Does end-tidal capnography confirm tracheal intubation in fresh-frozen cadavers?

Cliff Reid,[1,2] Ian Ferguson,[1,3,4] Brian Burns,[1,2] Karel Habig,[1,2] Mohammed Shareef[5]

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[1]Greater Sydney Area Helicopter Emergency Medical Service, New South Wales Ambulance, Sydney, New South Wales, Australia
[2]Discipline of Emergency Medicine, Sydney University Medical School, Sydney, New South Wales, Australia
[3]Department of Emergency Medicine, Liverpool Hospital, Sydney, New South Wales, Australia
[4]South West Sydney Clinical School, University of New South Wales, Sydney, New South Wales, Australia
[5]Surgical and Anatomical Science Facility, University of Technology, Sydney, New South Wales, Australia

Correspondence to
Dr Cliff Reid, Greater Sydney Area Helicopter Emergency Medical Service, New South Wales Ambulance, 670 Drover Road, Bankstown Airport, NSW 2200, Australia; reidcg@me.com

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ABSTRACT

Background Life-like end-tidal capnography ($ETCO_2$) waveforms have been demonstrated in recently deceased and fresh-frozen cadavers following tracheal intubation, offering potential for high fidelity airway simulation training. As the mechanism for carbon dioxide production is not fully understood, it is possible that oesophageal intubation may also generate a capnograph. Our aim was to measure $ETCO_2$ levels following (1) oesophageal and (2) tracheal intubation in fresh-frozen cadavers, and to observe the size, shape and duration of any capnographic waveform.

Methods Four fresh frozen cadavers underwent oesophageal intubation by an emergency medicine specialist with confirmation by a second specialist. Hand ventilation with room air via a self-inflating resuscitation bag was provided at 12 breaths per minute for 2 min or until $ETCO_2$ was zero for 10 consecutive breaths. $ETCO_2$ and waveform morphology were examined and video recorded. The oesophagus was then extubated and the process was repeated for tracheal intubation.

Results In no case was oesophageal $ETCO_2$ detected. For two cadavers, life-like $ETCO_2$ waveforms were achieved immediately after tracheal intubation, with maximum $ETCO_2$ achieved by the second breath. In these cases waveform morphology was normal and persistent.

Conclusions Cadaveric oesophageal intubation did not result in a capnography waveform, simulating live patients. When present, $ETCO_2$ following tracheal intubation showed normal morphology which was sustained for 2 min. However, $ETCO_2$ was not present following tracheal intubation in all cadavers. These results represent instrumentation on the cadavers for the first time after thawing and further work should assess the repeatability of the findings with subsequent intubations.

INTRODUCTION

We have previously demonstrated life-like end-tidal capnography ($ETCO_2$) waveforms following tracheal intubation of two fresh-frozen cadavers.[1] This has highlighted the potential for use of cadavers in airway management simulation training. It is possible that carbon dioxide (CO_2) remains in the lungs postmortem and is liberated by artificial ventilation. Alternatively, CO_2 could be present due to formation by a postmortem tissue process or bacterial respiration in which case one might also expect it to be present in the gastrointestinal tract and detectable following oesophageal intubation. It is therefore not known whether a failed tracheal intubation resulting in cadaveric oesophageal intubation would replicate the flat capnography appearance of a live patient situation. It is also not known whether tracheal carbon dioxide would be consistently demonstrated in other cadavers. We aimed to measure end-tidal carbon dioxide levels following oesophageal and tracheal intubation in fresh-frozen cadavers, and to observe the size, shape and duration of any capnographic waveform.

METHODS

Four fresh-frozen unembalmed adult human cadavers were used, consented in life for medical research and education. The study took place at the University of Technology Sydney Surgical and Anatomical Science Facility.

All cadavers underwent oesophageal intubation with a 7.0 cuffed tracheal tube via videolaryngoscopy (King Vision, King Systems, Noblesville, Indiana, USA) by an emergency medicine specialist. Confirmation of oesophageal placement was made by a second emergency medicine specialist, who visualised the passage of a bougie into the oesophagus, prior to the railroading of a tracheal tube, on the video screen; an empty larynx was visualised by the same means. After cuff inflation with 10 mL air, the tracheal tube was connected to a self-inflating bag (Disposable Manual Resuscitator, Mayo Healthcare Pty, Sydney, Australia), with a Zoll X Series (Zoll Medical, Chelmsford, Massachusetts, USA) sidestream CO_2 detector.

