	11	Unlimited	Probing Time Collisions Velocity Distance traveled	6	Yes	More experienced groups were each better regarding path length and time No. of probe collisions was significantly different between all groups except junior and senior OR Velocity better in experienced groups compared with inexperienced groups
Gomoll et al., <sup>21</sup> 2008, United States	IV	10	10 OR	Procedicus arthroscopy simulator	NA	10	Unlimited	Probing Time Collisions Velocity Distance traveled	6	No	3-yr follow-up of OR to evaluate simulator skills after additional residency training Improvements in all parameters
Howells et al., <sup>22</sup> 2009, United Kingdom	II	6	6 fellowship-trained lower-limb OS	Alex Shoulder Professor bench-top simulator	Yes, 5 min	1	Unlimited	Throw 1 Bankart suture	12	No	3×/session, 4 sessions, 1 session per week; repeat after 6 mo Time to complete tasks improved over first set of 4 sessions and second set of 4 sessions

(continued)

Table 1. Continued

Author, Year, Country	LOE	No. of Participants	Participant Details	Simulator Type	Practice Session Given	No. of Tasks	Time Allowed	Tasks Assessed	Attempts Given	Compared Between Different Levels of Training	Outcomes
Martin et al., <sup>23</sup> 2011, United States	II	19	15 OR 4 OS	Insight Arthro VR	Yes, 5 min	NA	3 min	Probing	3	Yes	No change from baseline to 6 mo Conclusions: no retention Arthroscopy with simulator and then, at least 2 wk later, arthroscopy of cadavers; compared time to complete tasks with each Performance on simulator strongly correlated with cadaver performance Experts were faster than novices
Martin et al., <sup>24</sup> 2012, United States	IV	27	27 OR (all years)	Insight Arthro VR	Yes, 5 min	3	Unlimited	NA	3	Yes	For every 1-yr increase in PGY, there was a 23-s decrease in time For every shoulder arthroscopy case performed as a resident, there was a 0.6-s decrease in time Total no. of arthroscopies performed and total No. of surgical cases completed during residency before completing simulator task correlated with shorter times
Henn et al., <sup>18</sup> 2013, United States	I	17	17 MS1 randomized to either simulator or no simulator training	Procedicus arthroscopy simulator	NA	5 on cadavers, 11 on simulator	NA	Controlling camera Standard series of tasks with probe	NA	No	All subjects completed baseline arthroscopy on cadaver and were then randomized to training or no training; finally, all repeated cadaver testing No difference in baseline skills Simulator group had significantly improved scores compared with baseline (speed, subjective performance) and compared with controls (speed) No difference between groups for subjective scores

LOE, level of evidence; MIS, minimally invasive surgery; MS, medical students; MS-1, first year medical student; NA, not available; OR, orthopaedic residents; ortho, orthopaedic surgery residency position; OS, orthopaedic surgeons; PGY, postgraduate year; sports, sports medicine fellowship position.

**Table 2.** Summary of Knee Arthroscopy Simulator Studies

Author, Year, Country	LOE	No. of Participants	Participant Details	Simulator Type	Practice Session Given	No. of Tasks	Time Allowed	Tasks Assessed	Attempts Given	Compared Between Different Levels of Training	Outcomes
McCarthy et al., <sup>35</sup> 1999, United Kingdom	IV	22	10 postgraduate scientists 6 OR 6 OS	Sheffield Knee Arthroscopy Training System	Yes, "brief"	1	Unlimited	Identify 10 structures	1	Yes	Experienced surgeons had fewer collisions and were faster at completing tasks
Sherman et al., <sup>33</sup> 2001, United Kingdom	IV	43	43 OR	Virtual Environment Knee Arthroscopy training system	Yes, unlimited time	NA	Unlimited	Identify anatomic landmarks	1	Yes	Poor correlation between year of training and performance on simulator
Strom et al., <sup>34</sup> 2004, Sweden	I	28	28 MS randomized to either simulator or no simulator training	Procedicus Virtual Arthroscopy (VA) Knee Simulator	No	6	Unlimited	Probe 6 locations Time Economy Collisions Score	1	No	Performance on simulator did not improve after training using other simulators with different visual-spatial components No significant correlation between different simulators No difference in any task between groups
Bliss et al., <sup>32</sup> 2005, United States	IV	9	9 psychology graduate students	Procedicus Virtual Arthroscopy (VA) trainer	Yes, 15 min	11	Unlimited	Identify 10 anatomic landmarks	1	No	Practice session followed by test session 1×/d for 5 consecutive days Tested 4 wk later Correctly identified 7.7 structures during first session and 9.5 during final session Collided 53.5 times with simulated tissues during first session and 13.2 times during final session No significant decrease over 4-wk period
McCarthy et al., <sup>30</sup> 2006, United Kingdom	IV	23	5 OS with 5-50 previous arthroscopies 7 OS with 50-100 previous arthroscopies 11 OS with >1,000 previous arthroscopies	Sheffield Knee Arthroscopy Training System (SKATS)	Yes, duration unknown	5	Unlimited	Locating loose bodies: time	10	Yes	10 separate sessions over 5-wk period More experienced OS significantly better and faster at locating loose bodies

