Comparison of end-tidal carbon dioxide, oxygen saturation and clinical signs for the detection of oesophageal intubation

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The reliability of various methods for detecting oesophageal intubation was assessed by means of a single blind study in rats. Both oesophagus and trachea were simultaneously intubated. The presence or absence of various clinical signs was noted during tracheal or oesophageal ventilation and arterial blood gases and end-tidal CO₂ were measured. Oesophageal ventilation for one minute was associated with significant decreases ($P < 0.001$) in pH, PaO₂ and SaO₂ and a significant ($P < 0.001$) increase in PaCO₂. Although mean PaO₂ decreased by 70 per cent and mean SaO₂ decreased by 31 per cent, 43 percent of rats failed to demonstrate a decrease in SaO₂ below 85 per cent. Oxygen saturation was the least reliable method for detecting oesophageal intubation (sensitivity = 0.5, specificity = 0.9, positive predictive value (PPV) = 0.8). Chest movement was the most reliable clinical sign for detecting oesophageal intubation (sensitivity = 0.9, specificity = 1.0, PPV = 1.0). Oesophageal rattle was the second most reliable clinical sign (PPV = 0.9). Moisture condensation in the tracheal tube (PPV = 1.0) and

abdominal distension (PPV = 0.9) were judged to be the least reliable because each had a high false negative rate of 0.3. The most reliable method for the early detection of oesophageal intubation in rats was end-tidal CO₂ (sensitivity 1.0, specificity = 1.0, PPV = 1.0). In addition, end-tidal CO₂ when used in conjunction with the four clinical signs improved the reliability of these signs.

Key words

COMPLICATIONS: intubation, tracheal; EQUIPMENT: analysers, carbon dioxide, oxygen; INTUBATION: oesophageal, tracheal; MONITORING: carbon dioxide, oxygen, clinical.

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A recent review¹ cites unrecognized oesophageal intubation as one of the important causes of anaesthesia-related deaths and medical liability claims. It is recognized that anaesthetists relying on clinical signs alone may fail to identify oesophageal intubation.¹⁻³ It has been suggested that end-tidal carbon dioxide (ETCO₂) monitoring may provide the most reliable method for detecting oesophageal intubation.¹ Unfortunately, with the exception of two descriptive studies^{4,5} the reliability of ETCO₂ monitoring for detecting oesophageal intubation has not been established by means of a systematic study. Recently, it has also been suggested that pulse oximetry may facilitate early detection of oesophageal intubation in children.⁶

The purpose of this study was to evaluate the reliability of ETCO₂, oxygen saturation (SaO₂) and four common clinical signs for the early detection of oesophageal intubation in the rodent model.

Methods

The study was carried out in three parts. In the first part, 20 non-fasted female Wistar rats (mean weight 257 gm; range 226-286), each with a chronically implanted carotid artery cannula, were studied. Each animal was anaesthetised with halothane in oxygen (50 per cent) and nitrous oxide (50 per cent). Ten minutes after commencing anaesthesia, blood samples for arterial blood gas analysis (ABGs) were drawn. Then, both trachea and oesophagus were intubated simultaneously with 14G Jelco® cannulae. The tracheal tube was first connected to

a fixed volume rodent ventilator (Harvard) and the lungs ventilated with halothane (1.5 per cent) in an oxygen/nitrous oxide mixture (FiO₂ 0.5). A respiratory rate of 100 min⁻¹ and a tidal volume of 4.5 ml were used as these settings had been previously found to yield physiological PaCO₂ values. The ET/CO₂ was monitored using a Beckman Medical Gas Analyser LB2 Model (Beckman; Illinois, U.S.A.). Continuous measurements were made during the study of heart rate, arterial blood pressure, and rectal temperature. Animal temperature was kept as near as possible to 37° C by means of a thermostatic overhead radiant heat lamp and a warm operating room table. Monitoring information was recorded continuously with a strip chart recorder and all ABG values were corrected to 37° C. Readings of ET/CO₂ were obtained at 40, 50 and 60 sec after commencing pulmonary ventilation. During this period the animal was closely observed by one investigator (HV) for the presence or absence of four clinical signs: symmetrical chest inflation, abdominal distension, condensation in the tracheal tube, and an audible rattle around the tracheal tube during inspiration. Blood was drawn for ABG analysis after one minute of tracheal ventilation and the ventilator was then connected to the oesophageal tube. Again the animal was observed for the presence or absence of the above clinical signs and ET/CO₂ readings were obtained at 40, 50 and 60 sec and blood for ABG analysis was drawn at 60 sec. Finally, the tracheal tube was reconnected to the ventilator and the lungs ventilated with oxygen (100 per cent) to determine if the animal would awaken from anaesthesia. This sequence was used in all animals. The standard to identify correct tracheal tube placement was two-fold – (a) direct visualization of the tube passing into the trachea during intubation and (b) awakening of the animal during ventilation with oxygen (100 per cent) at the end of the first part of the study.

