White paper

Educational technologies for simulation in spine courses

Version 1.4 (July 2023)

AO Spine Educational Strategies Taskforce

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This document has been developed for AO Spine Chairpersons and Faculty designing courses, for national and regional education officers, and for AO Spine Event Owners to help plan educational offerings (ie, to select educationally sound and cost-effective methods to design activities to enhance surgical skills in learners). The opinions expressed are those of the surgeons involved and do not constitute any endorsement of the products discussed. The authors disclose any financial relationship with the companies or products mentioned in the appropriate sections. The list of products is not exhaustive, and new reviews will be added each year if considered valuable.

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Contents

1 Introduction and terminology

In the Journal of Orthopaedic Surgery and Research 2014, Stirling et al define simulation as "any technology or process that recreates a contextual background in a way that allows a learner to experience mistakes and receive feedback in a safe environment". It aims to recreate the experience of patient care without compromising patient safety. The ability to modify a situation allows trainees to experience novel but often important situations that may not be commonly experienced in clinical practice. The benefits of simulation are recognized by many specialties and has been advocated by many medical bodies and colleges. The advantages of simulation extend beyond simple technical and procedural skills. Simulation allows trainees to engage with a multi-disciplinary team and focus on individual and team-based cognitive skills including problem solving, decision-making, and team behavior skills.

Stirling summarized the main modalities below and for the purposes of our white paper for AO Spine, we discuss five types of simulation technology: Dry bone models and enhanced versions, synthetic anatomical models, telementoring, virtual reality (VR), and augmented reality (AR).

Table 1 A summary of the main simulation modalities available to orthopaedic surgery trainees

Simulation model	Advantages	Disadvantages
Cadaveric simulation		Expensive
	High fidelity	Not easily accessible with specialist storage demands
		Time-consuming preparation time
	Shown to develop transferable operative skills	Relies on tissue donation
		Risk of disease transmission
	Allows understanding of relevant clinical anatomy and surgical approaches	Lack of uniformity amongst specimens
Synthetic bone simulation	Relatively inexpensive, portable and widely available	
	Widely available	Does not allow understanding of influence of soft tissues
	Develop understanding and familiarity with orthopaedic instruments and equipment	Lack of true haptic feedback
Arthroscopic simulation	Able to record progress and assess motion analysis	
	Allows for development of hand-eye co-ordination and triangulation	High initial setup costs
	Wide range of procedures may be possible	Limited realism
	Modern simulators can provide haptic feedback	
Virtual reality simulation	Able to record progress and assess motion analysis	
	Wide range of procedures may be possible	High initial setup costs
	Allows for scenario simulation	
Cognitive simulation	Potentially cost free	Limited evidence to support use in clinical training/improvement in technical procedural skills
	Accessible on mobile devices	
	Point of care education	

AR and VR are becoming more common as both operative and teaching tools in spine surgery, although their use is still relatively new and in constant evolution (Yuk et al, 2021). There are three types: VR, where the entire simulation is virtual, AR, a technology that superimposes a computer-generated image onto the view of the real world, and mixed reality (MR) which combines virtual and real experiences.

2 Rationale and goals

2.1 Current state and limitations

Most courses delivered by AO Spine teach surgical skills using dry bone models without any soft tissue or human anatomical specimens (HAS). These methods are both appropriate for enabling participants to complete steps or full procedures and to receive structured feedback from faculty as taught in AO faculty development programs. Peer interaction is enhanced through sharing the exercises between two or more participants. However, there are several limitations with these models. HAS are costly, vary in quality, rarely exhibit the relevant pathology, and are unavailable in many countries. Dry bone models, while anatomically correct, do not mimic the soft tissue environment present clinically nor do they provide realistic haptics critical in instrument handling. Finally, while feedback to participants comes from course faculty, there is no data collected that could provide an objective assessment of skill acquisition.

The current state and limitations of the addition of newer simulation options remain unknown or unconfirmed within the context of AO Spine courses and education. Reviewing the current literature provides some guidance that we can test in our context.

2.2 Aim and anticipated benefits

The intentions of this white paper are:

- provide information to help chairpersons make good planning decisions based on the available evidence
- encourage everyone to share experiences and outcomes data to plan future educational offerings
- identify and run research projects to answer the key open questions

The anticipated benefits of exploring alternative options on a larger scale are:

- more effective learning for the target audience level
- more cost-effective use of resources
- enhanced learning and teaching
- allow learners to acquire surgical skills in nontraditional environments (outside of courses and the OR). This has become essential as educational paradigms have changed in the post pandemic environment.

2.3 Technology evaluation process and metrics

To provide a structured approach to the assessment of new simulation technology and products, the educational strategies taskforce created a template to collect the following information (which we plan to develop further into more formal metrics for assessment). By collecting data and feedback in a standardized way, we can collate information and make comparisons when we add new reviews.

- Company and product name
- Procedures covered
- Realism
    - Realistic patient tissue (bone, soft tissue, tactile, realistic palpation)
    - Realistic instruments (feel, handling, behavior eg, on bone)
    - Realistic imaging (fluoroscopy, CT, 3D, endoscopy, microscopy)
- Assessment and recording
    - What feedback is provided to the learner?
    - What performance data are gathered (or recorded)?
- Cost and scalability
- Potential uses for AO Spine events and in the curriculum

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3 Review of simulation types and platforms

For each type of simulation, we describe the main features and summarize some advantages and limitations. We list the specific products we have reviewed in this area (details on the subsequent pages) and provide abstracts of key articles and additional product and company information in the Appendices.

3.1 Dry bone models and enhanced versions

Dry bone models are the standard for our basic hands-on teaching method for practical exercises and is relatively available and transportable. Trainees work on an artificial but anatomically correct bone model that can mimic certain fractures or pathologies. 3-D printed models based on CT or other data have become an option for complex pathology where small numbers are required (may be more suitable for demonstration rather than having at many workstations). However, the lack of critical soft tissues is one of its main limitations.

Dry bone models with an extra layer of 'soft tissue' simulate, to a certain extent, the intraoperative conditions.

Full trunk models with the full spine, ligaments, dura, muscle, and skin to allow for a more realistic simulation and alleviates some of the issues with the dry bone models that often lack critical structures.

Dry bone models with in-built data monitoring add some performance assessment systems through different types of sensors or cameras.

- Example products reviewed
    - Synbone, SurgiSTUD, Medability, DEHST

3.2 Synthetic anatomical models and enhanced versions

Spine model that simulates the bone structures of the real spine with skin, muscle, ligaments, dura, and cerebrospinal fluid. The addition of soft tissue and fluids offers experiences that are much closer to real spinal surgery. They provide realism and fidelity and require less maintenance and preparation compared with cadaveric models. The presence of cerebrospinal fluid also permits simulation of emergency situations. Though these are typically more expensive, they offer features for assessment and feedback options.

- Example products reviewed
    - Realists, UpSurgeOn

3.3 Telementoring (enhancing exercises or operations)

These are systems using video connections to an exercise, lab, or real operation where a faculty member can provide guidance remotely using software tools.

- Example products reviewed

* Proximie, Immertec, Swiss Surgical Video, Rods and Cones

3.4 Virtual reality

Virtual reality (VR) utilizes a computer processing unit with a head-mounted display to provide visual and auditory cues coupled with hand controllers, containing position trackers and force feedback, to provide an immersive experience. Based on a systematic review from 2021 analyzing 17 independent studies, immersive VR-trained surgeon groups performed 18% to 43% faster on procedural time to completion compared to control. Immersive VR trainees also demonstrated greater post-intervention scores on procedural checklists and greater implant placement accuracy compared to control. VR incorporation into surgical training programs also received positive user ratings, and it is cost-effective. (Immersive Virtual Reality for Surgical Training: A Systematic Review, Randi Q. Mao,2021, DOI:https://doi.org/10.1016/j.jss.2021.06.045)

VR equipment (goggles and handles) can also be shipped to remote places and in some cases the teaching modules can be saved locally with no need for internet connection. The applications go from procedural training to anatomical models, to virtual classrooms (where remote participants are virtually in the same room). Some disadvantages include the realism and the haptic feedback that is still basic and distant from the one provided by dry bone or synthetic anatomical models or specimens.

* Example products reviewed
    * NonNocere (virtual classroom), Precision OS

3.5 Augmented reality

AR is the superimposition of a computer-generated image onto the view of the real world (virtual component onto physical reality). A systematic review of 18 publications focusing on the impact of AR on motor skills training as compared with traditional techniques showed either no difference or improved performance from using AR. Regarding procedural time, the data tended to suggest use of AR was slower than traditional techniques. With regard to user opinion, AR was favored by surgeons in all but one of the studies—in which cadaveric models were preferred. Subjective opinion-style data must always be treated with caution as the novelty of new technology can sometimes be sufficient to sway opinion regardless of performance. (Augmented reality in surgical training: A systematic review. Available: https://www.researchgate.net/publication/340292072_Augmented_reality_in_surgical_training_A_systematic_review [accessed Aug 19 2022]).