(continued)

Table 2. Continued

Author, Year, Country	LOE	No. of Participants	Participant Details	Simulator Type	Practice Session Given	No. of Tasks	Time Allowed	Tasks Assessed	Attempts Given	Compared Between Different Levels of Training	Outcomes
Howells et al., <sup>28</sup> 2008, United Kingdom	I	20	20 junior OR randomized to either simulator or no simulator training	Arthroscopy knee bench-top simulator	NA	NA	NA	Identify, probe Speed Efficiency	NA	No	Simulator groups received 18 sessions of training Simulator group performed better (speed, efficiency) in operating room compared with no-simulator group
Tashiro et al., <sup>31</sup> 2009, Japan	II	30	12 surgical trainees 12 OR 6 OS	Sawbones knee simulator model	Yes, 5 min	2	Task 1: 5 min Task 2: 6 min	Joint inspection, probing, partial MX	1	Yes	More experienced subjects performed better (faster, less force exerted on joint, more direct path of their instruments) OS did better than OR, who did better than trainees
Escoto et al., <sup>27</sup> 2012, Canada	IV	15	5 OS 10 novices (OR, MS, engineers)	High-fidelity physical knee arthroscopy simulator	No	14	3 min	Probing, shaving, burring	NA	Yes	Novices applied uneven force when completing shaving and burring tasks compared with experts Novices were slower and less accurate with probing
Jackson et al., <sup>29</sup> 2012, United Kingdom	I	19	19 OR randomized to 3 groups: A: monthly training B: training once C: no simulation	Sawbones knee simulator model	No	1	Unlimited	Meniscal repair	12	No	All OR initially perform meniscal repair on simulator 12× over 3-wk period A: meniscal repair 1×/mo for 5 mo B: meniscal repair 1× total at 3 mo C: no simulation for 6 mo At 6 mo, all groups performed meniscal repair 12× over 3-wk period All OR improved with each meniscal repair at initial phase No groups with significant decrease in ability to perform meniscal repair at 6 mo

LOE, level of evidence; MIS, minimally invasive surgery; MS, medical students; MX, meniscectomy; NA, not available; OR, orthopaedic residents; OS, orthopaedic surgeons; PGY, post-graduate year.

**Table 3.** Summary of Hip Arthroscopy Simulator Studies

Author, Year, Country	LOE	No. of Participants	Participant Details	Simulator Type	Practice Session Given	No. of Tasks	Time Allowed	Tasks Assessed	Attempts Given	Compared Between Different Levels of Training	Outcomes
Pollard et al., <sup>36</sup> 2012, United States	II	20	20 OR randomized into lateral and supine groups for diagnostic arthroscopy	Hip arthroscopy bench-top simulator	No	12	Unlimited	Diagnostic arthroscopy Time Path No. of hand movements	12	Yes	Both groups improved significantly Lateral group initially slower but caught up by attempt 9 Junior OR initially worse but performed at level equal to senior OR by end of study

LOE, level of evidence; OR, orthopaedic residents.

