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Review Article

E-learning in orthopedic surgery training: A systematic review

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ABSTRACT

E-learning is the use of internet-based resources in education. In the field of surgical education, this definition includes the use of virtual patient cases, digital modeling, online tutorials, as well as video recordings of surgical procedures and lectures. In recent years, e-learning has increasingly been considered a viable alternative to traditional teaching within a number of surgical fields. Here we present (1) a systematic review of literature assessing the efficacy of e-learning modules for orthopedic education and (2) a discussion of their relevance. A systematic search of PubMed, Embase, Web of Science, and the Cochrane Library was conducted according to the guidelines defined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement (PRISMA). The search yielded a total of 255 non-duplicate citations that were screened using predetermined inclusion/exclusion criteria. A total of 9 full text articles met inclusion criteria, which included the use of an objective outcome measure to evaluate an orthopedic e-learning module. Six studies assessed knowledge using a multiple-choice test and 4 assessed skills using a clinical exam. All studies showed positive score improvement pre- to post-intervention, and a majority showed greater score improvement than standard teaching methods in both knowledge (4/6 studies) and clinical skills (3/4 studies). E-learning represents an effective supplement or even alternative to standard teaching techniques within orthopedic education for both medical students and residents. Future work should focus on validating specific e-learning programs using standardized outcome measures and assessing long-term knowledge retention using e-learning platforms.

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1. Introduction

The goal of medical education is to prepare students for the rigors of residency training. Despite this objective, lack of medical knowledge ranks among the top struggles of fourth year medical students from the viewpoint of residency program directors.[1] Traditionally, surgical sub-internship programs lack a uniform procedural curriculum.[2] One analysis, performed by Lindeman et al. in 2013 stated that nearly 80% of the surgical sub-internship programs were "devoid of technical and procedural skill laboratories."[3] This sentiment is likely shared among physician educators across a variety of surgical specialties, including orthopedic surgery.

One approach to addressing this problem has been implementation of e-learning. In its most rudimentary form, e-learning is the use of internet-based resources for teaching and learning. In surgical specialties, e-learning encompasses the use of virtual patient cases, digital modeling, online tutorials, and standardized videos and images.[4] Furthermore, developers may incorporate a variety of updated education strategies such as spaced-repetition learning and "blended-learning", which combines online and face-to-face instruction.[5]

The advantages of e-learning in the surgical setting are well-established. In addition to being easily accessed and updated, e-learning platforms accommodate a wide variety of learning styles and effectively teach a broad array of surgically relevant information. Interactive, web-based media significantly improves surgical skill and reduces error rates and operative time in both general surgery and plastic surgery resident operations.[6,7] Furthermore, the use of case-based e-learning software by medical students has significantly improved retention of clinical and theoretical knowledge over three weeks after use of the software ceased.[8] A number of studies indicate that both surgical residents and medical students who use e-learning programs are more satisfied with their learning experience compared to those who use traditional teaching methods.[9,10,11]

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Technological advances and sophisticated applications have increased the acceptance and widespread use of internet-based teaching methods.[12] While use of e-learning platforms in surgical training has expanded over recent years, the role of this technology within orthopedic surgery remains unclear. We present a review of current literature regarding e-learning methods related to training orthopedic surgeons. Given the innate propensity for rapid technological change within the field, we focus on relevant literature from the past 10 years specific to orthopedic surgery.

2. Materials and methods

This study was conducted following guidelines defined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement (PRISMA).[13] Inclusion criteria for this study were interventional studies that evaluated the efficacy of an e-learning program, software, or web-based curriculum for students and residents training specifically in orthopedic surgery. We took particular focus on studies published in English, in peer-reviewed journals from 2005 to 2015. Abstracts, reviews, and analyses of non- web based modalities and simulations were strictly excluded.

A medical librarian conducted systematic literature searches in four databases: PubMed, Embase (on Embase.com), Web of Science and the Cochrane Library. Both controlled vocabulary and text word searches were performed in PubMed and Embase. All search results were combined in a bibliographic management tool (Zotero). The final searches were run on June 18, 2015. Our search strategy had three concepts; the concepts were linked together with the AND operator: (1) e-learning; (2) orthopedic surgery education; and (3) medical students or residents.

