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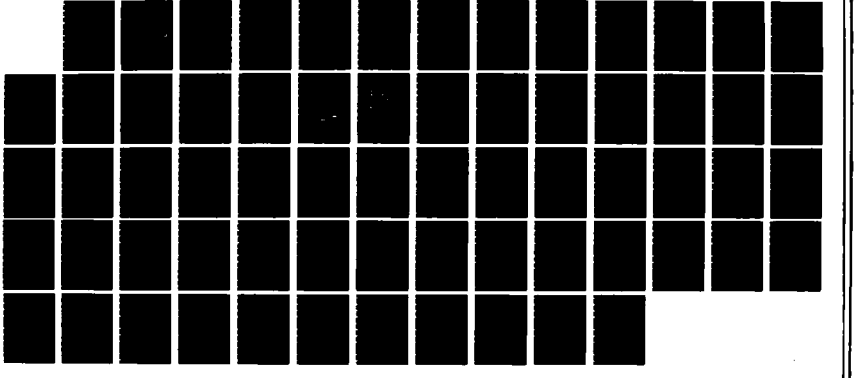

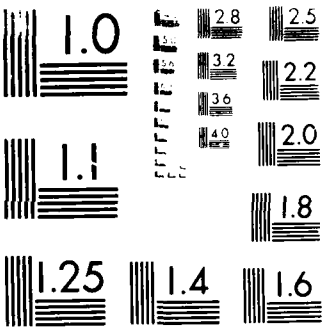
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ABSTRACT

THE EFFECT OF USING A WRITTEN PREANESTHETIC MACHINE CHECKLIST ON DETECTION OF ANESTHESIA MACHINE FAULTS

Capt. Thomas L. Saarie, U.S.A.F.

Medical College of Virginia/Virginia Commonwealth University, 1986

Major Director: Salvatore Ciresi, M.S., CRNAP

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Recommendations from several studies of anesthesia mishaps and equipment malfunction include the use of a written preanesthetic machine checklist to ensure the proper function of the anesthesia machine prior to initiating anesthesia. In an extensive literature search, no studies were found which examined the efficacy of a written preanesthetic machine checklist.

Thirty-six volunteer anesthesia practitioners examined a standard anesthesia machine which contained nine operational errors; 21 practitioners performed the machine check by memory (control group) while 15 practitioners

utilized a comprehensive written checklist while performing the machine check (experimental group). The average number of errors detected was 6.25 $\pm$ 1.48 (SD). There was a significant difference in the number of errors discovered by the two groups. The control group discovered a mean of 5.7 errors $\pm$ 1.23 (SD) while the experimental group discovered a mean of 7 errors $\pm$ 1.51 (SD), $p = .004$.

Consideration should be given to utilizing machine specific checklists and initiating specific educational programs which emphasize the preanesthetic machine check.

The Effect of Using a Written Preanesthetic Machine Checklist on Detection of Anesthesia Machine Faults

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Nurse Anesthesia at Virginia Commonwealth University

By

Thomas L. Saarie, B.S.N.

University of Florida, 1980

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Richmond, Virginia
August, 1986

Department of Nurse Anesthesia
School of Allied Health Professions
Virginia Commonwealth University

This is to certify that the thesis prepared by Thomas L. Saarie entitled THE EFFECT OF USING A WRITTEN PREANESTHETIC MACHINE CHECKLIST ON DETECTION OF ANESTHESIA MACHINE FAULTS, has been approved by his committee as satisfactory completion of the thesis requirement for the degree of Master of Science.

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Thirty-six volunteer anesthesia practitioners examined a standard anesthesia machine which contained nine operational errors; 21 practitioners performed the machine check by memory (control group) while 15 practitioners utilized a comprehensive written checklist while performing the machine check (experimental group). The average number of errors detected was 6.25 $\pm$ 1.48 (SD).

There was a significant difference in the number of errors discovered by the two groups. The control group discovered a mean of 5.7 errors $\pm$ 1.23 (SD) while the experimental group discovered a mean of 7 errors $\pm$ 1.51 (SD), $p = .004$.

Consideration should be given to utilizing machine specific checklists and initiating specific educational programs which emphasize the preanesthetic machine check.

Chapter I

INTRODUCTION

As the practice of inhalational anesthesia developed from the controlled dropping of ether onto a gauze mask to the use of inhalational devices using reservoirs and valves, the possibility of anesthetic error has increased. No longer is error attributable solely to the anesthetist's judgment and skill in administering anesthesia. Error can now be induced by mechanical error or machine malfunction.

The basic anesthesia machine design is a system of interconnected sections of tubing and flowmeters that enables the user to produce an oxygen/nitrous oxide mixture at a desired concentration, to which a variable concentration of anesthetic vapor may be added (1). As the practice of anesthesia has become increasingly sophisticated, the number of devices incorporated onto the basic anesthesia machine in order to deliver anesthesia and monitor the patient's condition has markedly increased. These devices are often attached onto the anesthesia

machine in a haphazard fashion, placed in whatever space is available with little to no consideration given to their visibility or line of sight.

McIntyre has shown that an angle subtended by a line from the anesthetist's head to the patient's head and a line from the anesthetist's head to the midpoint of the anesthesia machine ranged from 40°-50° to 170°-180° with a mode of 140°-150° (n=60) (2). Thus, as the anesthesia machine has grown in complexity, it has decreased in visibility so that any error in machine functioning is likely to go undetected for a greater period of time. In order to prevent, detect, or minimize the effects of anesthesia machine malfunction, it is essential that the anesthetist perform a preanesthetic machine check prior to using the anesthesia machine each day.

In a recent study of the detection of anesthesia machine faults, Buffington et al. found a low level of proficiency in the detection of five anesthesia machine errors (n=179) (3). The average number of anesthesia machine faults discovered was 2.2 ± 1.2 (SD). Recommendations from the Buffington study and other sources include the use of a comprehensive anesthesia machine checklist to improve error detection (4,5,6).

This study was designed to examine the effect of using a written preanesthetic machine checklist on the detection of anesthesia machine errors. Participants were divided into two groups:

1. Anesthesia personnel who performed the usual preanesthetic machine check without the aid of a written checklist.
2. Anesthesia personnel who performed the preanesthetic machine check with the aid of a written checklist.