these studies (75%) showing improvement after training<sup>18,28-30,32,36</sup>; 1 study (6%) noted no difference in performance after 1 hour of training.<sup>34</sup> Common arthroscopic tasks included probing identified structures, throwing a suture, hook manipulation of identified structures, and shaving/burring. Of the shoulder studies, only 2 studies tested subjects on the simulator both before and after training, with one showing improvement in speed<sup>18</sup> and the other showing improvement within each training session but not between training sessions.<sup>22</sup> Of the knee studies, 5 tested subjects on the simulator both before and after training, and 80% showed improvement in task performance after training<sup>28-30,32</sup> whereas the study by Strom et al.<sup>34</sup> showed no improvement in simulator task performance after 1 hour of training. The single study analyzing hip arthroscopy evaluated performance on the simulator both before and after training and showed improvement within the training sessions.<sup>36</sup>

A single study (6%) commented on improved operating room performance after simulator training: Howells et al.<sup>28</sup> randomized 20 junior orthopaedic residents to receive either a standardized protocol of knee arthroscopy simulator training or no training at all. All residents were then evaluated on their ability to perform a diagnostic knee arthroscopy on an actual patient by a blinded senior surgeon in the operating room. Of note, the training program consisted of 3 sessions of 6 simulated arthroscopies over the course of 1 week. The authors noted a statistically significant improvement in the simulator group compared with the control group.

No studies commented on the number of training sessions needed to translate technical skills learned on the models to the operating room, although the single study using a hip model examined the learning curve of performing diagnostic hip arthroscopy in either the supine or lateral position.<sup>36</sup> Only 2 studies (12%) incorporated the use of cadaveric specimens as part of their methodology.<sup>18,23</sup> There were 4 Level I studies,<sup>18,28,29,34</sup> 4 Level II studies,<sup>22,23,31,36</sup> and 11 Level IV studies.<sup>19-21,24-27,30,32,33,35</sup>

Seven studies listed potential COI information in the articles.<sup>18,23,24,26,29,31,36</sup> Four studies listed no potential COI,<sup>20,21,22,28</sup> whereas the remaining 9 studies did not provide information on COI.<sup>19,25,27,30,32-35</sup> Of the 7 studies reporting COI information, 5 reported conflicts related to the topic,<sup>18,26,29,31,36</sup> with all 5 receiving research grants supporting simulation studies. Of these 5 studies, only 1 showed a direct benefit from simulator training. Henn et al.<sup>18</sup> reported significantly a faster speed for an arthroscopic probing task in cadavers in subjects who underwent simulator training compared with the control group. Pedowitz et al.<sup>26</sup> reported significantly superior shoulder simulator performance in more experienced subjects but did not compare them



with a control group; Tashiro et al.<sup>31</sup> reported similar findings for a knee arthroscopy simulator model. Pollard et al.<sup>36</sup> showed improvement in hip arthroscopic task performance over the period of a single session but did not compare the participants with a control group or analyze the results over time. Finally, Jackson et al.<sup>29</sup> compared 3 randomized groups of orthopaedic residents who all initially performed a simulated arthroscopic meniscal repair and then underwent either monthly simulator training, a single session of training, or no simulator training. Overall, they found no loss of skill in all 3 groups over a 6-month period, including the group of residents without any simulator training.

## Discussion

The principal findings of this study include the following: (1) training on arthroscopic simulators improves performance on arthroscopic simulators, (2) more experienced subjects perform better on arthroscopic simulators than less experienced subjects, and (3) there is little evidence to correlate performance on simulators with performance in the operating room. A summary of the key findings is presented in [Table 4](#).

Since the popularization of arthroscopy in the United States in the late 1960s,<sup>37</sup> advances in technique and instrumentation have revolutionized our ability to diagnose and treat a wide variety of intra-articular pathology. To be performed safely and effectively, arthroscopic surgery requires a unique subset of skills, most of which require substantial hands-on training.<sup>38</sup> These skills include visual-spatial coordination to interpret 3-dimensional structures from 2-dimensional camera images, hand-eye coordination to triangulate and adjust the visual field, and psychomotor skills to perform the desired procedure without causing iatrogenic injury.<sup>26,38,39</sup> Often, and especially in open surgery, training occurs “on the job,” with residents learning skills and techniques by assisting with cases. With increasing restrictions on work hours combined with a demand for efficiency in the outpatient surgical setting, skill acquisition in arthroscopic cases is becoming progressively more challenging, often consisting of unsupervised “trial-and-error” training that is

not only inefficient but potentially harmful for patient care.<sup>26</sup> Residents may ultimately be spending less time obtaining these vital skills in the actual operating room and may find their arthroscopic skill set unacceptably deficient.<sup>40,41</sup>

