Jugular bulb desaturation during coronary artery surgery: a comparison of off-pump and on-pump procedures

J. C. Diephuis, K. G. M. Moons, A. N. Nierich, M. Bruens, D. van Dijk, and C. J. Kalkman

Background. Conventional coronary artery bypass surgery has been associated with cerebral injury attributed to cardiopulmonary bypass (CPB) and surgical manipulation of the ascending aorta. Off-pump coronary artery surgery avoids these factors and could prevent cerebral injury. However, moving the heart from its natural position affects the circulation and could compromise cerebral oxygenation and perfusion. We set out to compare episodes of poor global cerebral oxygenation, defined as a jugular bulb saturation less than 50%, between patients randomized to off-pump or (conventional) on-pump coronary artery surgery.

Methods. One hundred and eighty-seven patients were assigned randomly to off-pump or on-pump coronary artery surgery. Oxygen saturation in the jugular bulb ($S_{jO_2}$) was measured during revascularization of the three main coronary vessels in the off-pump group, and at the start of CPB, before rewarming, and after rewarming in the on-pump group. We compared samples with jugular bulb desaturation ($S_{jO_2} < 50\%$) between treatment groups.

Results. One hundred and seventy-five patients (81 in the off-pump group [93\%] and 94 in the on-pump group [94\%]) had complete jugular oxygen saturation data. Thirty-nine patients in the off-pump group (48\%) and 25 patients in the on-pump group (27\%) had one or more samples with desaturation during revascularization or CPB (odds ratio after adjustment for other factors, 0.39; 95\% confidence interval, 0.21–0.73, $P < 0.01$).

Conclusion. Jugular bulb desaturation occurs more frequently during off-pump coronary artery surgery than during conventional coronary artery surgery.

Keywords: surgery, coronary artery, off-pump and on-pump; veins, jugular, bulb saturation

Accepted for publication: October 22, 2004

Conventional coronary artery surgery is associated with brain injury, which has been attributed to the use of cardiopulmonary bypass and surgical manipulations of the ascending aorta.\textsuperscript{1–8} Because off-pump coronary artery surgery avoids these factors\textsuperscript{9–16} and brain emboli are less,\textsuperscript{17,18} it was expected that cerebral outcome would be better in these patients. Based on these considerations, a randomized trial (Octopus Trial) compared cognitive outcome in patients undergoing coronary artery bypass surgery (CABG) with and without cardiopulmonary bypass.\textsuperscript{19} To our surprise the cognitive outcome 3 months after surgery was only slightly better in off-pump patients and the difference at 12 months was negligible.

Off-pump procedures, in particular when the posterior wall of the heart is exposed, require movement of the heart from its natural position. This movement reduces cardiac output and arterial pressure and increases central venous pressure, because of mild right heart dysfunction. Central venous pressure is also increased by the Trendelenburg manoeuvre, which is applied to overcome the decrease in left ventricular preload.\textsuperscript{20–23} As a result, mean arterial pressure, cerebral perfusion pressure and cerebral blood flow...
flow might be diminished. Since off-pump coronary artery surgery is performed at normothermia, cerebral oxygen demand may be greater than with conventional procedures at mild hypothermia. As a consequence of both reduced flow and increased demand, global cerebral oxygenation could be compromised during off-pump coronary artery surgery.

We speculated that the lack of difference in cognitive outcome between patients undergoing on-pump and off-pump surgery might be explained by greater impairment of cerebral oxygenation in the off-pump group. We set out to compare episodes of poor global cerebral oxygenation, defined as a jugular bulb oxygen saturation less than 50%, in patients randomized to off-pump or (conventional) on-pump coronary artery surgery, with special emphasis on the period of graft placement during off-pump procedures.

Methods

Patients

All patients in this study had been enrolled in a multicentre randomized trial comparing outcomes between off-pump and conventional coronary artery bypass surgery. The design and the results of the Octopus trial have been published. Patients scheduled for first-time coronary artery surgery were randomly assigned to off-pump or on-pump CABG. Surgery was performed at three Dutch heart centres. We studied values from 202 patients whose operations were at the University Medical Centre Utrecht. In these patients intraoperative cerebral oxygenation was measured. In 15 patients (11 in the off-pump group and four in the on-pump group) measurements were not possible because equipment or personnel were not available. Hence, 187 (94%) patients were analysed: 90 patients in the off-pump group and 97 in the on-pump group. Three patients were converted from an off-pump procedure to an on-pump procedure. For the present analysis we included these patients in the on-pump group, so we compared 87 patients in the off-pump and 100 patients in the on-pump group.

