Preanesthesia detection of equipment faults by anesthesia providers at an academic hospital: Comparison of standard practice and a new electronic checklist

GEORGE BLIKE, MD
Lebanon, New Hampshire
CHUCK BIDDLE, CRNA, PhD
Richmond, Virginia

We hypothesized that our institutional standard practice for preanesthesia equipment checkout, based in part on US Food and Drug Administration recommendations, failed to detect a significant number of faults (absent or nonfunctional equipment). We designed a new, computer-based, highly interactive electronic checklist that emulated the checklist methods used in aviation and military settings and compared it to our standard practice in the detection of faulty equipment. Using a randomized, cross-over design, anesthesia providers searched for prearranged faults over a 2-day period using both the electronic and standard approaches. Faults (easy and difficult) found, faults missed, and time to complete the checkout were recorded. The electronic checklist was superior to standard practice in the detection of "easy" and "difficult" equipment faults. However, even when the electronic checklist was used, a high proportion of difficult faults were missed. Whether the failure represents a need for improved checkout procedures and provider training or better equipment design will require further study.

Key words: Anesthesia machines, computer checklist, equipment, pre-use checkout methods, US Food and Drug Administration anesthesia checklist.

Introduction

Despite the growth in the number and quality of anesthesia providers, human error remains a major cause of anesthesia-related morbidity and mortality. Human error has been estimated to account for up to 70% of anesthetic complications.[1,2] Although this estimate is dated to literature from the 1970s, the problem of human error remains significant today. Several studies have demonstrated that "failure to perform a preanesthetic check" of anesthesia equipment was the most common associated factor with anesthesia mishaps attributed to anesthesia systems failures.[3,4] Early work by Buffington et al[5] showed that anesthesiologists performing their routine equipment checkouts detected only 44% of prearranged machine faults. The US Food and Drug Administration (FDA) in collaboration with the American Society of Anesthesiologists (ASA) and anesthesia machine manufacturers developed *Anesthesia Apparatus Checkout Recommendations,* which were widely published in 1987.[6] This FDA checklist had become the de facto standard for anesthesia equipment checkout, when 1 major study attempt-

ing to validate the efficacy of this checklist failed to do so. In this study by March and Crowley,[7] anesthesia practitioners detected only 30% of prearranged machine faults whether or not they used the FDA checklist.

The FDA checklist has been rewritten, again using a collaborative group of experts. The revised *FDA Anesthesia Apparatus Checkout Recommendations* were approved in 1994 and published in several sources.[8] Competent validation studies have not been performed on this revised FDA checklist.

The goal of the current study was to perform a critical analysis of the procedures of the revised FDA checklist with adherence to accepted "human factors" design principles.[9,10] We believe the new FDA checklist still fails to emphasize functional tests of critical monitoring and recovery systems used in the practice of anesthesia. Further, the revised FDA checklist still limits its scope to the anesthesia machine. Since the anesthesia machine is not the only source of equipment failure in anesthesia, this singular focus does not appear to meet the goals of a global preuse anesthesia apparatus checklist.

To attempt to correct the deficiencies of the revised FDA checklist, a "philosophy of anesthesia apparatus checkout" (Table 1) was developed, upon which were designed a set of comprehensive procedures to achieve the stated goals of anesthesia apparatus checkout. We then implemented the procedures in an electronic fashion (with an incorporated video self-help feature) that used 2 accepted formats adopted from modern flight-deck checklist design: a challenge-response format for each task and task-indexing. A study was subsequently undertaken to explore 2 hypotheses: (1) the current use of the FDA checklist at our institution is inadequate; and (2) the electronic implementation of the checklist we developed (a modified FDA checklist) would improve the ability of anesthesia providers to detect anesthesia apparatus faults when compared to the FDA checklist.

Table 1. Philosophy of anesthesia apparatus checkout

To reduce patient injury that results from *critical anesthesia apparatus** omission or malfunction by 2 basic strategies:

1. The execution of procedures designed to confirm the presence and proper function of *critical anesthesia apparatus*
2. The confirmation of the presence and proper function of back-up equipment for all items deemed *critical anesthesia apparatus*

*Critical anesthesia apparatus was defined as: the equipment, monitors, and drugs required to provide emergent airway control, controlled ventilation, advanced cardiac life support, and a controlled level of surgical anesthesia.