AR has been applied in spine surgery in the form of a heads-up display in the positioning of pedicle screws, in deformity, kyphoplasty, and vertebroplasty. In all the studies it showed some benefits regarding improvement of surgical outcome (The utility of virtual reality and augmented reality in spine surgery. Doi: 10.21037/atm.2019.06.38 :http://dx.doi.org.)

* Example products reviewed
    * Brainlab (mixed reality), Xvision (Augmedics)

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4 Assessment of simulation products

4.1 Dry bone models and enhanced versions

Product/company **Synbone** **https://www.synbone.com/**	**Question**	**Rating and comments**
Scope	What procedure(s) does it address?	Spine fixation (all techniques) Ligamentotaxis Scoliosis derotation Deformity correction Other models can be developed and cost-effective soft tissue add on parts constantly explored
Realism: (rating 5 = ideal, down to 1 = not present) and add comments	Realistic patient tissue (bone, soft tissue, tactile, realistic palpation)	Bone = 5 Soft tissue (not available currently in most models – new developments coming) Tactile = 4
	Realistic instruments (feel, handling, behavior, eg, on bone)	5 (adding soft tissue would enhance the feel of instruments)
	Realistic imaging (fluoroscopy, CT, 3D, endoscopy, microscopy)	No Bones can be scanned and images/reconstructions provided
Assessment and recording (rating 5 = ideal, down to 1 = not present)	How does formative and summative assessment of the trainee (to allow learning curve display, etc.) work?	Very well as one can be assisted by a faculty and have real time feedback
	What feedback is provided to the learner?	Only from faculty: real time technical skills feedback
	What performance data is gathered (or recorded)?	None directly from the models
Cost and scalability	Cost	Lower than simulators (but expensive for some locations)
	Scalability (issues, requirements, etc)	High level (bulk purchasing may help). Scalability is probably limited more by instrument availability than the dry bone model access.
AO Spine events and curriculum	Potential best uses	Principles courses Hands-on demos in symposiums and congresses

Product/company **SurgiSTUD** https://surgistud.com/	**Question**	**Rating and comments**
Scope	What procedure(s) does it address?	Spine fixation (all techniques) Ligamentotaxis Scoliosis derotation Deformity correction Lateral/anterior approaches Incorporates actual anatomical structures encountered in different approaches for pathologies.
Realism: (rating 5 = ideal, down to 1 = not present) and add comments	Realistic patient tissue (bone, soft tissue, tactile, realistic palpation)	Bone 5 Soft tissue 2 Tactile 4
	Realistic instruments (feel, handling, behavior, eg, on bone)	
	Realistic imaging (fluoroscopy, CT, 3D, endoscopy, microscopy)	
Assessment and recording (rating 5 = ideal, down to 1 = not present)	How does formative and summative assessment of the trainee (to allow learning curve display, etc.) work?	Very well, as one can be assisted by a faculty and have real time feedback
	What feedback is provided to the learner?	None directly from the models. Real time faculty feedback
	What performance data is gathered (or recorded)?	None
Cost and scalability	Cost	Higher than plain dry bone models, especially for customized models
	Scalability (issues, requirements, etc)	Low, due to cost Ideally, have imaging integrated and need a translucent table.
AO Spine events and curriculum	Potential best uses	Principles courses (expensive) Hands-on demos in symposiums and congresses Remote training

Product/company **Medability** https://medability.de/	Question	Rating and comments
Scope	What procedure(s) does it address?	MISS procedures and interventional procedures where accurate imaging is crucial
Realism: (rating 5 = ideal, down to 1 = not present) and add comments	Realistic patient tissue (bone, soft tissue, tactile, realistic palpation)	4
	Realistic instruments (feel, handling, behavior, eg, on bone)	Behaves well and the real instruments integrated 4 or 5
	Realistic imaging (fluoroscopy, CT, 3D, endoscopy, microscopy)	This is the main quality of the product. Produces good x-ray and CT images. Includes fluoro, CT, navigation, and 3D anatomy view.
Assessment and recording (rating 5 = ideal, down to 1 = not present)	How does formative and summative assessment of the trainee (to allow learning curve display, etc.) work?	Very well, as one can be assisted by a faculty and have real time feedback Recorded performance scores and intraoperative images
	What feedback is provided to the learner?	Visual display of positioning – real time feedback. Anatomy. Objective performance scores (see below)
	What performance data is gathered (or recorded)?	X-ray use (and potential radiation), images • Precision of instrument/implant • placement • Critical anatomy injured (eg, • spinal cord, major vessels, • nerves) • Surgical outcome (eg, Gertzbein score) • X-ray intraop and postop images • X-ray time • Number of x-rays taken • C-arm alignment • Time to complete procedure
Cost and scalability	Cost	Medium/high
	Scalability (issues, requirements, etc)	Good. The whole system can be rented. Cartridges are changed several times to allow many participants to work. Can be expanded for most procedures. No calibration required
AO Spine events and curriculum	Potential best uses	Principles courses Advanced MISS courses Congress demos

Product/company **DEHST - Digitally enhanced hands-on surgical training** https://www.aofoundation.org/innovations/innovation-translation/technology-transfer/digitally-enhanced---hands-on-surgical-training	Question	Rating and comments
Scope	What procedure(s) does it address?	Development from AO ARI and AO Innovation Translation Center (AO ITC) DEHST is a novel modular, cost-effective and transportable platform for surgical skills training and assessment. It augments haptic stations for hands-on training with digital technologies to enhance training scope and improve user experience. A proprietary optical tracking technology is utilized to allow position and orientation tracking in 6 degrees of freedom from a single planar image projection. This tracking technology is adapted for use with a conventional video camera, enabling tracking of the specific movements during surgical tasks and providing comprehensive performance analysis in low-cost fashion. For spine surgery, the concept can be adapted for training/assessment of 1) Pedicle screw placement 2) SI screw placement Both modules focus on training/assessing the most important task, placing a k-wire/instrument/screw in an anatomical region under fluoroscopy guidance.
Realism: (rating 5 = ideal, down to 1 = not present) and add comments	Realistic patient tissue (bone, soft tissue, tactile, realistic palpation)	The stations need to be examined by surgeons to provide the ratings
	Realistic instruments (feel, handling, behavior, eg, on bone)	
	Realistic imaging (fluoroscopy, CT, 3D, endoscopy, microscopy)	

Assessment and recording (rating 5 = ideal, down to 1 = not present)	How does formative and summative assessment of the trainee (to allow learning curve display, etc.) work?	
	What feedback is provided to the learner?	Based on the metrics below, scores for performance can be shown
	What performance data is gathered (or recorded)?	Time to complete a task Number of x-rays taken Precision of positioning a drill/k-wire/screw into anatomical region Drilling/ insertion depth Positioning of implant/instruments and bone fragments Evaluation of C-arm alignment in relation to bone and implant False direction attempts Success rate (hit/miss) of a task
Cost and scalability	Cost	Not defined yet
	Scalability (issues, requirements, etc)	Concept is modular, can be extended to other applications with integration of other sensors (temperature, force, pressure)
AO Spine events and curriculum	Potential best uses	Training system as a box trainer in: • Hospital-based training • Courses Another product for biomechanics called OSApp is available that could also be developed for spine (refer to the appendices)

Product/company FUSETEC assessed only by visiting https://fusetec.com.au/training/neurology-spine/	**Question**	**Rating and comments**
Scope	What procedure(s) does it address?	It allows simulation of surgical procedures from approach to implant insertion
Realism: (rating 5 = ideal, down to 1 = not present) and add comments	Realistic patient tissue (bone, soft tissue, tactile, realistic palpation)	To be tested: Soft tissues such as muscles appear to be rubberized / plasticized and may not look real. May show different tissue layers.
	Realistic instruments (feel, handling, behavior, eg, on bone)	Instruments to be used are provided by the surgeon
	Realistic imaging (fluoroscopy, CT, 3D, endoscopy, microscopy)	No imaging included
Assessment and recording (rating 5 = ideal, down to 1 = not present)	How does formative and summative assessment of the trainee (to allow learning curve display, etc.) work?	Trainee can be watched - procedure can be recorded so that trainee can be given both live and 'post-op' feedback.
	What feedback is provided to the learner?	No inbuilt feedback
	What performance data is gathered (or recorded)?	None
Cost and scalability	Cost	To be clarified
	Scalability (issues, requirements, etc)	If affordable, the models may be transported easily
AO Spine events and curriculum	Potential best uses	Training course on surgical approaches and insertion of spine instruments