From the search results, relevant articles were selected based on abstract review. Non-relevant articles, as well as those that did not fit the predetermined search criteria, were strictly excluded and the remaining selections underwent full text review (Fig. 1). Information on these selections is presented based on type of intervention and overall result of study. Relevant subjective feedback on intervention and study design was noted if feasible.

3. Results

Using the search criteria previously defined, 9 studies were selected for further review (Table 1). Nine studies were identified that investigated and compared e-learning to traditional teaching methods. As outcome measures, one study looked at students' self-assessment of clinical abilities,[14] seven studies investigated learners' preparation for clinical procedures,[12,15,16,17,18,19] and two studies focused on students' performance in clinical skills.[20,21] These prospective randomized trials and pilot studies demonstrate that e-learning enhances knowledge acquisition and student satisfaction for preparation and performance in orthopedic skills.

Mehrpour et al. studied the efficacy of a supplemental video in medical student splinting training.[21] 473 medical students were divided into two groups, one received a lecture and the other received a training video to supplement the lecture. An Objective Structured Clinical Examination (OSCE) assessed the competency, knowledge, and skills of the students in thirteen areas of splinting six months after the training. Mehrpour et al. reported that the group with access to the educational video scored significantly higher on the OSCE, reflecting a positive association between e-learning and performance in clinical skills such as splinting (7.6 vs 2.0, $p < 0.001$).

Ceponis et al. also used instructional videos as an e-learning modality to teach diagnostic shoulder arthroscopy.[17] Ceponis randomly split ten PGY2-3 residents into a traditional cadaver-based teaching group and a composite model-plus-video teaching group. Ceponis found that only the composite group had a significant increase in score from pretest to posttest (cadaver

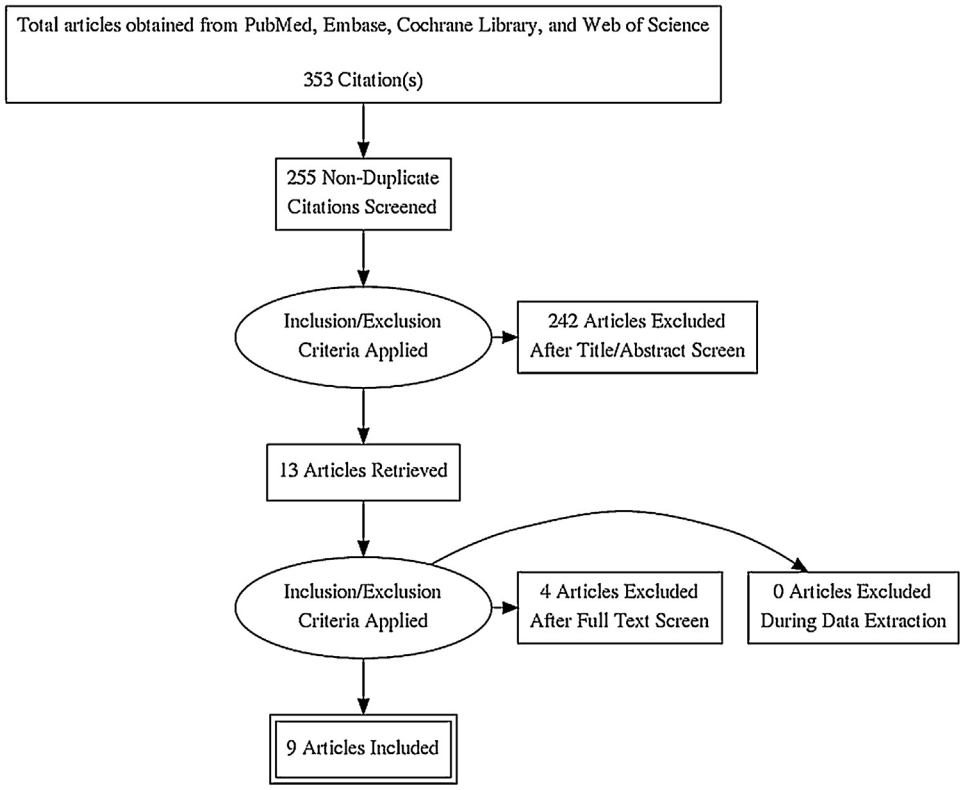

Fig. 1. Search algorithm.