In the second part of the study, the protocol described in the first part was repeated. The only difference was that the presence or absence of the four clinical signs was documented by the principal investigator (HV) as well as another investigator when both were blinded. This proce-

dure allowed assessment of the reliability and reproducibility of the principal investigator's clinical findings. Animals used in this part of the study were the same as those used in the first part.

In the third part of the study, results for all six variables (ET/CO₂, SaO₂, and the four clinical signs) were randomly presented either alone or in different combinations to a third anaesthetist who was blinded to the study and who was asked to diagnose whether the results were obtained with tracheal or oesophageal ventilation. Comparison of the diagnosis of the third anaesthetist with the correct diagnosis as determined by the two criteria enabled estimates of sensitivity, specificity, positive and negative predictive values to be computed for each of the six study variables.

Data were analyzed using Student's *t* test. Sample size calculation using previously published values of ET/CO₂ from trachea and oesophagus^{4, 5} with alpha (two-tailed) set at 0.001 and beta set at 0.1 yielded a value of *n* of 6.8. We therefore used 20 animals which provided the study with a power greater than 0.9. Estimates of sensitivity, specificity and predictive values were computed using standard criteria for diagnostic tests.^{7, 8} Reliability and reproducibility of the principal investigators' clinical findings were assessed by computing the Kappa statistic.⁹ Ninety-five per cent confidence intervals for zero numerators were calculated by using the "rule of three."¹⁰

Results

Mean ET/CO₂ readings were: oesophagus 0.41 per cent (range 0.1–0.7 per cent), and trachea 2.83 per cent (range 2.2–3.6 per cent, *P* = < 0.001). Tracheal ET/CO₂ readings were in the expected physiological range whereas the low readings obtained from the oesophagus probably reflected gastric gas sampling. As the rats were not fasted, CO₂ in the stomach was probably the result of gastric digestion or fermentation.

The results of arterial blood gas analysis are summarized in Table I. All components were significantly different after one minute of oesophageal ventilation compared with one minute of tracheal ventilation (*P* <

TABLE I Arterial blood gas changes (mean ± SD) during induction, after one minute of tracheal or oesophageal ventilation

	Induction	Tracheal ventilation	Oesophageal ventilation	<i>P</i> (2-tailed) Tracheal versus oesophagus
pH	7.31 ± 0.09	7.52 ± 0.07	7.39 ± 0.04	<0.001
PaCO ₂ (mmHg)	52.6 ± 13.4	28.2 ± 4.1	43.1 ± 5.8	<0.001
HCO ₃ ⁻ (mmol·L ⁻¹)	26.51 ± 2.30	23.09 ± 1.85	26.68 ± 2.84	<0.001
PaO ₂ (mmHg)	108.3 ± 45.6	147.8 ± 54.5	44.3 ± 21.5	<0.001
SaO ₂ (%)	95.3 ± 4.4	98.5 ± 2.5	67.8 ± 27.7	<0.001

0.001). Mean PaO₂ decreased by 70.0 per cent and mean SaO₂ decreased by 31.1 per cent after 1 min of oesophageal ventilation. However, 43 per cent of animals failed to demonstrate a decrease in SaO₂ below 85 per cent after one minute oesophageal ventilation (Figure).

Results of the Kappa statistic for the four clinical signs are summarized in Table II and confirm that the principal investigator's findings were reliable and reproducible when compared with another investigator.

The data of all six study variables are summarized in Table III using four-fold analysis. This enables computations to determine sensitivity, specificity, predictive values, false positive and negative rates for all study variables alone and in specific combinations, which are shown in Table IV.