In addition, with the constant evolution of complex, advanced arthroscopic techniques, there is a need to be able to teach practicing orthopaedic surgeons new skills or procedures in a safe and controlled environment. Given the already demanding time constraints on practicing surgeons, often, surgeons are forced to “learn” novel arthroscopic skills by simply attending a course or visiting another institution as an observer. Though educational, the limited, if any, hands-on training offered in these situations is insufficient to adequately allow surgeons to develop a level of proficiency with the skill set that would make them immediately comfortable in the operating room. Simulator training provides an opportunity for surgeons to practice the new skills learned in such courses, but a standardized objective measurement scheme to evaluate performance (and improvement) based on simulator use is necessary.

Thus alternative methods for garnering these essential arthroscopic skills are imperative, and simulation-based approaches are becoming more prevalent in residency programs. In fact, in July 2013, the ACGME introduced a drastic change in requirements for orthopaedic surgery residents in postgraduate year 1,<sup>42</sup> requiring all interns to complete a formal skills curriculum, including the development of basic arthroscopy skills. This new curriculum, and specifically the requirement for surgical skills training, is a reflection of the change in educational focus within orthopaedic surgery residency programs. Nevertheless, although it may seem intuitive that arthroscopic simulators should play a role in the development and objective evaluation of psychomotor skills, the operative translatability remains undetermined.

As described earlier, the correlation between simulator training and improved operative performance has been clearly shown in the general surgery literature.<sup>11-15</sup> During the 2009-2010 academic year, the American Board of Surgery implemented the requirement for surgeons seeking board certification to successfully complete the Fundamentals of Laparoscopic Surgery (FLS) training program.<sup>43</sup> The FLS is an education model that was designed for surgical trainees and practicing physicians “to learn and practice laparoscopic skills to have the opportunity to definitely measure and document those skills” and has been shown to directly translate to improved operative performance.<sup>43</sup> For example, Stefanidis et al.<sup>14</sup> conducted a randomized trial comparing operating room skills in a group of inexperienced subjects randomized to either receive FLS training or not (control group). They showed

**Table 4.** Key Points Regarding Modern Arthroscopy Simulation Training Models

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Residents are concerned about decreasing operative experience with increasing work-hour restrictions.
Simulation may be helpful for residents and practicing surgeons alike.
Training on arthroscopic simulation models improves performance on models.
More experienced subjects perform better on models than less experienced subjects.
Transferability of training on simulator models is unclear.
Author COI with simulator models does not appear to impact study results.

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significantly improved operative performance in subjects who underwent participation in the FLS suturing task module compared with control subjects.

Although most of the studies analyzed in this review showed improved simulator performance after simulator training, it remains unclear whether such training translates to the actual operating environment because only 1 study commented on improved operating room performance after simulator training.<sup>28</sup> In this study, Howells et al.<sup>28</sup> randomized 20 junior orthopaedic residents either to undergo a standardized protocol of knee arthroscopy simulator training or to receive no training at all. All residents were then evaluated on their ability to perform a diagnostic knee arthroscopy on an actual patient by a blinded senior surgeon in the operating room. The training program consisted of 3 sessions of 6 simulated arthroscopies over the course of 1 week, and subjects were evaluated with the Orthopaedic Competence Assessment Project score intraoperatively. This scoring system has been incorporated into the United Kingdom's competency-based surgical training structure and includes a total of 14 criteria, 9 of which are relevant to arthroscopy. Howells et al. noted a statistically significant improvement in the simulator group compared with the control group.

A perhaps more preferred approach to arthroscopic training uses cadaveric specimens, which are clearly best suited to simulate all facets of human tissue, especially with regard to appearance, texture, and quality.<sup>44</sup> Only 2 studies in this review incorporated cadaveric models, both performed for the analysis of shoulder simulator training. In 2013 Henn et al.<sup>18</sup> randomized 17 first-year medical students to either receive simulator training or not (control group). All students first completed a baseline arthroscopy on a cadaveric shoulder and then either received simulator training or received no training. All students then repeated the cadaveric arthroscopy 3 months after the initial arthroscopy. Subjects were evaluated on the basis of camera control and probing skills. The simulator group received 6 training sessions on the model over the 3-month period. There were no significant differences in baseline skills between the groups; however, at the final cadaveric session, although both groups improved, the simulator group was significantly faster at completing the tasks compared with the control group. Interestingly, there was no difference between the groups regarding subjective assessment of technical performance. Martin et al.<sup>23</sup> also evaluated arthroscopic task performance in simulator and cadaveric models. In this study 15 orthopaedic residents and 4 orthopaedic surgeons all underwent an orientation and 5-minute practice session with the Insight Arthro VR shoulder simulator (Immersion), followed by testing on the model with probing as the main task. Each subject then was tested on a cadaveric model at least 2 weeks after

