

## Low-Cost, Low-Fidelity, Self-Made Arthroscopic Surgical Simulators: A Systematic Review

Eric M Mason MD<sup>1\*</sup>, Cyrus Anthony Pumilia MD<sup>2</sup>, Bradley Richey MS<sup>3</sup>, Chris Garrett MD<sup>1</sup>, Ibrahim M Zeini, Ph.D., PMP, SA, CCRP<sup>4</sup>, Benjamin C Service MD<sup>1</sup> and Daryl C Osbahr MD<sup>5</sup>

<sup>1</sup>Sports Medicine Division, Orlando Health Orthopedic Institute, 1222 S Orange Ave, 5th Floor, Orlando, FL 32806.

<sup>2</sup>University of South Carolina, Columbia.

<sup>3</sup>University of Central Florida College of Medicine, 6850 Lake Nona Blvd, Orlando, FL 32827.

<sup>4</sup>AdventHealth Research Institute, 301 E Princeton St, Orlando, FL 32804.

<sup>5</sup>Rothman Orthopaedic Institute – Florida, 410 Lionel Way, Suite 201, Davenport, FL 33837.

### \*Corresponding author

Eric Mason, MD, Sports Medicine Division, Orlando Health Orthopedic Institute, 1222 S. Orange Ave, 5th Floor, Orlando, FL 32806

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### Abstract

**Purpose:** To systematically review the literature regarding low-cost, low-fidelity, self-made arthroscopic surgical simulators and provide an overview of their use in the teaching of arthroscopic surgical skills.

**Methods:** Systematic review of the literature following PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.

**Results:** A total of 10 studies met inclusion criteria. All studies utilized low-cost, low-fidelity, self-made arthroscopic simulators of varying designs. Five studies (50%) utilized low-cost, self-made arthroscopic cameras and three (30%) utilized commercial surgical arthroscopic cameras. One study (10%) demonstrated face validity, five (50%) demonstrated construct validity, and three (30%) demonstrated transfer validity. The assessed arthroscopic tasks varied, but generally consisted of a combination of triangulation, object grasping, and tissue manipulation. Seven (70%) studies evaluated total simulator construction costs, with six (60%) studies achieving total construction costs of < \$80 US Dollars.

**Conclusions:** A growing body of literature supports the use of low-cost, low-fidelity, self-made arthroscopic surgical simulators. The cost-effectiveness and practicality of these simulators remains a major benefit to their overall utility when compared to their commercially available and high-fidelity counterparts. Furthermore, studies utilizing low-fidelity arthroscopic simulators are beginning to place a large importance on the achievement of face, construct, and transfer validity. Evidence suggests that the true utility of low-cost, low-fidelity arthroscopic surgical simulators stem not from their ability to replicate operating room conditions, but rather from their ability to provide practical training in basic and essential arthroscopic skills that will then be further refined through possible additional simulation and future surgical training.

**Level of Evidence:** Level V

**Keywords:** Arthroscopy, Surgical simulation, Surgical education, Medical education

## Introduction

The development of arthroscopic surgical skill is a fundamental part of orthopedic residency training, yet many barriers exist that hinder the learning process, including resident work hour restrictions, restrictions on elective caseloads in light of the current pandemic, and inherent concerns for patient safety when junior trainees obtain basic training in the operating room [1-3]. Arthroscopic simulation technology offers a possible solution to these problems and has emerged as a surgical skills aid within orthopedic residency training over the past 20 years [3, 4]. Simulation training allows for the early development of key arthroscopic skills prior to stepping into the operating room [5]. With recent advancements in arthroscopic simulation technology, this training can now take

place in virtually any location, allowing for easy, effective, and efficient acquisition of arthroscopic surgical skill while protecting patient safety and reducing operative room costs [4-6].

The ideal arthroscopic surgical simulator should demonstrate the various characteristics of simulator validity that have been previously described (Table 1) [6]. Concurrent validity optimization remains the ultimate goal in arthroscopic surgical simulation, as it describes the ability of a simulator to provide training that correlates with improved performance in the operative room setting [6]. Previous studies have confirmed the validity of various arthroscopic surgical simulators and their ability to facilitate skill transfer from the simulator into the operative room setting [7-10].

