Title: PARAMETERS AFFECTING THE OCCURRENCE OF PARADOXICAL AIR EMBOLISM
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Introduction. Paradoxical air embolism (PAE) can be a devastating complication. Twenty-seven percent of patients with no known cardiac disease have a probe patent foramen ovale (PFO) and would be at risk for PAE in the presence of venous air embolism (VAE). This study examines the incidence of PAE during VAE in pigs with a surgically created atrial septal defect (ASD) in three respiratory situations and following a volume load.

Methods. A balloon atrial septostomy was created transvenously in fifteen anesthetized pigs. Monitoring included transesophageal echocardiography (TEE) of the right and left heart, ECG, EEG, direct arterial pressure (MAP), right and left atrial pressures (RAP and LAP), pulmonary artery pressure (PAP), and pulmonary capillary wedge pressure (PCWP). With the animal in a head up tilt, air was infused at a rate of 0.27 cc/kg/min for six minutes or until PAE was identified on the TEE. Four situations were studied—intermittent positive pressure ventilation (IPPV-ZEEP), intermittent positive pressure ventilation with 30 cm water positive end-expiratory pressure (IPPV-PEEP), spontaneous ventilation, and IPPV-ZEEP following infusion of 500 ml hetastarch. All animals were autopsied and the size of the ASD measured.

Results. The incidence of PAE was not different in any of the four situations (Table). Release of PEEP resulted in an increase in the amount of PAE or new PAE in 10 of 14 animals. PAE occurred both with and without mean RAP exceeding mean LAP and the incidence of PAE was not significantly different based on the atrial pressure gradient. In situations during which the mean LAP remained greater than mean RAP throughout the venous air infusion and PAE occurred, transient reversal of right to left atrial pressure gradient during a portion of each cardiac cycle was demonstrated (Figure). The occurrence of a RAP greater than LAP in the presence of an ASD did not always result in PAE and mean LAP exceeding mean RAP throughout venous air embolism did not eliminate PAE. PCWP did not accurately reflect LAP during VAE. The mean diameter of the ASD was 0.6 mm (range 4 mm to 18 mm).

Conclusion. There was no difference in the incidence of PAE between the situations. The lack of effect of the application of PEEP on the occurrence of PAE is consistent with animal studies suggesting that PEEP does not alter the interatrial pressure gradient. This study does not support a recommendation of any one mode of ventilation for the prevention of PAE.

Bidirectional flow through a surgically created ASD in an open chest model has been demonstrated. This study demonstrates pressure gradients which might explain such bidirectional flow.

Because of the potential for right to left shunting in the presence of a higher mean LAP than RAP and because PCWP is not an accurate measure of LAP during VAE, use of LAP-RAP or PCWP-RAP gradient as a predictor of risk for PAE is not warranted. The presence of a greater LAP than RAP does not eliminate the risk of PAE.

References.
3. Pearl RG, Larson CP: Hemodynamic effects of positive end-expiratory pressure during continuous venous air embolism in the dog. Anesthesiology 64:724-729, 1986

Table: Incidence Paradoxical Air Embolism

<table>
<thead>
<tr>
<th>Method</th>
<th>Incidence</th>
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<tbody>
<tr>
<td>IPPV-ZEEP</td>
<td>11/14 (79%)</td>
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<tr>
<td>IPPV-PEEP</td>
<td>7/14 (50%)</td>
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<tr>
<td>PEEP Release</td>
<td>10/14 (71%)</td>
</tr>
<tr>
<td>Spontaneous Ventilation</td>
<td>10/15 (67%)</td>
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<tr>
<td>Volume Load</td>
<td>7/13 (54%)</td>
</tr>
</tbody>
</table>

Figure

Atrial pressure gradient reversal associated with paradoxical air embolism.