Product/company TrainOS assessed only by visiting https://trainos.de/	**Question**	**Rating and comments**
Scope	What procedure(s) does it address?	Models to familiarize learners on implant insertion (pedicle screw insertion). Can be mated with a navigated equipment. Bones are imbedded in a translucent gel like matrix allowing the learner to see how learner is progressing.
Realism: (rating 5 = ideal, down to 1 = not present) and add comments	Realistic patient tissue (bone, soft tissue, tactile, realistic palpation)	Appears not too different from ordinary bones except for the gel like matrix where the bones are imbedded. Tactile feel and soft tissues need to be tested with hands on experience.
	Realistic instruments (feel, handling, behavior, eg, on bone)	To be tested
	Realistic imaging (fluoroscopy, CT, 3D, endoscopy, microscopy)	Based on the website pictures and video, this appears not to be a strong quality of the product.
Assessment and recording (rating 5 = ideal, down to 1 = not present)	How does formative and summative assessment of the trainee (to allow learning curve display, etc.) work?	2.5 The learner performing a procedure can be provide with feedback since the spine can be viewed thru the translucent matrix covering the bones.
	What feedback is provided to the learner?	Visual feedback on the progress of the instrumentation
	What performance data is gathered (or recorded)?	None
Cost and scalability	Cost	To be explored
	Scalability (issues, requirements, etc)	Likely easy to scale
AO Spine events and curriculum	Potential best uses	Some enhancements over an ordinary bone model but likely to be more expensive

Product/company VIOMERSE assessed using the website https://viomerse.com/	**Question**	**Rating and comments**
Scope	What procedure(s) does it address?	Simulation for approaches, instrumented procedures, and potentially also navigation using 'phantom' specimen
Realism: (rating 5 = ideal, down to 1 = not present) and add comments	Realistic patient tissue (bone, soft tissue, tactile, realistic palpation)	4.5 (based on website and YouTube video) System can present 'pathologic' conditions such as osteoporotic fractures, and other pathologies. Can mimic deformities based on a Dicom file, this can be amenable to navigation if available.
	Realistic instruments (feel, handling, behavior, eg, on bone)	Soft tissues like blood vessels, spinal cord and dura, tumor tissues can be incorporated. See video: https://www.youtube.com/watch?v=2jLSxroxx-4
	Realistic imaging (fluoroscopy, CT, 3D, endoscopy, microscopy)	Bone/vertebral column comes with Dicom file; can use with navigation to practice screw insertion. With C-arm, can have implant insertion, cement augmentation, etc.
Assessment and recording (rating 5 = ideal, down to 1 = not present)	How does formative and summative assessment of the trainee (to allow learning curve display, etc.) work?	Direct observation. Recording should be possible, and, remote training of learners.
	What feedback is provided to the learner?	Visual feedback of the anatomical structures, radiographic feedback (using fluoroscopy and navigation)
	What performance data is gathered (or recorded)?	How adequately the learner is able to identify structures, how accurate is the implant placement, etc
Cost and scalability	Cost	Phantom appears disposable. Adding other soft tissues into the phantom such as spinal cord, dura, etc will likely increase the cost.
	Scalability (issues, requirements, etc)	The phantom models appear to be transportable.
AO Spine events and curriculum	Potential best uses	Familiarization with surgical approaches, navigation, placement of implants, augmentation, etc.

4.2 Synthetic anatomical models and enhanced versions (in built data monitoring, etc)

Product/company **Realists** https://www.realists.de/realspine	**Question**	**Rating and comments**
Scope	What procedure(s) does it address?	Lumbar & cervical spine decompression and fusion - microdecompression (tubular, over the top, cervical foraminotomy) - TLIF, LLIF - Dural tear repair - Lumbar and cervical fixation techniques - Anterior cervical - Spondylolisthesis
Realism: (rating 5 = ideal, down to 1 = not present) and add comments	Realistic patient tissue (bone, soft tissue, tactile, realistic palpation)	Bone 4 Spine canal 4 Nervous tissue 4 Vessels 4 Soft tissue 4
	Realistic instruments (feel, handling, behavior, eg, on bone)	Excellent
	Realistic imaging (fluoroscopy, CT, 3D, endoscopy, microscopy)	Not adequate for X ray. Microscopy perfect Endoscopy good. They offer a good navigation set (no axial image)
Assessment and recording (rating 5 = ideal, down to 1 = not present)	How does formative and summative assessment of the trainee?	Very well, as one can be assisted by a faculty and have real time feedback Available sensors for measuring pressure in the dura
	What feedback is provided to learner?	Real time feedback as shown on camera monitor
	What performance data is gathered)?	
Cost and scalability	Cost	High
	Scalability (issues, requirements, etc.)	Good but expensive for each cartridge (participants can work together in groups of three ideally) Perhaps AO Spine can have stations in fixed locations where learners go instead of transporting No local staff being present as support at the courses (but training is given to the staff supporting the exercises)
AO Spine events and curriculum	Potential best uses	Advanced surgery training courses, MISS Comparable to human anatomical specimens (but with limited offer of surgical procedures) Some suggestions from AO faculty not integrated.

Product/company **Simulatory VRspine** **https://thesimulatory.com/**	**Question**	**Rating and comments**
Scope	What procedure(s) does it address?	Visual ‘journey’ into the spine using imagery and some substitute for tools used in the operating room. Lumbar discectomy any others procedures are available.
Realism: (rating 5 = ideal, down to 1 = not present) and add comments	Realistic patient tissue (bone, soft tissue, tactile, realistic palpation)	2 The video representation of the spine anatomy is not very realistic and more of an illustrative format. The tools used to simulate instruments are not similar to real instruments and the tactile feedback is not optimal.
	Realistic instruments (feel, handling, behavior, eg, on bone)	1
	Realistic imaging (fluoroscopy, CT, 3D, endoscopy, microscopy)	1
Assessment and recording (rating 5 = ideal, down to 1 = not present)	How does formative and summative assessment of the trainee (to allow learning curve display, etc.) work?	2
	What feedback is provided to the learner?	2 Uses illustrations rather than actual anatomic representations
	What performance data is gathered (or recorded)?	It may record the procedure done. May record complications.
Cost and scalability	Cost	Available on request
	Scalability (issues, requirements, etc)	Multiple stations available
AO Spine events and curriculum	Potential best uses	Rudimentary surgical approach familiarization. Could play a role in supporting AO In hospital modules.

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Product/company **UpSurgeOn** **https://www.upsurgeon.com/**	**Question**	**Rating and comments**
Scope	What procedure(s) does it address?	It aims to familiarize the learner on expected anatomical structures during surgery by providing realistic visual imagery and at a magnified capacity. Various pathologies available, particularly degeneration.
Realism: (rating 5 = ideal, down to 1 = not present) and add comments	Realistic patient tissue (bone, soft tissue, tactile, realistic palpation)	4
	Realistic instruments (feel, handling, behavior, eg, on bone)	No instruments provided since the product is one which provides an “anatomical” specimen
	Realistic imaging (fluoroscopy, CT, 3D, endoscopy, microscopy)	Compatible with x-ray, navigation, fluoroscopy, and microscopy, and augmented reality technology
Assessment and recording (rating 5 = ideal, down to 1 = not present)	How does formative and summative assessment of the trainee (to allow learning curve display, etc.) work?	4 Facilitated faculty feedback
	What feedback is provided to the learner?	Visual and tactile
	What performance data is gathered (or recorded)?	
Cost and scalability	Cost	Higher than dry bones, details available on request
	Scalability (issues, requirements, etc)	
AO Spine events and curriculum	Potential best uses	Possible replacement for anatomical specimens and also as stand-alone simulation of procedures

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4.3 Telementoring

Product/company **Proxomie** https://www.proximie.com/	**Question**	**Rating and comments**
Scope	What procedure(s) does it address?	Software platform that allows expert surgeons to scrub virtually from anywhere in the world empowering surgeons to share skills in real time surgery. (Remote mentoring during surgical procedures by utilizing a specific software platform including AR)
Realism: (rating 5 = ideal, down to 1 = not present) and add comments	Realistic patient tissue (bone, soft tissue, tactile, realistic palpation)	For the surgeon in the OR, it is all realistic For the other side it is live annotation and use the AR hand (3)
	Realistic instruments (feel, handling, behavior, eg, on bone)	For the one in the OR yes, no for the other part.
	Realistic imaging (fluoroscopy, CT, 3D, endoscopy, microscopy)	Realistic imaging – yes for both sides
Assessment and recording (rating 5 = ideal, down to 1 = not present)	How does formative and summative assessment of the trainee (to allow learning curve display, etc.) work?	Recording is done for all surgeries, saved, and assessment can be done.
	What feedback is provided to the learner?	Visual feedback. Faculty provide feedback and guidance on how to perform the procedure.
	What performance data is gathered (or recorded)?	Time only. All other data are provided by the faculty to participants
Cost and scalability	Cost	Limited related only to the expenses of the software and camera renting
	Scalability (issues, requirements, etc)	Can be expanded to be done for any procedure related to spine. Can be used extensively on a one-on-one setup with others as 'observer' learners
AO Spine events and curriculum	Potential best uses	Supportive educational tool for the less experienced surgeons doing procedure with guidance by expert and can also be used as an educational tool that the less experienced surgeon can learn by watching and annotation. MISS procedures are very appropriate.