Materials and methods

This study was approved by the Committee for the Protection of Human Subjects of Dartmouth College, and informed consent was received from each participant. Study subjects (N=22) were randomized into 2 matched groups (ie, matched for equal numbers of anesthesia residents, Certified Registered Nurse Anesthetists [CRNAs], and attending anesthesiologists). All participants were nationally certified individuals with at least 14 months of postgraduate experience (range 14 months to 28 years). Four anesthesia apparatus faults sets were randomly generated from a master list of 20 apparatus faults, all of which were considered critical and representative of actual faults discovered during equipment checks at our institution (Table 2). The 20 faults generated were randomly assigned to create 4 sets, each containing between 3 and 8 faults. Within each fault set, the faults did not interact. The faults originated from a pool of faults that had actually been observed in the preceding 2 years at the study site. All faults were arranged on standard equipment used at Dartmouth-Hitchcock Medical Center consisting of an Ohmeda Modulus II Plus Anesthesia System (Datex-Ohmeda, Tewksbury, Mass) anesthesia machine, an anesthesia cart, and a suction canister.

All study subjects were given standardized instruction consisting of a didactic lecture on the philosophy of anesthesia apparatus checkout and the rationale for the revised FDA checkout recommendations. Although the study subjects were not strictly required to use the FDA checklist, they were asked to read the preamble of the FDA checkout procedure, which strongly encourages the use of the FDA checklist or equivalent checkout procedures: "This checkout, or a reasonable equivalent should be conducted before administration of anesthesia. This is a guideline which users are encouraged to modify to accommodate differences in equipment design and variations in local practice. Such local modifications should have appropriate peer review...."[8]

Study subjects using the electronic checklist were given the "Philosophy of Anesthesia Checkout" (Table 1) and instructed to check the equip-

Table 2. Fault sets

A1-1. *O_2 calibration error:* The O_2 analyzer was calibrated to read 30% when exposed to room air. The analyzer should read 21%.

A1-2. *Absent AMBU-bag:* An AMBU-bag should be present and hanging on the back of each anesthesia machine.*

A1-3. *Absent electrocardiographic (ECG) cables:* The cable and wires necessary for monitoring not with the ECG device.

A1-4. *Occluded patient suction:* The reinforced suction tubing used before the present study at Dartmouth Hitchcock Medical Center had an rubber lining that was prone to fold over, occluding the lumen of the suction tubing at its connection to the suction canister.

A2-1. *Ventilator bellows leak:* A 2 L/min leak was created in the bellows apparatus where the rubber bellows attaches to the base of the ventilator unit. This leak occurs when the rubber bellows loses its elasticity.

A2-2. *Low pressure leak at vaporizer:* A small plastic washer was used to create a leak by preventing the vaporizer from seating on its mount properly. This leak has occurred when objects placed on the machine work surface wedge under a vaporizer, slightly lifting it.

A2-3. *Stuck unidirectional valve:* Clear plastic from a mask wrapper was positioned to create a stuck unidirectional valve (in the open position) in the expiratory limb of the breathing circuit.

A2-4. *Breathing circuit leak:* A 2 L/min leak was created by overfilling the upper sodalime canister with sodalime granules. This prevented the rubber gasket on the upper canister from sealing.

A2-5. *Low O_2 alarm:* The low O_2 alarm was set at 18%, a hypoxic mixture.

B1-1. *Endotrachial tubes (ETTs) absent:* No ETTs were present in the anesthesia cart provided.

B1-2. *O_2 cylinder low:* The auxiliary O_2 supply cylinder was at 800 psi, below that recommended by both checklists.

B1-3. *Scavenger positive pressure relief valve stuck closed:* Plastic was used to wedge the scavenger positive pressure relief valve shut, causing an increased circuit pressure.

B2-1. *Intravenous catheters absent:* No intravenous catheters were present in the anesthesia car provided.

B2-2. *Occluded end-tidal CO_2 sample line:* Clear glue was used to occlude the lumen of the sample line where the male connector attaches to the sampling tubing.

B2-3. *Loose vaporizer cap:* the refill cap for the vaporizer on the test machines was loosened by $^1/_2$ turn counterclockwise.