A Foregger 310 Anesthesia Machine (Puritan-Bennett Corporation) was modified by creating nine operational faults. Participants were asked to examine the anesthesia machine and to list or describe any errors found on the answer sheet provided (See Appendix A). The performance of personnel using a written checklist was compared to the performance of personnel who examined the machine without using a checklist.

Problem

What is the relationship between the use of the written preanesthetic checklist and the ability of anesthetists to detect anesthesia machine errors?

Theoretical Framework

The preanesthetic machine check is a procedure which is learned early in the anesthetist's education. The machine check consists of a series of equipment inspections, tests, and calibrations in order to validate the proper functioning of all the devices on the anesthesia machine before its use. Figure 1 illustrates the most basic anesthesia machine. A discussion of the intricacies of each monitoring device which can be incorporated onto the anesthesia machine is beyond the scope of this study. Since a common element of all anesthesia machines is the breathing circuit, an explanation of its proper function and the associated preanesthetic check will be given.

The properly functioning breathing circuit provides for the continuous delivery of oxygen and anesthetic gases to the patient during inhalation. An equally important function of the breathing circuit is to remove exhaled gases, preventing rebreathing and carbon dioxide retention. Figure 2 illustrates the circle system breathing circuit.

During inhalation, gas flows from the anesthesia machine through the carbon dioxide absorber to the patient via an open inhalation valve (A). The exhalation valve is closed at this time. During exhalation, the inhalation valve is closed by the cessation of gas flow through this valve and by back pressure through the breathing circuit.

Exhaled gas must then flow out through the exhalation valve (B) to the carbon dioxide absorber where carbon dioxide is removed by a chemical reaction. Excess gas is vented through an adjustable pressure limiting valve (C) to the exhaust gas scavenger system which removes waste gas from the operating room.

Before initiating the anesthetic process the anesthetist needs to ensure the capability to assist or control ventilation is available by having a functioning breathing circuit in place. The preanesthetic machine check need not be a time consuming process. A simple procedure to test the function of the breathing circuit and valves is described by Kim et al. (7). The time required for the test procedure is less than one minute.

While testing of the breathing circuit is common to all anesthesia machines, the total preanesthetic machine check varies with the type of anesthesia machine being used, as well as the amount and type of associated monitoring equipment. In learning to accomplish the preanesthetic machine check by memory, the anesthetist must learn general principles which apply to the full spectrum of anesthesia machines. Additional specific information must be acquired in order to operate devices incorporated onto selected anesthesia machines. Both motor and verbal learning are required for retention of the complex psychomotor task of the preanesthetic machine check.

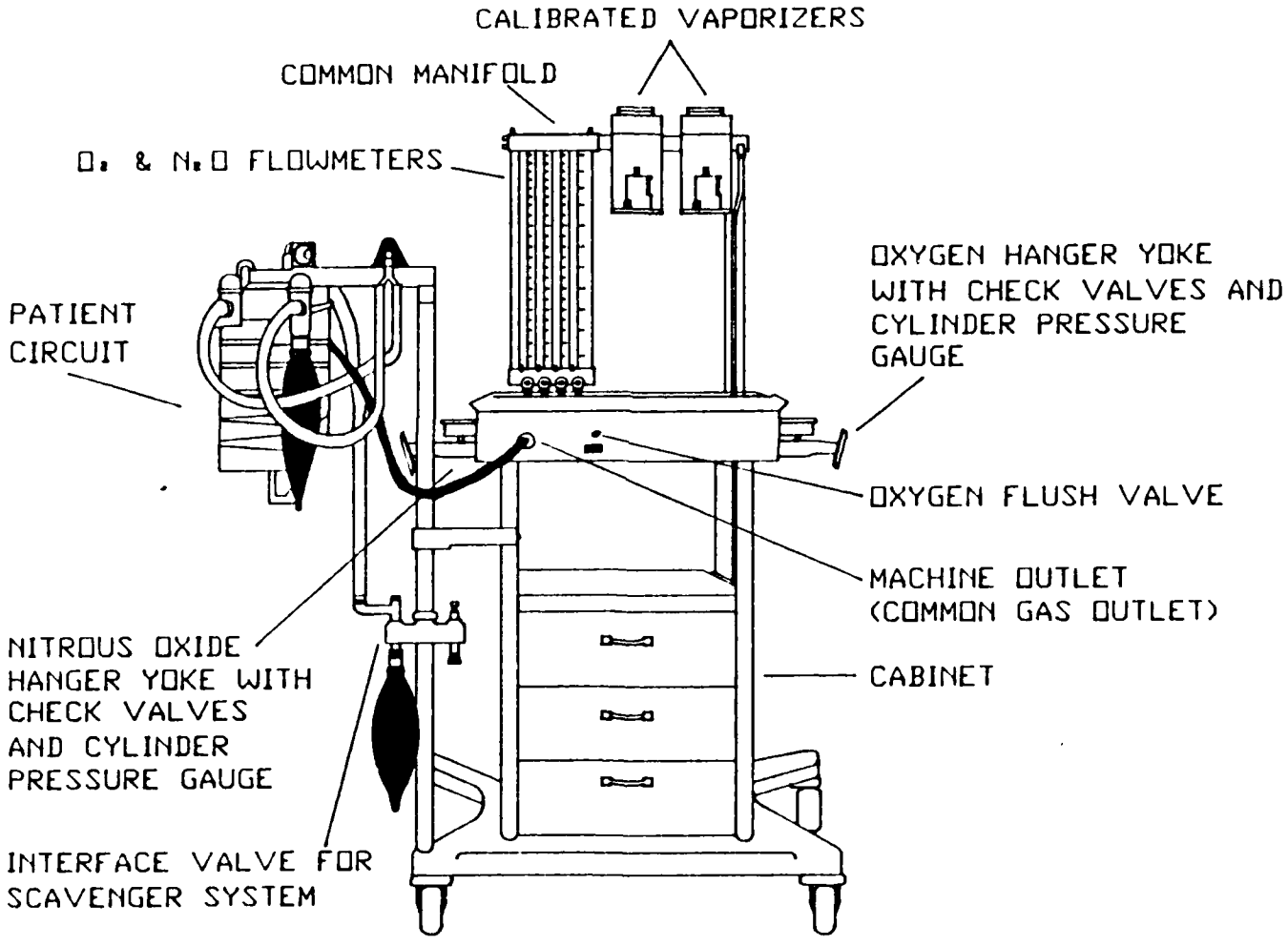

Figure 1. The Anesthesia Machine

(In Bowie and Huffman. The Anesthesia Machine: Essentials for Understanding. Ohmeda, A Division of the BOC Group, Inc. Madison, Wisconsin, 1985)

