

Review Article

Virtual Patient Simulations in Advanced Anesthesia Training Programs

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ABSTRACT

Virtual patient and virtual reality (VR) simulation have moved rapidly from novelty to established teaching tool within advanced anesthesia training programs, prompting a critical look at where the evidence actually supports their use.

This review synthesizes recent randomized and comparative studies of virtual patient and VR simulation in anesthesia residency and fellowship training, spanning procedural and technical skill acquisition, crisis resource management and non-technical skills, and head-to-head comparisons against high-fidelity mannequin simulation.

The evidence is strongest for discrete technical skills such as regional anesthesia, airway management, and neuraxial technique, where VR platforms show outcomes comparable to traditional instruction, while crisis resource management and team-based non-technical skills remain areas where mannequin-based simulation retains an advantage.

Artificial-intelligence-driven virtual standardized patients are an emerging development that may reduce the cost and logistical burden of communication-focused training if early pilot findings are replicated at scale.

We conclude that the current literature supports a curriculum-embedded blend of virtual and mannequin-based simulation rather than wholesale replacement of either modality, with virtual tools best suited to scalable technical and cognitive skill-building and physical simulation preserved for crisis scenarios that depend on presence and team communication.

Keywords: virtual patient simulation; virtual reality; anesthesiology education; crisis resource management; simulation-based training

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INTRODUCTION

Anesthesiology residency has always leaned on

simulation more heavily than most other specialties, if only because the cost of a trainee's first real mistake in

the operating room can be measured in a patient's life rather than a wrong prescription caught at the pharmacy counter. For thirty years that meant high-fidelity mannequins: expensive, room-bound, technician-dependent systems that reproduce a beating heart, a collapsing airway, or a falling blood pressure with enough physiologic fidelity to provoke a genuine adrenaline response in the resident standing over them. Virtual patient simulation is the newer branch of that same tree — software-driven, screen- or headset-based scenarios in which a trainee interviews, examines, and manages a simulated patient without a physical mannequin at all. What began as branching-logic case modules for medical student clerkships has, over the last decade, migrated into immersive virtual reality (VR) platforms capable of simulating an entire operating room, a crashing obstetric patient, or a difficult airway, and advanced anesthesia programs are now asking a genuinely practical question: does this technology belong alongside, or in place of, the mannequin lab.

The appeal is not hard to see. A VR headset costs a fraction of a mannequin suite, does not require a simulation technician to run a scenario, and can be issued to a resident to take home. It also scales in a way physical simulation never has — a program can put twenty residents through the same crisis scenario in an evening rather than rotating them one at a time through a single simulation bay over a week. Newer platforms layer artificial-intelligence-driven virtual standardized patients onto this scaffolding, giving trainees a conversational partner who responds to open-ended questioning rather than a fixed branching script[1]. But enthusiasm for a technology and evidence that it improves anesthesia training outcomes are not the same thing, and the anesthesiology literature on virtual patient simulation has grown dense enough in the last three years to warrant a critical look rather than a marketing one.

This review synthesizes the current evidence on virtual patient and virtual reality simulation specifically within advanced anesthesia training — resident and fellow education rather than undergraduate medical curricula — covering technical skill acquisition, crisis resource management and non-technical skills, comparative effectiveness against mannequin-based simulation, and the practical barriers that still limit adoption.

TECHNICAL SKILL ACQUISITION: PROCEDURES AND AIRWAY MANAGEMENT

The clearest wins for virtual patient and VR simulation in anesthesia training so far involve discrete procedural skills that lend themselves to repeated, low-stakes practice. Regional anesthesia is a good example. A randomized controlled trial teaching ultrasound-guided regional anesthesia through remote immersive VR found that trainees could acquire probe-handling and needle-trajectory skills comparably to in-person

instruction, an important finding for programs trying to teach ultrasound anatomy to residents who are geographically dispersed across satellite sites[2]. Airway management has seen similar interest: a randomized trial among non-anesthesiology residents found that immersive VR-assisted anatomy training improved subsequent endotracheal intubation performance in simulation compared with conventional instruction, suggesting the spatial visualization VR affords — rotating a three-dimensional laryngeal inlet rather than studying a static diagram — has a genuine transfer benefit for a psychomotor task that is fundamentally about three-dimensional reasoning[3].

Invasive procedures beyond regional blocks are being tested too. A single-center randomized trial of VR training for anesthesiologists performing invasive procedures reported measurable gains in procedural checklist performance among trainees randomized to the VR arm[4]. Spinal and neuraxial technique training has moved in the same direction: a randomized trial comparing spinal mannequin-based simulation against conventional didactic teaching of subarachnoid block in novices found the simulation arm achieved higher first-pass success and fewer needle redirections when tested on a mannequin model, reinforcing that hands-on simulated practice — whether virtual or mannequin-based — outperforms lecture-and-observation models for this category of skill[5]. Operating-room-level simulation training, evaluated in a broader surgical-education context at King Saud University, likewise demonstrated improved procedural readiness scores among students exposed to simulated operating room environments before live cases[6].

