

Simultaneous tracheal and oesophageal pH monitoring during mechanical ventilation

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Abstract

Objective—To simultaneously record tracheal and oesophageal pH in mechanically ventilated children to determine: (1) the feasibility and safety of the method; (2) the incidence of gastro-oesophageal reflux (GOR) and pulmonary contamination; and (3) their associated risk factors.

Design—Prospective study.

Setting—Paediatric intensive care unit in a university hospital.

Patients—Twenty mechanically ventilated children (mean age 6.7 years) who met the following inclusion criteria: endotracheal tube with an internal diameter of 4 mm or more (cuffed or uncuffed), mechanical ventilation for an acute disease, no treatment with antiacids, prokinetics, or H₂-receptor blockers, and no nasogastric or orogastric tube.

Methods—The tracheal antimony pH probe was positioned 1 cm below the distal end of the endotracheal tube. The oesophageal antimony pH probe was positioned at the lower third of the oesophagus. pH was recorded on a double channel recorder and analysed with EsopHogram 5.01 software and by examination of the trace. The following definitions were used: GOR index, percentage of time pH < 4; pathological GOR, GOR index > 4.8 %; tracheal reflux, fall in tracheal pH < 4, 4.5, or 5, or a decrease of one unit from baseline, in both cases preceded by an episode of GOR. The results were analysed statistically by Fisher's exact and the Kruskal-Wallis test.

Results—The procedure was well tolerated and the median duration of analysable recording was 6 hours (range 5–22.6). Pathological GOR was observed in eight (40%) children. GOR was more frequent with an uncuffed endotracheal tube than with a cuffed one ($p=0.01$). Tracheal reflux (pH < 4) was observed in four children (20%) without clinical evidence of pulmonary aspiration. Episodes of tracheal reflux were associated with a GOR index > 10% ($p < 0.01$) and were more frequent with a maximal inspiratory pressure of < 25 cm H₂O ($p = 0.03$), but were not related to the indication for mechanical ventilation, whether the endotracheal tube was cuffed or not, age, or drug treatment.

Conclusions—Simultaneous tracheal and oesophageal pH monitoring was feasible in the setting of this study. Tracheal reflux can occur without pathological GOR, and

GOR may occur without tracheal reflux. Further prospective studies in larger groups of patients are now justified.

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Keywords: aspiration, mechanical ventilation, tracheal pH recording.

The relationship between gastro-oesophageal reflux (GOR) and respiratory disease has been known for some time.¹ Pulmonary aspiration may cause pneumonia and bronchospasm, and plays a part in the pathogenesis of bronchopulmonary dysplasia.^{2,3} A high incidence in GOR has been demonstrated in ventilated adult patients, particularly during enteral feeding and in supine position,^{4,5} but data in children are limited and varied.^{6–8} Furthermore, in all these studies, no proof of pulmonary aspiration was provided. Thus, the deleterious effect of GOR during mechanical ventilation remains unclear.

Methods to document aspiration of gastric contents include direct sampling of tracheo-bronchial secretions for lipid laden macrophages,^{9–11} lactose,^{12,13} or glucose.¹⁴ Radioactivity in secretions may be used to detect aspiration of technetium-99m(^{99m}Tc) administered intragastrically.^{15–17} Evans blue placed on the tongue allows detection of oropharyngeal contents.^{18–20} These methods do not allow longitudinal monitoring and have a high incidence of false positive results.¹ As pH monitoring is reported as the 'gold standard' of GOR investigations,²¹ we speculated that tracheal pH recording, not hitherto evaluated during controlled ventilation,^{22,23} could be useful to document aspiration. Therefore, the purpose of this prospective study was to simultaneously record tracheal and oesophageal pH in mechanically ventilated children to determine: (1) the feasibility and safety of the method; (2) the incidence of GOR and pulmonary contamination; and (3) their associated risk factors.