Discussion

After intubation, the position of the tracheal tube must be confirmed by the detection of certain clinical signs. These include visualization of the tube entering the larynx, auscultation of the chest for breath sounds, watching the chest for expansion, the abdomen for distension and the tube for moisture condensation as well as listening for the escape of gases from the oesophagus. Other less commonly used tests have also been presented. On certain occasions, however, it may be impossible to visualize the vocal cords and reliance may have to be placed on one or more of these clinical signs. However, apart from direct visualization of the tube passing between the vocal cords,

TABLE II Reliability and reproductibility of four clinical signs. Moisture = condensation in tracheal tube; Rattle = audible rattle around tracheal tube during ventilation

Clinical sign	Kappa statistic
Chest movement	1.0
Rattle	0.90
Moisture	0.88
Abdominal distension	0.78

TABLE III Four-fold analysis of tracheal tube position as diagnosed by ETCO₂*, moisture condensation†, chest movement‡, abdominal distension§, an audible rattle¶, and SaO₂||

Oesophageal Intubation									
	Present			Absent					
Present	20*, 14§,	14†, 19¶,	18‡ 8	0*, 1§,	0†, 1¶,	0‡ 1	20*, 15§,	14†, 20¶,	18‡ 9
Absent	0*, 6§,	6†, 1¶,	2‡ 7	20*, 19§,	20†, 19¶,	20‡ 16	20*, 25§,	26†, 20¶,	22‡ 23
	20*, 20§,	20†, 20¶,	20‡ 15	20*, 20§,	20†, ¶,	20‡ 17	40*, 40§,	40†, 40¶,	40‡ 32

FIGURE 1 Changes in oxygen saturation (SaO₂) during induction, and after one minute of tracheal and oesophageal ventilation.

most of the other clinical tests have been shown to be fallible.^{2-3, 11-16} These clinical tests have received little objective scrutiny to determine their reliability or the circumstances under which their usefulness should be questioned.¹⁷ Similar criticism can be made for ETCO₂ monitoring.

Our experimental model was designed to assess systematically the reliability of four clinical signs, ETCO₂ and SaO₂ monitoring for the early detection of oesophageal intubation. Rodents were chosen for this study for two reasons - (1) such an experiment could not be ethically justified in patients scheduled for elective surgery without obtaining preliminary data in an animal model; and (2) we wished to simulate conditions of "difficult/uncertain"

TABLE IV Comparison of six methods for identifying oesophageal intubation in rats

	ETCO ₂	Moisture	Chest movement	Abdominal distension	Rattle	SaO ₂	All clinical	All clinical plus ETCO ₂
Sensitivity	1.0	0.7	0.9	0.7	0.9	0.5	0.9	1.0
Specificity	1.0	1.0	1.0	0.9	0.9	0.9	1.0	1.0
Positive predictive value	1.0	1.0	1.0	0.9	0.9	0.8	1.0	1.0
False positive rate	(0.15)	(0.15)	(0.15)	0.05	0.05	0.05	(0.15)	(0.15)
False negative rate	(0.15)	0.3	0.1	0.3	0.05	0.4	0.05	(0.15)

() 95% Confidence intervals for zero numerators.

intubation – rodents provide such a simulation because visualisation of the larynx and confirmation of tracheal tube position are both difficult. It should be noted that we are not aware of a similar study in other animal models. There is no information available on whether our data in rats can be extrapolated to humans.

Before discussing our results it is pertinent to review the criteria that an ideal test for detecting oesophageal intubation should satisfy. Firstly, the test should be highly specific (i.e., be negative whenever oesophageal intubation does not occur) and sensitive (be positive whenever oesophageal intubation does occur). Secondly, it should have a high positive predictive value (i.e., the likelihood of oesophageal intubation should be high given the test is positive). Finally, it should have no false positives.¹⁸ The false negative rate, however, does not need to be zero because if the test falsely suggests oesophageal intubation, the anaesthetist will merely check and repeat intubation if necessary. However, the false negative rate should be low so as to avoid unnecessary repetitious intubations.

