Best evidence topic - Cardiac general

In open heart surgery is there a role for the use of carbon dioxide field flooding techniques to reduce the level of post-operative gaseous emboli?

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Summary

A best evidence topic in cardiothoracic surgery was written according to a structured protocol. The question addressed was whether there is any benefit to the use of carbon dioxide (CO₂) field flooding techniques in open heart surgery in order to reduce post-operative gaseous emboli. Altogether 103 papers were found using the reported search, of which 3 presented the best evidence to answer the clinical question. The author, journal, date and country of publication, patient group studied, study type, relevant outcomes, results, and study weaknesses of these papers are tabulated. We conclude that there is no large clinical study to prove that there is a neurocognitive benefit to the use of CO₂ field flooding. However, experimental evidence shows that the solubility of CO₂ emboli justifies efforts to replace intracavitary air with CO₂ in open heart surgery to reduce gaseous emboli but that caution is warranted as use of excessive cardiotomy suction may result in hypercarbia.

Keywords: Evidence-based medicine; Cardiac surgery; Carbon dioxide field flooding; Air embolisation

1. Introduction

A best evidence topic was constructed according to a structured protocol. This protocol is fully described in the ICVTS [1].

2. Clinical scenario

You are a specialist registrar in cardiothoracic surgery attached to a new unit. Some surgeons are enthusiastic in their use of CO₂ field flooding to try to reduce air embolisation after cardiac procedures that have involved opening the heart or the aorta. Although you understand that as CO₂ is a more soluble gas than, air it would make sense that it would improve de-airing you wonder whether this has been proven to be the case.

3. Three part question

In [patients undergoing open heart surgery] can [carbon dioxide field flooding] reduce [gas embolisation]?

4. Search strategy


5. Search outcome

Using the above search 103 papers were found of which 15 were deemed to be relevant. Eleven were out of scope and 1 was rejected on the basis of poor methodology. Most of the papers out of scope concentrated on technical variations to the technique of carbon dioxide field flooding.
but did not concentrate on its clinical effect. Three papers that came closest to answering the question we asked were reviewed in full. These are listed in Table 1.

6. Results

Empirically in favour of CO$_2$ field flooding is CO$_2$’s solubility in blood in comparison to air and its weight which allows it to settle in the wound cavity. The safety of CO$_2$ has been proven by its injection directly into the aortic root in animal models. Clinically carbon dioxide field flooding was used as early as 1958 [2], though it was not adopted universally. The interest now in minimally invasive cardiac procedures where de-airing techniques are more difficult to perform has led to resurgence in the interest in and use of CO$_2$ field flooding.

Table 1
Table of best evidence papers

<table>
<thead>
<tr>
<th>Author, date, journal and country</th>
<th>Patient group</th>
<th>Study type (level of evidence)</th>
<th>Outcomes</th>
<th>Key results</th>
<th>Study weaknesses</th>
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<tbody>
<tr>
<td>Martens et al., 2001, <em>Ann Thorac Surg</em>, Germany [3]</td>
<td>62 elective patients assigned to either CO$_2$ (group I) insufflation to the thoracic cavity $N=31$ or to (group II) control group $N=31$</td>
<td>Prospective randomised controlled trial</td>
<td>Mortality</td>
<td>Group I 3% Group II 16% No significant difference</td>
<td>Small study confounded by the mismatch in risk stratification between the 2 groups</td>
</tr>
<tr>
<td>Martens et al., 2001, <em>Ann Thorac Surg</em>, Germany [5]</td>
<td>A porcine model using diffusion-weighted magnetic resonance imaging as a measure of acute brain infarction. 15 pigs injected with bolus of gas via the carotid artery</td>
<td>Experimental study in a porcine model</td>
<td>Clinical observations</td>
<td>Air ($N=5$) bradycardic 4, apnoea 5, hyperventilation 0, cardiac arrest 2. Low dose CO$_2$ ($N=5$) bradycardic 0, apnoea 0, hyperventilation 2, cardiac arrest 0. High dose CO$_2$ ($N=5$) bradycardic 2, apnoea 1, hyperventilation 1, cardiac arrest 0</td>
<td>The gas quantities injected in this animal model exceed realistic amounts of air accidentally embolising during cardiac surgery</td>
</tr>
<tr>
<td>Martens et al., 2001, <em>Ann Thorac Surg</em>, Germany [3]</td>
<td>1 ml/kg air ($N=5$)</td>
<td>Neuroradiologic results</td>
<td>Air ($N=5$) hyper intense signals ipsilateral 5, contralateral 4, persistent $&gt;25$ min 5. Low dose CO$_2$ ($N=5$) ipsilateral 3, contralateral 0, persistent $&gt;25$ min 0. High dose CO$_2$ ($N=5$) ipsilateral 5, contralateral 2, persistent $&gt;25$ min 2</td>
<td>Possible contamination with air in both carbon dioxide groups</td>
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<td>Martens et al., 2001, <em>Ann Thorac Surg</em>, Germany [3]</td>
<td>2 ml/kg carbon dioxide ($N=5$)</td>
<td>Neuroradiologic results</td>
<td>Air ($N=5$) hyper intense signals ipsilateral 5, contralateral 4, persistent $&gt;25$ min 5. Low dose CO$_2$ ($N=5$) ipsilateral 3, contralateral 0, persistent $&gt;25$ min 0. High dose CO$_2$ ($N=5$) ipsilateral 5, contralateral 2, persistent $&gt;25$ min 2</td>
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</tr>
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<th>WEBB et al., 1997, <em>Ann Thorac Surg</em>, USA [4]</th>
<th>Trans-oesophageal echocardiography studies were used to monitor the presence or air bubbles in the heart after open heart operations</th>
<th>Prospective non-randomised study</th>
<th>Trans-oesophageal appearance of air bubbles inside the heart or the aorta</th>
<th>Of the 56 patients with CO$_2$ flooding, no foam was observed at the time of cardiac contractions in 34 and in 14 additional cases all bubbles disappeared within the first minute. The remaining 8 patients had complete disappearance in 1–24 min</th>
<th>Non-randomised</th>
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After searching the literature and systematically reviewing the pertinent papers, 3 papers were finally included as the best evidence that was available on this topic. Martens et al.’s [3] prospective randomised study of CO2 insufflation to the thoracic cavity compared to conventional de-airing techniques found no statistically significant differences between the two groups in terms of mortality or neurocognitive function. Unfortunately, the study population was small and the results are confounded by the mismatch in risk stratification between the two groups. Although the mortality rates between the groups were not said to be significant, the mortality was lower in the group receiving CO2 (1 versus 5 deaths in the other group) and the number of high-risk patients was higher in this group. In addition, although the differences between groups were not said to be significant, the percentage of patients with a decline in performance was bigger in the group not receiving CO2 (16 versus 29%). Creatinine Kinase MB, however, was more elevated in the CO2 field flooding group post-operatively and 24 h after surgery. This group was a higher risk group though according to the parsonnet score and this is the likely explanation for the increased levels of Creatinine Kinase MB. Unfortunately, the study groups were definitely too small to reveal differences in mortality or in major neurologic adverse events.