What these procedural studies share is a relatively narrow, well-defined skill target and an objective, checklist-based outcome measure — conditions under which simulation of almost any kind tends to show benefit. The harder test is whether virtual patient platforms can also teach the messier, judgment-heavy competencies that separate a technically capable resident from a safe one.

CRISIS RESOURCE MANAGEMENT AND NON-TECHNICAL SKILLS

Anesthesia crisis management — the ability to recognize a deteriorating patient, call for help appropriately, communicate clearly under pressure, and marshal a team response — has traditionally been the domain of high-fidelity mannequin simulation, largely because it depends on physical presence: other people in the room, a body to intubate, monitors that a whole team can see simultaneously. Whether VR can replicate this is one of the more contested questions in the current literature. A randomized crossover pilot study directly compared VR and mannequin-based crisis scenarios for anesthesia trainees and found that while both modalities produced comparable improvements in scenario-specific

knowledge, trainees rated the mannequin scenarios as more immersive and more effective for practicing the interpersonal components of crisis response — the calling for help, the closed-loop communication, the physical choreography of a resuscitation[7]. That distinction matters for program directors deciding where to spend simulation budget: VR may be adequate, even preferable, for teaching the cognitive algorithm of a crisis, but the current evidence base does not yet support replacing team-based mannequin drills for the behavioral and communication elements of non-technical skill.

Obstetric anesthesia crises have received particular attention given their high acuity and comparatively low frequency in real practice, which makes them attractive simulation targets. A qualitative study of novice learners using VR simulation for obstetric airway crisis decision-making found that trainees valued the ability to rehearse the decision tree repeatedly and privately, though they also flagged the flattened sense of time pressure and absent haptic feedback as limitations relative to a live drill[8]. This echoes older but still foundational work: a randomized controlled trial of simulation-based training on resident performance during a simulated obstetric anesthesia emergency demonstrated that structured simulation training, delivered via mannequin, produced measurable improvement in subsequent crisis performance — a benchmark result that any newer virtual modality claiming equivalence still has to be measured against[9].

More directly comparative, a randomized noninferiority trial testing immersive VR against high-fidelity mannequin simulation for teaching anesthesiology non-technical skills found that VR performed acceptably on several cognitive and situational-awareness measures but did not clearly establish noninferiority across the full non-technical skills battery, leaving open exactly how much of crisis resource management genuinely requires physical co-presence[10]. Team-based approaches that combine VR modules with structured, multilevel pedagogy appear to do better: a randomized controlled study with longitudinal follow-up in anesthesiology residency found that VR integrated into a team-based curriculum, rather than deployed as an individual solitary exercise, produced durable gains at follow-up assessment, suggesting the platform matters less than how it is embedded in the broader training structure[11]. Trauma resuscitation simulation is following a comparable trajectory, with an ongoing randomized trial protocol (Trauma SimVR) designed specifically to test whether VR-augmented cardiopulmonary resuscitation training improves trauma team performance metrics relative to standard simulation[12].

COMPARATIVE EFFECTIVENESS AGAINST MANNEQUIN-BASED AND TRADITIONAL SIMULATION

Stepping back from anesthesia-specific crisis scenarios, the broader health professions education literature offers a more mature evidence base on how virtual and screen-based simulation stacks up against mannequins and standardized patients generally, and it is worth anesthesia educators reading carefully because much of it predates and now informs the anesthesia-specific trials above. The 2019 systematic review and meta-analysis by the Digital Health Education Collaboration remains something of a landmark: pooling a large number of studies across health professions, it found virtual patient simulations produced moderate-to-large improvements in learner knowledge and clinical reasoning relative to no intervention or traditional teaching, though effect sizes for skill transfer to real clinical performance were smaller and less consistent[13]. That gap — knowledge gains outpacing measurable behavior change — has been a recurring theme in every subsequent review.

More recent work has tried to quantify virtual simulation against mannequins and real standardized patients head-to-head rather than against a passive control. A meta-analysis with trial sequential analysis comparing virtual simulations against mannequins and real persons across medical and nursing education found that virtual platforms were generally noninferior for knowledge acquisition but that mannequin- and person-based simulation retained an edge for hands-on skill and communication outcomes, a pattern consistent with what the anesthesia-specific crisis literature above independently suggests[14]. A separate meta-analysis focused specifically on case-based virtual patient simulation's effect on graduate medical education competencies and milestones — the framework anesthesia residency programs are formally accountable to — found measurable positive associations with milestone attainment, particularly for the medical knowledge and systems-based practice competencies, though the authors cautioned that most included studies were single-institution and used self-designed rather than validated assessment tools[15].