the simulator model test. The authors noted a strong correlation with performance time on the simulator and performance time on the cadavers, and they noted the time required to complete tasks on the simulator to be a significant predictor of the time required to complete the same tasks on the cadaver. By using cadaveric shoulders as a proxy for actual patient shoulders, this study does suggest that simulator performance may correlate with actual operative performance. However, this study does not show any positive or negative effect of simulation model training, and thus it is difficult to make conclusions regarding the usefulness of simulator models in improving surgical skill.

Most of the studies in this analysis show that practicing arthroscopic skills with simulator training improves arthroscopic skills on the simulator. The clinical relevance of improving arthroscopic skills on a simulator remains undetermined. Interestingly, other variables, including the experience level of the trainee (student, resident, fellow, or attending), as well as the actual number of procedures performed before simulator training, were also shown to be correlated with simulator performance in most of the studies included in this review. Specifically, 12 of the 19 studies compared task performance among participants of different experience levels,<sup>19,20,23-27,30,31,33,35,36</sup> with all 12 studies showing a positive correlation between experience level and simulator performance. These data suggest that actual operative experience, as opposed to training on the simulator, is correlated with improved simulator performance and/or the ability to obtain a more beneficial experience from the simulator training.

Both Smith et al.<sup>25</sup> and Pedowitz et al.<sup>26</sup> analyzed subjects of all levels, ranging from medical students to orthopaedic surgeons experienced in arthroscopy. Interestingly, although both groups of authors noted significantly superior simulator performance in the experienced groups, the number of injury collisions (number of times the probe or arthroscope contacted any tissue beyond a threshold force) in each group was not significantly different. In contrast, Gomoll et al.<sup>20</sup> showed a significantly lower number of probe collisions in more experienced subjects compared with lesser experienced subjects (except between senior and junior residents). Interestingly, probe collision (in addition to average velocity) showed the largest improvement after training, suggesting that simulator training early in life may be beneficial in the development of skills to avoid collision.

One area in need of further study is the use of hip arthroscopy models because only a single study is available in the literature. In an elegant, Level I study, Pollard et al.<sup>36</sup> evaluated the performance of both junior (training years 1 and 2) and senior (training year

3 or above) residents in simulated hip arthroscopy in either the lateral or supine position. Trainees of all levels were randomized to simulation in either the lateral or supine position, and the task consisted of correctly probing multiple identified landmarks (multiple points on labrum, acetabular cartilage lesions, ligamentum teres) with the camera in both the anterolateral and anterior portals. Each subject probed all landmarks from 1 portal and then the other and repeated the process for a total of 3 times in weekly sessions for a total of 4 weeks (12 total sessions). Motion analysis software was used to determine subject hand path length, total number of hand movements, and time taken to complete the task. Both groups significantly improved in the median time to perform the task ( $P < .0001$ ), with the plateau for the learning curve reached after 9 training sessions in both groups, although the lateral group was slower. During weeks 1 and 2, the senior residents were substantially and marginally superior to the junior residents in all 3 parameters; however, by the last week, there were no significant differences between the groups with the exception that the juniors showed a superior distance traveled compared with the seniors. Although this study identifies a learning curve for performance on the model, no correlation of these data was made with actual operating room performance, and thus it is difficult to draw conclusions regarding the actual learning curve of hip arthroscopic simulation training.

Although no studies were able to evaluate the true learning curve of simulator training as it relates to operative skills, the previously described assessment, as well as the study by Jackson et al.,<sup>29</sup> did determine a "learning curve" for mastering a specific skill on a specific model. Jackson et al. evaluated the ability of residents to perform meniscus repair on an arthroscopy knee bench-top simulator (Sawbones Europe). In this study 19 residents initially performed a meniscal repair on the simulator 12 times over a period of 3 weeks; they were then randomized to perform either meniscal repair once per month for 5 months, 1 time total at 3 months, or no simulation for 6 months. At 6 months, all groups performed meniscal repair again 12 times over a period of 3 weeks, without significant differences. Some residents reached a plateau within 12 training episodes, whereas others continued to improve up to 21 episodes before achieving consistent performance. Interestingly, even the group who did not train at all during the 6-month period between evaluations showed improvement and retention of skill/performance.