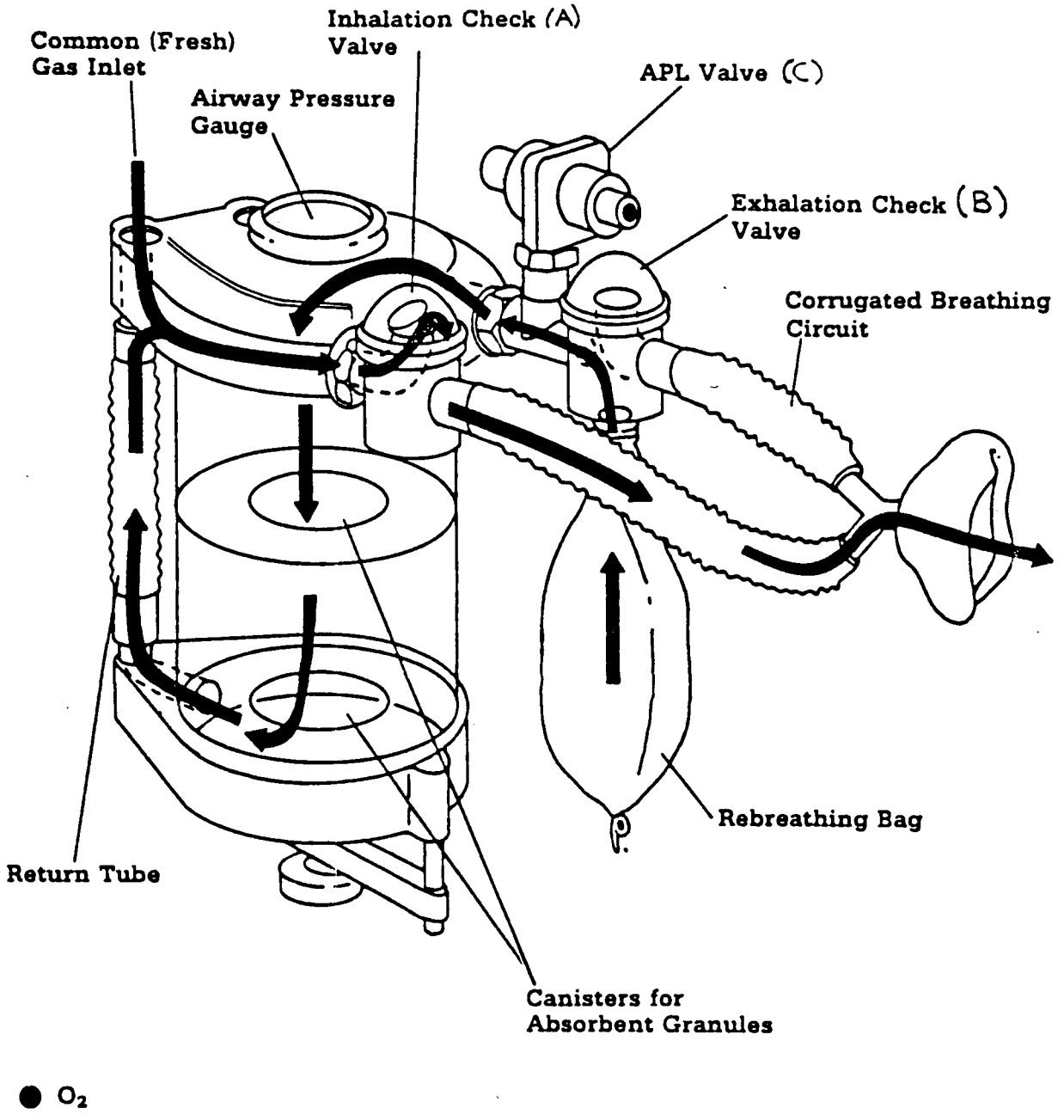

Figure 2. Oxygen Gas Flow Through the Carbon Dioxide Absorber

(In Bowie and Huffman. The Anesthesia Machine: Essentials for Understanding. Ohmeda, A Division of the BOC Group, Inc. Madison, Wisconsin, 1985)

Once the procedure is properly learned and stored in the long term memory, the role of forgetting becomes the dominant force which the anesthetist must overcome in order to properly perform the complete preanesthetic machine check. The basic theory on which this study was founded concerns the individual's ability to avoid forgetting.

A model of memory presented by Craik and Lockhart describes the various levels of information processing involved in memory (8). The preliminary level is concerned with analysis of physical or sensory features of the information presented; it is the level where awareness takes place. A medium level of processing is when recognition of the information takes place, triggering associations or images on the basis of past experience. Deeper levels of information processing are concerned with pattern recognition and the extraction of meaning. The deeper levels of analysis are associated with elaborate, longer lasting memory traces (9).

Retention is seen as a function of depth of processing. Factors such as the amount of attention devoted to the information, compatibility of the information with that which already exists, and the amount of time for processing are the major determinants of the depth of processing (10).

Once the information is processed, forgetting may occur due to any one or combination of three processes; interference, trace decay, failure to retrieve (11).

Interference occurs when events which took place either before or after the material was learned interfere with the material and decrease recall. With trace decay, material which is stored in memory spontaneously decays with time. Retrieval failure is said to occur when the learned material exists in memory but cannot be recalled without prompting.

Evidence exists for each of these theories of forgetting and it is likely that any memory lapse can be attributed to one or more of these theories. Anesthetists performing the preanesthetic machine checklist from memory need to overcome the forgetting process to ensure safe operation of the anesthesia machine. Use of a sequential, step by step checklist should lessen the impact of the forgetting process.

Assumptions

1. Participants were representative of the anesthesia department.
2. Participants made their best effort to properly perform the preanesthetic machine check.
3. Participants completed the data sheet accurately.
4. Participants had previously learned the proper preanesthetic machine check.

