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The "Educated Hand"

Can Anesthesiologists Assess Changes in Neonatal Pulmonary Compliance Manually?

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To determine whether anesthesiologists can manually detect significant changes in pulmonary compliance in neonates using an "educated hand," the authors tested whether clinicians could detect clamping of an endotracheal tube connecting a neonatal lung model to one of three anesthesia breathing circuits. The test lungs corresponded to the lung of a full-term neonate (large lung) or a premature neonate (small lung), and the circuits were a disposable Mapleson D and a disposable pediatric circle system with and without a humidifier. Clinicians having four levels of expertise (inexperienced anesthesia residents, experienced anesthesia residents, faculty not specializing in pediatric anesthesia, and specialized pediatric anesthesia faculty) were permitted to choose fresh gas flows, ventilatory pattern, and rate. After an acclimation period, the endotracheal tube connecting the test lung to the circuit was occluded once for 30 s. Clinicians were credited with a successful detection if they reported the occlusion within 15 s and had fewer than one false positive per minute. With the large lung model, only 4 of 24 clinicians detected occlusion with the Mapleson D circuit; similar results were obtained with the other circuits. With the small lung model, the only successful detection occurred with the Mapleson D circuit. Success at detecting occlusion was similarly low for clinicians with different levels of expertise. The authors conclude that the commonly held belief that the "educated hand" permits clinicians to detect subtle changes in pulmonary compliance in neonates during anesthesia (necessitating manual rather than mechanical ventilation) is not true. (Key words: Anesthesia: neonate. Equipment, breathing circuits: compliance. Ventilation: neonate.)

TEXTBOOKS of pediatric anesthesia frequently recommend that neonates' lungs be ventilated manually rather than mechanically during anesthesia. For example, Gregory wrote that "neonatal ventilators cannot adequately compensate for the changes in compliance and resistance caused by retractors and packs. Therefore, the patient probably should be ventilated by hand . . . [permitting] instantaneous compensation for changes in lung compliance and resistance."[1] Steward, similarly, states that "manual control of ventilation is preferable for thoracoabdominal surgery, as subtle changes in compliance can be detected rapidly and adjustments made to maintain ventilation."[2] Finally, Bikhazi and Davis claim that "manual ventilation . . . allows the anesthesiologist to sense continuously changes in compliance of the chest and airways."[3]

In contrast, our clinical experience has been that the circuits used commonly for neonatal anesthesia have sufficient compressible volume that even experienced clinicians are unable to detect marked changes in compliance during manual ventilation. For example, we have observed that clinicians, even those forewarned, are unable to detect brief episodes of endotracheal tube occlusion in neonates undergoing surgery. Accordingly, we tested whether clinicians having varying degrees of clinical experience were able to detect changes in "pulmonary" compliance manually *in vitro*.

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Materials and Methods

We tested 24 clinicians who had four levels of experience. There were 4 inexperienced residents (12–18 months of anesthesia residency), 7 experienced residents (18–36 months of anesthesia residency), 8 faculty not specializing in pediatric anesthesia, and 5 faculty fully trained in pediatric anesthesia (and, with one exception, also board-certified in pediatrics). The performance of each clinician was tested using three different anesthesia circuits and one or both lung models. The anesthesia circuits consisted of the following:

1. Mapleson D: a 60-cm (length), 22-mm (diameter) corrugated hose (Anesthesia Medical Specialties, Santa Fe Springs, CA) without a humidifier;
2. Pediatric circle system without humidifier: a circle consisting of two 150-cm (length), 15-mm (diameter)

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hoses (Marquest Medical Systems, Englewood, CO) without a humidifier;

3. Pediatric circle system with humidifier: a circle consisting of two 90-cm (length), 15-mm (diameter) hoses and one 150-cm (length), 15-mm (diameter) hose (Marquest Medical Systems), and a Marquest humidifier. The humidifier was filled to the maximum recommended level, with 300 ml water; compressible volume was 400 ml.

The Mapleson D circuit was connected to the fresh gas outlet of an Ohio Modulus anesthesia machine (Ohio Medical Products, Madison, WI). The circle systems were connected to this anesthesia machine *via* an Ohio Anesthesia Absorber (21DC) filled with soda lime. For all circuits, the reservoir bag was 500 ml and was made of latex.