		Its use can be expanded to be part of the diploma program by showing directly how to do a procedure or recording some procedures done that can be evaluated. There are medicolegal issues related to using this with live real patient surgery.

Product/company **Immertec** https://www.immertec.com/	**Question**	**Rating and comments**
Scope	What procedure(s) does it address?	Combined hardware and software setup including VR headsets and cameras that allows remote viewers to interact with operating room procedures (peer-to-peer collaboration - attendees view live 3D stream of an operating room)
Realism: (rating 5 = ideal, down to 1 = not present) and add comments	Realistic patient tissue (bone, soft tissue, tactile, realistic palpation)	Virtual through VR headsets Nothing real (1)
	Realistic instruments (feel, handling, behavior, eg, on bone)	No 1
	Realistic imaging (fluoroscopy, CT, 3D, endoscopy, microscopy)	3
Assessment and recording (rating 5 = ideal, down to 1 = not present)	How does formative and summative assessment of the trainee (to allow learning curve display, etc.) work?	Recording is possible for review and external assessment
	What feedback is provided to the learner?	Mostly passive. Faculty can provide feedback on knowledge but not on technical skills
	What performance data is gathered (or recorded)?	
Cost and scalability	Cost	VR and software and cameras
	Scalability (issues, requirements, etc)	
AO Spine events and curriculum	Potential best uses	Gives chance to participants in courses to interact with the surgeons in the OR without being physically with them Best used in blended/online

4.4 Virtual reality

Product/company **Surgical Theater** https://surgicaltheater.com/ and similarly **NonNocere** https://nonnocere.de/	Question	Rating and comments
Scope	What procedure(s) does it address?	Virtual reality representation of spine cases and group learning
Realism: (rating 5 = ideal, down to 1 = not present) and add comments	Realistic patient tissue (bone, soft tissue, tactile, realistic palpation)	1
	Realistic instruments (feel, handling, behavior, eg, on bone)	3
	Realistic imaging (fluoroscopy, CT, 3D, endoscopy, microscopy)	4
Assessment and recording (rating 5 = ideal, down to 1 = not present)	How does formative and summative assessment of the trainee (to allow learning curve display, etc.) work?	Provides a computer generated VR environment representing actual cases and it may help the trainee to have a visual perspective of structures not seen directly
	What feedback is provided to the learner?	Visual feedback 3
	What performance data is gathered (or recorded)?	Unclear
Cost and scalability	Cost	Undefined
	Scalability (issues, requirements, etc)	Undefined
AO Spine events and curriculum	Potential best uses	For early learners

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Product/company Precision OS, OSSO VR, etc	Question	Rating and comments
Scope	What procedure(s) does it address?	VR learning using VR goggles mated with hand-held devices as navigation control for some spine procedures
Realism: (rating 5 = ideal, down to 1 = not present) and add comments	Realistic patient tissue (bone, soft tissue, tactile, realistic palpation)	1
	Realistic instruments (feel, handling, behavior, eg, on bone)	1
	Realistic imaging (fluoroscopy, CT, 3D, endoscopy, microscopy)	2
Assessment and recording (rating 5 = ideal, down to 1 = not present)	How does formative and summative assessment of the trainee (to allow learning curve display, etc.) work?	Through feedback by faculty or guide
	What feedback is provided to the learner?	Onscreen and some feeling Mostly faculty feedback
	What performance data is gathered (or recorded)?	Steps and time
Cost and scalability	Cost	Variable
	Scalability (issues, requirements, etc)	Possible, with logistical challenges and costs
AO Spine events and curriculum	Potential best uses	Introduce a procedure to a trainee or a new procedure to experienced Online group learning

4.5 Augmented reality

Product/company **Brainlab** https://www.brainlab.com/surgery-products/overview-platform-products/mixed-reality-applications/	**Question**	**Rating and comments**
Scope	What procedure(s) does it address?	Familiarization on the use of navigation using bone models with the specimen 'pre-operatively' registered in a brainlab computer as what is done in an actual navigated surgery
Realism: (rating 5 = ideal, down to 1 = not present) and add comments	Realistic patient tissue (bone, soft tissue, tactile, realistic palpation)	4 The bone specimen was made to approximate, according to the developers, the actual feel of bony tissue. Soft tissue may be added to "hide" the bone underneath
	Realistic instruments (feel, handling, behavior, eg, on bone)	4 The realistic 'feel' of the bone will depend on the quality of the bone specimen provided
	Realistic imaging (fluoroscopy, CT, 3D, endoscopy, microscopy)	4
Assessment and recording (rating 5 = ideal, down to 1 = not present)	How does formative and summative assessment of the trainee (to allow learning curve display, etc.) work?	5 Navigated instrumentation, specially placing pedicle screws. Brainlab is capable of showing the 'teacher' what the learner is doing by way of how accurate is his screw placement. The process should be easy to record.
	What feedback is provided to the learner?	Visual feedback mostly and depending on the quality of the swa bone used, tactile feedback can also be good
	What performance data is gathered (or recorded)?	Accuracy of screw placement
Cost and scalability	Cost	May be costly - brainlab equipment as well as the bone and implants
	Scalability (issues, requirements, etc)	Scalable if a training site is available (transport will have costs)
AO Spine events and curriculum	Potential best uses	Training on the insertion of pedicle screws using navigation.

Product/company **xvision** https://augmedics.com/	**Question**	**Rating and comments**
Scope	What procedure(s) does it address?	
Realism: (rating 5 = ideal, down to 1 = not present) and add comments	Realistic patient tissue (bone, soft tissue, tactile, realistic palpation)	If used in live surgeries, it will be very realistic (artificial models or human anatomical specimens will depend on the quality)
	Realistic instruments (feel, handling, behavior, eg, on bone)	
	Realistic imaging (fluoroscopy, CT, 3D, endoscopy, microscopy)	
Assessment and recording (rating 5 = ideal, down to 1 = not present)	How does formative and summative assessment of the trainee (to allow learning curve display, etc.) work?	Based on videos show, it is sort of like a Brainlab setup on steroids whereby the navigational guidance is not provided by any outside machines but thru a headset alone
	What feedback is provided to the learner?	It gives the learners instantaneous feedback as to where their implants are going but this needs to be verified thru other means like intraoperative fluoroscopic shots, intraop or postop x-rays and or CT scans
	What performance data is gathered (or recorded)?	Speed of surgery Accuracy of implant placement
Cost and scalability	Cost	Undefined
	Scalability (issues, requirements, etc)	Undefined
AO Spine events and curriculum	Potential best uses	Promising but undefined

5 Next steps for AO Spine community

5.1 Informing event chairpersons and faculty

This white paper will be circulated to all chairpersons and faculty through the Chairperson Education Program (CEP) and through regional communication from the education committee.

5.2 Feasibility of implementation

In the "Fundamentals of Surgical Simulation: Principles and Practice" (2012), Gallagher and O'Sullivan emphasized that the simulator used is probably not that important because there are numerous others that will probably do a similar job. What is important is that the right simulator is chosen for the job (taking costs into account). What is probably of paramount importance for trainers is that a simulator is simply a tool for delivering the curriculum. When assessing the functionality of a potential simulation task there are two important questions:
Will this simulation task allow you to teach and train the required skills?
Will the simulation task allow you to assess the skills you wish the trainee to acquire?

The planning process is a series of steps in the design of the program and the selection of educational methods that are appropriate to achieve the learning objectives selected form the AO Spine curriculum. The chosen activities must then be costed for the event and have an influence on the registration fee for participants. (The final decision has to be made by the event team together.)

During the AO Education Platform meeting in 2022, the clinical divisions of the AO shared experiences and identified several aspects of a multidimensional matrix to define which type of simulation is best applicable to achieve which outcome:

Technology is not the driver of the selection but adds educational value

- Dimensions to be considered:
  - Scalability
  - Accessibility
  - Portability
  - Space needs/location
  - Cost
- Task-based potential assessment criteria:
  - Haptic (force) feedback
  - Fidelity /closeness to reality needed
- Other potential dimensions:
  - Level of experience of learner (Principles, Advanced, Masters)
  - Simple tasks vs complex tasks (eg, suturing, drilling, putting in screw)
  - Type of task: (eg, planning, approach, reduction, fixation)
- Additional considerations:
  - Platform agnostic – content should stay transferrable
  - Metrics should be owned and validated by AO
  - Bring your own device

5.3 Preparing the faculty

As with all new teaching, it is essential to prepare your faculty for any activities where there is a new simulation technology (eg, just like over the past few years when a lot of education moved online). Faculty must be clear on their roles and must have experienced the simulation themselves in advance. Final planning should be integrated in online and onsite faculty precourse meetings, and feedback should be gathered after each event.