Table 1
Articles that incorporate e-learning in orthopedics training.

Authors	Subjects	Intervention	Outcome measure	Results
Mehrpour et al.	474 6th-year medical students	Lecture series with vs without online video series for injured-limb splinting.	Performance on Objective Structured Clinical Examination (OSCE) for splinting ability.	Video students scored better on clinical splinting exam ($p < 0.001$).
Obdeijn et al.	28 medical students	Computer-based learning module (CBL) vs pre-recorded lectures for wrist arthroscopy training.	Independently developed MC exam pre/post intervention, follow-up exam at 1 week	CBL students showed greater score improvement post-intervention ($p = 0.021$); no difference at 1 week ($p = 0.194$).
Vivekananda-Schmidt et al.	354 3rd-year medical students	Standard curriculum with vs without CBL module for MSK anatomy and clinical skills at 2 sites.	Knee and shoulder OSCE; Confidence Log score	CBL students scored higher on OSCE at both sites ($p = 0.002$; $p = 0.04$); CBL students scored higher on C-Log at one site ($p = 0.005$), no difference at other site ($p = 0.582$).
Wunschel et al.	160 5th-year medical students	Use of virtual orthopedic patient module for diagnostic practice.	Independently developed MC exam pre/post intervention.	Students showed significant score improvement post-intervention ($p = 0.0001$).
Back et al. (Jan 2014)	53 5th-year medical students	Standard curriculum with vs without NESTOR CBL module.	Independently developed and validated MC exam pre/post intervention, follow-up MC exam and OSCE at 3 months.	Both groups improved scores on both post-intervention exams ($p < 0.001$). NESTOR users further improved from post-intervention to f/u MC exam ($p = 0.009$), non-users did not. No difference observed in OSCE scores.
Back et al. (May 2014)	217 4th-year medical students	Voluntary (2009–10) vs mandatory (2010–11) usage of NESTOR CBL module.	Independently developed and validated MC exam pre/post intervention.	Mandatory-use students showed a greater absolute increase in exam scores following intervention ($p = 0.015$).
Ceponis et al.	10 orthopedic surgery residents (PGY1-2)	Cadaveric-based vs composite model/video training groups for diagnostic shoulder arthroscopy.	Independently developed MC exam (based on institutional guidelines) pre- and post-intervention.	Composite students improved exam scores pre- to post-intervention ($p = 0.0016$); cadaveric students did not ($p = 0.1103$).
Hearty et al.	28 Orthopedic surgery residents (PGY2-PGY4)	E-learning surgical training module (Computer-Enhanced Visual Learning platform) vs standard text book learning.	Independently developed and validated MC exam (post-intervention) on closed reduction and percutaneous pinning of a pediatric supracondylar humeral fracture.	Video module group had higher scores than the control group overall ($p < 0.001$), and amongst their respective PGY classes (PGY2, $p < 0.001$; PGY3, $p = 0.006$).
Heiland et al.	12 Surgery residents (PGY1-PGY5)	Video-based training modules with supervisor feedback vs standard supervisor feedback on intraoperative skills.	Validated quality score based on exposition of important anatomy, intraoperative bleeding, and efficacy of using bipolar cauterization.	Mean quality score of video group was higher than that of control ($p = 0.04$). Video group had a smaller learning curve than control group ($p = 0.02$).

20.8 ± 1.98 to 25.4 ± 1.12, $p = 0.11$ vs composite $18.2 \pm .66$ to 24.8 ± 1.02, $p = 0.0016$).