Patients and methods

pH MONITORING

Antimony electrodes were chosen as they are robust and were available with a 1.2 mm external diameter, smaller than available glass pH electrodes, although the latter may be more accurate.²¹ Our aim was to monitor tracheal pH below the endotracheal tube. Before beginning the study we measured the effect of the tracheal antimony microelectrode (prototype with a 1.2 mm external diameter) upon airway resistance in a 3 mm internal diameter

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Table 1 Population characteristics and ventilator settings

Patient No	Age (months)	Internal diameter of ETT	Disease*	Mode†	FiO ₂	RR (/min)	Pi max (cmH ₂ O)	PEEP (cmH ₂ O)	MAP (cmH ₂ O)	ITV (ml/kg)
1	49	4.0(u)	R	VC	0.30	25	26	0	9	13
2	49	4.0(u)	R	VC	0.37	25	28	4	12	13
3	37	4.0(u)	R	VC	0.30	28	30	6	14	11
4	5	4.0(u)	R	VC	0.40	30	37	6	‡	16
5	32	4.5(c)	N	VC	0.21	18	22	0	7	13
6	33	5.0(c)	R	PC	0.65	32	42	10	26	16
7	32	4.0(c)	C	VC	0.21	30	24	0	8	9
8	99	6.0(c)	R	PC	0.60	30	29	0	12	6
9	33	4.0(u)	N	VC	0.30	25	29	0	10	12
10	144	7.0(c)	C	VC	0.30	16	21	0	7	9
11	138	7.0(c)	N	VC	0.21	15	15	0	5	9
12	137	6.5(c)	N	VC	0.40	20	40	6	17	11
13	28	4.5(u)	N	VC	0.40	25	20	0	7	15
14	6	4.5(u)	R	PS	0.30	25	8	0	‡	7
15	150	7.5(c)	R	VC	0.40	20	26	0	9	9
16	206	6.5(c)	N	VC	0.40	16	20	0	7	8
17	7	4.0(u)	N	PC	0.21	30	24	0	7	11
18	156	6.0(c)	R	VC	0.30	25	25	0	8	6
19	165	7.0(u)	N	VC	0.25	14	22	0	7	8
20	137	5.5(c)	R	VC	0.60	40	35	10	18	9
Median value	37	4.5			0.30	25	25	0	8	9

ETT = endotracheal tube (u = uncuffed, c = cuffed).

* Disease : R = respiratory, N = neurological, C = cardiovascular.

† Mode : VC = volume controlled, PC = pressure controlled, PS = pressure support.

FiO₂ = fractional inspiratory oxygen; RR = respiratory rate; Pi max = maximal inspiratory pressure; PEEP = positive end expiratory pressure; MAP = mean airway pressure; ITV = inspiratory tidal volume.

‡ Absent data.

endotracheal tube, by using the technique described by Rossi *et al.*²⁴ At a flow rate of 0.4 l/s, resistances of 3, 3.5, and 4 mm internal diameter endotracheal tubes were respectively 103, 43, and 22 cm H₂O/l/s without the micro-electrode, and respectively 146, 57, and 27 cm H₂O/l/s with the microelectrode inserted through the tube. Thus, we decided to perform the study only in children with a 4 mm or more internal diameter endotracheal tube to avoid problems in gas exchange and tracheal secretion drainage. The tracheal probe, inserted through a specially built manifold, was placed 1 cm below the distal extremity of the endotracheal tube, and withdrawn during mucus suction.

The oesophageal probe (external diameter 2.1 mm), introduced through a nostril, was placed at the level of the distal third portion of the oesophagus, using the Strobel formula.²¹ The position of the probes was controlled radiologically.²¹

Tracheal and oesophageal pH were measured with the use of a double channel recorder (Digitrapper Mark II Synetics). Before and after each recording session, electrodes were calibrated to pH 1.0 and 7.0. An external skin reference electrode was used. The pH recording was performed the child being in the supine position.

