An evaluation of flowmeters

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Flowmeters, vital in anesthesia delivery, must be accurate to ensure proper anesthetic concentrations. Accuracy of flowmeters varies with time and maintenance, necessitating periodic recalibration. In this study undertaken at the Rush-Presbyterian-St. Luke’s Medical Center involving anesthesia machines of various manufacture and age, the authors found that a 20% error was common and higher errors were not infrequent.

The analysis of anesthetic vapor concentrations delivered by various pieces of apparatus is uncommon even in university teaching centers. The ability to administer an accurate concentration of agents is important to the physiological result of an anesthetic. Physical signs and past experience help one determine the anesthetic concentrations to be delivered. Though one can give an anesthetic with inaccurate equipment, only accurate equipment can promote true efficiency and safety in patient care.

One must not negate the importance of clinical observation; but, it is a tremendous variable. Frequently, significant errors or mechanical defects that have continued for days are unobserved even by good clinicians in so-called, good departments with clinically skilled individuals using the equipment. Although most hospitals have a maintenance contract with machine manufacturers or their representatives, such routine maintenance does not include flowmeter calibration checks.

Recently, after a routine check of a machine by a reputable company, two patients were found to be unusually susceptible to vascular depression. Suspiciously, two other patients required very little anesthesia. A check revealed that the vaporizer flowmeter was in error by an excess of 125%.

This prompted the authors to question the accuracy of flowmeters and, accordingly, to study all of them. A water displacement method was attempted, but too many difficulties ensued. A calibrating flowmeter was employed, but the mathematics were found confusing by those in the training phases of anesthesia. A simple unit for use by an average resident, intern, or nurse had to be devised.

The first type of equipment used was a standard laboratory burette employed in the calibration of “the carrier gas flow” in gas chromatographs. Basically, a soap solution was placed in the burette, and a soap ring formed which ascended the burette. By timing the ascent with a stop watch, one could easily determine the flow rate of gas and compare it to the flowmeter reading.

A tube calibrated by a water displacement technique was then made. A bypass valve and a method for inserting the soap solution was added to the assembly. Using this device, the flowmeter readings of all machine flowmeters were checked against the flow rates deter-
mined directly from the burette. In order to check the volatizing flow-through vaporizers, the anesthetic had to be removed, ensuring that the chamber was dry so as to avoid the added vapor volume to the flow reading.

In order to check high-flow as well as low-flow flowmeters, it was necessary to have two sizes of calibration tubes. These were then checked by water displacement and with a Fischer-Porter calibrating flowmeter. The study of all anesthesia flowmeters was then undertaken at the Rush-Presbyterian-St. Luke's Medical Center and affiliated hospitals. (See Figure 1.)

**Study design**

A pure statistical study was not intended. Our interest was dual: (1) to obtain the results of testing a group of approximately 60 machines, and (2) to ascertain the accuracy of our low-flow and high-flow-bypass vaporizer flowmeters.

A college student was trained in checking both high and low flowmeters until he obtained accuracy within 3% upon repetition. Several determinations were made of each flow.

Machines used in patient care were selected at random—some recently used, some recently serviced, and some not serviced for several months. All flowmeters on the machines were calibrated. No attempt was made to study a specific manufacturer or to date the machines, but a large percentage of the equipment was purchased within the last five years.

**Results**

Many of the observations and conclusions which follow are known and need no proof; others are new.

1. Flowmeters are difficult to read. Many do not lend themselves to accurate and easy "setting". The correct position of the important point of the float is frequently unclear. Some floats need a direct frontal view to accurately set a specific calibration.

2. On many of the older machines, the markings on the lower end of the scale are extremely close to one another; hence, readings are difficult and relatively inaccurate.

3. Some newer machines have gas flows which pass through both a low-flow and high-flow flowmeter controlled by a single needle valve. Frequently, there is an obvious discrepancy between the two flow readings indicated by the two flowmeters.

4. In some systems, where wall gases are employed, the level of the "high flow rate" float changes. Frequently, the float gradually descends in the period immediately after it is set. Floats must be observed at intervals, but particularly soon after the first setting.
5. Some floats are very sensitive to the movement and/or levelness of the machines.

6. Some flowmeters, especially those of cyclopropane, have a marked instability and continuously bob up and down due to a lack of good cleaning and maintenance.

7. Many machines have leaks. These leaks, observed or unobserved, are often simple while others are extremely difficult to correct. In one relatively new type of machine at low flows through the vaporizers, a significant portion of the flow is vented into the room.

8. Some cylindrical-type floats are not parallel to the glass wall, and the resultant errors can be greater than 33%.

9. Generally, flowmeters are reasonably accurate when the rate of flow is above 2 liters/min, that is, within 10% of indicated flow. Only about 6% of the machines tested had a greater inaccuracy at these high flows for the nitrous oxide and oxygen flowmeters.

10. At the 20 cc to 50 cc flow rate setting through the low-flow bypass flowmeters, the measured flows were from 50% above to 20% below the indicated flow. Some flows, however, were as high as 150% above that indicated and, on very rare occasions, even higher.

11. At 100 cc to 300 cc indicated flow settings, the average measured flow was closer to ± 20% of the indicated value.

12. At 500 cc to 750 cc settings, the error was somewhat less than 20%; however, there was a tendency to drift after the initial setting.

13. Around one liter flow settings for non-bypass gases such as oxygen and nitrous oxide, the approximate error was ± 20% for the high-flow flowmeters.

14. When all the calibrations were grouped, 40% were too high. The majority of these errors occurred below the 200 cc/min setting—most often in the 50 cc to 100 cc/min range. The degree of error increased markedly as the flow settings were decreased. In these lower ranges, the measured flow varied from no detectable flow due to internal leaks to an error of 303% excess flow.

15. The measured error in the cyclopropane flowmeters was in a range of 80% above to 50% below indicated flows. A number of observed machines were 200% too high. As a group, cyclopropane flowmeters were extremely inaccurate.

Discussion

Flowmeter inaccuracies on machines under continuous maintenance contracts, especially those machines that had been recently inspected and maintained, were common. A maintenance man calibrating a flowmeter is indeed an oddity, and unless error is apparent, flowmeters are rarely serviced.

While some of the errors were unimportant, others could not be tolerated. Simple equipment to check flowmeter accuracy is important to every anesthesiology department. Machines should be checked at frequent intervals; and the test date should be marked on the machine. A simple card system similar to those on fire extinguishers to facilitate recording of specific inspection items is strongly recommended by the authors. Regardless of clinical acumen, faulty and erroneous flowmeters should not be tolerated.

Conclusion

This study indicates both that routine evaluation of flowmeter accuracy is necessary and that more accurate vaporizing and drug administering systems are necessary. At present, the percent of error in flowmeters increases as the rate of flow decreases, and at flows below one liter in vaporizer flowmeters, the errors become clinically significant. Routine flowmeter checks are only an intermediate step until all flows, all concentrations, and all important parameters are continuously detected, recorded, analyzed, interpreted, and integrated.

Even with equipment recently checked for accuracy, a high index of caution, suspicion, and alertness is always necessary in anesthesia. Any ab-
normal reaction to an anesthetic should alert the anesthetist to a possible equipment malfunction. The patient and his variabilities, especially the debilitated patient, present a sufficient challenge to anesthesia without the addition of easily eliminated hazards.

REFERENCES

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