Title: THE SENSITIVITY OF END-TIDAL NITROGEN IN THE DETECTION OF BOLUS VENOUS AIR EMBOLISM IN DOGS

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Introduction. End-tidal nitrogen (ETN_2) measured by mass spectrometry (MS) has been used to quantitate bolus venous air embolism (BVAE).[1] This study was done to compare the sensitivity of ETN_2 concentration measured by MS with other clinical detection methods (precordial Doppler (PD), end-tidal CO_2 ($ETCO_2$), and mean pulmonary artery pressure (PAP)) during graded BVAE.

Methods. Five preconditioned mongrel dogs (10-17 kg) were anesthetized with IV pentobarbital 30 mgm/kg, intubated, and ventilated with a volume cycled ventilator (Engstrom 312) at an FIO_2 of 1.0 (0.04% N_2 contamination) to maintain $PaCO_2$ between 35-40 mmHg, checked prior to each VAE. Anesthesia was maintained by constant infusion of low dose thiamylal and pancuronium 0.1 mg/kg/h. Maintenance fluids were given at 5 cc/kg/h. Direct blood pressure and blood gases were obtained from a femoral arterial catheter; a pulmonary artery catheter was inserted to the wedge position and the balloon deflated. A forelimb vein was used for air injection by hand over 5 seconds. One hour of denitrogenation preceded BVAE.

Mean arterial pressure (MAP), PAP, PD, ETN_2, $ETCO_2$ (Medspec II MS) were displayed continuously on a strip chart recorder. Temperature was maintained between 36-37°C. Pressure transducers were calibrated to atmospheric pressure and a 50 mmHg fluid column. The MS was calibrated with 3 gas combinations: room air; 100% O_2; and N_2 3.5%, CO_2 5.5%, O_2 91% (factory calibrated ± 0.003%). The MS sensitivity for N_2 and CO_2 was 0.01% and 0.1% respectively. Calibration of the MS was verified at the end of the experiment and was stable. Baseline (BL) measurements were taken prior to each BVAE (.25, .5, .75, 1.0 cc/kg) and 20-30 minutes were allowed for return of all parameters to BL. In preliminary studies, these doses caused minimal changes in cardiovascular dynamics.

Following each BVAE, the time to appearance and magnitude of the initial and peak changes in ETN_2, $ETCO_2$, PAP were observed. $PaCO_2$ and PaO_2 were measured at the time of maximal depression of $ETCO_2$. Changes in MAP, PAP were measured at end-expiration. Intrapulmonary shunt and cardiac output were not measured.

The pooled standard deviation (SD) of the baseline ET (N_2 and CO_2) values was .0074% and .092% respectively. Changes in ET values after BVAE were considered significant if they exceeded BL values by 3SD. A change in PAP was considered significant if it exceeded BL by 25%. The Wilcoxon paired sample rank sum test and the t-test for paired differences were used in data analysis.

Results. Changes in the PD sounds were heard with all air doses in all animals. **ETN_2:** The peak increase in ETN_2 (Δmax) was dose-related and significant in all animals at all air doses (Table 1). The time to Δmax ETN_2 was earlier than Δmax $ETCO_2$ after all BVAEs ($p < .05$). The time to peak ETN_2 and $ETCO_2$ decreased with increasing air doses and Δmax ETN_2 was not significantly earlier than Δmax PAP (Table 2). **$ETCO_2$:** The peak decrease in $ETCO_2$ was dose-related and significant in all animals at all doses. The Δmax in $PaCO_2$ and a-$ADCO_2$ were dose-related (Table 1). The time to Δmax $ETCO_2$ was later than Δmax ETN_2 in all BVAEs (Table 2). **PAP:** The increase in PAP was significant in 2 of 5 animals at .25 cc/kg BVAE, in 4 of 5 animals at .5 cc/kg and in all animals at .75 and 1 cc/kg. The absolute increase in PAP was dose-related (Table 1). The time to Δmax PAP was intermediate compared to Δmax ETN_2 and Δmax $ETCO_2$ (Table 2).

MAP: The maximum decrease in MAP was 10% or less at all doses. The time to return to BL of all parameters was between 3 and 30 minutes and was not dose-related. PaO_2 did not change more than 10 mmHg in any animal at any BVAE dose at the time of maximum depression of $ETCO_2$. The animals were not terminated therefore there was no definitive indication that pulmonary and cardiac abnormalities were absent.

Discussion. ETN_2 is as sensitive as $ETCO_2$ in the detection of BVAE and more sensitive than PAP. Increases in ETN_2 are more often diagnostic than increases in PAP and they occur approximately 60 seconds prior to decreases in $ETCO_2$ at all air doses. The time to Δmax ETN_2 vs Δmax $ETCO_2$ is reduced with increasing air doses. The shorter the difference in time to appearance of changes in ETN_2 compared to $ETCO_2$ may support the clinical diagnosis of BVAE or large infusion VAE.

Table 1: Maximum Change (mean ± SD) from Pre-Embolism Control (BVAE)

cc/kg	.25	.50	.75	1.0
Δ ETN_2 %	.04 ± .02*	.14 ± .1*	.16 ± .09*	.26 ± .20*
Δ $ETCO_2$ %	.52 ± .16*	1.0 ± .24**	1.60 ± .35**	1.7 ± .57*
Δ PAP mmHg	2.8 ± 1.3*	5.4 ± 3.7*	9.5 ± 5.5*	14.6 ± 7.92*
Δ $PaCO_2$ mmHg	1.3 ± 1.0*	3.7 ± 2.7*	4.7 ± 1.9*	4.1 ± 3.1*
a-A D CO_2 mmHg	8.2 ± 1.6**	15.8 ± 2.5**	21.5 ± 3.2**	24.5 ± 3.9**

*p < .05 **p < .001

Table 2: Time to Δ max (mean ± SD) (seconds) (BVAE)

cc/kg	.25	.50	.75	1.0
ETN_2%	39 ± 4	37 ± 14	35 ± 3	32 ± 8
$ETCO_2$%	106 ± 39	103 ± 37	99 ± 32	95 ± 56
PAP mmHg	144 ± 120	43 ± 27	42 ± 20	57 ± 34

[1]Losee JM, Sherill D, Virtue RW, Lechner AJ: Quantitative detection of venous air embolism in the dog by mass spectrometry measurement of end-tidal nitrogen. Anesthesiol 57:A146, 1983.

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