5.4 Opportunities for regional collaboration and sharing of best practices

The educational strategies taskforce requests that all chairpersons of events where new simulation technology is used should prepare a report to their regional education committee and AO SEC member regarding the outcomes (a template for reporting is available from the regional director). It is also recommended that regional or international faculty who can share experiences or have a strong interest in these new educational approaches be considered when finalizing the faculty, and to encourage experience sharing when possible. The educational taskforce members are available to attend the regional education committee meetings or individual event planning meetings to provide support.

6 Appendices

6.1 Abstracts from key articles

- Dry bone models and enhanced versions
- Simulators (soft tissue enhancement, etc)
- Telementoring
- Virtual reality
- Augmented reality

Article abstracts related to: Dry bone models and enhanced versions

Park HJ, Wang C, Choi KH, Kim HN. Use of a life-size three-dimensional-printed spine model for pedicle screw instrumentation training. J Orthop Surg Res. 2018 Apr 16;13(1):86. doi: 10.1186/s13018-018-0788-z. Erratum in: J Orthop Surg Res. 2021 May 8;16(1):303. PMID: 29661210; PMCID: PMC5902859.

Background: Training beginners of the pedicle screw instrumentation technique in the operating room is limited because of issues related to patient safety and surgical efficiency. Three-dimensional (3D) printing enables training or simulation surgery on a real-size replica of deformed spine, which is difficult to perform in the usual cadaver or surrogate plastic models. The purpose of this study was to evaluate the educational effect of using a real-size 3D-printed spine model for training beginners of the free-hand pedicle screw instrumentation technique. We asked whether the use of a 3D spine model can improve (1) screw instrumentation accuracy and (2) length of procedure.

Methods: Twenty life-size 3D-printed lumbar spine models were made from 10 volunteers (two models for each volunteer). Two novice surgeons who had no experience of free-hand pedicle screw instrumentation technique were instructed by an experienced surgeon, and each surgeon inserted 10 pedicle screws for each lumbar spine model. Computed tomography scans of the spine models were obtained to evaluate screw instrumentation accuracy. The length of time in completing the procedure was recorded. The results of the latter 10 spine models were compared with those of the former 10 models to evaluate learning effect.

Results: A total of 37/200 screws (18.5%) perforated the pedicle cortex with a mean of 1.7 mm (range, 1.2-3.3 mm). However, the latter half of the models had significantly less violation than the former half (10/100 vs. 27/100, $p < 0.001$). The mean length of time to complete 10 pedicle screw instrumentations in a spine model was 42.8 ± 5.3 min for the former 10 spine models and 35.6 ± 2.9 min for the latter 10 spine models. The latter 10 spine models had significantly less time than the former 10 models ($p < 0.001$). Conclusion: A life-size 3D-printed spine model can be an excellent tool for training beginners of the free-hand pedicle screw instrumentation.

Koh JC, Jang YK, Seong H, Lee KH, Jun S, Choi JB. Creation of a three-dimensional printed spine model for training in pain procedures. J Int Med Res. 2021 Nov;49(11):3000605211053281. doi: 10.1177/03000605211053281. PMID: 34743631; PMCID: PMC8579332.

Objective: Technological developments have made it possible to create simulation models to educate clinicians on surgical techniques and patient preparation. In this study, we created an inexpensive lumbar spine phantom using patient data and analyzed its usefulness in clinical education.

Methods: This randomized comparative study used computed tomography and magnetic resonance imaging data from a single patient to print a three-dimensional (3D) bone framework and create a mold. The printed bones and structures made from the mold were placed in a simulation model that was used to train residents. The residents were divided into two groups: Group L, which received only an audiovisual lecture, and Group P, which received an additional 1 hour of training using the 3D phantom. The performance of both groups was evaluated using pretest and post-test analyses.

Results: Both the checklist and global rating scores increased after training in both groups. However, some variables improved significantly only in Group P. The overall satisfaction score was also higher in Group P than in Group L.

Conclusions: We have described a method by which medical doctors can create a spine simulation phantom and have demonstrated its efficiency for procedural education.

Keywords: Autonomic nerve block; epidural anesthesia; high-fidelity simulation training; imaging; lumbar vertebra; magnetic resonance imaging; phantom; printing; simulation training; three-dimensional.

Sayari AJ, Chen O, Harada GK, Lopez GD. Success of Surgical Simulation in Orthopedic Training and Applications in Spine Surgery. Clin Spine Surg. 2021 Apr 1;34(3):82-86. doi: 10.1097/BSD.0000000000001070. PMID: 33044270.

Objective: This study aimed to review the current literature on surgical simulation in orthopedics and its application to spine surgery.

Summary of background data: As orthopedic surgery increases in complexity, training becomes more relevant. There have been mandates in the United States for training orthopedic residents the fundamentals of surgical skills; however, few studies have examined the various training options available. Lack of funding, availability, and time are major constraints to surgical simulation options.

Methods: A PubMed review of the current literature was performed on all relevant articles that examined orthopedic trainees using surgical simulation options. Studies were examined for their thoroughness and application of simulation options to orthopedic surgery.

Results: Twenty-three studies have explored orthopedic surgical simulation in a setting that objectively assessed trainee performance, most in the field of trauma and arthroscopy. However, there was a lack of consistency in measurements made and skills tested by these simulators. There has only been one study exploring surgical simulation in spine surgery.

Conclusions: While there has been a growing number of surgical simulators to train orthopedic residents the fundamentals of surgical skills, most of these simulators are not feasible, reproducible, or available to the majority of training centers. Furthermore, the lack of consistency in the objective measurements of these studies makes interpretation of their results difficult. There is a need for more simulation in spine surgery, and future simulators and their respective studies should be reproducible, affordable, applicable to the surgical setting, and easily assembled by various programs across the world.

Bhatia N, Palispis WA, Urakov T, Gruskay J, Haghverdian J, Yang DS, Uong J, Albert T, Vaccaro A, Levi AD, Gupta R. Establishing validity of the fundamentals of spinal surgery (FOSS) simulator as a teaching tool for orthopedic and neurosurgical trainees. Spine J. 2020 Apr;20(4):580-589. doi: 10.1016/j.spinee.2019.11.008. Epub 2019 Nov 18. PMID: 31751611.

Background context: Pedicle screw placement is a demanding surgical skill as a spine surgeon can face challenges including variations in pedicle morphology and spinal deformities. Available CT simulators for spine pedicle placement can be very costly and hands-on cadaver courses are limited by specimen availability and are not readily accessible.

Purpose: To conduct validation of a simulated training device for essential spine surgery skills.
Design: Cross-sectional, empirical study of physician performance on a surgical simulator model.
Sample: Spine attending physicians and residents from four different academic institutions across the United States.
Outcome measures: Performance metrics on two surgical simulator tasks.

Methods: After IRB approval, an inexpensive ($30) simulator was developed to test two main psychomotor tasks (1) creation of the pedicle screw path with a standard gearshift probe without cortical breaks and (2) the ability to palpate for the presence or absence of cortical breaches as well as determine the location of wall defects. Orthopedic and neurosurgery residents (N=72) as well as spine attending surgeons (N=26) participated from four different institutions. To test construct validity, performance metrics were compared between participants of different training status through one-way analysis of variance and linear regression analysis, with significance set at p<.05.

Results: Spine attending surgeons consistently scored higher than the residents, in the screw trajectory task with triangular base (p=.0027) and defect probing task (p=.0035). In defect probing, performance improved with linear trend by number of residency training years with approaching significance (p=.0721). In that task, independent of institutional affiliation, PGY-2 residents correctly identified an average of 1.25±0.43 fewer locations compared with attending physicians (p=.0049). More than 80% of the spine attendings reported they would use the simulator for training purposes.
Conclusions: This low-cost fundamentals of spine surgery simulator detected differences in performances between spine attending surgeons and surgical residents. Programs should consider implementing a simulator such as fundamentals of spine surgery to assess and develop pedicle screw placement ability outside of the operating room.

Article abstracts related to: Simulators (soft tissue enhancement, etc)

Melcher C, Hussain I, Kirnaz S, Goldberg JL, Sommer F, Navarro-Ramirez R, Medary B, Härtl R. Use of a High-Fidelity Training Simulator for Minimally Invasive Lumbar Decompression Increases Working Knowledge and Technical Skills Among Orthopedic and Neurosurgical Trainees. Global Spine J. 2022 Feb 28:21925682221076044. doi: 10.1177/21925682221076044. Epub ahead of print. PMID: 35225716.

Objective: To quantify the educational benefit to surgical trainees of using a high-fidelity simulator to perform minimally invasive (MIS) unilateral laminotomy for bilateral decompression (ULBD) for lumbar stenosis.

