Haemodynamic effects of moderate normovolaemic haemodilution in conscious and anaesthetized patients

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Summary

We have assessed the haemodynamic effects of moderate normovolaemic haemodilution in ASA I patients, either conscious or during enflurane–fentanyl anaesthesia (10 patients in each group). Cardiac index (CI), stroke index (SI) and ejection fraction (EF) were measured by transthoracic electrical bioimpedance and, in the anaesthesia group, arterial and central venous blood samples were obtained to assess oxygen delivery ($D_{O2}$), oxygen consumption ($V_{O2}$) and oxygen extraction ratio ($O_2$ER). In conscious patients, heart rate (HR) remained unchanged as SI, EF and CI increased. When haemodilution was performed during anaesthesia, CI remained stable in spite of a slight increase in SI, as HR decreased. This produced a reduction in $D_{O2}$ which was compensated for by an increase in $O_2$ER, allowing maintenance of $V_{O2}$ without alteration in blood lactate concentration. (Br. J. Anaesth. 1996; 76: 81–84)

Key words


Patients and methods

The study was approved by the local Ethics Committee and informed consent was obtained from each patient.

CONSCIOUS PATIENTS

We studied 10 consecutive ASA I patients, aged 23–48 yr, undergoing orthopaedic surgery. Haemodilution was performed the day before surgery in unpremedicated patients. The blood volume to be withdrawn to achieve a PCV of about 30 % [2] has been shown to be relatively safe, as the decrease in arterial oxygen content is compensated for by an increase in cardiac output, maintaining oxygen delivery. The increase in cardiac output results from an increase in stroke volume rather than heart rate [3–6] and occurs in response to a decrease in blood viscosity and increased myocardial contractility [7, 8]. The reduction in blood viscosity plays a fundamental role by decreasing myocardial afterload [4] and increasing venous return [9]. In order to explain the increased myocardial contractility, an increase in sympathetic tone has been suggested [10], mediated by baroreceptors and chemoreceptors [11]. In contrast with these data obtained from studies performed under light anaesthesia [3, 5, 6], an increase in cardiac output during haemodilution does not occur during neuroleptanalgesia [12] or during enflurane–nitrous oxide anaesthesia [13]. As most anaesthetic agents decrease myocardial contractility and venous return, they might attenuate the haemodynamic response to acute haemodilution. However, these two studies were performed in elderly patients [12] or in patients with cardiovascular disease, or both [13], factors which may compromise the cardiovascular changes occurring during haemodilution.

The aim of this study was to assess the haemodynamic changes after normovolaemic haemodilution in ASA I patients, either conscious or under anaesthesia, in order to examine the effect of anaesthetic agents on the cardiovascular response.

Preoperative acute isovolaemic haemodilution is commonly used to avoid the adverse consequences of homologous blood transfusion [1]. Moderate haemodilution, defined by a decrease in packed cell volume (PCV) of approximately 30 % [2] has been shown to be relatively safe, as the decrease in arterial oxygen content is compensated for by an increase in cardiac output, maintaining oxygen delivery. The increase in cardiac output results from an increase in stroke volume rather than heart rate [3–6] and occurs in response to a decrease in blood viscosity and increased myocardial contractility [7, 8]. The reduction in blood viscosity plays a fundamental role by decreasing myocardial afterload [4] and increasing venous return [9]. In order to explain the increased myocardial contractility, an increase in sympathetic tone has been suggested [10], mediated by baroreceptors and chemoreceptors [11]. In contrast with these data obtained from studies performed under light anaesthesia [3, 5, 6], an increase in cardiac output during haemodilution does not occur during neuroleptanalgesia [12] or during enflurane–nitrous oxide anaesthesia [13]. As most anaesthetic agents decrease myocardial contractility and venous return, they might attenuate the haemodynamic response to acute haemodilution. However, these two studies were performed in elderly patients [12] or in patients with cardiovascular disease, or both [13], factors which may compromise the cardiovascular changes occurring during haemodilution.

The aim of this study was to assess the haemodynamic changes after normovolaemic haemodilution in ASA I patients, either conscious or under anaesthesia, in order to examine the effect of anaesthetic agents on the cardiovascular response.

