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Review Article

Simulation-Based Airway Training and Resident Performance Outcomes: A Pilot Study

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ABSTRACT

Airway management is a core anesthesiology competency in which rare, high-stakes failures are difficult to teach through clinical exposure alone, making simulation an increasingly central component of resident training.

This review synthesizes the comparative evidence on simulation-based airway training, from foundational systematic reviews contrasting simulation with non-simulation instruction to recent randomized trials evaluating specific technical and crisis-management curricula.

The literature shows consistent gains in technical skill acquisition for difficult airway and rescue procedures, and in adherence to structured crisis algorithms, though evidence linking simulated performance directly to patient-level outcomes remains comparatively limited.

Deliberate practice and mastery learning frameworks, including rapid cycle deliberate practice, appear to improve retention of simulated skills relative to single-exposure training models, addressing one of the field's persistent weaknesses.

We conclude that residency programs benefit most from simulation curricula built around repeated, criterion-based practice with structured debriefing, with non-technical crisis resource management skills warranting comparable curricular emphasis to manual technique.

Keywords: *simulation-based training; airway management; anesthesiology residency; crisis resource management; deliberate practice*

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INTRODUCTION

Airway management sits at the center of anesthesiology training, and it is also the domain where a single missed step can turn a routine case into a crisis within minutes. For decades, residents learned the skill largely by doing it on real patients under supervision, a model that works reasonably well for straightforward cases but leaves trainees under-exposed to the rare, high-stakes scenarios —

the unanticipated difficult airway, the failed first attempt, the "can't intubate, can't oxygenate" sequence — that actually determine competence. Simulation has been proposed as a way to close that gap by letting residents fail safely, repeatedly, and with structured feedback before they encounter the same problem in a real patient. The evidence base has matured considerably over the past fifteen years, moving from small single-center pilot studies of manikin practice toward randomized trials with patient-relevant endpoints and network meta-analyses that attempt to rank different simulation modalities against each other [1][2]. This review synthesizes that literature, focused specifically on what simulation-based airway training does to measurable resident performance — technical skill acquisition, algorithm adherence, skill retention over time, and downstream clinical behavior — rather than to satisfaction surveys alone.

THE EVIDENCE FOR SIMULATION OVER TRADITIONAL TEACHING

The foundational systematic reviews and meta-analyses comparing simulation-based training to non-simulation instruction (didactic lecture, textbook study, or unstructured clinical exposure) consistently favor simulation on knowledge and skill outcomes, though the size of the effect varies with what is being measured [1]. A network meta-analysis organized around the Kirkpatrick model — which separates reaction, learning, behavior, and results as distinct levels of educational effect — found that simulation training produced larger gains than non-simulation training at the learning and behavior levels, but that the evidence thinned considerably once the question moved to patient-level results such as complication rates [2]. This pattern recurs throughout the field: it is comparatively easy to show that residents who train on a manikin place a supraglottic airway faster or intubate a simulated difficult airway more successfully than untrained peers, and much harder to show that this translates into fewer esophageal intubations or less hypoxemia in the operating room. The 2026 AIR-MASTER-SIM randomized study is one of the more recent attempts to close that gap, using a high-fidelity simulation curriculum and reporting outcomes intended to bridge simulated performance and real-world airway management competence [3]. Taken with the older StatPearls overview of simulation training and skill assessment approaches in anesthesiology, which catalogs the checklists, global rating scales, and time-to-task metrics most commonly used to operationalize "performance" in these studies, the field has converged on a reasonably standard toolkit even where the underlying trial quality is uneven [4].