Methods: Twelve orthopedic and neurologic surgery residents performed three MIS ULBD procedures over 2 weeks on a simulator guided by established AO Spine metrics. Video recording of each surgery was rated by three blinded, independent experts using a global rating scale. The learning curve was evaluated with attention to technical skills, skipped steps, occurrence of errors, and timing. A knowledge gap analysis evaluating participants' current vs desired ability was performed after each trial.

Results: From trial 1 to 3, there was a decrease in average procedural time by 31.7 minutes. The cumulative number of skipped steps and surgical errors decreased from 25 to 6 and 24 to 6, respectively. Overall surgical proficiency improved as indicated by video rating of efficiency and smoothness of surgical maneuvers, most notably with knowledge and handling of instruments. The greatest changes were noted in junior rather than senior residents. Average knowledge gap analysis significantly decreased by 30% from the first to last trial (P = .001), signifying trainees performed closer to their desired technical goal.

Conclusion: Procedural metrics for minimally invasive ULBD in combination with a realistic surgical simulator can be used to improve the skills and confidence of trainees. Surgical simulation may offer an important educational complement to traditional methods of skill acquisition and should be explored further with other MIS techniques.

Mehren C, Korb W, Fenyöházi E, Iacovazzi D, Bernal L, Mayer MH. Differences in the Exposure of the Lumbar Nerve Root Between Experts and Novices: Results From a Realistic Simulation Pilot Study With Force Sensors. Global Spine J. 2021 Mar;11(2):224-231. doi: 10.1177/2192568220917369. Epub 2020 Apr 8. PMID: 32875893; PMCID: PMC7882829.

Objective: Several studies could demonstrate "learning curves" in almost every single surgical procedure for unexperienced surgeons. This is in sharp contrast to the rising quality requirements in public health care to provide surgical training at patients "expense." The aim of this study was to visualize, measure, and set a baseline of the pressure load on the spinal nerve root during a simulated microdiscectomy on a standardized and validated model (RealSpine) under the influence of the level of surgical experience and individual skills.

Methods: Five highly experienced spine surgeons and 5 trainees without considerable surgical experience were selected to perform a standardized microsurgical discectomy on a validated RealSpine simulator. Force-torque sensors were integrated in this simulator to measure the load on the nerve root. The forces were recorded every 125 ms.

Results: We could identify cumulative for the total intervention as well as for defined single surgical steps of this procedure and as well in between the single subjects a significant higher tension and contusion forces on the nerve for the trainee group.

Conclusion: We could measure a difference between unexperienced and experienced surgeons regarding the manipulations of the nerve root during a standardized simulated microdiscectomy. This possibility could be the starting point for a new and innovative surgical education to improve outcome without negative side effects of "learning curves."

Transformation of neurosurgical training from “see one, do one, teach one” to AR/VR & simulation – A survey by the EANS Young Neurosurgeons. Brain and Spine Available online 15 August 2022, 100929. https://www.sciencedirect.com/science/article/pii/S2772529422000704?via%3Dihub

Introduction
Modern technologies are increasingly applied in neurosurgical resident training. To date, no data are available regarding how frequently these are used in the training of neurosurgeons, and what the perceived value of this technology is.

Research question
The aim was to benchmark the objective as well as subjective experience with modern- and conventional training technologies.

Material and methods
The EANS Young Neurosurgeons Committee designed a 12-item survey. It was distributed to neurosurgical residents and board-certified neurosurgeons between 6th of February and April 13, 2022.

Results

We considered 543 survey responses for analysis. Most participants (67%) indicated not having gained any training experience with modern technology. Most (40.7%) indicated lack of any modern or conventional training technology. Cadaver training was available to 27.6% while all modern training technology to <10%. Participants from countries with high gross domestic product per capita had more access to modern training technologies ($p < 0.001$). The perceived value of the different technologies was highest for hands-on OR training, followed by cadaver lab. The value of these was rated higher, compared to all modern technologies ($p < 0.001$).

Discussion and conclusion
Our survey reveals that cadaver labs are used more frequently than modern technologies for today's neurosurgical training. Hands-on training in the operating room (OR) was rated significantly more valuable than any conventional and modern training technology. Our data hence suggest that while modern technologies are well perceived and can surely add to the training of neurosurgeons, it remains critical to ensure sufficient OR exposure.

Pastor T, Pastor T, Kastner P, Souleiman F, Knobe M, Gueorguiev B, Windolf M, Buschbaum J. Validity of a Novel Digitally Enhanced Skills Training Station for Freehand Distal Interlocking. Medicina (Kaunas). 2022 Jun 7;58(6):773. doi: 10.3390/medicina58060773. PMID: 35744036; PMCID: PMC9229787.

Background and Objectives: Freehand distal interlocking of intramedullary nails is technically demanding and prone to handling issues. It requires precise placement of a screw through the nail under fluoroscopy guidance and can result in a time consuming and radiation expensive procedure. Dedicated training could help overcome these problems. The aim of this study was to assess construct and face validity of new Digitally Enhanced Hands-On Surgical Training (DEHST) concept and device for training of distal interlocking of intramedullary nails. Materials and Methods: Twenty-nine novices and twenty-four expert surgeons performed interlocking on a DEHST device. Construct validity was evaluated by comparing captured performance metrics—number of X-rays, nail hole roundness, drill tip position and drill hole accuracy—between experts and novices. Face validity was evaluated with a questionnaire concerning training potential and quality of simulated reality using a 7-point Likert scale. Results: Face validity: mean realism of the training device was rated 6.3 (range 4–7). Training potential and need for distal interlocking training were both rated with a mean of 6.5 (range 5–7), with no significant differences between experts and novices, p 0.234. All participants (100%) stated that the device is useful for procedural training of distal nail interlocking, 96% wanted to have it at their institution and 98% would recommend it to colleagues. Construct validity: total number of X-rays was significantly higher for novices (20.9 6.4 versus 15.5 5.3, $p = 0.003$). Success rate (ratio of hit and miss attempts) was significantly higher for experts (novices hit: n = 15; 55.6%; experts hit: n = 19; 83%, $p = 0.040$). Conclusion: The evaluated training device for distal interlocking of intramedullary nails yielded high scores in terms of training capability and realism. Furthermore, construct validity was proven by reliably discriminating between experts and novices. Participants indicate high further training potential as the device may be easily adapted to other surgical tasks.

Article abstracts related to: Telementoring

Hickman MS, Dean WH, Puri L, Singh S, Siegel R, Patel D. Ophthalmic Telesurgery with a Low-Cost Smartphone Video System for Surgeon Self-Reflection and Remote Synchronous Consultation: A Qualitative and Quantitative Study. Telemed Rep. 2022 Jan 31;3(1):30-37. doi: 10.1089/tmr.2021.0037. PMID: 35720448; PMCID: PMC9049828.

Summary: More than a third of the global burden of blindness is due to cataracts, yet cataract surgery is one of the most cost-effective surgical treatments in medicine. Poor surgical outcomes in many settings remain a major challenge, raising concerns about the quality and efficacy of surgical training. Reflective learning from video recordings of a trainees' surgical performance has a high educational impact and is available routinely for surgical training within high-resource institutions. However, the prohibitive cost and limited portability of current surgical video recording systems make its use problematic in low-resource settings and outreach environments.

Objective: The study's aim was to evaluate the potential of smartphone-captured surgical videos for surgeon learning via self-recording and self-review as well as the potential to support live telesurgical consultation.

Methodology: A quantitative and qualitative methodology was used to explore and describe the utility and acceptance of smartphone videos in two training facilities in Nepal. Twenty surgeries were recorded on the smartphone for surgeon self-review, to assess image quality, and its application to measure performance against the International Council of Ophthalmology (ICO) Ophthalmology Surgical Competency Assessment Rubrics (OSCAR) SICS Rubric. The same system was used to transmit 15 different surgeries live via Skype from Nepal to an ophthalmologist surgical trainer in South Africa to evaluate the feasibility of live consultation.

Findings: Overall video quality was described as high in 65% and moderate in 35% for the videos recorded for self-review. In the surgeries streamed via Skype, quality was described as high in 92.9% and moderate in 7.1%. There were no instances where the video quality was described as poor. The video quality was good enough that the surgeons could measure against ICO-OSCAR rubric in all cases.

Discussion: The video quality of smartphone-captured surgical videos was found to be high and gained acceptance for reflective teaching and learning purposes. The extended telesurgical potential and portability of the smartphone enables use across many settings. More studies over a longer period are needed to determine how they can support training and learning in cataract surgery.

Bohl MA, McBryan S, Pais D, Chang SW, Turner JD, Nakaji P, Kakarla UK. The Living Spine Model: A Biomimetic Surgical Training and Education Tool. Oper Neurosurg (Hagerstown). 2020 Jul 1;19(1):98-106. doi: 10.1093/ons/opz326. PMID: 31740969.

Background: The Living Spine Model (LSM) is a three-dimensionally printed, surgical training platform developed by neurosurgical residents.