B2-4. *Noninvasive blood pressure (NIBP) cuff absent:* No NIBP cuff was present with the NIBP device.

B2-5. *Occluded adjustable pressure limiting (APL) valve:* The APL set screw was tightened until 10 cm H_2O remained when the APL valve was in full open position.

B2-6. *O_2 supply line not connected:* The O_2 supply line connector was incompletely attached to the wall outlet (not snapped in all the way).

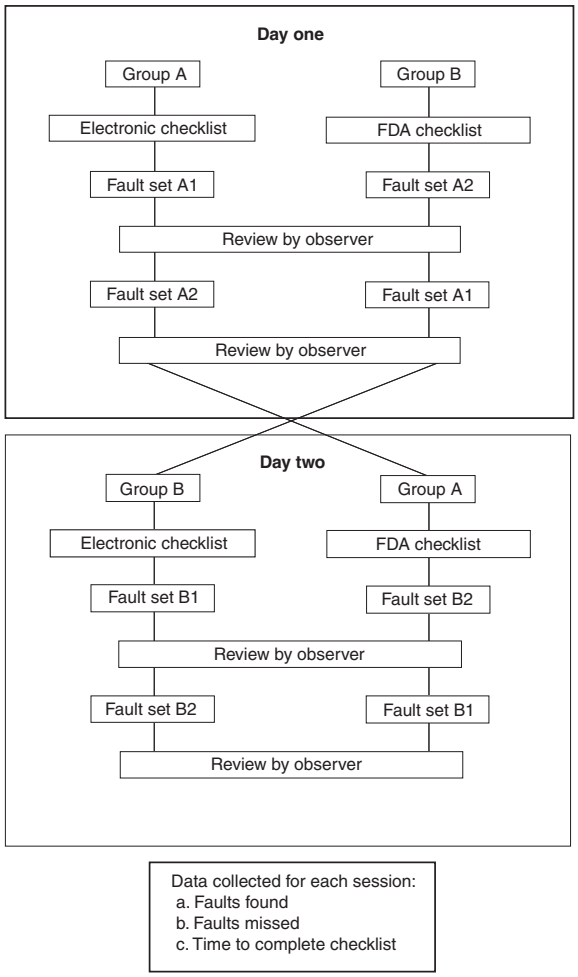
B2-7. *Scavenger vacuum setting low:* The scavenger vacuum valve was tightened. At fresh gas flows greater than 2 L/min, waste gases exited the positive pressure relief valve into the environment.

B2-8. *Sodalime canisters empty:* No sodalime was present in either canister.

* Institutional standards/conventions known to all study subjects.

ment as though the apparatus were being set up in preparation for a "STAT" (emergency) cesarean delivery. Subjects using the FDA checklist were not given the philosophy statement, but they were given the FDA checklist and again instructed to set up and check the equipment as if it might be used for an emergency cesarean delivery. The study was conducted during a 2-day period using a cross-over design (Figure 1). Day 1: group A searched for faults using the electronic checklist on first one, then another machine with prearranged faults (fault set A1, then fault set A2, respectively); while group B similarly searched 2 different machines with the same prearranged faults using the FDA checklist. Day 2: group A used the FDA checklist, and group B used the electronic checklist to search for 2 different sets of faults (fault set B1 and fault set B2). At the com-

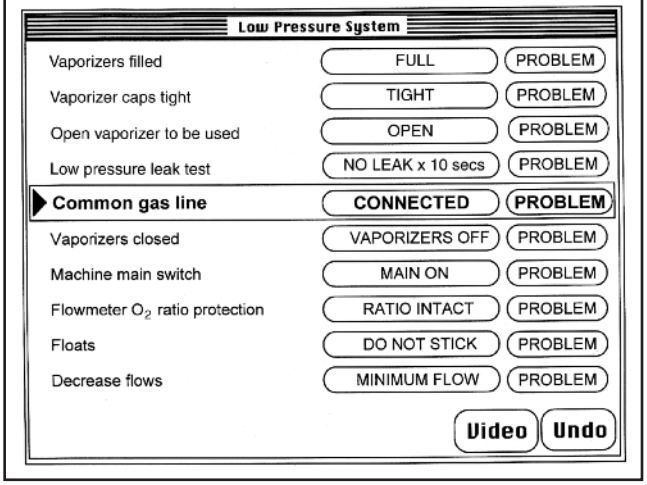
Figure 1. **Didactic lecture/philosophy of preuse checklist/review of US Food and Drug Administration (FDA) checkout recommendations**



pletion of each round of testing, performance of checkout procedures was reviewed, and feedback was provided to each participant. Faults found, faults missed, and time to complete the checkout were recorded.