Procedures

Off-pump coronary artery surgery

Anaesthetic technique was dictated by the trial protocol. Briefly, if there were no contraindications for placement of an epidural catheter, thoracic epidural anaesthesia with local anaesthetics was used, combined with light general (propofol) anaesthesia. The lungs of the patients were ventilated with a mixture of 40% oxygen in air. Ventilation was adjusted to achieve an arterial partial pressure of carbon dioxide ($P_{a\text{CO}_2}$) of 35–40 mm Hg. If thoracic epidural anaesthesia was not feasible, a total i.v. technique was used as described below for the on-pump cases. The use of vasodilators, vasopressors and inotropes was left to the discretion of the attending anaesthetist. Surgical access was through a median sternotomy in all cases in which revascularization was targeted on two or more vessels. When only the left anterior descending coronary artery was to be treated, a small anterolateral approach was used. In these cases a double-lumen tracheal tube was inserted to allow deflation of the left lung during harvesting of the left internal mammary artery and to facilitate revascularization. Regional immobilization of the cardiac wall during revascularization was achieved with the Octopus Stabilizer. All measurements during revascularization were made when conditions were judged to be sufficiently stable to complete the coronary anastomosis.

Conventional (on-pump) coronary artery surgery

A standardized anesthetic technique was used. Anaesthesia was induced with sufentanil and maintained with a continuous infusion of sufentanil and midazolam. The lungs of the patients were ventilated with a mixture of oxygen 40% in air. Ventilation was adjusted to achieve a $P_{a\text{CO}_2}$ of 35–40 mm Hg. After systemic heparinization (activated clotting time >480 s) the ascending aorta and right atrium were cannulated in all cases. The extra corporeal circuit consisted of a hollow-fibre membrane oxygenator, arterial line filter (40 µm) and a roller pump (Sarns 9000). The CPB was primed with a crystalloid-colloid mixture and the minimal nasopharyngeal temperature was maintained at 32°C. A pump flow rate of 2.4 litre m$^{-2}$ min$^{-1}$ and α-stat management were used throughout the procedure. During aortic cross-clamping, cold crystalloid cardioplegia (St Thomas solution) was used for myocardial protection. To reduce blood loss, blood was recollected using a suction cardiotomy reservoir in the CPB group, whereas a cell-saver was used in the off-pump group. Rewarming to achieve a nasopharyngeal temperature of 37°C was started when the last distal anastomosis was performed.

Outcome: jugular bulb desaturation

The primary outcome of this analysis was the incidence of episodes of jugular desaturation, defined as one or more measurements of oxygen saturation in the jugular bulb ($S_{j\text{O}_2}$) less than or equal to 50% during revascularization or CPB. For this purpose a blood sampling catheter (Hydrocath® 16 G) was inserted after induction of anaesthesia via the internal jugular vein and advanced in a retrograde direction to the jugular bulb. A lateral X-ray of the cervical spine confirmed the correct position. The position was judged to be correct if the tip of the catheter was superior to the first cervical vertebra.

We decided to use intermittent sampling of blood from the jugular bulb to measure $S_{j\text{O}_2}$ because fibre-optic measurements are cumbersome, especially during on-pump procedures when negative venous pressures often cause unreliable readings by wall artifacts. In the off-pump group measurements were performed at baseline (after induction of anaesthesia) and during revascularization of the coronary artery (right coronary artery [RCA], the left anterior descending
artery [LAD] or its diagonal branch or the obtuse marginals from the circumflex artery [RCX]). In the on-pump group measurements were performed at baseline, after starting CPB, just before rewarming and after rewarming. We considered that these sampling times best reflect the true course of $S_o2$ in both groups and were most likely to detect jugular venous samples with desaturation in both study groups.

At the same time as the jugular venous sample, we recorded mean arterial pressure and measured haemoglobin concentration, arterial oxygen saturation ($S_aO2$), nasopharyngeal temperature and $P_aCO2$. Jugular blood samples were drawn slowly (60 s) from the catheter to avoid contamination with venous blood from other veins. Because $S_o2$ is highly influenced by arterial $P_aCO2$, correction of $S_o2$ for the actual $P_aCO2$ could be applied to allow assessment of the association between type of surgery and jugular bulb desaturation, if consistent differences in $P_aCO2$ were present between the study groups.\(^{25,26}\) The arterial–cerebrovenous oxygen content difference [Δ(a–v)$O2$], expressed in ml dl\(^{-1}\), was calculated according to the formula

$$\Delta(a-\text{v})O2=Hb(\text{mmol litre}^{-1})\times1.38\times1.61\times(S_o2-S_jo2)$$

The factor of 1.61 is included to convert the haemoglobin concentration from mmol litre\(^{-1}\) to g dl\(^{-1}\).