PATIENT SELECTION

The protocol was approved by the local ethical committee, and informed consent was obtained from the parents. From November 1990 to August 1993, 20 mechanically ventilated children (mean age 6.7 years; range 5 months–17 years) met the inclusion criteria: nasotracheal tube with an internal diameter of 4 mm or more (cuffed or uncuffed), mechanical ventilation for an acute disease, no treatment with antacids, prokinetics, or H₂-

receptor blockers, and no nasogastric tube or orogastric tube. Children were ventilated with a Servoventilator 900 C (Siemens), an Advent or a CPU (Ohmeda). Fifteen children (75%) were ventilated in volume controlled mode, four (20%) in pressure controlled mode, and one (5%) in pressure support mode. Population characteristics, categories of disease (respiratory, cardiovascular, neurological), and ventilatory parameters are given in table 1. The choice of a cuffed or uncuffed endotracheal tube was made by the intensivist who was present at admission, taking in account age and disease (a cuffed tube was preferred in case of severe respiratory disease).

CLINICAL SURVEILLANCE

Clinical surveillance included monitoring of oxygen saturation (pulse oximeter, Nellcor), capillary blood gas analysis immediately before and one hour after tracheal microelectrode insertion, and ventilatory parameters (fractional inspiratory oxygen concentration, respiratory rate, maximal inspiratory pressure (Pi max), positive end expiratory pressure, mean airway pressure, inspiratory and expiratory tidal volumes). On a special sheet, the following were recorded hourly or in case of any event: time of tracheal suction, regurgitation or vomiting, cough, crying, pain, bradycardia, cyanosis, and pallor. Drugs (neuromuscular blocking agent: two children, fentanyl: two; benzodiazepine: nine; antiepileptic drug: four) were also noted.

METHODS OF ANALYSIS

pH recordings were analysed with EsopHogram 5.01 software (Gastrosoft Inc), and by examination of the trace. For oesophageal pH, the following parameters were measured: number of GOR episodes, number of GOR episodes longer than 5 minutes, duration of the

Table 2 pH recording results in 20 children

Patient No	Duration of pH recording (hours)	GOR index (%)	Duration of longest GOR episode (min)	GOR episodes/hour	GOR episodes > 5 min	TRI (%)	TR
1	5.8	7.9	8	1.3	2	0	No
2	5.6	0	0	0	0	0	No
3	5.1	9.7	2	4.3	0	0	No
4	5.8	0	0	0	0	0	No
5	5.9	0	0	0	0	0	No
6	5.0	4.0	12	0.2	1	0	No
7	6.1	1.1	1	0.5	0	0.7	Yes
8	5.9	0	0	0	0	0	No
9	5.8	24.8	35	5.0	4	0	No
10	5.9	14.6	48	0.8	1	0	Yes
11	5.9	0	0	0	0	0	No
12	7.9	0	0	0	0	0	No
13	20.0	82.6	369	0.6	11	0	Yes
14	20.3	12.0	13	3.5	6	0	Yes
15	15.9	0.1	1	0.1	0	0	No
16	22.6	2.1	27	0.1	1	0	No
17	18.6	4.9	11	1.0	3	0	No
18	6.2	0.2	1	0	0	0	No
19	17.7	7.5	80	0.1	1	0	No
20	19.6	0.1	1	0	0	0	No
Median value	6.0	1.1	1	0.5	0	0	

TRI = tracheal reflux index; TR = tracheal reflux.

longest GOR, and percentage time at pH < 4 (GOR index). The GOR index, the most widely used overall measurement of reflux, was used for statistical analysis.²¹ GOR was considered pathological when the GOR index exceeded 4.8%.²¹

The tracheal reflux index was measured as the percentage time at pH < 4, taking account only of episodes of more than 30 seconds' duration and excluding periods of tracheal suction. In addition the total number of episodes of tracheal reflux was recorded. Here, tracheal reflux was defined as a fall in the tracheal pH below 4, 4.5, or 5, or a decrease of one unit from baseline, whatever the duration, which was preceded by an episode of GOR. Statistical evaluation was achieved with Epi Info Software (Centers for Disease Control), using Fisher's exact test and Kruskal-Wallis test, with a level of significance of 0.05.

Results

The procedure was clinically well tolerated: mean capillary carbon dioxide tension values before and after insertion of the tracheal microelectrode were not significantly different (range 3.07–8.66 (median 4.67) *v* 2.93–9.33 (median 5.33) kPa). Mean values for oxygen saturation before and after insertion of the tracheal microelectrode were not significantly different (range 88–99% (median 96) *v* 87–100% (median 96)).