The electronic checklist was developed on a computer workstation consisting of a Macintosh Quadra 700 (Apple Computer, Inc, Cupertino, Calif) computer using the object-oriented programming language Prograph. The video-HELP movies were developed using videotaped segments ranging from 10 to 36 seconds, with a video digitized board and video editing software. A 19-inch color monitor with an integrated touchscreen allowed the user to "run" the checklist and activate the assist videos with a finger touch on the color monitor screen (Figure 2). The design and integration of this technology were entirely novel and developed exclusively by the study authors.

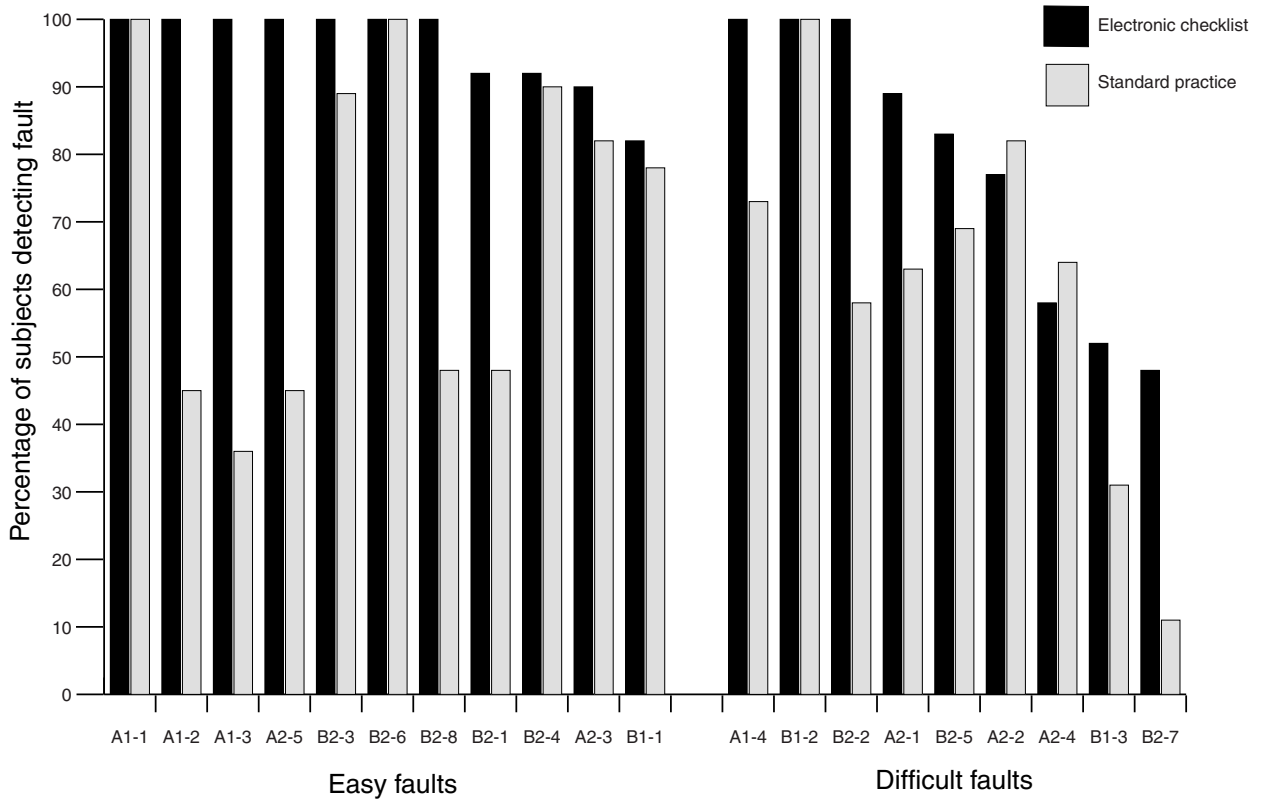
Figure 2. **Electronic checklist color monitor screen**