The test lung (Star Neonatal/Pediatric Test Lung, Infrasonic, San Diego, CA) consisted of a 1,000-ml (small lung) or a 2,000-ml (large lung) plastic bottle filled with copper wool and connected to the breathing circuits by 10 cm of 2.5- or 3.0-mm endotracheal tubing for the small and large lungs, respectively. Based on the assumptions that the copper wool maintains constant gas temperature in the lung models, that the walls of the lung models are rigid (so that the delivered tidal volume actually results from gas compression rather than expansion of the lung model), and that the system obeys the ideal gas law regarding changes in pressure and volume, static compliance was 0.95 ml/cmH_2O and 1.9 ml/cmH_2O for the small and large lung models, respectively. Therefore, a peak inspiratory pressure (PIP) of 15 cmH_2O would produce a maximal tidal volume of 14 ml with the small lung, and a PIP of 20 cmH_2O would produce a tidal volume of 38 ml with the large lung. (The actual tidal volume will be less depending on the size of the endotracheal tube, flow rates, and the resulting resistance). Assuming that a tidal volume of 10 ml/kg is a desirable target, the small and large models correspond to the lung of a premature (approximately 1–1.5 kg, tidal volume 10–15 ml) and a full-term neonate (approximately 3–4 kg, tidal volume 30–40 ml), respectively.

The performance of each clinician was tested first using the large-lung model with all three circuits and then using the small lung with only the circuits in which the clinician had accurately detected changes in compliance in the large lung. All were asked to ventilate to produce a consistent breath-to-breath PIP of 20 cmH_2O for the large lung or 15 cmH_2O for the small lung; airway pressure was measured with a conventional pressure manometer attached to the carbon dioxide absorber or a similar device attached by a sidearm connector to the Mapleson D circuit. Each clinician was also permitted to select a fresh gas flow and respiratory rate and to ventilate the test lung until breath-to-breath ventilation was consistent and no further adjustments of the overflow valve were required. Each clinician was allotted a 5-min period of acclimation. Throughout the study, clinicians were permitted to observe a pressure gauge in the anesthesia circuit but not to auscultate for gas exchange. To simulate the environment of the operating room, anesthesiologists were asked to record artificial values for oxygen saturation, heart rate, systolic and diastolic blood pressures, and temperature. A Bair Hugger® (Augustine Medical, Eden Prairie, MN) provided a low and constant level of background noise. Clinicians were informed that the endotracheal tubing might be clamped at some time during the trial, but the time and duration of clamping were not provided. They were asked to report whenever they detected that the endotracheal tube was clamped.

At a predetermined random time varying from 1 to 5 min after the acclimation period, the endotracheal tubing was silently (and outside the visual field of the anesthesiologist) clamped (*i.e.*, completely occluded) once for 30 s. We credited a clinician with having detected an occlusion if both of the following criteria were met:

1. The occlusion was detected within the first 15 s.
2. The number of false positives was fewer than one per 60 s.

Using Fisher's exact test, we determined whether the ability to detect occlusion varied as a function of the type of circuit. $P < 0.05$ was considered statistically significant.

Results

Clinicians selected fresh gas flows of 1–5 l/min and were acclimated to the breathing circuit within 4.0 min. With the Mapleson D circuit, only 4 of 24 clinicians were able to detect changes in compliance in the large-lung model, and only 1 was able to detect them in the small-lung model (table 1). With the pediatric circle system without a humidifier, 4 clinicians detected the change in compliance of the large lung, and none detected it in the small lung. With the pediatric circle system with a humidifier, 3 clinicians detected the change in compliance in the large lung, and none detected it in the small lung. The type of anesthesia circuit did not influence the likelihood of detection.

Several clinicians reported changes in compliance during endotracheal tube clamping but were not credited with successful detection because they reported occlusion more than 15 s after clamping or reported an excessive number of false positives (table 2). For example, one pediatric faculty clinician reported an occlusion 6 s after clamping but also reported ten false positives over a 4-min period when the tube was not clamped. According to our criteria, this number of false positives precluded crediting him with successful detection.

TABLE 1. Detection of Changes in Pulmonary Compliance

	Lung	Mapleson D	Pediatric Circle Without Humidifer	Pediatric Circle With Humidifier
Inexperienced residents (n = 4)	Large	1/4	0/4	0/4
	Small	0/1	—	—
Experienced residents (n = 7)	Large	2/7	0/7	1/7
	Small	0/2	—	0/1
Nonpediatric faculty (n = 8)	Large	0/8	3/8	2/8
	Small	—	0/3	0/2
Pediatric faculty (n = 5)	Large	1/5	1/5	0/5
	Small	1/1	0/1	—
Total (n = 24)	Large	4/24	4/24	3/24
	Small	1/4	0/4	0/3

Anesthesiologists having varying degrees of clinical experience were asked to assess manually changes in pulmonary compliance induced by clamping an endotracheal tube connecting each of three breathing circuits to one of two test lungs. Values indicate the number of successful detections and the number of trials. Clinicians were tested using the small lung model only if they detected occlusion in the large lung with the specified circuit.