Results of pH recording are given in table 2. The median duration of analysable recording was 6 hours (range 5–22.6). Eight children (40%) had a pathological GOR; their mean GOR index was 20.5% (median 12; range 4.9–82.6). GOR was not related to age, drugs, indication for mechanical ventilation, or ventilatory parameters, but was more frequent with an uncuffed endotracheal tube than with a cuffed one ($p = 0.01$).

Tracheal reflux below pH 4 was seen in four children, without clinical evidence of aspiration. Patients 7, 10, and 14 had one episode of tracheal reflux < 30 seconds, and patient 13

had three episodes < 30 seconds and one episode of 1 minute (table 2). Three of these four children had pathological GOR (GOR indices 14.6, 82.6, and 12%), and one very little reflux (GOR index 1.1%). In patient 13, who had a GOR index of 82.6 (table 2), it is possible that the probe was in the stomach, although probe position was confirmed radiologically. Among these four children, only one had any episode of tracheal reflux longer than 30 seconds, with a tracheal reflux index of 0.7%. Overall, the tracheal reflux index and the total number of episodes of tracheal reflux did not show a statistically significant relationship to the GOR index. However, tracheal reflux episodes were associated with a GOR index greater than 10% ($p < 0.01$). Analysis of tracheal reflux at a cut off of 4.5 or 5, or using a decrease of one unit from baseline did not alter results. Tracheal reflux was not related to age, drugs, cause of mechanical ventilation, type of endotracheal tube (cuffed or uncuffed). The only ventilatory parameter related to tracheal reflux was Pi max: tracheal reflux was more frequent with a Pi max less than 25 cm H₂O ($p = 0.03$).

Discussion

In this study, tracheal pH recording was easy and safe to perform. The added resistance of the tracheal antimony microelectrode was not a problem. Endotracheal tube obstruction has been reported with transtracheal catheters,²⁵ through the suspected mechanism of mucous plug formation, but we saw no evidence of this. In our patients, GOR was present in 40% and tracheal reflux in 20%. We may have underestimated GOR with the shorter duration of monitoring in 13 of our children.²¹ As confidence in our technique grew, the presence of an intensivist was no longer thought to be necessary throughout the recording period, and for the last eight patients prolonged surveillance was performed.

Incidence of GOR in mechanically ventilated patients has been reported as 37% in 51 critically ill adults with a nasogastric tube,⁴

74% (37/50) in orally intubated adults with a nasogastric tube, and 35% (7/20) in those without a nasogastric tube.⁵ Incidence of GOR was 14% in 28 children, who ranged in age from 2 weeks to 2 years, with a nasogastric tube⁶ and 36% in 42 ventilated and parenterally fed preterm infants.⁷ Numerous factors are suspected to induce GOR in critically ill patients^{16, 26}: coma, supine position, cough, presence of a nasogastric tube, use of an uncuffed endotracheal tube, and drugs that modify tonicity of the lower oesophageal sphincter such as benzodiazepines and morphine.^{1, 5, 16, 26} Conversely, GOR seems to be less frequent when neuromuscular blocking agents are used.⁶ In our study, GOR was more frequent with an uncuffed endotracheal tube, but there was no relationship between age, drugs, and incidence of GOR. In premature neonates, GOR index was significantly higher during spontaneous ventilation than during mechanical ventilation.⁸ Like others,^{7, 27} we found no relationship between the incidence of GOR and the ventilator settings.