Objective: To evaluate the face and content validity of this model as a training tool for open posterior lumbar surgery. Methods: Six surgeons with varying experience were asked to complete L3-5 pedicle screw fixation and L3-4 laminectomy on an LSM. Face validity was measured using a questionnaire, and content validity was measured using the National Aeronautics and Space Administration Task Load Index (NASA TLX) tests. Student's t-test was used to compare NASA TLX responses between junior and senior residents and to compare responses for live surgery vs simulated surgery on the LSM. Results: Junior residents took the longest time to complete the procedure, followed by senior residents and the attending surgeon (136.5, 98.3, and 84 min, respectively). The junior residents placed fewer successful pedicle screws (7/12) than senior residents and attending surgeon (18/18). All tested components of the model had excellent face validity, with scores ranging from 60% to 97%. Content validity testing demonstrated that the LSMs created overall workloads and specific types of work like live operating conditions. Conclusion: The overall validity testing of the LSM demonstrates the high-potential utility of this model as a surgical education and testing platform for open posterior lumbar procedures. The LSM has great potential as an adjunct to surgical education, and it may become an increasingly important component of surgical resident curricula in the future.

A297 at GSC 2022: The efficacy of blended learning in a pediatric spinal deformity management program in Tanzania. Alaa Azmi Ahmad, Abdullah Abu-Shihab, Francois Waterkeyn, Massimo Balsano, Christopher Bonfield, Beverly Cheserem, Hamisi Shabani, Juma Magogo, Bryson Mcharo, Costansia Bureta, Fabian Sommer, Branden Medary, Ibrahim Hussain, and Roger Härtl.

Introduction: Blended learning, which combines in-person learning and e-learning, has grown rapidly in education. Advantages of this modality include control over content, learning sequence, and pace of learning, allowing participants to tailor their experiences to meet their personal learning objectives. Blended learning enables adaptive and collaborative learning and transforms the teacher's role from transmitting knowledge (instructing) to facilitating learning. Objectives: Our study aimed to assess the efficacy of blended learning in a pediatric scoliosis training program through the largest Surgical Training Institution in Sub-Saharan Africa, The College of Surgeons of East, Central and Southern Africa (COSECSA). Material and Methods: The course comprised of three parts; 1- the online portion, which allowed participants to review lectures, papers, and audiovisual materials over a 3-week period; 2- the in-person session, where participants spent a full day with an international expert, reviewing cases in a team-based approach and coming to a consensus on treatment strategy; and 3- a one week, in-person experience where participants were exposed to pre-surgical planning conferences, clinic, casting, and scrubbing into surgeries with international experts. All participants completed a Needs Assessment (NA) and quiz prior to the course. The NA contained 6 various topics, with 3 questions for each topic scored by a 10-point scale in pediatric spine deformity. The quiz included 15 surgical and clinical questions related to the pediatric spine deformity topics. The NA and quiz were taken before the course, after the online session, and after the in-person session. A final survey was conducted at the end of the in-person surgical week. Results: Thirty-six orthopedic surgeons and neurosurgeons enrolled in the course primarily from Tanzania, Kenya, and Malawi. The NA assessment scores improved significantly over the course of the three surveys from 67.3 prior to the course, to 90.9 mid-course, and 94.0 after the course ($p = 0.0007$). The clinical quiz scores improved over the 3 time points from 9.91 to 11.9, and 12.3, respectively. At the end of the in-person surgical week, 100% of respondents stated that they had improvement in knowledge and 92% considered the knowledge sufficient to change their clinical practice. In surveying the persistent obstacles to translating knowledge gained through blended learning to clinical practice, the top responses were constraints in personnel and cost of implants at their home institution. Conclusion: The blended learning approach in a pediatric spine deformity program is effective, feasible, and shows a statistically significant change in participants' confidence and knowledgebase in these complex pathologies. Our results are limited due to the small sample size. Future studies will evaluate larger number of participants in the post-COVID era and translation to other areas of spine surgery, such as minimally invasive surgery.

AO SPINE

Article abstracts related to: Virtual Reality (VR)

Yuk FJ, Maragkos GA, Sato K, Steinberger J. Current innovation in virtual and augmented reality in spine surgery. Ann Transl Med. 2021 Jan;9(1):94. doi: 10.21037/atm-20-1132. PMID: 33553387; PMCID: PMC7859743.

In spinal surgery, outcomes are directly related both to patient and procedure selection, as well as the accuracy and precision of instrumentation placed. Poorly placed instrumentation can lead to spinal cord, nerve root or vascular injury. Traditionally, spine surgery was performed by open methods and placement of instrumentation under direct visualization. However, minimally invasive surgery (MIS) has seen substantial advances in spine, with an ever-increasing range of indications and procedures. For these reasons, novel methods to visualize anatomy and precisely guide surgery, such as intraoperative navigation, are extremely useful in this field. In this review, we present the recent advances and innovations utilizing simulation methods in spine surgery. The application of these techniques is still relatively new, however quickly being integrated in and outside the operating room. These include virtual reality (VR) (where the entire simulation is virtual), mixed reality (MR) (a combination of virtual and physical components), and augmented reality (AR) (the superimposition of a virtual component onto physical reality). VR and MR have primarily found applications in a teaching and preparatory role, while AR is mainly applied in hands-on surgical settings. The present review attempts to provide an overview of the latest advances and applications of these methods in the neurosurgical spine setting.

Godzik J, Farber SH, Urakov T, Steinberger J, Knipscher LJ, Ehredt RB, Tumialán LM, Uribe JS. "Disruptive Technology" in Spine Surgery and Education: Virtual and Augmented Reality. Oper Neurosurg (Hagerstown). 2021 Jun 15;21(Suppl 1):S85-S93. doi: 10.1093/ons/opab114. PMID: 34128065.

Background: Technological advancements are the drivers of modern-day spine care. With the growing pressure to deliver faster and better care, surgical-assist technology is needed to harness computing power and enable the surgeon to improve outcomes. Virtual reality (VR) and augmented reality (AR) represent the pinnacle of emerging technology, not only to deliver higher quality education through simulated care, but also to provide valuable intraoperative information to assist in more efficient and more precise surgeries. Objective: To describe how the disruptive technologies of VR and AR interface in spine surgery and education. Methods: We review the relevance of VR and AR technologies in spine care, and describe the feasibility and limitations of the technologies. Results: We discuss potential future applications, and provide a case study demonstrating the feasibility of a VR program for neurosurgical spine education. Conclusion: Initial experiences with VR and AR technologies demonstrate their applicability and ease of implementation. However, further prospective studies through multi-institutional and industry-academic partnerships are necessary to solidify the future of VR and AR in spine surgery education and clinical practice.

Yoo JS, Patel DS, Hrynewycz NM, Brundage TS, Singh K. The utility of virtual reality and augmented reality in spine surgery. Ann Transl Med. 2019 Sep;7(Suppl 5):S171. Doi: 10.21037/atm.2019.06.38. PMID: 31624737; PMCID: PMC6778272.

As the number of advances in surgical techniques increases, it becomes increasingly important to assess and research the technology regarding spine surgery techniques in order to increase surgical accuracy, decrease overall length of surgery, and minimize overall radiation exposure. Currently, augmented reality and virtual reality have shown promising results in regard to their applicability beyond their current functions. At present, VR has been generally applied to a teaching and preparatory role, while AR has been utilized in surgical settings. As such, the following review attempts to provide an overview of both virtual reality and augmented reality, followed by a discussion of their current applications and future direction.

Mao, R. Q., Lan, L., Kay, J., Lohre, R., Ayeni, O. R., Goel, D. P., & Sa, D. (2021). Immersive Virtual Reality for Surgical Training: A Systematic Review. The Journal of surgical research, 268, 40–58. https://doi.org/10.1016/j.jss.2021.06.045

Background: Immersive virtual reality (iVR) simulators provide accessible, low cost, realistic training adjuncts in time and financially constrained systems. With increasing evidence and utilization of this technology by training programs, clarity on the effect of global skill training should be provided. This systematic review examines the current literature on the effectiveness of iVR for surgical skills acquisition in medical students, residents, and staff surgeons.

Methods: A literature search was performed on MEDLINE, EMBASE, CENTRAL, Web of Science and PsycInfo for primary studies published between January 1, 2000 and January 26, 2021. Two reviewers independently screened titles, abstracts, and full texts, extracted data, and assessed quality and strength of evidence using the Medical Education Research Quality Instrument (MERSQI) and Cochrane methodology. Results were qualitatively synthesized, and descriptive statistics were calculated.

Results: The literature search yielded 9650 citations, with 17 articles included for qualitative synthesis. The mean (SD) MERSQI score was 11.7 (1.9) out of 18. In total, 307 participants completed training in four disciplines. Immersive VR-trained groups performed 18% to 43% faster on procedural time to completion compared to control (pooled standardized mean difference = -0.90 [95% CI=-1.33 to -047, I2=1%, P < 0.0001]). Immersive VR trainees also demonstrated greater post-intervention scores on procedural checklists and greater implant placement accuracy compared to control.