Recently, Modi et al. performed a systematic review of 9 studies assessing the validity of computer simulation software as it relates to teaching arthroscopic skills.<sup>45</sup> Although there is some overlap between the included studies in the review of Modi et al. and in our

review, the purposes and analyses of each review are distinct. In their study, Modi et al. showed that simulators with force feedback, haptic technology, and computer-generated outcome data produce high levels of internal consistency and reliability. They noted that the measures best able to discriminate skill level and user experience included time to task completion, distance traveled by probe, path taken by probe, and number of probe collisions, but they noted that additional work is needed to determine the transferability of such training to the operating room.

The potential influence of author/institution COI was assessed in this review. Only 58% of the studies listed either the presence or absence of COIs, and of the 7 studies that listed potential COI information in the articles,<sup>18,23,24,26,29,31,36</sup> only 5 reported conflicts related to the topic<sup>18,26,29,31,36</sup> and only 1 of these showed a direct benefit in arthroscopic skill development from simulator training.<sup>18</sup> Given the substantial expense of the hardware and software components of arthroscopic simulators, an awareness of the potential for author bias in reporting outcomes is essential to fully interpret a given study's results. Nearly all sources of funding for these studies came from national or societal grants as opposed to industry, showing the desire for better understanding the potential role for simulators in arthroscopic skill development.

### Limitations

To our knowledge, this is the first study to analyze the operative translatability of arthroscopic surgical simulation training. This review, however, is not without limitations, most of which are inherent to the limitations of the studies it describes. Given the different methods used in each of the studies, quantitative statistical analysis of the studies as a whole was not possible, and instead descriptive analysis was performed. This type of analysis makes it difficult to draw statistical conclusions; however, given the variability in outcomes reported in each individual study, direct comparison was not feasible. The studies in this review vary with regard to level of evidence; however, multiple Level I studies were included. The method for evaluating simulator task performance was extremely variable among studies, making it difficult to compare outcomes even among studies analyzing the same joint with the same simulator, thus introducing detection bias. Heterogeneity among the subjects (i.e., age, gender, and experience level) also contributed to bias. Finally, the lack of standardized performance measures confounds the conclusions drawn.

Overall, the question of translatability of arthroscopic simulation trainers is still unanswered. Furthermore, the learning curve of simulation training, and specifically the number and timing (daily, weekly, monthly, and so on) of repetitions required to achieve proficiency

**Table 5.** Current Limitations of Modern Arthroscopy Simulation Training Models

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There is significant variability among modern arthroscopic simulator models:
No current systematic approach
Not proficiency based
Not based on performance metrics
Efficiency (and cost) of training on current arthroscopy models is unclear.
Validation of arthroscopy models as a whole is not yet available.
Studies analyzing performance on models of the wrist and ankle are not yet available.
There is no clear correlation (yet) between model training and cadaveric operative performance.
There is no clear correlation (yet) between model training and actual operative performance.
No data are available on the learning curve.

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or, more importantly, to maintain proficiency of these skills in the operating room, has not yet been analyzed. Similarly, methods for evaluating arthroscopic simulator performance have not been standardized, making it difficult to compare 1 simulation system with another. Further research on knee, shoulder, and hip arthroscopy simulation, as well as on other joints including the wrist, elbow, and ankle, is warranted. In addition, more investigation is required to determine the type and number of training sessions required to translate technical skills learned on the models to the operating room, to determine the best way of using this training as a core component of resident education. A summary of the limitations of current arthroscopy simulator models is provided in Table 5.

## Conclusions

Arthroscopic simulators have the potential to enable residents and surgeons to further develop their skills in a safe environment. This review supports the belief that practice on arthroscopic simulators improves performance on arthroscopic simulators. We cannot, however, definitively comment on whether simulator training correlates to an improved arthroscopic skill set in the operating room. Further work is needed to determine the type and number of training sessions needed to translate technical skills learned on the models to the operating room.

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