Definition of Terms

1. Anesthesia Machine - A mechanical device for the delivery of anesthetic gases and monitoring the patient's condition. In this study, the machine is the Foregger 310 manufactured by Puritan Bennett.
2. Preanesthetic Machine Check - A sequence of simple machine tests which the anesthetist learns early in the educational process. The purpose of the machine check is to ensure correct operation of the anesthesia machine prior to use.
3. Written Preanesthetic Machine Checklist - A written checklist which, when performed, fulfills the requirement of a complete preanesthetic machine check. For this study, the checklist from Ohmeda entitled Anesthesia Machine Inspection Procedure was used.
4. Detection of Error - Discovering error in the proper function of the anesthesia machine as evidenced by written response on the answer sheet provided.

Limitations

1. Participation in the study was voluntary, introducing the possibility of poor performers choosing to not participate.
2. Participants were aware that the machine contained errors which may result in increased error detection.
3. Test conducted over a 12 hour period with possibility that outside discussion of errors found may have influenced later participants scores.
4. Observer remained in the room which may have increased the participant's anxiety.

Delimitations

1. Results of all machine errors were not posted until after the completion of the testing period.
2. Length of study was restricted to 12 hours to minimize the effect of outside discussion of test results.
3. Participant's cooperation in not discussing test results was solicited.
4. Test was conducted in an OR suite to simulate actual daily considerations.

5. All participants had at least six months experience.

Hypothesis

There is no relationship between the use of the written preanesthetic machine checklist and the detection of anesthesia machine error.

Chapter II

LITERATURE REVIEW

While the anesthesia machine has an established reputation for reliability, serious malfunctions can and do continue to occur. Of the 125 avoidable anesthesia deaths in Great Britain and Ireland during 1979-1980, equipment failure was implicated 5% of the time (12). In a 1984 analysis of errors and equipment failures in the operating rooms of four U.S. hospitals, Cooper et al. describe equipment failure occurring in 13.4% of 855 incidents reported (13). Of the 191 errors described by Utting et al. which resulted in death or severe cerebral damage, 21% are attributed to hypoxic gas mixtures and failure of automatic ventilation (14). These mishaps may have been prevented by a properly functioning ventilator and an oxygen concentration monitor on the anesthesia machine.

As the anesthesia machine and related monitoring equipment becomes more complex, detection of equipment malfunction grows more difficult. In a 1985 study of anesthesia equipment malfunction by Holley and Carroll, 311 pieces of anesthesia equipment used on a daily basis were

carefully checked; 40% of the items were in need of repair to bring them into the manufacturer's specified range of accuracy (15). None of the errors discovered in the equipment had been previously detected during clinical use. The inaccuracies included a ventilator that cycled correctly but vented to the atmosphere instead of the breathing system and vaporizers which delivered half the indicated concentration.

Missing or incomplete unidirectional valves in the anesthesia breathing circuit result in rebreathing, carbon dioxide retention, and severe respiratory acidosis. In a survey of 715 anesthesia machines by Kim et al., there was a 15% incidence of unidirectional valve incompetence (16). Apparently, the current procedures utilized in performing the preanesthetic machine check are inadequate.

Cooper et al. as well as Craig and Wilson cite the failure to perform a normal check as the factor most commonly associated with equipment failure (17, 18). Buffington, Ramanathan and Turndorf had 191 anesthesia practitioners examine an anesthesia machine which contained five intentional faults to determine if professional background or anesthesia experience level influenced fault finding ability (19). While participants with ten or more years of anesthesia experience scored significantly higher in fault finding than those with less experience, the average number of faults detected was less than 50% even

with experienced practitioners. Therefore, even if a normal preanesthetic check is performed, the practitioner is more likely to fail than succeed in detecting anesthesia machine error.

The use of a written preanesthetic checklist is a frequent recommendation in studies reporting anesthetic mishaps (20, 21, 22, 23). In an extensive literature review, there were no studies found which examined the use of a written preanesthetic machine checklist in the detection of anesthesia machine error.

The focus of this study is to examine the relationship between the use of the written preanesthetic machine checklist and the detection of common anesthesia machine errors.

Chapter III

METHODOLOGY

Sample

To answer the question, "What is the relationship between use of the written preanesthetic machine checklist and the detection of anesthesia machine error?" a quasi-experimental study was utilized. The study took place over a twelve hour period during one day at a large Mid-Atlantic regional medical center. Participation was on a voluntary basis and all individuals in the anesthesia department had an equal opportunity to participate. Participation in the study was solicited by announcement at the departmental meeting three days prior to the study, by poster, by computer message, and by verbal request of any anesthesia personnel present in the operating room complex on the day of the study.

Protocol

A Foregger 310 anesthesia machine was modified to serve as the test device. The following nine faults were created:

1. The oxygen concentration monitor was calibrated to erroneously display a reading of 100% oxygen when 60% oxygen was given.
2. The electrical power supply cord to the electrocardiograph monitor was disconnected where the cord attaches to the monitor, rendering the device inoperable.
3. The Forane [R] vaporizer was empty, leaving the anesthetist unable to use Forane [R] without refilling the vaporizer.
4. The cap to the filling port of the Halothane [R] vaporizer was missing, causing the flow of anesthetic vapor to vent to the room.
5. The carbon dioxide absorber was only 1/4 full, which would lead to premature exhaustion of the absorbent.
6. The oxygen low pressure alarm was turned to the off position, rendering it non-functional. The anesthetist would not hear an alarm if the oxygen supply was lost.

7. There was a 1/2" hole in the plastic tubing of the oxygen circle system, creating a leak in the breathing system and negating the possibility of sustained positive pressure.
8. The oxygen power hose to the Air-Shields [R] ventilator was disconnected, rendering the device inoperable. The anesthetist would have no mechanical device to assist or control the patient's ventilation.
9. The exhalation valve in the breathing system was warped, allowing continuous rebreathing of exhaled gases.

The modified anesthesia machine was arranged for testing in an available operating room from 0630-1830 hours on one weekday. The study was restricted to one day in order to minimize the possibility of outside discussion altering the test results. Participants who presented to the operating room were provided with a written explanation of the study (Appendix B). Participants were then randomly assigned by coin toss to one of two groups. Anesthetists assigned to Group A, or the control group, were asked to perform the preanesthetic machine check by memory, just as they normally would. Anesthetists in Group B, or the experimental group, were given the written preanesthetic machine checklist entitled "Anesthesia Machine Inspection

Procedure" (Appendix C). Group B was asked to complete the preanesthetic machine check using the checklist as their guide.