In this study, chest movement was judged as the best clinical sign in view of its high sensitivity, specificity and positive predictive value, zero false positive rate and a low false negative rate. "Oesophageal rattle" was judged the second best clinical sign. "Moisture condensation" and "abdominal distension" had lower sensitivities and unacceptably high false negative rates.

The results of this study also help to quantify the risk of missing oesophageal intubation when sole reliance is placed on one or more clinical signs. The risks of missing oesophageal intubation in rats with the four clinical signs are as follows: 30 per cent (moisture condensation), 30 per cent (abdominal distension), ten per cent (chest movement), five per cent (oesophageal rattle) and five per cent (all four clinical signs used together). Such a quantification of risk has not been previously possible and helps us to understand why unrecognized oesophageal intubation remains a problem in modern anaesthetic practice. Our results also demonstrate that the risk of missing an esophageal intubation can be reduced by using more than one clinical sign.

End-tidal CO₂ was perfectly predictive of oesophageal intubation with high sensitivity and specificity. In addition, the false positive and negative rates were zero (95 per cent confidence limit = (0.15). The risk of missing oesophageal intubation with ETCO₂ was also zero. Interestingly, ETCO₂ increased the sensitivity and lowered the false negative rate of all four signs when used in conjunction with them.

Oxygen saturation had the worst performance of all six tests. This is not surprising because changes in oxygen saturation were unpredictable with oesophageal intubation (Figure). Thus, routine pulse oximetry is unlikely to facilitate the early diagnosis of unrecognized oesophageal intubation.

Finally, consideration should be given to the need for any test of oesophageal intubation to be unequivocal when positive.¹⁸ Clinical signs fail to satisfy this criteria because they are subjective. On the other hand, ETCO₂ does not have such a limitation in view of the marked difference between tracheal and oesophageal readings. Even in clinical situations where mixed expired air has been forced down the oesophagus during previous mask ventilation, it has been possible to identify oesophageal intubation because the ETCO₂ readings decreased with a few positive pressure breaths.^{5, 19}

In summary, the results of this study indicated that ETCO₂ monitoring was the best test for early detection of oesophageal intubation in rats. It was more reliable than oxygen saturation monitoring and the four clinical signs studied (moisture condensation, chest movement, abdominal distension and an audible rattle). In addition, ETCO₂, when used in conjunction with the four clinical signs, improved their reliability. These results add weight to earlier recommendations that end-tidal carbon dioxide monitoring be considered an essential clinical monitor.^{20,21}

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Résumé

La fiabilité des différentes méthodes de détection de l'intubation oesophagienne chez les rats a été évaluée par une étude à simple insu. L'oesophage et la trachée ont été simultanément intubés chez les rats. La présence ou l'absence de différents signes cliniques a été notée durant la ventilation oesophagienne ou trachéale. Les gaz artériels et le CO₂ en fin d'expiration ont été mesurés. La ventilation oesophagienne pour une minute était associée à une diminution significative ($P < 0.001$) du pH, PaO₂ et de la SaO₂ et une augmentation significative ($P < 0.001$) de la PaCO₂. Même si la PaO₂ moyenne a diminué de 70 pour cent et la SaO₂ moyenne a diminué de 31 pour cent après un minute de ventilation oesophagienne, 43 pour cent des rats n'ont pas démontré une diminution de la SaO₂ inférieure à 85 pour cent. La saturation de l'oxygène était la moins fiable pour détecter l'intubation oesophagienne (sensibilité = 0.5, spécificité = 0.9, valeur positive de prédiction (PPV) 0.8). L'expansion thoracique représentait le signe clinique le plus fiable pour détecter une intubation oesophagienne (sensibilité = 0.9, spécificité = 1.0, PPV = 1.0). Le crépitement oesophagien représentait le deuxième signe clinique le plus fiable (PPV = 0.9). La condensation de l'humidité dans le tube endotrachéal (PPV = 1.0) et la distension abdominale (PPV = 0.9) étaient considérées comme étant les moins fiables avec chacun un taux de faux négatif de 0.3. On conclut que la méthode la plus fiable pour une détection précoce de l'intubation oesophagienne chez les rats était la CO₂ en fin d'expiration (sensibilité = 1.0, spécificité = 1.0, PPV = 1.0). De plus, la CO₂ en fin d'expiration lorsqu'utilisée avec les quatre autres signes cliniques améliore leur fiabilité.