**Table 1: Summary of Research According to Simulator Validity Outcomes**

Validity Type	Definition	No. of Studies	References
Face	Extent to which the simulator resembles clinical scenarios	1	12
Content	Whether the domain or criterion being measured is actually being measured by the assessment tool or simulator	0	
Construct	Ability of the simulator to discriminate between different levels of expertise	5	12,13,29,31,33
Transfer	A measure of whether the system has the effect that it proposes to have (i.e., whether the simulator is able to produce a learning effect and improve performance with continued use)	3	16,29,30
Concurrent	To what extent the results of the simulator correlates with the gold standard (the operative theatre) for the same domain	0	

**Note:** Adapted from “Simulation training: A systematic review of simulation in arthroscopy and proposal of a new competency-based training framework.” by Tay et al. (2014) [36].

Validity of arthroscopic surgical simulators may vary based on their fidelity, or how well they mimic the “gold standard” when correlated to the intended surgical procedure in the operating room. This is especially true in the case of face validity, or the extent to which a simulator mimics clinical or operative scenarios, which is a key component of the design construct of many high-fidelity simulators. However, previous studies have confirmed the validity and transferability of learned skills to the operating room across varying levels of simulator fidelity [11-23]. High-fidelity arthroscopic surgical trainers use advanced virtual-reality technology, often include haptic feedback, and account for much of the ongoing research within this field; however, the inherently high costs associated with these modalities often impede their use in many orthopedic residency and medical school training programs [11, 14, 15, 17-19, 21-27].

Low-fidelity arthroscopic surgical trainers, often referred to as “benchtop” models, have the potential to provide training at a much lower cost. These models are often less focused on recreating in situ anatomy, and prioritize instead skill acquisition that is meant to translate well into the operating room setting, at a lower cost than high-fidelity models. Although most of these simula-

tors are commercially available, there has been a recent surge in literature describing the use of self-made simulators [12, 13, 16, 28-34]. These simulators are often constructed using readily available resources and may offer several potential benefits, including decreased financial burdens and greater availability to training programs. Accordingly, such low-fidelity, self-made simulators may offer a valuable and accessible opportunity for orthopedic residents and medical students to develop essential arthroscopic surgical skills with significant cost savings to institutions.

The purpose of the present study is to systematically review the literature regarding low-cost, low-fidelity, self-made arthroscopic surgical simulators and provide an overview of their use in the teaching of arthroscopic surgical skills. The authors hypothesized that sufficient evidence exists within the literature to support the use of low-cost, low-fidelity, self-made arthroscopic surgical simulators, with the primary outcomes of interest being 1) cost of construction and 2) assessments of validity. If such evidence exists, such simulators may represent pragmatic, useful tools for enhancing the early development of basic arthroscopic skills in orthopedic residents and medical students prior to training in the operative room setting.

## Methods

A systematic review of the literature regarding the use of low-cost, low-fidelity, self-made arthroscopic surgical simulators was performed using PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines [35]. A search in the PubMed/MEDLINE and EMBASE databases was performed in April 2020 using the key terms shown in Table 2. Articles describing the use of low-fidelity, low-cost, self-made arthroscopic surgical simulators were included. For inclusion criteria purposes, included studies were determined to be those that utilized arthroscopic simulators that were:

1. Self-made and/or constructed (non-commercially available) using readily available resources.
2. Constructed for less than \$1,000 US Dollars.
3. Low-fidelity (non-virtual reality, non-cadaveric, & non-haptic feedback enabled).

Articles that utilized self-made, low-fidelity arthroscopic trainers with commercially available arthroscopic cameras were included. Non-English language articles, editorial commentaries, and review

articles were excluded. The references of those articles (as well as those of the articles that were eventually included in the present review) were also screened with use of the same selection criteria and were included if these criteria were met. In accordance with PRISMA guidelines, duplicates were then removed and all titles and abstracts were independently screened for relevance by two authors (E. M. & C. A. P.) [35]. Disagreements in determination of relevance for inclusion were not encountered. The remaining relevant articles were then read in full to determine their final eligibility in the systematic review by two authors (E. M. & C. A. P.). In total, 10 articles were determined to be eligible for analysis (Figure 1) and ranged in original publication date from 1993 to 2019. Study methodologies were summarized and their outcomes were analyzed for validity in accordance to the definitions described by Tay et al. (Table 1) [36]. The level of evidence for each study was also recorded according to the Oxford Centre for Evidence-Based Medicine definitions [37]. Additional data regarding materials used and construction principles for simulator and arthroscopic camera creation was also collected if available.