CONSCIOUS PATIENTS

We studied 10 consecutive ASA I patients, aged 23–48 yr, undergoing orthopaedic surgery. Haemodilution was performed the day before surgery in unpremedicated patients. The blood volume to be withdrawn to achieve a PCV of about 30 % was calculated from basal PCV levels using a chart. Blood was collected into standard citrate–phosphate–glucose blood storage bags and replaced simultaneously by i.v. administration of an equal volume of dextran 60 (Hemodex). The characteristics of this colloid are: 6 % concentration, molecular weight of approximately 60 000 Da and oncotic pressure 7.46 kPa. The likelihood of an anaphylactic reaction was reduced by hapten inhibition with dextran 60 (Promit) 3 g.

PCV was measured using the micromethod (Compur M 1101, Compur Electronic GmbH, Munich, Germany) before, during and 5 min after haemodilution. Heart rate (HR) was measured from an electrocardiogram and mean arterial pressure (MAP) using an automated method (Trend BP 5000, Colin Electronics Co. Ltd, Japan). Cardiac index (CI), stroke volume index (SI) and left ventricular...
ejection fraction (EF) were measured or calculated non-invasively by transthoracic electrical bioimpedance (TEB) using the Bomed NCCOM3 with software version R-7 (Bomed Medical Manufacturing Ltd, Irvine, CA, USA). For TEB data, three recordings were averaged over the time taken to record arterial pressure. Haemodynamic variables were measured at rest, before haemodilution (T0) and 5 min after (T1).

ANAESTHETIZED PATIENTS

We studied 10 consecutive ASA I patients, aged 18–55 yr, undergoing major elective orthopaedic surgery with haemodilution. Patients received midazolam 0.1 mg kg\(^{-1}\) i.m. as premedication. Anaesthesia was induced, without preloading, with fentanyl 5 \(\mu\)g kg\(^{-1}\), thiopentone 5 mg kg\(^{-1}\) and vecuronium 0.1 mg kg\(^{-1}\), and maintained with fentanyl 0.08 \(\mu\)g kg\(^{-1}\) min\(^{-1}\) and 0.8 % enfurane. After tracheal intubation, patients’ lungs were ventilated with 50 % nitrous oxide in oxygen and tidal volume was adjusted to maintain end-tidal carbon dioxide values of 4.5 kPa.

Cannulae were inserted in a radial artery and the right internal jugular vein. Normovolaemic haemodilution was performed as described previously, after induction and insertion of the cannulae. PCV and haemodynamic variables (HR, MAP, CI, SI and EF) were measured using the same method as in the conscious group. Additionally, central venous pressure was measured and arterial and central venous blood samples obtained just before to maintain end-tidal oxygen content (\(CaO_2\)), central venous oxygen content (\(CvO_2\)) and arterial blood lactate concentration. Blood samples were analysed immediately using an automated system for blood gases (Radiometer ABL 330, Radiometer CO\(_2\), Copenhagen, Denmark). Oxygen saturation, haemoglobin (Radiometer OSM2, Radiometer CO\(_2\), Copenhagen, Denmark) and blood lactate concentrations (enzymatic method) were measured also. Oxygen delivery (\(Do_2\)), oxygen consumption (\(V\dot{O}_2\)) and oxygen extraction ratio (\(O_2\)ER) were calculated with standard formulae using central venous data instead of mixed venous measurements. Haemodynamic measurements were performed and blood samples obtained just before haemodilution (T0) and 5 min after (T1).

Table 1 Patient characteristics (mean (range or SD))

<table>
<thead>
<tr>
<th></th>
<th>Age (yr)</th>
<th>Height (m)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conscious patients</td>
<td>38 (23–48)</td>
<td>1.74 (0.11)</td>
<td>69 (14)</td>
</tr>
<tr>
<td>Anaesthetized patients</td>
<td>36 (18–55)</td>
<td>1.71 (0.07)</td>
<td>69 (11)</td>
</tr>
</tbody>
</table>

**Results**

Haemodilution was performed in three women and seven men (table 1). The mean volume of blood withdrawn was 1058 (261) ml over a period of 49 (16) min. PCV decreased from 41 (4) % at T0 to 30 (1) % at T1 (\(P < 0.05\)). After haemodilution, SI, EF and CI increased as HR and MAP remained unchanged (table 2).

STATISTICS

Data are expressed as mean (SD). Statistical analysis was performed using the Wilcoxon test. The level of significance was defined as \(P < 0.05\).

