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Adaptive simulation training using cumulative sum: a randomized prospective trial

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Abstract

BACKGROUND: Cumulative sum (Cusum) is a novel tool that can facilitate adaptive, individualized training curricula. The purpose of this study was to use Cusum to streamline simulation-based training.

METHODS: Preclinical medical students were randomized to Cusum or control arms and practiced suturing, intubation, and central venous catheterization in simulation. Control participants practiced between 8 and 9 hours each. Cusum participants practiced until Cusum proficient in all tasks. Group comparisons of blinded post-test evaluations were performed using Wilcoxon rank sum.

RESULTS: Forty-eight participants completed the study. Average post-test composite score was 92.1% for Cusum and 93.5% for control ($P = .71$). Cusum participants practiced 19% fewer hours than control group participants (7.12 vs 8.75 hours, $P < .001$). Cusum detected proficiency relapses during practice among 7 (29%) participants for suturing and 10 (40%) for intubation.

CONCLUSIONS: In this comparison between adaptive and volume-based curricula in surgical training, Cusum promoted more efficient time utilization while maintaining excellent results.

Surgical resident operative preparedness in an era of work-hour restrictions, and stringent outcomes scrutiny is a subject of mounting concern.[1] As a result, 2 widespread movements have begun to gain momentum: the growing role of simulation and the exploration of competency-based curricula.[2,3] The residency review committee has increasingly emphasized simulation's role as a major supplement to technical training.[4] Meanwhile, the surgical skills curriculum is a promising first step toward proficiency-based training both in the operating room and at the benchtop.[5]

Theoretically, combining simulation with proficiency-based training should efficiently prepare trainees to take full advantage of operative experiences. Cumulative sum (Cusum) is a quality-control tool suitable for real-time proficiency monitoring during training and has been used to depict learning curves for simulation techniques including airway endoscopy and robotic surgery.[6,7] At the bedside, Cusum has been applied—usually in a retrospective manner—to an even broader range of invasive skills.[8–11]

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Cusum's overall principle is that proficiency for a given procedure can be determined by tracking the temporal trend of successful and failed attempts at that procedure. By comparing Cusum records against prespecified acceptable thresholds, performance by an individual—or an institution—can be categorized as proficient or subproficient. Advantages of Cusum within a proficiency-driven curriculum include its objectivity, ease of use, and graphic depiction of learning progress. However, Cusum has not been rigorously validated in surgical education nor has it been used to prospectively guide training in a proficiency-driven manner. Needless to say, there have been no randomized trials comparing Cusum-based training to the traditional "time-spent" model of surgical education.

The purpose of this study was 2-fold. First, we aimed to describe a prospective, Cusum-guided simulation training curriculum to demonstrate the variability in learning rates among inexperienced trainees. Second, we sought to report the first randomized, prospective trial comparing an adaptive, proficiency-based simulation protocol to a traditional, "time-spent" system. We hypothesized that although the traditional system can effectively confer technical proficiency, the Cusum-guided protocol would attain equivalent results with less overall practice time.

Methods

Simulation modules

Three simulated invasive skills were incorporated within an elective medical student training curriculum: orotracheal intubation, basic surgical suturing, and subclavian central venous catheterization (CVC). Details regarding each skill's methods and scoring criteria have been reported in a prior publication.[12] In brief, the intubation task involved single-operator bag-valve-mask ventilation, direct laryngoscopy, and orotracheal intubation. The suturing task tested 2-handed, instrument, and 1-handed tie techniques using a series of figure-of-eight stitches. The CVC task involved right subclavian central venous access without ultrasound guidance.

Assessment checklists were created by expert consensus based on task-specific objective structured assessments of technical skills as previously reported.[12–15] Minimum proficiency scores for each task were 32/36 for suturing, 16/18 for intubation, and 32/36 for CVC. Time limits for the 3 tasks were 5, 2.5, and 10 minutes, respectively. For each practice attempt at any task, both the checklist and time criteria must be satisfied in order for the attempt to be considered successful.

Cusum analysis

Cusum methodology was based on the work by Bolsin and Colson.[16] In brief, Cusum is founded on the binary outcome of each attempt at a given task: success or failure. Each success is given a numeric reward—represented by a downward deflection on a Cusum graph, whereas each failure is associated with a penalty—an upward deflection. By accumulating rewards and penalties through repetitive practice attempts, a classic learning curve is generated with a learning phase (incline) and a proficient phase (flat or decline). Because a Cusum curve is updated after every task attempt, relapses in proficiency can be detected, which trigger retraining. A relapse is defined as a period of subproficient performance following an earlier period of proficiency. On a Cusum curve, this manifests as a curve which trends upward after a downtrending or flat segment.

Cusum uses several parameters defined a priori. The acceptable and unacceptable failure rates (p_1 and p_0, respectively) describe the maximum acceptable level of human error ($p_1 - p_0$).[8] The false-positive rate (α) defines the allowable risk of falsely labeling a proficient practitioner as subpar. These parameters determine the numeric reward (negative) or penalty (positive) associated with each successful or failed attempt, respectively. They also determine the unacceptable decision interval. A Cusum curve that trends upward and crosses a decision interval over a series of attempts is indicative of subproficient performance. For the present study, the following Cusum parameters were set a priori by consensus: $p_1 = .1$, $p_0 = .2$, $\alpha = .3$. These values yielded a reward of $-.15$, a penalty of .85, and a decision interval of 1.05. A participant was considered Cusum proficient in a given task as long as no decision interval had been crossed over the 5 most recent practice attempts.

Participants and training

Volunteer participants were recruited from the 1st- and 2nd-year medical school classes, before enrollment in clinical clerkships. Participants first completed a 2-hour orientation session which addressed proper techniques for each task. Instructional videos demonstrating each simulation task were also provided for independent review. Following orientation, participants were randomized to 1 of the 2 experimental arms: Cusum and control. All participants then underwent weekly 1-on-1 practice sessions proctored by trained assistant instructors on a rotating schedule to minimize teaching biases.[12]

The control arm's practice protocol was designed to emulate a traditional surgical training paradigm based primarily on a requisite amount of time spent in practice. Participants were asked to complete a total of 7 weekly 1-on-1 practice sessions combining to roughly 8.75 hours of practice. During each session, participants could choose to practice any task, in any order. After each task attempt, the task-specific checklist was used by the assistant instructors to provide objective feedback regarding task components which were missed or improperly performed. Additional positive or negative feedback beyond the task-specific checklists was neither encouraged nor discouraged.