Conclusions: Immersive VR incorporation into surgical training programs is supported by high-quality, albeit heterogeneous, studies demonstrating improved procedural times, task completion, and accuracy, positive user ratings, and cost-effectiveness.

Article abstracts related to: Augmented Reality (AR)

Yanni DS, Ozgur BM, Louis RG, Shekhtman Y, Iyer RR, Boddapati V, Iyer A, Patel PD, Jani R, Cummock M, Herur-Raman A, Dang P, Goldstein IM, Brant-Zawadzki M, Steineke T, Lenke LG. Real-time navigation guidance with intraoperative CT imaging for pedicle screw placement using an augmented reality head-mounted display: a proof-of-concept study. Neurosurg Focus. 2021 Aug;51(2):E11. doi: 10.3171/2021.5.FOCUS21209. PMID: 34333483.

Objective: Augmented reality (AR) has the potential to improve the accuracy and efficiency of instrumentation placement in spinal fusion surgery, increasing patient safety and outcomes, optimizing ergonomics in the surgical suite, and ultimately lowering procedural costs. The authors sought to describe the use of a commercial prototype Spine AR platform (SpineAR) that provides a commercial AR head-mounted display (ARHMD) user interface for navigation-guided spine surgery incorporating real-time navigation images from intraoperative imaging with a 3D-reconstructed model in the surgeon's field of view, and to assess screw placement accuracy via this method.

Methods: Pedicle screw placement accuracy was assessed and compared with literature-reported data of the freehand (FH) technique. Accuracy with SpineAR was also compared between participants of varying spine surgical experience. Eleven operators without prior experience with AR-assisted pedicle screw placement took part in the study: 5 attending neurosurgeons and 6 trainees (1 neurosurgical fellow, 1 senior orthopedic resident, 3 neurosurgical residents, and 1 medical student). Commercially available 3D-printed lumbar spine models were utilized as surrogates of human anatomy. Among the operators, a total of 192 screws were instrumented bilaterally from L2-5 using SpineAR in 24 lumbar spine models. All but one trainee also inserted 8 screws using the FH method. In addition to accuracy scoring using the Gertzbein-Robbins grading scale, axial trajectory was assessed, and user feedback on experience with SpineAR was collected.

Results: Based on the Gertzbein-Robbins grading scale, the overall screw placement accuracy using SpineAR among all users was 98.4% (192 screws). Accuracy for attendings and trainees was 99.1% (112 screws) and 97.5% (80 screws), respectively. Accuracy rates were higher compared with literature-reported lumbar screw placement accuracy using FH for attendings (99.1% vs 94.32%; p = 0.0212) and all users (98.4% vs 94.32%; p = 0.0099). The percentage of total inserted screws with a minimum of 5° medial angulation was 100%. No differences were observed between attendings and trainees or between the two methods. User feedback on SpineAR was generally positive.

Conclusions: Screw placement was feasible and accurate using SpineAR, an ARHMD platform with real-time navigation guidance that provided a favorable surgeon-user experience.

Cofano F, Di Perna G, Bozzaro M, Longo A, Marengo N, Zenga F, Zullo N, Cavalieri M, Damiani L, Boges DJ, Agus M, Garbossa D, Calì C. Augmented Reality in Medical Practice: From Spine Surgery to Remote Assistance. Front Surg. 2021 Mar 30;8:657901. doi: 10.3389/fsurg.2021.657901. PMID: 33859995; PMCID: PMC8042331.

Background: While performing surgeries in the OR, surgeons and assistants often need to access several information regarding surgical planning and/or procedures related to the surgery itself, or the accessory equipment to perform certain operations. The accessibility of this information often relies on the physical presence of technical and medical specialists in the OR, which is increasingly difficult due to the number of limitations imposed by the COVID emergency to avoid overcrowded environments or external personnel. Here, we analyze several scenarios where we equipped OR personnel with augmented reality (AR) glasses, allowing a remote specialist to guide OR operations through voice and ad-hoc visuals, superimposed to the field of view of the operator wearing them. Methods: This study is a preliminary case series of prospective collected data about the use of AR-assistance in spine surgery from January to July 2020. The technology has been used on a cohort of 12 patients affected by degenerative lumbar spine disease with lumbar sciatica co-morbidities. Surgeons and OR specialists were equipped with AR devices, customized with P2P videoconference commercial apps, or customized holographic apps. The devices were tested during surgeries for lumbar arthrodesis in a multicenter experience involving author's Institutions. Findings: A total number of 12 lumbar arthrodesis have been performed while using the described AR technology, with application spanning from telementoring (3), teaching (2), surgical planning superimposition and interaction with the hologram using a custom application for Microsoft hololens (1). Surgeons wearing the AR goggles reported positive feedback for the ergonomy, wearability and comfort during the procedure; being able to visualize a 3D reconstruction during surgery was perceived as a straightforward benefit, allowing to speed-up procedures, thus limiting post-operational complications. The possibility of remotely interacting with a specialist on the glasses was a potent added value during COVID emergency, due to limited access of non-resident personnel in the OR. Interpretation: By allowing surgeons to overlay digital medical content on actual surroundings, augmented reality surgery can be exploited easily in multiple scenarios by adapting commercially available or custom-made apps to several use cases. The possibility to observe the operatory theater directly through the eyes of the surgeon might be a game-changer, giving the chance to unexperienced surgeons to be virtually at the site of the operation, or allowing a remote experienced operator to guide wisely the unexperienced surgeon during a procedure.

Bernardo A. Virtual Reality and Simulation in Neurosurgical Training. World Neurosurg. 2017 Oct;106:1015-1029. doi: 10.1016/j.wneu.2017.06.140. PMID: 28985656.

Recent biotechnological advances, including three-dimensional microscopy and endoscopy, virtual reality, surgical simulation, surgical robotics, and advanced neuroimaging, have continued to mold the surgeon-computer relationship. For developing neurosurgeons, such tools can reduce the learning curve, improve conceptual understanding of complex anatomy, and enhance visuospatial skills. We explore the current and future roles and application of virtual reality and simulation in neurosurgical training.

Williams, M. A., McVeigh, J., Handa, A. I., & Lee, R. (2020). Augmented reality in surgical training: a systematic review. Postgraduate medical journal, 96(1139), 537–542. https://doi.org/10.1136/postgradmedj-2020-137600

The aim of this systematic review is to provide an update on the current state of augmented reality (AR) in surgical training and to further report on any described benefits compared with traditional techniques. A PICO (Population, Intervention, Comparison, Outcome) strategy was adopted to formulate an appropriate research question and define strict search terms to be entered into MEDLINE, CENTRAL and Google Scholar. The search was returned on 12/09/2019. All returned results were screened first by title and then abstract. The systematic search returned a total of 236 results, of which 18 were selected for final inclusion. Studies covered the full range of surgical disciplines and reported on outcomes including operative duration, accuracy and postoperative complication rates. Due to the heterogeneity of the collected data, no meta-analysis was possible. Outcome measures of competency, surgical opinion and postoperative complication rate were in favour of AR technology while operative duration appears to increase.

6.2 Profiles of companies and specific products (links and profiles)

- Dry bone models and enhanced versions
  - Synbone
    - https://www.synbone.com/products/orthopaedic-models/
  - SurgiSTUD
    - https://surgistud.com/
  - DEHST - Digitally enhanced hands-on surgical training
    - https://www.aofoundation.org/innovations/innovation-translation/technology-transfer/digitally-enhanced---hands-on-surgical-training
  - Medability https://medability.de/
  - Phacon https://phacon.de/en/
  - The Simulatory https://www.thesimulatory.com/
  - Fusetec https://fusetec.com.au/training/neurology-spine/
  - Viomerse https://viomerse.com/spine-phantoms
  - TrainOS https://trainos.de/
- Simulators with soft tissue enhancement
  - Realists, RealSpine https://www.realists.de/realspine
  - UpSurgeon https://store.upsurgeon.com/product/anterior-cervical-spinebox/
- Telementoring
  - Proximie https://www.proximie.com/
  - Immertec https://www.immertec.com/
  - Swiss Surgical Video https://swissurgicalvideo.com/
  - Rods and Cones https://www.rods-cones.com/
- Virtual reality
  - NonNocere (VR for teaching 2022)
    - https://nonnocere.de/
  - Surgical Theater (VR)
    - https://surgicaltheater.com/
  - Precision OS
    - https://www.precisionostech.com/
  - Osso VR
    - https://www.ossovr.com/
  - Fundamental Surgery (VR)
    - https://fundamentalsurgery.com/
- Augmented reality
  - Brainlab (mixed reality)
    - https://www.brainlab.com/surgery-products/overview-platform-products/mixed-reality-applications/
  - Xvision (Augmedics)
    - https://augmedics.com/

6.3 Some examples of AO Spine experiences