**Table 2: Search Terms**

“Arthroscopy”	“Simulator”	“Low-fidelity”
“Arthroscopic”	“Simulation”	“Low-cost”
	“Trainer”	“Homemade”
	“Training”	“Self-made”
		“Box”
		“Benchtop”

**Note:** aSearch terms were combined with Boolean operators. Terms within each column were combined with “OR” statements. “AND” statements were used to combine terms between columns.

## Results

From the initial search criteria, 956 articles were identified. A total of 870 articles were excluded due to irrelevance, non-English language, reviews, and editorial commentaries. The remaining 86 articles were read in full and reviewed for study inclusion criteria (Figure 1), after which 72 articles were excluded due to unavailable simulator description (n = 2), commercially available low-fidelity

simulator use (n = 21), commercially available high-fidelity simulator use (n = 51), and non-commercially available high-fidelity simulator use (n = 9). Six of the excluded studies utilized both commercially available low-fidelity and high-fidelity simulators. Ten articles were determined to be eligible for final study inclusion (Table 3).

**Table 3: Summary of Included Studies**

Study	Simulator Design	Validity	No. and Type of Participants	Method	Measured Outcomes	Level of Evidence	Overview of Results	Total Construction Price Included?
Arealis G et al.28, (2016)	Benchtop box model was constructed using a cardboard box material with puncture holes for portals.  Arthroscopic camera was constructed using a USB web camera (iTrust Primo) connected to a computer monitor.	None	None	N/a	N/a	VII	<ul style="list-style-type: none"> <li>Proposed that a low-cost, low-fidelity box model and low-cost arthroscopic camera can be constructed and used to train orthopedic faculty and residents in arthroscopic techniques.</li> </ul>	No
Bra-man et al.12, (2015)	Benchtop box model was constructed using a plastic material with drilled holes for portals.  USB-driven arthroscopic camera (SAWBONES) was connected to a computer monitor.	Face, Construct	8 medical students (novice group) and 8 fellowship-trained orthopedic surgeons (expert group)	All groups performed 2 tasks: triangulation skills and manipulation skills tasks.	Time to complete, No. of errors, no. of trials to steady state (achieved when two trials were completed within 10% of each other for time and errors)	III	<ul style="list-style-type: none"> <li>Expert group outperformed the novice group in both task completion time and No. of errors for both tasks.</li> <li>Expert group more frequently achieved steady state compared to novice group.</li> </ul>	No
Cola-co et al.29, (2017)	Benchtop box model was constructed using a translucent polypropylene container with drilled holes for portals. Arthroscopic camera was constructed using a USB-powered 0o “pencil” scope with 4 LED light source connected to a computer monitor.	Construct, Transfer	9 medical students (student group), 12 surgical and non-surgical trainees (trainee group), and 7 orthopedic surgeons (consultant group)	All groups performed 6 consecutive attempts at a triangulation task.	Time to completion, No. of times participants looked at their hands	III	<ul style="list-style-type: none"> <li>More experienced participants were faster at completing the task.</li> <li>Medical students were significantly slower than both trainees and consultant groups</li> </ul>	Yes, less than \$72 USD (United States Dollars)