**Statistical analysis**

We compared the incidence of desaturation in blood samples from the jugular bulb between the two treatment groups using odds ratios (OR) with 95% confidence interval (CI) and Fisher’s exact test. Adjustments for baseline differences in risk factors were made using multivariate logistic regression modelling. In the off-pump group we also compared the effect of surgical exposure between the three territories (RCA, LAD and RCX) on jugular bulb saturation.

**Results**

Baseline characteristics are shown in Table 1. There were no great differences between the two treatment groups, except that there were more patients with hypertension in the on-pump group. Eighty per cent of the patients in the off-pump group received high thoracic epidural anaesthesia with local anesthetics in combination with propofol maintenance, while anaesthesia in the remaining 20% of the patients in the off-pump group and almost all patients in the on-pump group consisted of high-dose opioids in combination with midazolam. One hundred and seventy-five patients (81 in the off-pump group [93%] and 94 in the on-pump group [94%]) had complete data for jugular oxygen saturation. In the off-pump group more patients had baseline $S_jo2$ values ≤50% after induction of anaesthesia (Table 1).

Surgical data, $S_jo2$ and $P_aCO2$ are presented in Table 2. There was a trend towards a larger number of distal anastomoses in the on-pump group, especially in the surgically more demanding territories. Partial clamping of the aorta was avoided in most patients in both groups, but more often in the off-pump group. Table 2 also shows that $P_aCO2$ was similar for the off- and on-pump groups at all intraoperative time points, whereas the corresponding $S_jo2$ value was on average higher in the on-pump group at each measurement (except at baseline).

Thirty-nine patients in the off-pump group (48%) and 25 patients in the on-pump group (27%) had one or more measurements of jugular desaturation during revascularization or CPB (OR 0.39; 95% CI 0.21–0.73; P<0.01). After
adjustment for differences in hypertension and for the number of baseline $S_{jO_2}$ measurements $\leq50\%$ (Table 1), the OR was 0.42 (95% CI 0.21–0.84).

Movement of the heart to expose the three different territories in the off-pump patients was associated with small, non-significant changes in cerebral oxygenation. Revascularization of the right coronary artery was associated with the lowest $S_{jO_2}$, and in 45% of the patients $S_{jO_2}$ was $\leq50\%$ at that time. The number of $S_{jO_2}$ measurements $\leq50\%$, the $S_{jO_2}$ values and the $(a–v)O_2$ difference were not significantly different between the three territories. Other variables were not significantly different between the three territories (Table 3).

### Discussion

We believe this is the first study reporting jugular bulb oxygenation during off-pump coronary artery surgery. We found that jugular desaturation was more frequent during off-pump CABG than during CABG with cardiopulmonary bypass.

The incidence of jugular desaturation in the on-pump group in the present study (27%) supports the results of others, even when only the 14 patients with jugular desaturation after rewarminig are considered. Croughwell and colleagues found an association between jugular desaturation and lower cerebral blood flow, higher cerebral metabolic oxygen consumption and low mean arterial pressure. They suggested that poor cerebral blood flow (autoregulation impairment) or increased metabolic demand caused jugular desaturation. They found a strong association between low $S_{jO_2}$ after rewarminig from mild hypothermic CPB and postoperative cognitive decline. In contrast, others have associated a high $S_{jO_2}$ during CPB with postoperative cognitive decline.

Investigation of a causal association between jugular bulb desaturation and cognitive outcome would have been interesting, but the design of the Octopus trial did not allow this to be addressed directly. Anesthetic techniques differed for each treatment group. Thoracic epidural anaesthesia, combined with propofol and lower opioid doses in the off-pump group, were chosen in the design of the Octopus trial, because patients randomized to off-pump procedures need less heparin. We expected that this approach would allow more rapid discharge from the intensive care unit for off-pump patients. Thus the causal relationship between differences in cognitive outcome and the occurrence of desaturation, comparing off-pump and on-pump surgery, could not be considered because of differences in anaesthetic technique.

In the off-pump group, shed mediastinal blood was washed in a cell-saver before it was returned to the patient. Activated leucocytes and fat from unwashed mediastinal blood could impair lung function and reduce $P_{aO_2}$, but this effect would only be evident after stopping CPB. If activation of the blood increased the formation of microemboli, affecting cerebral vessels, this could cause lower $S_{jO_2}$ values in the on-pump group. Fat globules reaching the brain could also reduce oxygen saturation in the jugular vein.

Stabilizing the posterior wall for revascularization of the obtuse marginals reduces stroke volume more than stabilizing the anterior or inferior wall for revascularization of the left anterior descending or the right coronary artery. However, our data suggest that shifting the heart to expose the inferior wall compromised the cerebral circulation more than surgical exposure of the other territories (although this finding was not statistically significant). This may be explained by obstruction of the venous inflow to the right ventricle when the stabilizer is placed to immobilize the territory of the right coronary artery.