The capnograph display was observed from the first breath and recorded in high-definition video using an iPhone 6 Plus (Apple, Cupertino, California, USA). The cadavers were hand-ventilated, at a rate of 12 breaths per minute, with room air until the capnometer reached zero or 2 min elapsed. If the initial $ETCO_2$ was zero, ventilation was continued for 10 breaths and then discontinued if it remained zero for 10 consecutive breaths.

The oesophagus was then extubated and the process was repeated for tracheal intubation. No facemask or supraglottic ventilation of the lungs took place prior to tracheal intubation.

Four cadavers were assessed, ranging in age at death from 65 to 92. All were frozen within 2 days of death. Six days prior to intubation they were moved to a cool room (7°C –9°C) and 3 days prior to intubation they were placed under room temperature (16°C –18°C). Further details of the cadavers are available in the online supplementary information.

Ethics

Cadaveric research is approved by the University of Technology Sydney External Advisory Board. Premortem consent includes cadaveric research undertaken at the Surgical and Anatomical Science Faculty. Video recordings were only made of the

Table 1 End-tidal capnography ($ETCO_2$) values and waveform morphology for oesophageal and tracheal intubation in four cadavers

Cadaver	Site of intubation	$ETCO_2$ initial kPa (mm Hg)	$ETCO_2$ maximum kPa (mm Hg)	No. of breaths to reach maximum	$ETCO_2$ minimum kPa (mm Hg)	Waveform morphology	Duration assessed
1	Oesophagus	0	0	1	0	N/A	10 breaths
	Trachea	1.5 (11)	6.2 (47)	2	1.5 (11)	Normal	2 min
2	Oesophagus	0	0	1	0	N/A	10 breaths
	Trachea	3.6 (27)	7.2 (55)	2	1.5 (11)	Normal	2 min
3	Oesophagus	0	0	1	0	N/A	10 breaths
	Trachea	0	0	1	0	N/A	10 breaths
4	Oesophagus	0	0	1	0	N/A	10 breaths
	Trachea	0	0	1	0	N/A	10 breaths

capnography monitor screen, ensuring no recording of any cadaveric images.

RESULTS

For all four cadavers, the initial, maximum and minimum $ETCO_2$ are shown in table 1.

In no case was oesophageal $ETCO_2$ detected.

For two cadavers, life-like $ETCO_2$ waveforms were achieved immediately after tracheal intubation, with maximum $ETCO_2$ achieved by the second breath. In these cases, waveform morphology was normal and continued to the 2 min cessation point.

Videos of the waveforms are available as online supplementary files numbers 1–8. Images of the waveforms are shown in figure 1.

DISCUSSION

Capnography is the gold standard for tracheal intubation in live humans but there is no agreed non-invasive gold standard in cadavers. We chose videolaryngoscopic visualisation of the glottis by two senior critical care physicians as the most reliable standard.

Our data show that in four fresh-frozen cadavers, initial oesophageal intubation did not result in a capnographic waveform, suggesting that carbon dioxide reservoirs are likely to be specific to lung tissue.

We have also demonstrated that tracheal intubation can result in life-like $ETCO_2$ waveforms and values, but this did not occur in all cadavers.

We have only evaluated $ETCO_2$ in the context of first intubations of the trachea and oesophagus after thawing. It is not known how subsequent intubations of either trachea or oesophagus would be represented capnographically.

It was noted during the experiment that cadaver 3 was of larger mass and appeared colder than the others, with initial difficulty in opening the mouth due to some residual freezing, and more limited chest movement during tracheal ventilation. It is therefore possible that the completeness of thawing may have influenced the results, either through chest wall or lung rigidity or decreased presence or production of CO_2.

Coats *et al* showed that tracheal $ETCO_2$ was detectable with a life-like waveform 33 hours after death in a non-frozen cadaver, and that after a decline with time the $ETCO_2$ again increased with the institution of external chest compressions, with circulatory flow confirmed by demonstration of movement of intravenous radiological contrast. After a pause in ventilation the $ETCO_2$ again rose, 'presumably due to diffusion of CO_2 down a concentration gradient created by the ventilation-induced fall in alveolar partial pressure, or ongoing bacterial activity.'[2] Chest compressions were not performed in our study, but it would have been interesting to observe whether they might have generated $ETCO_2$ in cadavers 3 and 4. However, it is important to note that Coats *et al* used non-frozen cadavers.