Results

The detection rate for each fault is shown in Figure 3 as a function of the checkout method utilized. Fault detection for each fault except A2-2 using the electronic checklist was either equal to or superior to the detection rate achieved using the FDA checklist. Faults were grouped according to the procedure skill level required to detect the fault; we named the groups "easy" faults and "difficult" faults. Detection of easy faults (discovery required a simple "present" vs "not present" determination—eg, fault A1-2: *AMBU-bag on back of machine*) was superior when the electronic checklist was used with a greater than 95% fault detection rate compared with only a 70% fault detection rate when the FDA checklist was used ($P<.01$, chi-square). Detection of "difficult" faults (discovery required performance of a complex procedure—eg, a negative pressure leak check to detect fault A2-2: *Low pressure leak at vaporizer*) was also superior using the electronic checklist. The fault detection rate using the electronic checklist was 73%, while the fault detection rate using the FDA checklist was only 38% ($P<.01$, chi-square). Overall, the fault detection rates for difficult faults were significantly lower than the detection rates for easy faults regardless of the checklist method used (eg, using the electronic checklist 95% of easy faults were identified vs 73% of difficult faults). There was a difference ($P<.05$, *t*-test) in terms of time to complete the FDA (14.8 ± 4.3 minutes) vs the electronic checklist (23.3 ± 7.2 minutes); however, the time needed to complete the electronic checklist decreased by a mean of 5.2 ± 4.1 minutes with the second exposure to its use, suggesting

Figure 3. **Detection rates of individual faults**



that users rapidly ascended the learning curve associated with its use.

Discussion

Of the first 2,000 incidents reported to the Australian Incident Monitoring Study, 177 (9%) were due to equipment failure according to predefined criteria.[11] Ninety-seven (55%) were considered potentially life-threatening. Multiple studies have confirmed that anesthesia providers often fail to check their anesthesia apparatus or perform inadequate checks. The use of checklists to combat human error is prevalent outside the medical domain. Historically, the airline industry, which is charged with transporting people safely using airplanes as the vehicle, has endorsed the use of checklists. Checklists are used by airline pilots to ensure that critical equipment is both present and functional during all phases of flight (the preflight phase, the phase before takeoff, and the phase before landing). Such checklists are mandatory, are performed with another person, and require documentation of performance.[12]

Using the aviation model design principles proved successful in the airline industry, "...a checklist should facilitate, prescribe and stipulate a progression of sub-tasks or actions which ensure that the procedure at hand will be completed in a fashion that is logical, efficient and error resistant."[9] It is important to develop this design strategy completely in any domain in which it is used. Consider a paper shopping list used as a reminder of what to buy on a trip to the market. In lay terminology this might be called a checklist. However, "human factors" experts would not consider this a well-designed checklist. In lay terminology, checklists, algorithms, and protocols are used interchangeably, and all infer a simple schema for organization mostly focused on reducing errors of omission. In contrast, human factors experts consider all of the required task-related modes for errors in a given system. In a study titled "Human factors of flight-deck checklists," Degani and Wiener[10] identified many problems that interfere with proper checklist execution. They determined that humans may misuse checklist procedures

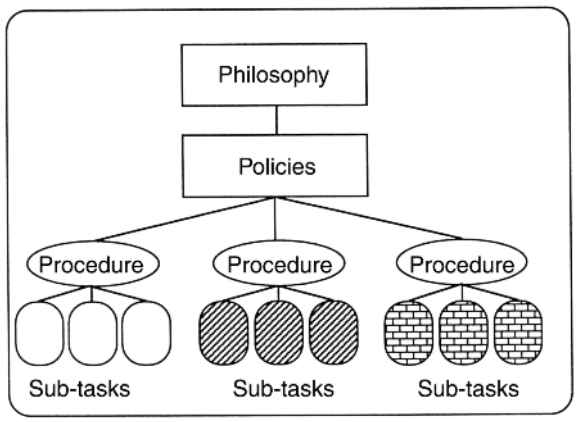
when the guiding philosophy for the checklist is unclear, and policies governing the proper use of the checklist are inconsistent. They suggest that effective checklist design must have the three "Ps": a guiding *philosophy*, with *procedures* designed to achieve the goal of the philosophy using consistent *policies* for implementation (Figure 4).