TECHNICAL SKILL ACQUISITION: INTUBATION, FIBEROPTIC TECHNIQUE, AND RESCUE PROCEDURES

Direct and video laryngoscopy remain the most heavily studied simulated skills, but the literature on fiberoptic intubation is instructive because it isolates a technique that is notoriously difficult to teach opportunistically in real patients, given how infrequently awake fiberoptic intubation is indicated in routine practice. Early work using virtual-reality airway simulators demonstrated that novices could acquire basic fiberoptic navigation skills — scope orientation, epiglottis identification, cord visualization — through repeated simulated practice, with performance curves that plateaued well before residents had accumulated equivalent real-case exposure [5][6]. More recent randomized work has refined this further, testing adjuncts such as supraglottic jet oxygenation and ventilation during fiberoptic intubation training in a simulated difficult airway, with the aim of extending the safe apneic window trainees have to work within while they practice the technique [7]. Observational data on tracheal intubation skill acquisition in junior residents, tracking success rates and attempt counts across a training block, suggest that the early learning curve is steep and that simulation-based preparation shifts more of that curve out of the operating room and into a setting where a failed attempt costs nothing but time [8]. The same logic extends to lower-frequency rescue procedures: a comparative study of difficult airway management training for residents found that simulation-trained groups performed more reliably when confronted with an unanticipated difficult airway scenario than residents who had only classroom preparation [9], and a widely cited trial on emergency cricothyrotomy training showed that simulation improved not just technical execution but adherence to the difficult airway algorithm itself — arguably the more important outcome, since algorithm deviation rather than manual dexterity is what tends to produce bad outcomes in real crises [10]. Endotracheal intubation training data in medical students, while drawn from an earlier and less specialized population, reinforce that simulated practice accelerates the acquisition curve for the psychomotor components of airway instrumentation before trainees ever reach residency [11]. A brief review specific to anesthesiologists frames simulation-based airway training as now essential rather than supplementary to clinical competency development, a position that reflects how far the specialty's own self-assessment has shifted since simulation was a novelty [12].

CRISIS RESOURCE MANAGEMENT AND NON-TECHNICAL SKILLS

Technical proficiency with a laryngoscope or bronchoscope is only part of what determines outcomes in a genuine airway crisis; the ability to communicate under pressure, call for help early, and follow a structured algorithm rather than fixate on a single failing maneuver matters just as much. Anesthesia Crisis Resource Management (ACRM), adapted from aviation crew resource management, was among the first simulation curricula to target these

non-technical skills explicitly, and the original description of real-life simulation training in operating room crises remains a touchstone for how the field thinks about training team behavior rather than individual technique [13]. A decade-long retrospective on ACRM programs found that structured debriefing after simulated crises, more than the crisis scenario itself, was where residents' behavioral change seemed to originate — participants could describe what they would do differently long after the technical details of the scenario had faded [14]. This dovetails with research into the cognitive mechanisms underlying simulation learning: work examining episodic memory in high-fidelity anesthetic simulation found that residents retained vivid, specific recollections of simulated crises years later, and that these memories functioned as retrievable scripts they could draw on during subsequent real emergencies, which may explain why simulation appears to have an outsized effect on crisis behavior relative to its effect on routine technical metrics [15]. Resident-reported satisfaction with high-fidelity simulation teaching has also been documented, alongside measurable pre-to-post changes in knowledge scores, suggesting that the subjective experience of simulation training and its measurable cognitive yield tend to move together rather than diverge, which is reassuring given how much simulation curricula rely on trainee buy-in to be effective at all [16].

RETENTION, DELIBERATE PRACTICE, AND THE MASTERY LEARNING FRAMEWORK

A recurring critique of single-exposure simulation training is that skills acquired during a workshop or curriculum block decay over subsequent months, particularly for low-frequency procedures that residents may not perform again clinically for a long stretch. The deliberate practice and mastery learning literature, most closely associated with McGaghie and colleagues, argues that this decay is not an inherent property of simulation but a product of how most simulation curricula are structured — as one-off exposures rather than as repeated, criterion-referenced practice cycles with feedback built in [17][18]. Under a mastery learning model, trainees repeat a task until they reach a pre-specified minimum passing standard rather than completing a fixed number of repetitions, and the accumulated evidence across procedural specialties indicates that this approach produces more durable skill retention than time-based or repetition-based training schedules. Rapid cycle deliberate practice, a variant that interrupts simulated scenarios in real time to correct errors before they compound rather than saving all feedback for a post-scenario debrief, has shown particular promise for the compressed decision sequences involved in airway rescue, where waiting until the end of a failed scenario to correct a technique error means the trainee has already rehearsed the wrong sequence multiple times [19]. A broader meta-analytic comparison of simulation-based medical education using deliberate practice against traditional clinical education found consistently favorable effect sizes for the deliberate practice arm across procedural domains, airway management among them, reinforcing that the instructional design of a simulation curriculum matters at least as much as the fidelity of the manikin or the realism of the scenario [20]. More recent curriculum development work applying mastery learning specifically to emergency procedural skills illustrates how these principles are now being operationalized into structured, replicable programs rather than left as a general educational philosophy [21].