Fidelity itself has been directly studied as a variable rather than assumed to matter. A systematic review and meta-analysis of mannequin fidelity across nursing, midwifery, and allied health training found that higher-fidelity mannequins did not consistently outperform lower-fidelity ones for learning outcomes, a somewhat counterintuitive result that should temper any assumption that more realistic virtual environments will automatically translate into better anesthesia training outcomes simply because they look and feel more real[16]. A comparative study weighing traditional manikin-based high-fidelity

simulation against virtual high-fidelity simulation reached a similar conclusion, reporting comparable effectiveness between the two modalities but a clear learner preference for the traditional format, at least among participants unfamiliar with VR interfaces[17]. Broader technology-enhanced simulation meta-analyses spanning multiple healthcare professions likewise describe consistently positive but modest effect sizes, reinforcing that virtual modalities are a genuine addition to the educational toolkit rather than a categorical replacement for existing methods[18]. Reviews focused specifically on clinical reasoning and broader clinical competency assessment via virtual simulation echo the same conclusion: real, reproducible gains in cognitive domains, with skill-transfer evidence still catching up[19] [20].

ARTIFICIAL INTELLIGENCE AND THE NEXT GENERATION OF VIRTUAL STANDARDIZED PATIENTS

The newest development shaping this field is the integration of large-language-model-driven conversational agents into virtual patient platforms, moving the technology from fixed branching scripts toward something closer to an open-ended standardized patient encounter. The randomized pilot study combining AI-driven virtual standardized patients with scenario-based simulation in anesthesiology training is among the first to test this specifically in an anesthesia population, and it found that trainees engaging with the AI-driven virtual patient demonstrated communication and history-taking performance comparable to trainees working with a human standardized patient, while requiring substantially less faculty and actor time to run[1]. If that finding holds up across larger and multi-institutional replications, it addresses one of the most persistent practical barriers to standardized-patient-based teaching in anesthesia programs, which have always struggled to justify actor costs and scheduling for a specialty where most clinical encounters are brief, intraoperative, and hard to script around a conscious, conversational patient in the first place.

Reviews cataloguing the broader landscape of VR applications in anesthesia simulation similarly point to AI-augmented adaptive scenarios — where the simulated patient's physiologic trajectory or conversational responses shift based on the trainee's actions in real time — as the direction the field is moving, even as they acknowledge that most currently published anesthesia-specific studies remain small, single-center, and short in follow-up duration[21].

PRACTICAL BARRIERS AND IMPLEMENTATION CONSIDERATIONS

None of the encouraging findings above answer the question every simulation director actually has to answer, which is whether adopting virtual patient

simulation is worth the disruption to an established mannequin-based curriculum. Cost is the most obvious factor in the technology's favor: a VR headset and licensed scenario library run a fraction of the capital and recurring cost of a mannequin simulation suite with a dedicated technician, and the marginal cost of adding a trainee to a session is close to zero once the software exists. Scheduling flexibility follows from the same logic — a resident on a home-call rotation can run a VR crisis scenario from a call room at 2 a.m. in a way that is simply impossible with a mannequin lab.

Set against that are recurring, consistent findings across the studies reviewed above: learner preference still tilts toward physical mannequin simulation for team-based and communication-heavy scenarios, cybersickness and unfamiliarity with headset interfaces remain a nontrivial minority complaint in several of the VR trials, and objective skill-transfer data — as opposed to knowledge or in-simulation performance data — remains thinner than knowledge-outcome data across the entire field, anesthesia-specific studies included. Programs that have integrated VR most successfully appear to be the ones using it as a supplement embedded within a structured, faculty-guided curriculum rather than as a stand-alone replacement for mannequin-based crisis training[11], a pattern that matches the broader graduate medical education finding that milestone-linked outcomes track more closely with curricular integration than with the simulation modality itself[15].

CONCLUSION

Virtual patient and virtual reality simulation have earned a genuine place in advanced anesthesia training, and the evidence supporting that place has thickened considerably over the past two to three years. The strongest, most consistent findings are for discrete technical and procedural skills — regional anesthesia, airway management, neuraxial technique — where VR platforms now have randomized trial support showing outcomes comparable to or approaching traditional instruction. The picture is more nuanced for crisis resource management and non-technical skills, where mannequin-based team simulation retains an edge that current VR platforms have not yet closed, particularly for the interpersonal and communication components of a crisis response. Artificial-intelligence-driven virtual standardized patients represent the most active area of near-term innovation and may, if larger trials confirm the early pilot data, meaningfully reduce the cost and logistical burden of standardized-patient-based communication training. For program directors, the pragmatic conclusion the current literature supports is neither wholesale replacement of mannequin simulation nor dismissal of virtual platforms as a novelty, but a deliberate, curriculum-embedded blend: virtual patient tools for scalable, repeatable technical and cognitive

skill-building, and physical, team-based mannequin simulation preserved for the crisis scenarios where presence, communication, and choreography still appear to matter most.

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Conflict of Interest

The authors declare no conflicts of interest relevant to this work.

Author Contributions

IG conceived the review and drafted the initial manuscript. IO performed the literature search and synthesized the sections on technical skill acquisition and comparative effectiveness. CA synthesized the sections on crisis resource management and implementation considerations and critically revised the manuscript. All authors read and approved the final version.

Ethics Statement

This is a literature review that did not involve new human or animal data collection and did not require institutional review board approval.

Data Availability

No new data were generated for this review. All sources discussed are publicly available published articles cited in the reference list.

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