There were no differences in intraoperative $P_{aO_2}$ between study groups, so we did not adjust $S_{jO_2}$ values for $P_{aCO_2}$. The different incidence of jugular bulb samples with desaturation, comparing off- and on-pump surgery, was unlikely to be caused by differences in $P_{aO_2}$. The slightly greater incidence of jugular desaturation at baseline (after induction of anaesthesia) in the off-pump group suggests an effect of propofol on jugular oxygen saturation. However, as propofol has no influence on metabolic coupling, and pressure autoregulation and carbon dioxide reactivity are preserved during low- and high-dose propofol, the differences in jugular desaturation during surgery cannot be explained solely by the use of propofol in off-pump patients. Moreover, this difference in incidence of jugular desaturation remained after correction for baseline differences in desaturation. Also, relative luxury perfusion after propofol has been reported. Only when compared with inhalation anaesthesia are jugular samples with desaturation more likely to occur during propofol anaesthesia. It seems unlikely that the more frequent incidence of jugular desaturation in the off-pump group is attributable to the use of propofol.

In conclusion, jugular bulb desaturation is more frequent during off-pump coronary artery surgery than during coronary artery surgery with cardiopulmonary bypass, after adjustment for other risk factors for jugular bulb desaturation. Since off-pump surgery has shown modest improvements in cognitive outcome, the clinical relevance of this surrogate marker for cerebral ischaemia remains to be determined.

### Table 3 Jugular samples with desaturation and other measurements at three revascularization sites in the off-pump group. Data are mean (SD). $S_{jO_2}<50\%$, percentage of jugular bulb oxygen saturation measurements $\leq50\%$; $S_{jO_2}$ jugular bulb oxygen saturation; $(a–v)O_2$, arteriojugular oxygen difference; MAP, mean arterial pressure; $P_{aCO_2}$, arterial pressure of carbon dioxide; Tnph, nasopharyngeal temperature; Hb, haemoglobin concentration.

<table>
<thead>
<tr>
<th></th>
<th>Baseline $n=87$</th>
<th>RCA $n=48$</th>
<th>LAD $n=80$</th>
<th>RCX $n=40$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_{jO_2}&lt;50%$ (%)</td>
<td>27</td>
<td>45</td>
<td>36</td>
<td>32</td>
</tr>
<tr>
<td>$S_{jO_2}$ (%)</td>
<td>58 (11)</td>
<td>55 (13)</td>
<td>57 (13)</td>
<td>59 (12)</td>
</tr>
<tr>
<td>$(a–v)O_2$ (ml O_2 per 100 ml)</td>
<td>6.7 (1.9)</td>
<td>6.6 (2.1)</td>
<td>6.2 (2.0)</td>
<td>6.1 (2.0)</td>
</tr>
<tr>
<td>MAP (mm Hg)</td>
<td>72 (13)</td>
<td>68 (12)</td>
<td>66 (12)</td>
<td>66 (12)</td>
</tr>
<tr>
<td>Hb (mmol litre$^{-1}$)</td>
<td>7.5 (0.9)</td>
<td>6.9 (1.0)</td>
<td>6.7 (1.1)</td>
<td>7.0 (0.9)</td>
</tr>
<tr>
<td>Tnph ($^\circ$C)</td>
<td>35.9 (0.4)</td>
<td>35.8 (0.9)</td>
<td>35.0 (0.6)</td>
<td>35.7 (0.7)</td>
</tr>
<tr>
<td>$P_{aCO_2}$ (mm Hg)</td>
<td>40 (5)</td>
<td>40 (6)</td>
<td>40 (5)</td>
<td>40 (6)</td>
</tr>
</tbody>
</table>
Acknowledgements

Financial support was received from the Department of Anaesthesiology, University Medical Centre Utrecht.

References


31 Doyle PW, Matta BF. Burst suppression or isoelectric encephalo gram for cerebral protection: evidence from metabolic suppression studies. Br J Anaesth 1993; 83: 580–4


34 McCulloch TJ, Visco E, Lam AM. Graded hypercapnia and cerebral autoregulation during sevoflurane or propofol anesthesia. Anesthesiology 2000; 93: 1205–9

35 Harrison JM, Girling KJ, Mahajan RP. Effects of target-controlled infusion of propofol on the transient hyperaemic response and...


37 Strebel S, Kaufmann M, Guardiola PM, Schaefer HG. Cerebral vasomotor responsiveness to carbon dioxide is preserved during propofol and midazolam anesthesia in humans. Anesth Analg 1994; 78: 884–8