Webb et al.’s [4] prospective non-randomised trial of CO2 field flooding versus normal de-airing techniques in patients undergoing valve surgery found that patients who had not had field flooding had persistent air bubbles for at least 30 min and usually for 45 min whereas the group who had CO2 field flooding had no air bubbles remaining in less than 1 min in 48 out of 56 patients. The patients in this study were not randomised to one technique or the other and the trans-oesophageal echocardiography observer was not blinded as to which technique had been used.

Martens et al.’s [5] porcine model of gas embolus and its effects on cerebral damage involves sophisticated imaging techniques and clinical observations to detect evidence of brain ischaemia induced by emboli of air or CO2. No statistical analysis is attempted within the paper though it is apparent that animals injected with air emboli had more evidence of neuroradiological brain damage and adverse clinical events. The study shows that air emboli are more detrimental than CO2 emboli, however, this is an unrealistic model of the embolic phenomena which occur during cardiac surgery with unrealistically large volumes of gasses being injected.

The use of carbon dioxide is not completely innocuous in every case. Several case reports [6,7] have mentioned the elevated blood levels of CO2 which can be reached with field flooding techniques. The high blood CO2 levels can be accompanied by a marked acidosis. Use of CO2 insufflation into the surgical field should be matched with a cautious use of cardiotomy suckers as there can be an accumulation of the gas in the venous reservoir where it can be absorbed into the blood. Webb et al. [3] measured perfusion circuit CO2 tensions and found that they were usually within normal limits, most often ranging from 36 to 50 mmHg and did not cause significant acid-base disturbance. Increased carbon dioxide tension levels correlated with intensive intracardial suctioning and quickly returned to normal when suctioning was discontinued. Martens et al. [8] conducted a study to determine the optimal technique for the delivery and amounts of CO2 which should be delivered into the operative field. They measured arterial blood gasses and found that they could deliver CO2 at up to 10 l/min without causing an increase in arterial \( P_{CO2} \) or acidosis.

### 7. Clinical bottom line

There is no large clinical study to prove that there is a neurocognitive benefit to the use of CO2 field flooding. A single small study which was inadequately powered could not detect a significant benefit to the use of CO2 field flooding but the results pointed towards a superior outcome in the treatment group and it is possible that a larger study would confirm a benefit. Despite this, we conclude that the inherent solubility of carbon dioxide emboli justifies efforts to replace intracavital air by CO2 in open heart surgery but that caution is warranted as use of excessive cardiotomy suction may result in hypercarbia, and a large clinical controlled randomised prospective study has not been conducted to prove that there is any benefit. A large clinical controlled randomised prospective study with risk stratification would be of interest, but would be difficult to undertake.

### References

Appendix A. ICVTS on-line discussion

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Message: One other study is worth mentioning, published in March 2004 Circulation [1]. (After the search timeframe in this BET). Svenarud et al. performed a prospective randomized controlled trial in 20 patients undergoing first time single valve replacement via a median sternotomy. Of note they used a gas diffuser in the sternotomy wound which they state gives a carbon dioxide environment of over 99% in the sternotomy. They found that the median number of microemboli registered during the whole study period by a blinded investigator on TOE was 161 in the CO2 group versus 723 in the control group ($P < 0.001$). Furthermore the median number of detectable microemboli after CPB fell to zero 7 minutes after CPB versus 19 minutes in the control group ($P < 0.001$). This is an important study, published in a high impact journal, that reports highly significant reductions in gaseous emboli on TOE. Of note this paper does not report the acid base status of the patients post-CBP, which remains a possible limiting factor with this technique, that has not yet been fully addressed in these clinical trials.

Reference