Participants were allowed a maximum of fifteen minutes to complete the preanesthetic machine check with verbal notice being given when there were five minutes remaining in the time allotted. As the participants finished, cooperation in refraining from outside discussion of the study was requested, and they were informed that all of the possible errors would be posted in the anesthesia office at the completion of the study.

A total of 36 participants took part in the study over the twelve hour period. There were 21 participants in Group A and 15 participants in Group B.

Chapter IV

RESULTS

The data was analyzed using a standard statistical package (STATPACK by Northwest Analytical, Inc., Portland, Oregon). One-tailed and two-tailed student t-tests were used. A p value of less than 0.05 was considered significant.

Out of a total of nine possible errors, the overall average number of errors detected was 6.25 $\pm$ 1.48 (SD). Table 1 reports the detection of anesthesia machine error by the control group and the experimental group. The experience level of participants did not affect error detection ($p = .61$).

There was a significant difference in the number of errors discovered by the two groups. The control group discovered a mean of 5.7 errors $\pm$ 1.23 (SD) while the experimental group discovered a mean of 7 errors $\pm$ 1.51 (SD), $p = .004$. Analysis of data indicated two of the anesthesia machine errors were more likely to be discovered by the experimental group; the missing Halothane ^{R} vaporizer cap ($p = .003$) and the disarmed oxygen pressure alarm ($p = .016$).

Table 2 describes the demographics of the two groups. There were no significant differences in the two groups. In the experimental group, professional background had no influence on error detection ($p = .49$). In the control group, nurses scored significantly higher on error detection than physicians ($p = .03$).

Table 3 reports error detection by professional status while the distribution of overall error detection is shown in Table 4.

The disconnected EKG monitor, empty Forane^{R} vaporizer, and inoperable ventilator were uniformly discovered by 92% of the participants with little intergroup variation. Conversely, the warped exhalation unidirectional valve was discovered by only 39% of the participants, the missing Halothane^{R} cap by 42%, and the erroneous oxygen concentration monitor by 58%.

The distribution of error detection is illustrated by Figure 3. Two participants described errors which did not exist. One participant did not fully open the oxygen cylinder on the machine, thereby describing the low pressure in the cylinder as an error. Another participant listed that the wrench needed to open the oxygen cylinder was missing when it was in place on the nitrous oxide tank. These errors were not reported in the data since the anesthetist acting upon them would cause no patient harm.

One participant described two errors which could technically be considered errors while failing to detect three of the more obvious errors. The audible alarm on the automated blood pressure machine, which triggers if the blood pressure registered markedly differs from the previous reading, was disarmed. This is a normal position for the alarm at the start of an anesthetic. The alarm limits on the EKG monitor were set on the extremes; these limits are usually set after the anesthetist notes the patient's pulse rate and sets the limits within an acceptable range. These two errors were not represented in the data due to their tenuous nature.

Table 1

ERRORS DETECTED

	Memory (Control)	Written Checklist (Experimental)	Total
N	21	15	36
Mean Experience	3.7 yrs.	4.8 yrs.	4.1 yrs.
Experience Range	0-29 yrs.	0-16 yrs.	0-29 yrs.
Mean Error	5.7	7	6.25

Errors	Memory (Control)	Written Checklist (Experimental)	Total
Oxygen Concentration Monitor	11/52%	10/67%	21/58%
EKG Disconnect	19/91%	14/93%	33/92%
Forane [R] Vaporizer Empty	19/91%	14/93%	33/92%
Halothane [R] Cap Missing	4/19%	11/73%	15/42%
Carbon Dioxide Absorber	13/62%	9/60%	22/61%
Oxygen Pressure Alarm	13/62%	14/93%	27/75%
Hole in Breathing Circuit	14/67%	13/87%	27/75%
Ventilator Inoperable	20/95%	13/87%	33/92%
Exhalation Valve Warped	7/33%	7/47%	14/39%

Table 2

PROFESSIONAL STATUS

	Control	Experimental	Total
Attending M.D.	4	3	7
Resident M.D.	4	2	6
CRNA	4	5	9
Nurse Anesthetist Resident	9	5	14

Table 3

MEAN ERRORS DETECTED

	Control	Experimental
Attending M.D.	5.25	6
Resident M.D.	4.75	6
CRNA	6.25	6.8
Nurse Anesthesia Resident	6.11	7.6

Table 4

ERRORS DETECTED

N	Control	Experimental	Total
9	1/5%	3/20%	4/11.1%
8	0	4/26.7%	4/11.1%
7	4/19%	4/26.7%	4/11.1%
6	6/29%	3/20%	13/36.1%
5	7/33%	0	7/19.5%
4	3/14%	1/6.6%	4/11.1%