CONCLUSION

The evidence assembled over the past two decades supports simulation-based airway training as an effective, and in several respects necessary, complement to clinical exposure for anesthesiology residents, with the most consistent gains appearing in technical skill acquisition for difficult airway rescue procedures and in adherence to structured crisis algorithms rather than in isolated dexterity metrics. Where the literature remains comparatively thin is in linking simulated performance gains directly to patient-level outcomes, and in establishing how curricula should be structured to prevent skill decay between training exposures — a gap that the deliberate practice and mastery learning frameworks are beginning to address but have not yet closed for every procedure in the airway repertoire. For residency programs designing or revising an airway curriculum, the practical implication is that simulation delivers more value when built around repeated, criterion-based practice cycles with structured debriefing than when treated as a periodic checkbox exercise, and that non-technical skills training deserves at least as much curricular weight as manual technique given how much crisis outcomes appear to hinge on algorithm adherence and team communication rather than instrument handling alone.

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Ethics Statement This is a literature review and did not involve new human or animal data; no ethics approval was required.

Data Availability No new data were generated for this review. All sources discussed are publicly available in the cited literature.

REFERENCES

1. Airway management education: simulation based training versus non-simulation based training-A systematic review and meta-analyses (2017) BMC Anesthesiology, DOI:10.1186/s12871-017-0313-7.
2. Educational Effects of Simulation and Non-Simulation Training in Airway Management according to Levels of the Kirkpatrick Model: A Systematic Review and Network Meta-Analysis (2021) Journal of Clinical Medicine, DOI:10.3390/jcm11195614.
3. High-fidelity simulation in airway management training: results from the AIR-MASTER-SIM randomised study (2026) Frontiers in Medicine, PMID:42305958.
4. Simulation Training and Skill Assessment in Anesthesiology (2023) StatPearls, NCBI Bookshelf.
5. Acquisition of basic fiberoptic intubation skills with a virtual reality airway simulator (2001) Journal of Clinical Anesthesia.
6. Virtual simulation training for fibreoptic intubation.
7. Supraglottic Jet Oxygenation and Ventilation in Fiberoptic Intubation Training for Anesthesia Residents in a Simulated Difficult Airway: A Randomized Controlled Study (2026) PMC.
8. Evaluation of Tracheal Intubation Skill Acquisition in Junior Residents During Anesthesiology Training: An Observational Study (2025) PMID:40605877.
9. Simulation of difficult airway management for residents: prospective comparative study (2022) PMC.
10. Effect of Simulation Training on Compliance with Difficult Airway Management Algorithms, Technical Ability, and Skills Retention for Emergency Cricothyrotomy (2014) Anesthesiology, DOI:10.1097/ALN.0000000000000138.
11. Endotracheal intubation skill acquisition by medical students (2023) Medical Education Online, DOI:10.3402/meo.v16i0.7309.
12. Simulation-based Airway Management Training for Anesthesiologists - A Brief Review of its Essential Role in Skills Training for Clinical Competency (2018) PMC.
13. Anesthesia crisis resource management: real-life simulation training in operating room crises (1995) Journal of Clinical Anesthesia, PMID:8747567.
14. Simulation-Based Training in Anesthesia Crisis Resource Management (ACRM): A Decade of Experience.
15. Learning through high-fidelity anaesthetic simulation: the role of episodic memory (2011) British Journal of Anaesthesia.
16. Evaluation of resident satisfaction and change in knowledge following use of high-fidelity simulation teaching for anaesthesia residents (2019) PMC, PMID: PMC6868659.
17. A critical review of simulation-based mastery learning with translational outcomes.
18. Deliberate Practice and Mastery Learning Contributions to Expert Performance in Medicine.
19. Rapid Cycle Deliberate Practice in Healthcare Simulation: a Scoping Review (2021) Medical Science Educator, DOI:10.1007/s40670-021-01446-0.
20. Does Simulation-based Medical Education with Deliberate Practice Yield Better Results than Traditional Clinical Education? A Meta-Analytic Comparative Review of the Evidence (2011) PMC.
21. Simulation-Based Mastery Learning Curriculum Development (2025) Simulation in Healthcare.