Coughlin et al.13, (2015)	<p>Benchtop box model was constructed using an opaque material. Sides of the box were composed of a synthetic membrane with portal holes to simulate native skin tissues.</p> <p>30o surgical arthroscope was used with camera, light source, and video monitor.</p>	Construct	15 medical students (novice group), 12 junior orthopedic residents, 16 senior orthopedic residents, and 6 orthopedic surgeons	All groups performed 6 arthroscopic tasks: Triangulation and probing, grasping and transferring objects, tissue resection, tissue-shaving, tissue liberation and suture-passing, and tissue approximation and arthroscopic knot-tying tasks.	Time to completion (subtracted from a set maximum allotted time for each task) and errors performed. Total scores were calculated by deducting penalty scores from timing scores.	II	<ul style="list-style-type: none"> <li>More experienced participants achieved significantly higher mean total scores in all arthroscopic tasks</li> </ul>	Yes, \$800 USD (However, this value is an overestimate of the true cost to build the model as a substantial portion of the material was wasted on earlier prototypes)
Ling et al.30, (2019)	<p>Benchtop box model was constructed using a thermoplastic splint material with drilled holes for portals. Portals were covered using a leather material to simulate native skin tissues.</p> <p>Arthroscopic camera was constructed using an IMAC endoscopic camera fixed at 30° inclination to 2 parallel Kirschner wires with bicycle handle fitted to the end opposite of the camera.</p>	Transfer	153 orthopedic surgery residents	Participants were randomized to either the low-cost, self-made arthroscopic camera (LAC) group (n = 77) or the commercial arthroscopic camera (CAC) group (n = 76). Both groups performed 4 arthroscopic tasks in: Transferring objects, stacking objects, probing numbers, and stretching rubber bands tasks. All participants performed each task 3 times; before practice, immediately after practice, and after a period of 3 months.	Time to completion	II	<ul style="list-style-type: none"> <li>Significant improvements in time to completion were seen in the post-practice test for both groups in all tasks.</li> <li>No significant differences in task completion time were seen between the groups for any task or for total cumulative task completion times.</li> </ul>	Yes, \$70-\$80 USD
Lopez et al.31, (2016)	<p>Benchtop model was constructed using a 90o PVC elbow connector with drilled holes for portals was stabilized to a wooden post to mimic a flexed knee.</p> <p>Arthroscopic camera was constructed using a USB camera connected to a computer monitor that was placed within a galvanized pipe shell (Supereyes B005 USB Portable Digital Microscope).</p>	Construct	20 medical students, 27 junior orthopedic residents, 19 senior orthopedic residents, and 9 orthopedic surgeons	All groups performed 6 arthroscopic tasks: Dominant hand peg transfer at 60o, Non-dominant hand peg transfer at 60o, Dominant hand peg transfer at 180o, Non-dominant hand peg transfer at 180o circle drawing, and suture retrieval tasks.	Time to completion and accuracy (assessed based upon the number of breaks from the desired area subtracted from a maximum number of breakages)	III	<ul style="list-style-type: none"> <li>Medical student and junior resident groups scored significantly lower than the senior resident and orthopedic surgeon groups in all tasks</li> </ul>	Yes, \$79 USD

Meyer et al.32, (1993)	Benchtop box knee model was constructed using a black acrylic box material with holes drilled for portals. Portals were fitted with a rubber material to simulate native skin tissues. Box contents contained a plastic knee model with anterior cruciate ligament and meniscus components.  Arthroscopic camera use was not described.	None	None	N/a	N/a	VII	<ul style="list-style-type: none"> <li>Proposed the construction and use of a low-cost, low-fidelity box model that was used to successfully train orthopedic faculty and residents in arthroscopic techniques.</li> </ul>	No
Molho et al.33, (2017)	Benchtop model was constructed using a hollowed-out grapefruit skin with puncture holes for portals that was secured within a polypropylene container.  30o surgical arthroscope was used with camera, light source, and video monitor.	Construct	5 Medical students, 7 orthopedic residents who participated in ≤ 50 arthroscopic cases, and 7 orthopedic residents and attending surgeons who participated in ≥ 51 arthroscopic cases	All groups performed 4 arthroscopic tasks: Clearing the operating environment, implant placement, object transfer, and foam bite tasks.	Time to completion and points earned (point system was assessed by deducting points for errors from a maximum score of 32, with errors being assessed by a single evaluator).	III	<ul style="list-style-type: none"> <li>Medical student group exhibited longer times to completion and had more errors than the more experienced groups.</li> <li>Orthopedic residents who participated in ≤ 50 arthroscopic cases exhibited longer completion times and had more errors than orthopedic residents and attending surgeons who participated in ≥ 51 arthroscopic cases.</li> </ul>	Yes, < \$50 USD
Patil et al.34, (2009)	Benchtop box model was constructed using a cardboard box material with puncture holes for portals. Arthroscopic camera was constructed using a USB webcam attached at a 30° tilt to an embolectomy catheter.	None	None	N/a	N/a	VII	<ul style="list-style-type: none"> <li>Proposed that a low-cost, low-fidelity box model and low-cost arthroscopic camera can be constructed and used to train orthopedic faculty and residents in arthroscopic techniques.</li> </ul>	Yes, \$11.09 USD