ANAESTHETIZED PATIENTS

Haemodilution was performed in three women and seven men (table 1). The mean time from induction of anaesthesia to haemodilution (T0) was 54 (5.8) min. The mean volume of blood withdrawn was 926 (294) ml over 38 (10) min. PCV decreased from 38 (3)% at T0 to 29 (2)% at T1 (\(P < 0.05\)), corresponding to a decrease in arterial haemoglobin from 12.4 (1) g 100 ml\(^{-1}\) to 9.5 (0.6) g 100 ml\(^{-1}\) (\(P < 0.05\)). After normovolaemic haemodilution, MAP and HR decreased, SI and EF increased, as CI and CVP remained unchanged (table 3). \(CaO_2\) and \(Do_2\) decreased considerably, central venous saturation (\(SvO_2\)) decreased while \(V\dot{O}_2\) did not change significantly and \(O_2\)ER increased. Blood lactate concentrations remained unchanged and \(PaO_2\) remained stable (table 4).

Discussion

We have shown that the haemodynamic effects of moderate normovolaemic haemodilution were different in conscious and anaesthetized ASA I patients. When haemodilution was performed on conscious patients, the classic haemodynamic response described previously [3–6] was observed. The significant increase in CI resulted from an increase in SI as HR remained unchanged; the increase in SI was related to the increase in EF. Conversely, when haemodilution was performed under anaesthesia, CI remained stable, in spite of a slight increase in SI, as HR decreased. This produced a reduction in \(Do_2\) compensated for by an increase in \(O_2\)ER which induced a decrease in \(SvO_2\). This metabolic response allows maintenance of \(\dot{V}O_2\) without alteration in blood lactate concentration, evidence of adequate global tissular oxygenation.

In this study, we used the non-invasive bio-

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Table 2 Haemodynamic changes after haemodilution in conscious patients. Comparison between mean arterial pressure (MAP), heart rate (HR), stroke volume index (SI), cardiac index (CI) and ejection fraction (EF), measured before (T0) and 5 min after (T1) normovolaemic haemodilution (mean (SD)). **\(P < 0.01\)

<table>
<thead>
<tr>
<th></th>
<th>MAP (mm Hg)</th>
<th>HR (beat min(^{-1}))</th>
<th>SI (ml m(^{-2}))</th>
<th>CI (litre min(^{-1}) m(^{-2}))</th>
<th>EF (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T0</td>
<td>93 (11)</td>
<td>83 (9)</td>
<td>44 (11)</td>
<td>3.6 (0.9)</td>
<td>62 (8)</td>
</tr>
<tr>
<td>T1</td>
<td>93 (12)</td>
<td>87 (11)</td>
<td>51 (11)**</td>
<td>4.5 (1.2)**</td>
<td>68 (4)**</td>
</tr>
</tbody>
</table>
Haemodynamics of haemodilution

Table 3 Haemodynamic changes after haemodilution performed under general anaesthesia. Comparison between mean arterial pressure (MAP), central venous pressure (CVP), heart rate (HR), stroke volume index (SI), cardiac index (CI) and ejection fraction (EF), measured before (T0) and 5 min after (T1) normovolaemic haemodilution (mean (sd)). *P < 0.05

<table>
<thead>
<tr>
<th></th>
<th>T0</th>
<th>T1</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAP (mm Hg)</td>
<td>38.0 (3.9)</td>
<td>34.0 (4.2)*</td>
</tr>
<tr>
<td>CVP (mm Hg)</td>
<td>4.6 (3.3)</td>
<td>4.2 (3.2)*</td>
</tr>
<tr>
<td>HR (beat min⁻¹)</td>
<td>61 (12)</td>
<td>58 (10)*</td>
</tr>
<tr>
<td>SI (ml m⁻²)</td>
<td>33 (5)</td>
<td>2 (0.4)</td>
</tr>
<tr>
<td>CI (litre min⁻¹ m⁻²)</td>
<td>34 (3)*</td>
<td>2 (0.4)</td>
</tr>
<tr>
<td>EF (%)</td>
<td>50 (7)</td>
<td>45 (7)*</td>
</tr>
</tbody>
</table>

Table 4 Effects of haemodilution performed during general anaesthesia on arterial and central venous blood gases, arterial and central venous oxygen content (\(C_{O2a}, C_{O2cv}\)) oxygen delivery (\(D_O2\)), oxygen consumption (\(\dot{V}_{O2}\)), oxygen extraction ratio (\(O_2ER\)) and arterial blood lactate concentration (lactate). Comparison between values measured before (T0) and 5 min after (T1) normovolaemic haemodilution. **P < 0.05, ***P < 0.01