The simple shopping list example can be used to illustrate human factors design principles using these "three Ps." The overall *philosophy* might be to: "optimize the maintenance of food supplies in the home using organized visits to the grocery store that are economical and efficient." *Procedures* might include: (1) identifying items to purchase (eg, have a paper and pen on the refrigerator to facilitate adding items to the list when the supply of the item is low); (2) developing a paper form that organizes where you write down an item on the shopping list that maps onto the store layout (eg, group items to be retrieved by the aisle in which they are located); (3) having a shopper use a pencil to cross off each item successfully retrieved (indicating task completion); and (4) specifying a procedure for loading items into a cart so that items are placed in bags and grouped in a way that maps onto the location in which the items will be stored in the shopper's home. Grocery shopping *policies* would dictate the "who, how, when, and where" the checklist procedures are to be performed. Finally, *validation* of the procedures must be done prior to implementing policy recommending use of the checklist.

There is precedent for the effective development and implementation of checklists in medicine. advanced cardiac life support (ACLS) is a proven, comprehensive system designed to improve the performance of well-established procedures and protocols by healthcare personnel during life-threatening situations. Unfortunately, a myriad of unproven "protocols" exist in medicine as well. Checklists that do not meet their design objectives are often based on intuition rather than sound design strategy. The lessons learned from the successful implementation of checklists is that research is required to elucidate what is effective (eg, ACLS is being continually improved by research supported by the American Heart Association).

The FDA *Anesthesia Apparatus Checkout Recommendations* were developed using expert opinion in a collaborative effort with anesthesiologists, members of the FDA, and machine manufacturers; however, the study conducted by March and Crowley[7] failed to demonstrate improved fault detection when operators used the checklist.

Figure 4. **Philosophy, policies, and procedures for effective checklist design**



Although the FDA checklist was revised, we find the revised FDA checklist still fails to utilize the "three P's" of checklist design. We developed an electronic checklist specifically attentive to the "three P's" to test the hypothesis that improved anesthesia checklist design would improve the anesthesia checklist efficacy. We then implemented the checklist in an electronic format borrowing the challenge-response format with "task-indexing'' widely used in aviation.

Our study results appear to confirm that the electronic checklist greatly improved the detection of prearranged anesthesia equipment faults. For 19 of 20 faults studied, fault detection using the electronic checklist was either equal (n=8) or superior (n=11) to the fault detection using the paper FDA checklist. A simplified task analysis looking at the procedures required to detect each fault revealed that 2 broad categories of faults exist. We grouped faults with respect to the complexity of the procedures that the operator was required to perform to detect them. We named the fault groups "easy" faults and "difficult" faults. Data for the detection rates for easy and difficult faults were pooled and added significant power for subsequent statistical analysis. For this discussion, checklist design issues that have an impact on checklist efficacy will be addressed separately.

Easy faults

The detection of "easy" faults required operators to: (1) read the checklist item from the list, (2) visually determine the presence or absence of the checklist item, and (3) advance the checklist to

the next active item on the electronic checklist by touching the proper button on the screen. Failures to detect a fault for this type of easy fault almost universally represented a failure to check. A fault detection rate of greater than 95% using the electronic checklist supports the use of a well-designed checklist for performing easy checks. Several design issues used to develop the electronic checklist may account for its success.

Checklists in general serve as excellent memory aids, regardless of the format used (electronic vs paper format). Unfortunately, not all anesthesia providers use the FDA equipment checklist preoperatively. It is common knowledge that those who do perform the FDA checkout, or a hybrid version, often do so exclusively from memory. Even in a study situation, individuals often execute a paper checklist, especially one they have used many times before, from memory. Relying on memory for a long list of items invariably results in errors of omission. In our study, approximately 20% of the subjects executed the FDA checklist from memory, which may account for some fault "misses." The electronic checklist is interactive and does not accommodate execution from memory, making it more resistant to human error.