The demonstration of cadaveric $ETCO_2$ has implications for resuscitation education. Cadavers have an important role in airway management training, being preferred to manikins[3] and contributing to subsequent intubation success.[4] While capnography has the potential to improve the fidelity of cadaver-based simulation training in terms of specificity for tracheal intubation (no false positives), 50% of our sample gave false negatives (low sensitivity for tracheal intubation), which may limit its utility in terms of interpreting and acting upon a flat capnograph.

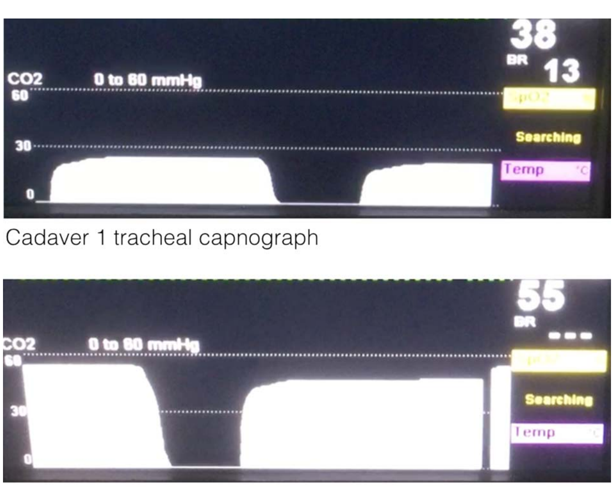
Further research should assess $ETCO_2$ in the context of repeated tracheal and oesophageal intubations, and evaluate the completeness of tissue thawing prior to $ETCO_2$ measurement.

Limitations

Adequate thawing was not confirmed as core temperature was not measured. Rather, the facility's standard thawing protocol was followed. In all cases, the oesophagus was intubated first. It is not known whether this influenced the results. Future studies might use a randomised order of tracheal versus oesophageal first intubation in a larger sample size.

CONCLUSION

Oesophageal intubation of fresh-frozen cadavers did not result in a capnography waveform, simulating live patient oesophageal intubation. However, $ETCO_2$ was not present following tracheal intubation in all cadavers. Further study should assess whether this is related to incomplete thawing.



Cadaver 1 tracheal capnograph

Cadaver 2 tracheal capnograph

Figure 1 Tracheal capnographs for cadavers 1 and 2.

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Contributors CR conceived the study and provided first draft of the manuscript. All authors contributed to manuscript revision, study design and study procedures, including intubation, data recording and video recording.

Competing interests None declared.

Ethics approval University of Technology Sydney External Advisory Board.

Provenance and peer review Not commissioned; externally peer reviewed.

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IMAGE CHALLENGE

A young woman with fever and low back pain

CLINICAL INTRODUCTION

A previously healthy, 20-year-old woman taking oral contraceptives presented to the Emergency Department (ED) with fever (body temperature, 39.2°C) and low back pain. Physical examination showed right costovertebral angle tenderness. Laboratory tests revealed elevated white blood cell count (13.2×10^9/L) and C-reactive protein level (9.75 mg/dL). Coagulation test results were unremarkable except for D-dimer level (1.5 μg/mL). Urinalysis results were normal. Abdominal CT with contrast was performed (figure 1).

QUESTION

What is the most likely diagnosis?
A. Renal infarction
B. Acute focal bacterial nephritis
C. Renal Abscess
D. Antiphospholipid syndrome

For the answer see page 346

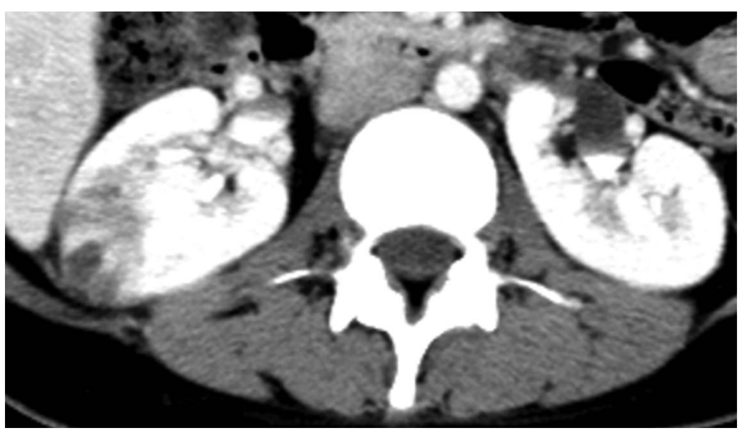

Figure 1 CT scan with contrast.