In surgical training, a certain number of surgeries must be performed before a surgeon hits a learning plateau.[20] Heiland et al. used a video training model to decrease the number of repetitions needed for the residents to hit their plateaus (surgery 7 vs 12). Heiland reports that the difference in surgical skill changes significantly between PGY1 to PGY2 ($p = 0.04$), making the beginning of surgical training an ideal window to test new teaching methods. Twelve residents were divided into two groups, with only one group using a surgical microscope Zeiss Pentero 800 with video recording capability. The residents in the video-based training group reviewed their recorded surgeries with an experienced attending after the operation. The gradient of linear regression curve between scores for the first and seventh surgery reveals a significantly steeper curve for the video-based training group ($p = 0.02$). After the twelfth surgery, the control group improved to the level of the video-based learning group and there was not a final difference.

Back et al. developed a novel e-learning platform, called NESTOR, which features orthopedic examination videos covering inspection, palpation, motion, special tests; interactive radiology cases with X-rays, MRI, CT images and patients histories; audiovisual podcasts for diseases; multiple choice questions to enable self-assessment by the students; and online contacts who answer questions promptly.[15] 35 of 53 fifth-year medical students chose to supplement their orthopedic course with NESTOR and both NESTOR-users and non-users completed pre-tests, two post-tests, an OSCE, and a questionnaire. The NESTOR non-users and the NESTOR-users both improved their scores from pretest to posttest ($p < 0.001$) with slightly higher scores on the post-tests by NESTOR users. NESTOR-users significantly improved from post-test 1 to post-test 2 whereas non-users did not ($p = 0.009$). The OSCE scores did not differ between the groups. Students who used NESTOR reported that they were satisfied with the e-learning modality (92%), approved its structure (83%), had fun with the program (91%), and considered NESTOR useful in preparing for clinical situations (74.3%). Students rated the physical examination videos highest, followed by interactive X-ray cases. In another study to apply e-learning to long-term course development, Back et al. investigated changes in e-learning efficacy and popularity after NESTOR became mandatory.[16] The study showed that appreciation of the e-learning course remained high, significantly more students felt prepared for clinical situations ($p < 0.001$), and overall satisfaction with learning resources rose. Back et al. reported that final level of knowledge was not significantly

different when e-learning was mandatory compared to when e-learning was voluntary.

In a multisite, prospective randomized controlled study, Hearty et al. divided 28 PGY2-4 residents into one group that used a textbook for case preparation and another that supplemented the book with Hearty et al.'s independently developed e-learning module on closed reduction and pinning of supracondylar humeral fractures.[18] The e-learning module was presented in an outline format organized into 12 sequential components, each divided into a series of steps. The module was narrated with detailed explanations and a road map with incorporated diagrams, radiographs, animations, and video clips of surgical cases. Each component had defined goals and incorporated key surgical principles into the presentation and narration. There was also an evaluation tool that allowed the attending surgeons to add information and evaluate the residents' knowledge and technique. The post-test scores on the pre-surgery 60-question test were significantly higher for the group that used the e-learning module ($90.9 \pm 6.8\%$ vs $73.5 \pm 6.4\%$). The residents unanimously agreed that the module was a useful supplement to conventional training and would like to use the platform for other orthopedic procedures. Twenty-two of the residents agreed that the e-learning module reduced their anxiety during cases and improved their attention to surgical detail. The eight pediatric orthopedic attending surgeons surveyed agreed that residents who trained with e-learning were better prepared than previous residents.

Obdeijn et al. harnessed the possibilities of e-learning for diagnostic wrist arthroscopy training by developing and validating a computer-based learning (CBL) module.[19] The CBL module was a flexible system with interactive images and animations with narration to clarify various aspects of the procedure. Obdeijn's module was approved by an international panel of experts in wrist arthroscopy and validated against conventional teaching methods. 28 medical students were randomly divided into two groups, one learned from lecture and the other used the CBL module. The participants were given a pretest and posttests directly after the module and one week later. The group who used CBL indicated a significantly higher level of pleasantness when learning the material (Mann–Whitney U test $p = 0.015$) and scored significantly higher on the immediate post-test (Mann–Whitney U test $p = 0.044$), but did not score any higher on the one week post-test (Mann–Whitney U test, $p = 0.194$). 55 of 65 surveyed experts in wrist arthroscopy indicated that a computer program could be an asset for teaching this skill. The CBL module and the lecture were equal lengths, but the students in the control group indicated the lecture was too long, while the interactive CBL group reported the time was adequate.