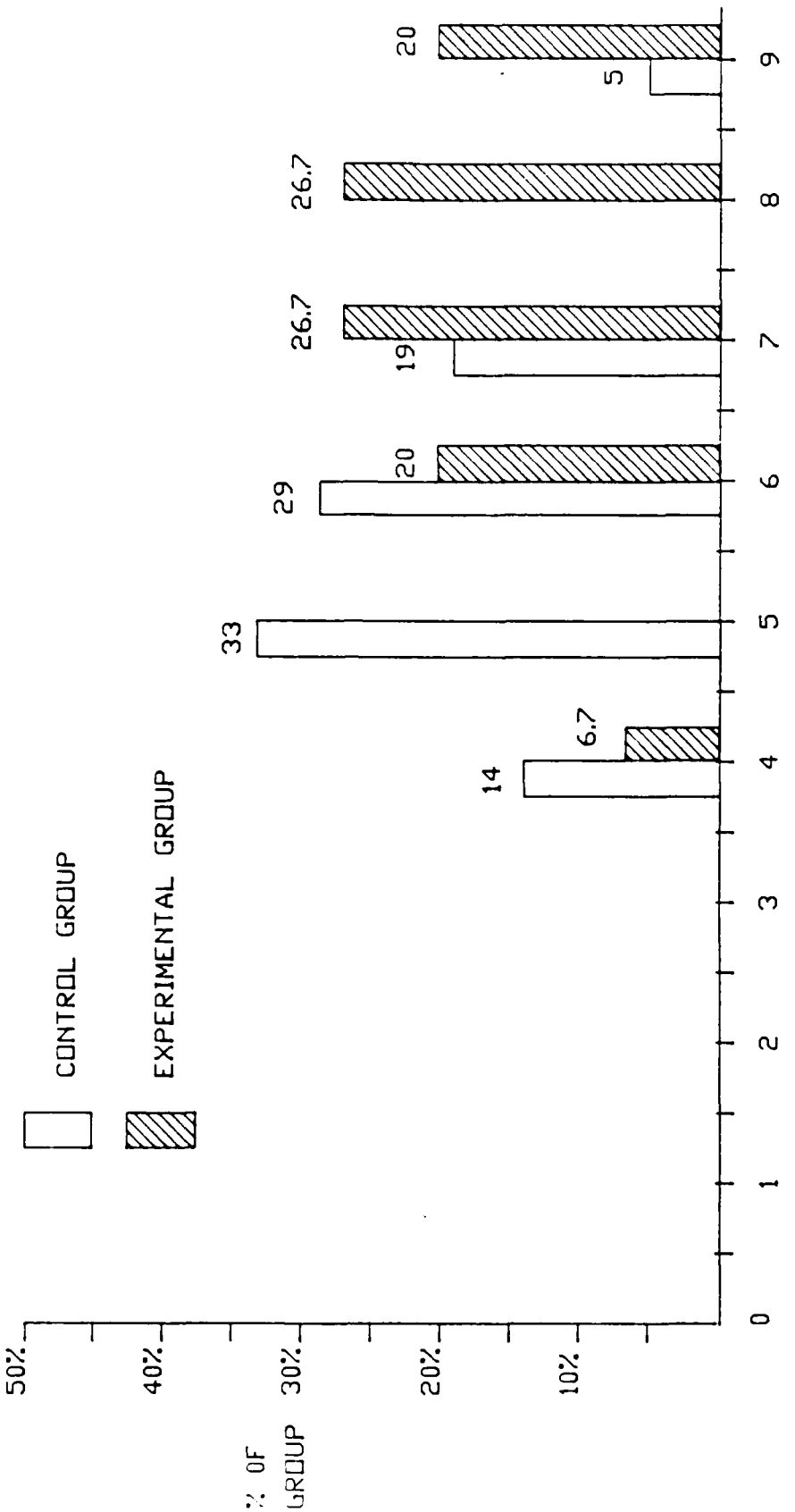

Figure 3. Distribution of Error Detection

Chapter V

DISCUSSION

The finding that the preanesthetic checklist improves error detection supports the previous recommendation that a written preanesthetic checklist should be utilized (24, 25, 26, 27). Herr states that "the development of a written checklist similar to those used by pilots for preflight is the most reasonable solution to the problem of failure to check equipment" (28).

It is somewhat surprising that with the use of a written preanesthetic checklist an average of two errors remained undetected. There may be several reasons for their continued oversight. First, the checklist used was a comprehensive checklist which listed many items which did not exist on the anesthesia machine used as a test device. If there was a specific checklist for each specific machine, error detection may be improved even more. Secondly, this was the first time the experimental group utilized this written checklist. The fifteen minute time limit did not prove to be a hindrance, but participants may

have felt rushed and avoided utilizing the checklist as intended. Participants may have been unduly anxious having an observer remain in the room during the study.

One other observed possibility exists. While persons in the experimental group were asked to utilize the checklist in performing the preanesthetic machine check, the participants seemed to naturally fall into two groups. One group performed the preanesthetic machine check as they normally would by memory, then used the checklist as a review to ascertain that all items were checked. Others followed the written checklist word by word, step by step. Several of this later group commented that they would have overlooked errors if they had not utilized it in this manner.

Not all of the errors appear to have equal clinical significance. An unplugged EKG monitor and a low amount of sodalime in the carbon dioxide absorber are relatively minor errors. These errors can be easily corrected when discovered and have a low probability of causing direct patient harm.

The vaporizer errors and the hole in the breathing circuit fall in the intermediate range. All can be rapidly corrected but can be harmful to the patient if they remain undetected for any length of time. The hole in the breathing circuit can lead to inadequate ventilation and loss of anesthetic agent. Either of the vaporizer errors result in no anesthetic gas being delivered to the patient,

creating an undue physiologic stress for the patient. The hole in the breathing circuit may have been missed by setting too high a gas flow when checking the circuit. The 1/2" hole created a variable leak, from 800 ml to 2 liters per minute. The variation in the gas leak was due to the flexible corrugated nature of the tubing which allowed for a partial sealing of the hole at times. If the fresh gas flow exceeded the leak, the participant may have easily missed discovering the leak.

Two plausible explanations exist for the frequent oversight of the missing Halothane ^{R} vaporizer cap. The cap is located on the back of the machine out of the usual line of sight of the anesthetist. In the institution where the study took place, the use of Halothane ^{R} is restricted to pediatric procedures. Many of the participants may have overlooked the vaporizer cap by assuming they weren't scheduled to do pediatric cases that day. Emergency or add-on pediatric surgical cases can arise at any time which require the use of Halothane ^{R}. The anesthetist doing the preanesthetic machine check at the start of the day should prepare for all eventualities. No apparent explanation exists to explain the oversight of the empty Forane ^{R} vaporizer.

The inoperable ventilator becomes significant when the anesthetist needs free use of both hands for tasks other than ventilating the patient, such as inserting a central venous catheter. The major significance of overlooking the

inoperable ventilator is that it indicates that the anesthetist is not verifying the function of the ventilator. The study of anesthesia equipment malfunction by Holley and Carroll included the discovery of a ventilator which cycled correctly but delivered the gas to the atmosphere instead of to the breathing circuit (29). Checking the operation of the ventilator takes less than one minute and can detect ventilator malfunction.

The remaining three errors have a direct impact of the patient's safety and well being during anesthesia. The warped exhalation unidirectional valve was frequently missed by both groups with an overall detection rate of only 39%. Warping of either the inhalation or exhalation unidirectional valve will result in rebreathing of exhaled gases leading to carbon dioxide retention or hypercarbia. Physiological responses to hypercarbia include an increased ventilating effort, frequency, and tidal volume as well as an increase in heart rate and blood pressure. Hypercarbia leads to vasodilation by vascular smooth muscle. The respiratory acidosis which accompanies carbon dioxide retention may cause cardiac dysrhythmias. At levels greater than 250 mm Hg, hypercarbia can lead to convulsions and coma (30).

The most likely reason for overlooking the warped unidirectional valve is unfamiliarity with the simple test procedure available. Another possible cause is that the clear plastic dome which covers the unidirectional valves is often clouded by condensation of water vapor.