Discussion

We found that clinicians ranging in experience from early anesthesia residency training to extensive clinical care of neonates generally were unable to manually detect major changes in compliance of the breathing circuits tested. Most of those clinicians who accurately reported an occlusion accurately did so only in a context that included many false positives, suggesting that their "educated hand" may be a sensitive monitor but is not specific. It is likely that few occlusions would have been accurately detected had clinicians not been forewarned that clamping would occur; *i.e.*, the expectation of clamping probably resulted in the large number of false positives. If the "educated hand" truly existed, clinicians should be able to detect occlusion without false positive or negative results.

We produced changes in pulmonary compliance more marked than those that might occur during surgery and have clinical import. For example, if surgical manipulation decreased compliance 50% in a full-term neonate, changes in compliance would be smaller than those tested in our lung model. Nevertheless, most clinicians were unable to detect the changes we produced *in vitro*, suggesting that smaller, but clinically important, changes in the clinical setting would be undetected.

A similar study using models of adult lungs demonstrated that anesthesiologists did not compensate for decreases in compliance from 30 to 15 ml/cmH_2O, and that, with decreases in compliance, tidal volume decreased from the target value of 350 ml by as much as 50%.[4] Assuming that the ratio of the target tidal volume (350 ml) to the compression volume of the anesthesia circuit used in that study was higher than in the present study, we should have found, and did, even less satisfactory clinical performance.

Most of the clinicians who participated in the present study complained that they were unable to detect occlusion because they were not permitted to auscultate the "lung." Despite this limitation, they believed that their "educated hands" alone would permit them to detect occlusions. We disagree. We contend that clinicians may have "educated" eyes or ears—*i.e.*, they are able to detect changes in tidal volume visually or by auscultation of breath sounds—but that their hands *per se* contribute little to assessing changes in pulmonary compliance. Our data support this contention.

If clinicians are unable to detect changes in compliance manually, then the benefits of mechanical rather than manual ventilation must be considered. Mechanical ventilation offers several advantages to the anesthesiologist,

TABLE 2. Frequency with Which Occlusion of the Endotracheal Tube Was Detected

	Mapleson D	Pediatric Circle Without Humidifer	Pediatric Circle With Humidifier
Occlusion detected	4	4	3
Occlusion not detected			
No true positives	13	15	16
False positives, >1 per min	4	2	2
True positive reported >15 s after clamping	3	3	3

Anesthesiologists were asked to report when an endotracheal tube was clamped with three breathing circuits and one of two test lungs. The distribution of detections or reasons for lack of success with the large lung are shown.

particularly in caring for a critically ill patient. First, the anesthesiologist's hands are freed to perform many other necessary tasks. Second, ventilators such as the Ohmeda 7800 (Madison, WI) or the Air-Shields Ventimeter (Healthdyne, Hatboro, PA) deliver the same volume regardless of changes in compliance; the actual tidal volume varies as a function of compliance. However, because the delivered volume is constant, changes in PIP indicate changes in compliance. When our large test lung was ventilated with the Air-Shields Ventimeter ventilator at a rate of 20 breaths per min, an inspiratory:expiratory ratio of 1:2, and a PIP of 20 cmH_2O, clamping the endotracheal tube increased PIP 5 (with the circle systems) to 10 (with the Mapleson D circuit) cmH_2O; with the small lung, at a PIP of 15 cmH_2O, increases varied from 2 to 5 cmH_2O. If anesthesiologists combine an assessment of changes in PIP with observation of chest excursion, breath sounds, end-tidal carbon dioxide measurements, and arterial oxygen saturation to indicate adequacy of ventilation, manual ventilation appears to offer no advantage over mechanical ventilation for detection of changes in compliance.

There is one possible advantage to manual ventilation, that it might permit more rapid detection of leaks from the breathing circuit than would be possible with a mechanical ventilator. The results of the present study do not permit us to address this issue.

Another possible interpretation of our results is that all three circuits tested are too compliant. It is possible that a circuit with markedly less compliance (for example, a Mapleson D circuit with a very short reservoir) might have yielded different results. However, we selected circuits commonly used in our institution and representative of those we have seen in other teaching institutions.

In summary, we tested clinicians who had varying degrees of clinical experience to determine whether they could manually detect marked changes in compliance in neonatal lung models with a pediatric circle system and a Mapleson D circuit. Most clinicians, regardless of experience, were unable to detect changes in compliance or reported many false positives with the circuits tested. Our results suggest that the traditional recommendation that neonates' lungs be ventilated manually during anesthesia so that "subtle changes in compliance can be detected rapidly" is flawed when commonly used compliant pediatric breathing circuits are used.

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