Another benefit of an electronic checklist over a paper one is that indexing is easily implemented. Indexing implies that some type of pointer and/or marker is used to indicate which tasks are completed and which tasks remain to be done (the electronic checklist in this study uses small plain gray text for completed tasks, large bold black text for active task, and small plain black text for pending tasks—see Figure 2). Operators are often distracted in the real world while performing checklists and can lose their place on a paper checklist, which can result in skipped items if the operator re-enters the checklist at the wrong step. Indexing is probably less relevant in our study situation given that none of the distractions of the real world anesthesia environment (last-minute schedule changes and room swaps in the middle of performing equipment checkout) were present. However, one would predict that a more realistic study would amplify the superiority of the electronic checklist over the nonindexed FDA checklist.

Finally, the electronic checklist in this study used a challenge-response format. The challenge-response paradigm specifies that 1 operator read a challenge statement (eg, "flaps up, in take-off position") while another operator performs the check then reports back an accepted positive or negative response (eg, "flaps up" or "flaps not up—malfunction"). The electronic checklist in this study was designed to allow a single operator to interact with the computer screen to perform both actions of a typical challenge-response. The operator reads the highlighted active task challenge (eg, AMBU-bag present on back of machine), performs the check, then interacts with the computer touch-screen to select the appropriate response (eg, "present" or "not present"). The action of selecting a response advances the checklist index to highlight the next task. Chopra et al[13] demonstrated that 2 anesthesia providers performing a *paper* checklist in a challenge-response fashion could achieve excellent fault detection rates. In the United States, however, most anesthesia providers execute their equipment checkout solo, as it was done in our study. The lack of a challenge-response format in the FDA checklist may be another contributor to the clear superiority of the electronic checklist for detecting easy faults in this study.

Difficult faults

Detection of "difficult" faults requires that operators execute a complex set of procedures (the military refers to these as standard operating procedures—SOPs) in a precise way. Obviously, if one fails to remember to perform a difficult check, problems will go undetected, as with the "easy" checks. However, unlike the easy faults, difficult faults were missed mainly because the procedures required to detect the fault were executed improperly. In aviation, the SOPs for the flight-deck are taught through drill exercises and the use of simulators. Pilots do not learn 10 ways to start an engine, just 1 method that a group of experts has designed and recommended. Furthermore the efficacy of these procedures often has been demonstrated in simulator studies. Again, most of the misses of the difficult faults in our study were characterized as failure-to-execute errors, in contrast to the simple failure-to-check errors associated with the easy faults.

Both the electronic checklist and the current FDA checklist improved upon the first version of the FDA checklist by describing in greater detail the techniques for performing complicated functional checks (eg, a negative pressure leak check to detect fault A2-2: *Low pressure leak at vaporizers*). In this study, all subjects were given didactic training regarding the revised FDA apparatus checkout recommendations. However, our study did not drill subjects to teach proper technique for the perform-

ance of difficult checks. Both the electronic checklist and the FDA paper checklist assume the operator is both knowledgeable and facile regarding the SOPs for anesthesia apparatus checkout. This assumption may not be valid. The observers collecting data during this study noted that participants missed the difficult faults primarily because the SOPs were performed improperly. For example, several individuals who missed a breathing circuit leak of 2 L/min. failed to: (a) reduce gas flows to the minimum, (b) completely close the adjustable pressure limiting valve, or (c) observe the pressure gauge for an adequate duration (about 5 seconds), when performing the check.

Anesthesia providers in our study missed 30% of the difficult faults presented. This is a clinically significant error rate. However, the electronic checklist was still much better than the FDA checklist, which was associated with a greater than 60% error rate accompanying its use to detect difficult faults. We believe that the video-HELP feature made possible by using an electronic computer system acted as a procedure guide, which subjects used when confused about checkout procedure. Although we did not measure how often the video-HELP component was used, it was used frequently by study participants. We believe the video aids were not equal to the types of drills advocated by the military. However, the videos did improve performance when compared with a simple text description offered by the FDA checklist. Our results suggest that providing didactic education to teach the SOPs of anesthesia equipment checkout is inadequate if the goal is to achieve high (> 95%) fault detection rates. Indeed, training may need to focus on practice sessions similar to that used in simulators, to learn and retain the necessary skills to execute "difficult" checks properly.

In summary, this study confirms what has been found in aviation: (1) indexed electronic checklists are superior to either memorized or nonindexed paper checklists in reducing errors of omission (especially significant for easy fault detection); and (2) neither checklist was as successful at reducing false-negative checks due to error in operator technique (ie, difficult fault detection).