The oversight of the oxygen low pressure alarm is disconcerting. In four of nine incidents of loss of oxygen supply in a machine equipped with a failsafe system, the pressure failsafe was known to be activated before the absence of oxygen flow was noticed by the anesthetist (31). The failsafe system on the test device had both an audible and visual alarm. When the machine is not in use, the alarm is switched to the off position to conserve the battery supply. Only 75% of the participants in this study noticed that the alarm was off. In the study by Utting et al., 11 deaths were reported due to oxygen cylinders running out (32). Without the alarm system, the anesthetist relinquishes a frontline defense against hypoxia.

Last to be discussed yet possibly foremost in significance is the poor detection rate of the oxygen concentration monitor malfunction by only 58% of the participants. Time and time again, it is stated that the last line of defense against delivery of a hypoxic gas mixture is the use of a calibrated oxygen concentration monitor (33, 34, 35).

Many of the participants turned the monitor on the battery check position and went no further in their check of the device. Perhaps this is a flaw in their educational process. Several of the anesthesia machines where the study was conducted have no oxygen concentration monitor. If participants frequently utilized machines without oxygen concentration monitors, they may no longer routinely check for the monitors function when they encounter one. Frequent false alarms or monitor malfunction may contribute to the oversight of the oxygen concentration monitor.

Three of the four most common types of anesthesia mishaps described by Cooper et al. could be easily detected by a properly functioning anesthesia machine with standard monitoring (36). We live in a litigation oriented society. More than 10% of all money paid for malpractice claims involves anesthesia, with the average settlement for anesthesia related incidents costing more than $100,000 (37). Various studies have found anesthetic error in 69% to 89% of anesthetic deaths (38). It has been estimated that approximately one death per 10,000 anesthetics was totally attributable to anesthesia while two deaths per 10,000 anesthetics were totally or in part due to anesthetic management (39).

In this study, the written preanesthetic machine checklist was shown to increase the detection of anesthesia machine error. By ensuring the proper functioning of the anesthesia machine, the anesthetist can deliver anesthesia in a safer manner.

Recommendations

Since some errors continue to be overlooked by participants utilizing the written checklist, methods to improve the checklist may be investigated. Consideration could be given to utilizing a machine specific checklist to see if improved error detection occurs. One might explore the effect of initiating specific educational programs regarding the anesthesia machine and related monitoring devices.

Conclusions

The hypothesis that there is no relationship between the use of the written preanesthetic machine checklist and the detection of anesthesia machine error is rejected ($p = .004$). It can be concluded that the written preanesthetic machine checklist can increase detection of anesthesia machine error and serve as a valuable tool for the anesthetist.

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APPENDICES

Appendix A

DATA COLLECTION FORM

Professional Status:

(Attending M.D., Resident M.D., CRNAP, Nurse Anesthesia Resident)

Years of anesthesia experience:_____ (If under one year, list 0)

Errors Detected (Describe each error as fully as possible).

	Error	Description
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
11.		
12.		
13.		
14.		
15.		

Thank you for your time and cooperation.

Appendix B

INSTRUCTIONS

The purpose of this study is to determine if there is a relationship between use of a written preanesthetic machine checklist and the detection of anesthesia machine error. You will be assigned to one of two groups by coin toss. If the coin shows "heads," you will perform the preanesthetic machine check by memory. If the coin shows "tails," I ask that you use the written preanesthetic machine checklist I will provide. You will be given 15 minutes to complete the preanesthetic machine check. When there are five minutes remaining, I will inform you.

Participants in this study will remain anonymous and confidential. I ask that you refrain from outside discussion of this study until the study is complete at 1830 hours today. At that time, a list of the possible errors will be posted in the anesthesia office. Thank you for your time and cooperation.

Appendix C

ANESTHESIA MACHINE INSPECTION PROCEDURE

(From the Ohmeda Training Course, "The Anesthesia Machine: Essentials for Understanding")

Important Point: This checklist is a general one, and may not be the one selected for use in your own department. This is a guideline only and may not be specific for particular configurations on some machines. Also, it is not a substitute for the particular manufacturer's instructions regarding checkout specifics for each model.

The following inspection procedure (or a similar one that is used in your department) should be conducted in preparation for anesthesia. These guidelines are based in part on the ongoing work of the ASTM F29.01.01 subcommittee.

*1. Inspect anesthesia machine for:

* Machine number (note on anesthetic record); valid inspection sticker.
* Undamaged flowmeters, vaporizers, gauges, supply hoses.
* Complete, undamaged breathing system with fresh CO_2 absorbent.
* Correct mounting of cylinders in yokes.
* Presence of cylinder wrench and test lung.

*2. Inspect and turn on:

* Electrical equipment requiring warm-up, e.g., ECG/pressure monitor, oxygen monitor, oximeter, CO_2 monitor, etc.

3. Connect waste gas scavenging system:

* Check for integrity of system.
* When the flow rates are established at start of case and after the flow rates are changed during the case, the exhaust flow (needle valve) must be adjusted accordingly.

4. Check that:

* Flow control valves are off.
* Vaporizers are off.
* Vaporizers are filled (not overfilled).
* Filler caps, if present, on vaporizers are sealed tightly.
* CO_2 absorber bypass (if any) is off.

*5. Check oxygen cylinder supplies:

a. Close cylinder valves.

b. Disconnect pipeline supply (if connected) and "bleed" pressure in the machine to zero, using O_2 flush.

c. Open one O_2 cylinder; check pressure; close cylinder and observe gauge for high pressure leak.

d. Using O_2 flush, empty piping.

e. Open other O_2 cylinder; check as in c. and d. above.

f. Verify adequate oxygen supply. At least one oxygen cylinder should be full.

g. Reconnect oxygen supply (pipeline).

6. Turn on master switch (if present).

*7. Check nitrous oxide cylinder supplies:

a. Use same procedure as with O_2 cylinders.

Note: After first cylinder is checked, empty system via flow-control valve. Check second cylinder (if present).

b. Replace any cylinder less than 600 psi or at least one of a pair of cylinders if neither is at maximum pressure (745 psi).

c. Reconnect nitrous oxide supply (pipeline).