Sandberg et al.16, (2017)	<p>Benchtop box model was constructed using a wooden cigar box with drilled holes for portals. Portals were covered with rubber bicycle tubing to simulate native skin tissues.</p> <p>30o surgical arthroscope was used with camera, light source, and video monitor.</p>	Transfer	14 first year medical students and 10 second year medical students	<p>Participants were evenly randomized to the cigar box arthroscopy trainer (CBAT) group (n = 8), Sawbones anatomic knee arthroscopy trainer (AKAT) group (n = 8), or control group (n = 8). All subjects were provided reading assignments and videos covering the basics of arthroscopy techniques and diagnostic knee arthroscopy. Arthroscopic trainer groups completed 4-hours of preassessment simulator training in 1-hour blocks over a 24-day period. Students assigned to the control group received no preassessment training. On the day of cadaveric assessment, all students attended a 1-hour didactic session on basic diagnostic arthroscopy principles. All students performed underwent final assessment in which 1-hour was given to complete as many attempts as possible at a diagnostic knee arthroscopy in a cadaveric knee.</p>	Basic Arthroscopic Knee Skill Scoring System (BAKSSS)	II	<ul style="list-style-type: none"> <li>• Students in the CBAT and AKAT groups reached minimum proficiency (determined as a BAKSS score of 33) more frequently than students in the control group.</li> <li>• No significant difference was found in the number of attempts to reach proficiency between the CBAT and AKAT groups.</li> </ul>	Yes, \$44.12 USD
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All studies (100%) utilized low-cost, low-fidelity, self-made arthroscopic simulators of varying designs (Table 3) [12, 13, 16, 28-34]. Five studies (50%) utilized low-cost, self-made arthroscopic cameras and three (30%) utilized commercial surgical arthroscopic cameras [13, 16, 28-31, 33, 34]. One study used a commercial non-surgical arthroscopic camera and one study did not discuss the arthroscopic camera that was utilized [12, 32]. One study (10%) demonstrated face validity, five (50%) demonstrated construct validity, and three (30%) demonstrated transfer validity [12, 13, 16, 29-29-31, 33]. No studies demonstrated content validity or concurrent validity. Seven studies (70%) assessed simulator training outcomes [12, 13, 16, 29-31, 33]. Three studies (30%) exhibited level II evidence, four (40%) exhibited level III evidence, and three (30%) exhibited level VII evidence [12, 13, 16, 28-34]. Seven (70%) studies evaluated total simulator construction costs, with six (60%) of these studies achieving total construction costs of <

\$80 US dollars [13, 16, 29-31, 33, 34]. Interestingly, one study (10%) exhibited a total approximated simulator construction cost of \$800 US dollars [13]. However, the group stated that this value was not an accurate representation of total simulator construction costs as this value reflected total material costs that were spent on earlier prototype models [13]. Labor costs for construction of the simulators were not included in the ten reviewed studies.

### Discussion

The results above demonstrate that within the current body of literature there exists evidence that arthroscopic surgical simulators may be constructed affordably, from readily available supplies, and in such a manner as to demonstrate validity as surgical trainer devices. In general, arthroscopic surgical simulation has emerged as an essential tool for skill acquisition and training within all levels of orthopedic training and is considered a mandatory re-

quirement for many institutions [38, 39]. With the creation of the Fundamentals of Arthroscopic Surgery Training (FAST) Program as a collaborative effort by the American Board of Orthopedic Surgery, American Academy of Orthopedic Surgery (AAOS), and the Arthroscopy Association of North America (AANA), best-practice training guidelines for arthroscopic surgical training are now being implemented in orthopedic training institutions worldwide [20, 40-42]. These advancements in orthopedic training guidelines for arthroscopic surgery have paralleled the technological advancements in arthroscopic surgical simulation, with the recent engineering of numerous high-fidelity simulators that exhibit transferability of learned arthroscopic skills into the operative room setting [7-10].