Wünschel et al. designed and implemented a web-based virtual outpatient clinic with orthopedic patients into a medical school curriculum to enhance problem-based learning skills and augment the teaching load.[12] This blended learning approach incorporated virtual patients into the practical training curriculum by combining in-person training with e-learning simulations. 160 medical students participated in the study and Wünschel et al. found that exam results significantly improved after using the simulation (7.66 vs 8.37, $p < 0.0001$). 80% of participants reported an enjoyable experience with the simulator, citing the comprehensive patient cases, artistic design, and valuable commentary as particularly helpful and applicable to real cases. 87% of participants indicated that the virtual orthopedic clinic was appropriate to teach content and 56% had a heightened interest in orthopedics after engaging with the virtual patients. Although students were required to see seven virtual patients, the average was nine, supporting Wünschel's assertion that students enjoyed the system. Medical student performance was strongly dependent on the amount of time the students used the simulation, with those spending more time scoring significantly higher ($49\% < 1.5$ h, $57\% < 6$ h, $59\% > 6$ h; $p < 0.05$).

4. Discussion

Increased accessibility of the Internet has created a new portal for education resources with enhanced pleasantness and efficacy.[12] Known for its recipient-oriented approach,[22] e-learning has broadened learning experiences beyond face-to-face interactions and textbooks to enhance individualized student preparation and accommodate learning preferences.[16] The nine studies in this review validate and demonstrate the potential for e-learning in orthopedic education at the medical school, residency, and attending continuing-education levels.

The studies in this review demonstrate the diversity in e-learning's accessible multimedia platforms ranging from videos to interactive patient simulations with various options for learner interaction. Mehrpour et al. and Ceponis et al. used instructional videos as their e-learning modalities.[17,21] Heiland et al.'s e-learning platform included videos of the residents' own surgeries.[20] Back et al. created NESTOR, a program that allows learners to choose between examination videos, diseases podcasts, interactive radiological cases, and virtual patients to learn orthopedic topics from student-selected lectures.[15] Hearty et al. developed a surgical training platform with a detailed step-by-step roadmap of an orthopedic surgery and Obdeijn made a computer-based module for performing diagnostic wrist arthroscopy.[18,19] Wünschel et al. designed a virtual orthopedic outpatient clinic with twelve virtual patients.[12] The many ways e-learning can be applied to orthopedics presents great opportunity for incorporation into a variety of programs at every level of training.

Surgical skills are difficult to teach and master due to the challenges of working with new equipment and the extensive knowledge required.[19] A comprehensive background in indications, complications, therapy, anatomy, physiology, and equipment puts the student in a better position to train in the use of arthroscopic instruments, entry points, and patient positioning during a procedure.[19] Orthopedics training involves psychomotor skill development and hands-on physical examination techniques that can be improved and expedited through e-learning modalities. Ceponis found that employing standardized, video-taped shoulder arthroscopies with model demonstrations is effective in familiarizing the resident with equipment, the sequence and steps of a procedure, identifying bony landmarks and standard arthroscopy portals, understanding the orientation of the scope, sheath, and camera, and identifying normal and pathological shoulder anatomy, which provides a good base for skill development.[17] Students ranked the lecture records and physical examination videos highest, signifying e-learning's suitability for teaching practically oriented subjects in orthopedics. Mehrpour and Heiland both showed that video assisted training enhances performance in orthopedic clinical skills.