Incidence of aspiration in intubated patients has been reported with ranges from 11% to 80% depending on the method used, the presence or not of a nasogastric tube and a cuffed endotracheal tube.²⁸ Several methods detecting aspiration have been proposed. By measuring radioactivity hourly over eight hours in tracheal secretions after the injection of ^{99m}Tc sulphur colloid in the nasogastric tube, incidence of tracheobronchial contamination was 42% in 31 ventilated neonates.^{15, 16} With the same method, incidence of aspiration in 25 adults fitted with an endotracheal tube and a nasogastric tube was 32%.¹⁷ Detection of aspiration by lactose assay in tracheal fluid has been proposed in ventilator dependent infants: 14% (6/42) had a lactose concentration highly suggestive of aspiration, and 48% (20/42) had questionably positive samples.¹² The sensitivity and specificity of this method are unknown. Recently, measurement of glucose in tracheal secretions has been shown to be inaccurate to detect aspiration in intubated enterally fed adults.¹⁴ With Evans blue placed on the patient's tongue incidence of aspiration was 50% in 22 children who ranged in age from 1 week to 18 years,¹⁹ 16% in 50 infants intubated with an uncuffed endotracheal tube,²⁰ and 80% in 20 preterm neonates intubated with an uncuffed endotracheal tube.¹⁸ Lipid laden alveolar macrophages as markers of aspiration have not been tested specifically in ventilated children⁹⁻¹¹; furthermore, this method requires the use of bronchoscopy to obtain bronchoalveolar fluid. Tracheal pH recording, as used in this study, is easy to perform and allows a true monitoring of acid aspiration.

Tracheal reflux was arbitrarily defined, according with the poor data from the literature.^{22, 23} As proposed in GOR,²⁹ we have studied different cut off limits (4, 4.5, and 5), and taken into account a decrease of one unit from the baseline. A threshold of pH 4 seems satisfactory, and altering the criteria did not allow the identification of other children with tracheal reflux. The short duration of all but

one episode of tracheal reflux in our four children might indicate that acid aspiration was rapidly buffered by tracheobronchial secretions. One child with tracheal reflux had no pathological GOR; this accords with the finding of 'normal' GOR with hypopharyngeal reflux,³⁰ and indicates the risk of tracheal reflux even with minimal GOR.

Theoretical risk factors for aspiration in ventilated patients are numerous.^{17, 31, 32} Like Demont *et al*,¹⁶ we found no relationship between aspiration and age. In contrast to Browning and Graves, who observed a 77% incidence of aspiration with an uncuffed endotracheal tube versus a 11% incidence with a cuffed one,¹⁹ we found no relationship between the incidence of tracheal reflux and the type of endotracheal tube. It has been demonstrated in adults that a cuffed endotracheal tube does not prevent aspiration.³² In our study and that from Demont *et al*,¹⁶ aspiration was more frequent when Pi max was low (< 25 cm H₂O and < 20 cmH₂O respectively). Conversely, Goodwin *et al*¹⁸ and Goitein *et al*²⁰ did not observe such a relationship. Our patients were explored in the supine position that favours aspiration. In mechanically ventilated adults, radioactivity recovered in endobronchial aspirates while patients were semirecumbent was significantly lower than that found while patients were in the supine position.³² In the study of Ibáñez *et al* less GOR was seen in semirecumbent patients, but this was not significant.⁵

In conclusion, pathological GOR is not necessary for aspiration to occur in the child receiving mechanical ventilation with a cuffed or uncuffed endotracheal tube. GOR does not imply aspiration, confirming previous studies, performed in non-ventilated patients, that demonstrated that GOR is often distal.³³ This method of simultaneous tracheal and oesophageal recording allows detection of aspiration of gastric contents. However, it detects only acid aspiration and ignores alkaline or neutral GOR with aspiration.³⁴ A number of questions remain: (1) What is the tracheal pH threshold indicative of aspiration? (2) What are the risk factors of aspiration (age, drugs, disease, position, type of endotracheal tube, presence of a nasogastric tube, modalities of feeding, and ventilator settings)? (3) What are the consequences of tracheal reflux in terms of pulmonary morbidity? Incidence of nosocomial pneumonia may be increased as mucociliary transport is diminished after aspiration,³⁵ and clinical studies have isolated the same microorganisms from stomach and bronchial samples.^{32, 36} Recurrent aspiration may prolong duration of mechanical ventilation and intensive care unit stay. Further prospective studies, involving larger groups of patients and using this simple and safe method of simultaneous oesophageal and tracheal pH recording are now justified.

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