The challenge now remains as to how training institutions may effectively and feasibly incorporate these principles into their training curriculums. In a recent publication by Rasched et al, their team described an important increase in the proportion of low-fidelity, low-cost arthroscopic simulator research in the post-2014 era [5]. The trend was supported by a relative decline of 46% in high-fidelity virtual reality arthroscopic simulator research in the post-2014 era [5]. This trend may be attributed to multiple causes, but suggests that there is an increasing role for low-cost, low-fidelity arthroscopic surgical simulators as a component of the future of orthopedic surgical skills training.

The current review included seven studies that constructed self-made arthroscopic surgical simulators for < \$80 US dollars [16, 29-31, 33, 34]. Of these very-low-cost simulators, three demonstrated construct validity and three demonstrated transfer validity [16, 29-31, 33]. A majority of the included studies utilized common and/or universally available materials to construct their arthroscopic simulators and arthroscopic cameras. The study by Sandberg et al. (2017) was especially interesting as the team was able to construct a low-cost benchtop arthroscopic trainer, which resulted in no significant differences between a group trained on this model and that of a commercially available Sawbones anatomic knee arthroscopy trainer (Sawbones-Pacific Research Laboratories, Vashon, WA) in terms of reaching minimum proficiency on subsequent cadaveric diagnostic arthroscopy (determined as a BAKSS score of 33). Total material costs for their low-cost benchtop model were \$44.12 US Dollars compared to the commercial price of \$324.33 US Dollars for the Sawbones knee trainer [16]. The authors do acknowledge that the time to construct these low-cost, low-fidelity, self-made trainers may add additional labor and manufacturing costs that were not accounted for in this example.

Another interesting finding was the number of studies utilizing self-made arthroscopic cameras by means of adaptations of industrial, USB-connecting endoscopic cameras [28-31, 34]. Ling et al. (2019) investigated their use by comparing outcomes of a benchtop simulator training session in a cohort of 153 orthopedic surgical residents [30]. Residents were randomized to use either a low-cost, self-made arthroscopic camera or a commercial arthroscopic camera on the same set of training tasks. When tested immediately after the session on a commercial arthroscopic camera, they found that both groups were able to significantly improve in task time-to-completion and that no significant differences in these improvements were present between groups<sup>30</sup>. These findings support the utility of low-cost cameras in performing basic

simulator training to further help decrease simulator training costs.

Another interesting finding was the number of studies utilizing self-made arthroscopic cameras by means of adaptations of industrial, USB-connecting endoscopic cameras [28-31, 34]. Ling et al. (2019) investigated their use by comparing outcomes of a benchtop simulator training session in a cohort of 153 orthopedic surgical residents [30]. Residents were randomized to use either a low-cost, self-made arthroscopic camera or a commercial arthroscopic camera on the same set of training tasks. When tested immediately after the session on a commercial arthroscopic camera, they found that both groups were able to significantly improve in task time-to-completion and that no significant differences in these improvements were present between groups [30]. These findings support the utility of low-cost cameras in performing basic simulator training to further help decrease simulator training costs.