All nine e-learning platforms allowed the learner to go through the material at any pace, backwards and forwards, to maximize flexibility and individualized lessons. Mehrpour et al. suggested that allowing students to navigate through videos to resolve uncertainties in orthopedics allowed students to spend their time more efficiently by focusing on portions of the module that addressed their questions.[21] Obdeijn demonstrated that students in a passive learning environment think that time moves more slowly than students who are actively engaged in e-learning.[19] The flexible learning system likely contributes to the high satisfaction ratings in both voluntary and mandatory e-learning implementation settings reported by Obdeijn, Wünschel, Ceponis, Back, and Hearty.

Medical students and residents who use the Internet to supplement their orthopedic knowledge often encounter difficulty identifying appropriate, accurate resources because they are inexperienced in the field in which they are investigating.[19] E-learning programs in orthopedic surgery can ameliorate this issue by providing a reliable, consistent, updated source of orthopedic knowledge. Although textbooks and websites with peer-reviewed lectures and literature exist, e-learning is unique in its reciprocal interaction with the learner. Obdeijn showed that students who used the more interactive system have enhanced information uptake, but do not retain their knowledge long-term if the material is not utilized or practiced. Due to e-learning's instant accessibility, residents can navigate the lesson prior to applying their knowledge in clinical practice. For example, the e-learning platforms created by Hearty et al. and Obdeijn et al. each encompassed full procedures with step-by-step tangible goals.[18,19]

Orthopedic training is adapting with technology and with new regulations and hospital policies.[18] New work hour restrictions and heightened focus on patient safety and reduced surgery times indicates a need for new methods to train surgical residents outside of the operating room.[18] Rapid development of surgical skills is important in training due to the increased cost for longer surgeries typically associated with resident training.[17,20] E-learning has the potential to increase surgical residents' preparedness, confidence, and comfort with surgery prior to entering the operating room.[18] Acquisition of surgical skills follows a learning curve influenced by practice, exercises, feedback, and training.[20] Heiland et al. showed that e-learning provides a type of intensive response and intraoperative analysis that can increase the speed of improvement in surgical skills.

Access to orthopedic teaching patients is challenging due to short hospitalization times and an increasing number of patients treated on an outpatient basis. Virtual patients fill the gap and ensure a broad spectrum of training that does not rely solely on textbook knowledge.[12] E-learning reduces the workload for the instructor and creates consistency and convenience for the student.[23,24] Many orthopedic programs train with cadavers, which are not standardized, require dedicated space, cost, supply, and legal issues.[17] E-learning platforms are flexible, standardized, archived, reused, and free the institution from the costly specialized facilities necessary to house a cadaver-based program to prepare residents for operating room.[17]

5. Limitations

This review is limited by the vast array of e-learning modalities presented in the different studies, making it difficult to make broad claims about the application of Internet learning. Because each study utilized a different e-learning platform, drawing conclusions about which type is best for different programs is difficult. By including this variation, we intend to show that e-learning has the flexibility both for the students and program directors to integrate into and enhance a vast array of curricula. This study also lacks the conclusive power of a quantitative meta-analysis.

6. Future work

E-learning proponents theorize that if residents have a better under understanding of the steps and goals of a surgery, they will be more precise and faster-learners in the operating room.[18] Future work must look beyond student and instructor satisfaction ratings and test scores designed to gauge preparation for surgical procedures. The goal of orthopedic training programs is to train adept, agile surgeons. Thus, direct connection between e-learning teaching methods and final surgical skills should be assessed more broadly. Only Heiland et al. looked at surgical outcomes and found a steeper learning curve in residents who trained with an e-learning platform. While connections between enhanced preparation and enhanced performance are likely, more data is necessary to evaluate this connection and investigate the efficacy of E-learning in orthopedic surgery performance.

7. Conclusions

As technology advances and training pressures rise, e-learning is an economical, innovative, and reputable platform for program directors to incorporate into their curricula. These studies demonstrate the value of e-learning for enhanced orthopedic learning, improved clinical skills, and heightened learner satisfaction. The various implementations of blended learning highlight its flexibility and potential for e-learning to contribute to the future of orthopedics.

Conflicts of interest

The authors have none to declare.

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