<table>
<thead>
<tr>
<th></th>
<th>T0</th>
<th>T1</th>
</tr>
</thead>
<tbody>
<tr>
<td>(P_{O2}) (kPa)</td>
<td>99.5 (0.3)</td>
<td>99.5 (0.3)</td>
</tr>
<tr>
<td>(D_{O2}) (ml min⁻¹)</td>
<td>17.3 (1.4)</td>
<td>13.5 (0.9)**</td>
</tr>
<tr>
<td>(C_{O2a}) (ml 100 ml⁻¹)</td>
<td>345 (8)</td>
<td>268 (6)**</td>
</tr>
<tr>
<td>(P_{CVO2}) (kPa)</td>
<td>5.2 (0.5)</td>
<td>4.8 (0.5)*</td>
</tr>
<tr>
<td>(SC_{O2}) (%)</td>
<td>71.8 (3.8)</td>
<td>66.5 (5.9)*</td>
</tr>
<tr>
<td>(G_{CVO2}) (ml 100 ml⁻¹)</td>
<td>12.1 (1.5)</td>
<td>8.7 (4.1)**</td>
</tr>
<tr>
<td>(\dot{V}_{O2}) (ml min⁻¹)</td>
<td>102.2 (18)</td>
<td>94.3 (20)</td>
</tr>
<tr>
<td>(O_2ER) (%)</td>
<td>30.1 (5)</td>
<td>35.4 (6)*</td>
</tr>
<tr>
<td>Lactate (mmol litre⁻¹)</td>
<td>1.9 (0.7)</td>
<td>2 (0.8)</td>
</tr>
</tbody>
</table>

impedance method [14], the accuracy of which has been controversial. In critically ill patients with water and electrolyte disorders, measurement of CI by TEB lacks precision [15–17] but the technique is accurate in normal subjects and in high risk surgical patients [18–21]. Measurement of EF by the TEB method has been validated also [22]. Changes in PCV have little influence on the calculation of CI by the Sramek formula used by the Bomed NCCOM3 [17, 23]. Blood obtained from the superior vena cava was used for measurement of venous oxygen saturation. However, adequate correlation between central venous and mixed venous oxygen saturation [24–26] has been questioned recently in critically ill patients [27–29].

Our findings agree with the study of Van der Linden and colleagues where CI remained stable, in spite of a slight increase in SI, as HR decreased when haemodilution was performed during enflurane–nitrous oxide anaesthesia [13]. This results in a significant decrease in \(D_{O2}\), \(\dot{V}_{O2}\) was maintained by an increase in \(O_2ER\). The smaller increase in SI and the decrease in HR seem to be related to the inotropic and bradycardiac effects of the anaesthetic agents. Enflurane is known to have both a depressant effect on the myocardium [30, 31] and on cardiac conduction [32]. Vencuronium and thiopentone with or without fentanyl have been associated with significant bradycardia [33]. Cases where CI has failed to increase during moderate haemodilution have been described also during neuroleptanalgesia [12].

On the other hand, those studies which reported an increase in CI with maintenance of \(D_{O2}\) during haemodilution were conducted in conscious patients [34] or using low concentrations of anaesthetic agents [3, 5, 6].

The metabolic repercussions of this inadequate haemodynamic response to acute anaemia when haemodilution is performed under anaesthesia are difficult to determine. It is unlikely that a global measure such as \(D_{O2}\), \(\dot{V}_{O2}\) or blood lactate concentration can predict adequately the responses of specific tissues to decreased oxygen delivery [35]. For example, haemodilution improves the micro-circulation with more homogeneous distribution of capillary flow resulting in improvement in local oxygen supply [1]. Additionally, \(\dot{V}_{O2}\) decreases during general anaesthesia. The myocardium is one of the principal organs at risk during haemodilution as \(O_2ER\) exceeds 50 %; nevertheless, haemodilution is tolerated well in patients with coronary disease [4, 36, 37]. However, if oxygen demand increases, the magnitude of haemodilution may be inappropriate, which explains the higher incidence of postoperative cardiac ischaemia in atherosclerotic patients when PCV is less than 29 % [38]. The major problem is during the recovery period when oxygen demand increases. A critical level of haemodilution is therefore difficult to define, particularly in patients with coronary artery disease [35, 39, 40].

In summary, we found that haemodynamic response to moderate normovolaemic haemodilution was impaired in ASA I patients during enflurane–fentanyl anaesthesia. \(\dot{V}_{O2}\) was maintained by a corresponding increase in \(O_2ER\). In high-risk patients this metabolic adaptation may be inadequate, resulting in a \(\dot{V}_{O2}\) which is dependent on oxygen supply thus leading to local tissue ischaemia.

References