Despite current evidence regarding the utility and effectiveness of low-cost, low-fidelity arthroscopic training, much debate remains regarding their effectiveness and their transferability to operating room performance, or concurrent validity. Frank et al. (2018) conducted a systematic review of both high and low fidelity arthroscopic simulators training models, finding that four studies investigating operating room outcomes showed improved performance following training on simulator devices, though all investigated only diagnostic arthroscopy [4]. Three of these studies used high-fidelity simulators and one used the anatomic, low-fidelity Sawbones dry knee arthroscopy model [4]. Since the Frank et al. publication, Ledermann et al. (2020) demonstrated that the anatomic, low-fidelity Sawbones simulator also improved procedure-based operating room performance, evaluating subject's ability to perform arthroscopic partial meniscectomy [10]. To the authors' knowledge, only one study has investigated the concurrent validity of non-anatomic, low-fidelity, arthroscopic simulators<sup>43</sup>. Roberts et al. demonstrated significant post-training improvements in diagnostic arthroscopy, but the training group was exposed to low-fidelity simulator training with both the Sawbones anatomic dry knee arthroscopy model and a non-anatomic, AANA-endorsed simulator (FAST Workstation, Sawbones – Pacific Research Laboratories, Vashon, WA). The exposure in the study group to both the anatomic and non-anatomic low-fidelity simulators limited analysis of the specific effectiveness of this non-anatomic, low-fidelity, low-cost arthroscopic simulator [43].

Further debate remains regarding the effectiveness of low-fidelity arthroscopic simulators compared to their high-fidelity counterparts [44]. Though Banaszek et al. (2017) showed that training with the Sawbones model was inferior to that with a higher-fidelity, advanced virtual-reality trainer on cadaveric model testing, multiple studies have shown the potential for training on low-fidelity simulators to transfer into higher performance on high-fidelity, virtual-reality simulators [44-47]. This evidence supports the theory that low-cost, low-fidelity arthroscopic surgical simulators offer a practical means of allowing trainees to develop basic arthroscopic skills that may then be further trained with progressive incorporation of high-fidelity simulation as proficiency is reached. This validated, stepwise training model is referred to as proficiency-based progression and is incorporated in the AANA orthopedic



residency course [38, 39, 48-50]. Hence, the authors would like to suggest the idea that the true utility of low-cost, low-fidelity arthroscopic surgical simulators stem not from their ability to replicate operative room conditions, but rather from their ability to provide practical training in basic and essential arthroscopic skills that will then be further refined through possible additional simulation and future surgical training. Furthermore, an emphasis must be placed on achieving transfer validity in future studies; this is fundamentally paramount to the future advancement of this field, as it would subsequently allow for the successful application of low-fidelity arthroscopic simulation within the classic proficiency-based progression training model.

At the present time, the reproducibility of low-cost, low-fidelity, self-made arthroscopic simulators have not been investigated. Limitations in the reproducibility of these simulators between institutions may affect their validity and therefore their widespread implementation in training programs. Furthermore, self-made simulators require time and labor to build that may or may not be efficient for said training programs. Though at a potentially higher cost, commercially available, low-fidelity arthroscopic simulators may provide for consistent reproducibility and lack of labor requirements while still being a significant margin cheaper than their high-fidelity counterparts. Future studies should aim to compare the reproducibility and validity of low-cost, low-fidelity, self-made simulators to that of low-cost, low-fidelity, commercially available simulators. Additionally, the average time and labor requirements to build self-made simulators should be reported to allow for accurate cost comparison to commercially available simulators.

### Limitations

The present review had multiple limitations. The current literature volume is relatively scarce and is further limited by low sample sizes and low level of evidence studies. Furthermore, arthroscopic tasks and methods of assessment varied widely in the included studies, limiting accurate cross-study comparison. Additionally, the review included only studies that were published in the English language and further articles may exist outside the authors' knowledge, representing a potential for publication bias. Future studies in this field should focus on utilizing standardized approaches to simulator training and skill assessment. Randomized controlled trials should be completed with larger sample sizes comparing concurrent validity not only between low-fidelity and high-fidelity arthroscopic simulators but also among the different types of low-fidelity simulators to define an appropriate proficiency-based progression across arthroscopic surgical training.

### Conclusions

A growing body of literature supports the use of low-cost, low-fidelity, self-made arthroscopic surgical simulators. The cost-effectiveness and practicality of these simulators remains a major benefit to their overall utility when compared to their commercially available and high-fidelity counterparts. Furthermore, studies utilizing low-fidelity arthroscopic simulators are beginning to place a large importance on the achievement of face, construct, and transfer validity. Evidence suggests that the true utility of low-cost, low-fidelity arthroscopic surgical simulators stem not from their ability to replicate operative room conditions, but rather from their ability to provide practical training in basic and essential ar-

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