*8. Test O_2 supply failure system:

a. Set O_2 and N_2O flows at about 5 L/min.

b. Disconnect the oxygen pipeline momentarily and flush system to release O_2 pressure.

c. Verify that N_2O float falls to zero flow before the oxygen float falls to zero.

d. Close flow control valve(s).

e. Reconnect oxygen supply (pipeline).

*9. Test flowmeters:

a. Check that float (flow indicator) is at zero flow with valves closed)or at preset minimum O_2 flow is so equipped).

b. Manipulate flows at least to mid-range, and check for erratic movements of float (flow indicator).

*10. Test oxygen: nitrous oxide flow proportioning system, if present:

* Attempt to create hypoxic O_2/N_2O mixture, and verify appropriate change in gas flows and/or alarm.

11. Calibrate O_2 monitor and set alarms:

*a. Calibrate O_2 monitor in accordance with manufacturer's specifications.

*b. Test alarms in accordance with manufacturer's specifications.

12. Add any necessary equipment to the breathing system (humidifiers, PEEP valve, etc.), and verify correct installation and function.

**13. Test for leaks in machine and breathing system.

a. Adjust APL valve to a minimum setting, and occlude system at patient end.

b. Using O_2 flush, fill the bag and readjust APL valve to approximately 40 centimeters of water pressure.

c. Stop oxygen flush, and set the oxygen flow to not more than 300 mL/min. (on machines capable of this low flow). This set flow of 300 mL should maintain a system pressure of at least 20 centimeters of water.

d. For other machines not capable of delivering such a low flow, fill the system as in b. Squeeze the bag slowly to maintain at least 20 centimeters of water. If a leak is present, continue to squeeze the bag and estimate the rate of leakage from the rate of bag collapse.

14. Breathing system valve assemblies:

a. Inspect inspiratory and respiratory valve assemblies and confirm presence of intact valves.

b. Verify proper function using a test lung.

15. Exhaust valve and scavenger system:

a. Pressurize breathing system, and observe release of pressure.

b. Occlude patient end of breathing system, fully open APL valve, and verify that breathing system pressure does not rise above 3 cm of water with a 3 liter per minute flow from the machine and the breathing bag full at the beginning of the test.

16. Test ventilator:
    a. If a selector valve is present, test its function in both bag and ventilator function in both bag and ventilator mode to ensure that it appropriately connects the ventilator or bag into the patient circuit.
    b. Attach test lung at patient end of breathing system, fill system and cycle ventilator. Ensure filling and emptying of test lung.
    c. Test for leaks and pressure relief by appropriate cycling. (Exact procedure will vary with type of ventilator).
17. Connect and verify function of all other monitors and accessories. (Temperature, airway pressure, ECG, blood pressure, volume monitor, etc.)
18. Verify appropriate setting of all controls.
19. Set, and enable, appropriate alarm system on the anesthesia machine and on other equipment to be used.

This is a guideline that will vary according to differences in equipment design and variations in clinical practice. Modification is necessary for non-circle breathing systems. The user should refer to the operator's manual for special procedures or precautions.

* If an anesthetist uses the same machine in successive cases, the steps marked with an asterisk (*) need not be repeated before each case or may be abbreviated after the initial daily checkout.

** A vaporizer leak can only be detected if the vaporizer is turned on during this test. Even then, a relatively small leak may still be obscure.

Appendix D

RAW DATA

Control Group

Status	Experience (yrs)	Used Check-list	Errors not detected	O_2 Monitor	EKG	Forane Vaporizer	Halothane Vaporizer	Soda Lime	O_2 Low Pressure Alarm	Hole in Breathing Circuit	Ventilator Inoperable	Warped Exhalation Valve
ATT. MD	29	NO	2	X			X					
CRNA	8	NO	4				X	X	X			X
CRNA	7	NO	2				X					X
CRNA	7	NO	3				X		X			X
ATT. MD	6	NO	3	X		X		X				
CRNA	6	NO	2				X					X
ATT. MD	4	NO	5	X			X		X	X		X
ATT. MD	3	NO	5		X		X	X			X	X
RES. MD	2	NO	4				X	X	X	X		
NUA	1	NO	3	X				X				X

Appendix D

RAW DATA

Control Group, cont.

Status	Experience (yrs)	Used Check-list	Errors not detected	O_2 Monitor	EKG	Forane Vaporizer	Halothane Vaporizer	Soda Lime	O_2 Low Pressure Alarm	Hole in Breathing Circuit	Ventilator Inoperable	Warped Exhalation Valve
NUA	1	NO	0									
NUA	1	NO	4	X			X			X		X
NUA	1	NO	2			X						X
NUA	1	NO	3				X		X			X
NUA	1	NO	3				X		X			X
RES. MD	0	NO	5	X			X	X	X			X
RES. MD	0	NO	4	X	X		X			X		
RES. MD	0	NO	4				X	X	X	X		
N.Anes.Res.	0	NO	4	X			X	X				X
NUA	0	NO	3	X			X			X		
NUA	0	NO	4	X			X			X		X

Appendix E

RAW DATA

Experimental Group

Status	Experience (yrs)	Used Check-list	Errors not detected	O_2 Monitor	EKG	Forane Vaporizer	Halothane Vaporizer	Soda Lime	O_2 Low Pressure Alarm	Hole in Breathing Circuit	Ventilator Inoperable	Warped Exhalation Valve
CRNA	16	YES	0									
CRNA	14	YES	5	X	X	X					X	X
CRNA	12	YES	3				X			X		X
ATT. MD	6	YES	3				X	X			X	
ATT. MD	5	YES	3				X	X				X
ATT. MD	5	YES	0									
CRNA	5	YES	3	X				X				X
CRNA	4	YES	0									
RES. MD	2	YES	3	X				X				X
NUA	1	YES	1							X		
NUA	1	YES	1									X
RES. MD	0	YES	3	X				X				X
NUA	0	YES	1	X								
NUA	0	YES	3					X	X			X
NUA	0	YES	1				X					

VITA

Thomas L. Saarie was born on July 8, 1955 in Syracuse, New York, and is an American citizen. He graduated from Vanguard High School, Ocala, Florida in 1973. He received a Bachelor of Science in Nursing from the University of Florida, Gainesville, Florida, in 1980. While on active duty in the United States Air Force, he was selected for sponsorship by the Armed Forces Institute of Technology to enter the Master of Science program in Nurse Anesthesia at the Medical College of Virginia, Virginia Commonwealth University.

END

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