Unfortunately, the electronic checklist system described in this study would be expensive to implement when compared with paper checklists. However, as dedicated medical information systems become more common in the anesthesia domain, installing checklist software on existing hardware will be economical. Another approach to checklist implementation is to integrate an electronic checklist into an existing control panel on the anesthesia machine (ie, this type of checklist exists on some models of the North American Draeger [Telford, Pa] Narcomed Machine). Perhaps the most intriguing approach to anesthesia equipment checkout would employ modern sensor technology to remove the human element through automation. It is plausible that the machine and equipment deemed critical could be designed so that the system checks itself (in the same way that an automobile driver is warned that his car door is ajar or that his seat belt is not fastened). For example, the machine could be designed to test its high and low pressure systems for leaks and test vital alarm systems by emulating a disconnection.

Human error is to be expected in any system (aviation, nuclear power, or the operating room) in which complex interactions between people and technology occur. We believe this study confirms the efficacy of well-designed checklists to confirm the proper function of "mission critical" components of the anesthesia apparatus used daily. Although the relative importance of training was not quantified in this study, there is little doubt that anesthesia providers who can execute the SOPs of anesthesia apparatus checkout properly will be less likely to miss equipment malfunction preoperatively.

REFERENCES

(1) Cooper JB, Newbower RS, Long DC, McPeek B. Preventable anesthesia mishaps: a study of human factors. *Anesthesiology.* 1978;49: 399-406.

(2) Gaba DM. Human error in anesthetic mishaps. *Int Anesthesiol Clin.* 1989;27:137-147.

(3) Cooper JB, Newbower RS, Kitz RJ. An analysis of major errors and equipment failures in anesthesia management: considerations for prevention and detection. *Anesthesiology.* 1984;60:34-42.

(4) Craig J, Wilson ME. A survey of anesthetic misadventures. *Anesthesia.* 1981;36:933-936.

(5) Buffington CW, Ramanathan S, Turndorf H. Detection of anesthesia machine faults. *Anesth Analg.* 1984;63:79-82.

(6) United States Food and Drug Administration. *Anesthesia Apparatus Checkout Recommendations.* Rockville, MD: *Federal Register*; February 1987.

(7) March MG, Crowley JJ. An evaluation of anesthesiologists' present checkout methods and the validity of the FDA checklist. *Anesthesiology.* 1991;75:724-729.

(8) FDA publishes final version of revised apparatus checkout. *Anesthesia Patient Safety Foundation Newsletter.* 1994;9(3):35.

(9) Degani AW, Wiener EL. Philosophy, policies, and procedures: the three P's of flight deck operations. Paper presented at: 6th International Symposium on Aviation Psychology; November 1991; Columbus, Ohio.

(10) Degani AW, Wiener EL. Human factors of flight-deck checklists: the normal checklist. *NASA Contractor Report.* Hampton, Va: Langley Research Center; May 1991. NASA CR177549.

(11) Webb RK, Russell WJ, Klepper I, Runciman WB. Equipment failure: An analysis of 2000 incident reports. *Anaesth Intensive Care.* 1993;21:673-677.

(12) Federal Aviation Regulation (FAR) 121.315.

(13) Chopra V, Bovill JG, Spierdijk J. Checklists: aviation shows the way to safer anesthesia. *Anesthesia Patient Safety Newsletter.* 1991;6:26-29.

AUTHORS

George Blike, MD, is assistant professor of Anesthesiology and Obstetrics and Gynecology, Department of Anesthesiology, Dartmouth Hitchcock Medical Center, Lebanon, NH.

Chuck Biddle, CRNA, PhD, is a professor at Virginia Commonwealth University, Richmond, Va, and a staff anesthetist at Health South Hospital, Richmond, Va. He is the editor in chief of the *AANA Journal*.

ACKNOWLEDGMENTS

We would like to thank John Stys for producing the numerous video-HELP movies used in the Electronic checklist; Peter Witherell, MD, for his assistance in conducting this study; Ohmeda, Inc., for providing a Modulus II anesthesia machine; and the Foundation for Anesthesia Education Research (FAER-Grant #11561) for funding this study.