Haemodynamic and metabolic response to endovascular repair of infra-renal aortic aneurysms


Summary

We have examined whether or not endovascular insertion of a bifurcated aorto-iliac graft resulted in greater intraoperative haemodynamic and metabolic stability than that achieved during conventional open graft placement. We studied 20 patients prospectively during surgery for asymptomatic infra-renal aortic aneurysm. All patients received the same anaesthetic technique. Haemodynamic data were collected continuously using indwelling radial artery and pulmonary artery catheters, allowing calculation of mean arterial pressure (MAP), cardiac output (CO) and systemic vascular resistance (SVR). Blood samples were obtained for measurement of serum lactate concentrations. Variables were compared within each group before and after specific critical events, namely occlusion of femoral or aortic blood flow, or both, and sequential reperfusion of each lower limb. Patients undergoing open repair showed significant changes in CO, MAP and SVR related to aortic cross-clamping and lower limb reperfusion, and a significant increase in blood lactate concentration after distal tissue reperfusion. The only significant changes during endovascular repair were a transient increase in SVR secondary to application of the femoral artery clamps, and sequential decreases when each limb was reperfused. Endovascular aneurysm repair imposed significantly less intraoperative haemodynamic and metabolic stress on the patient compared with conventional open surgery. (Br. J. Anaesth. 1996; 77: 581–585)

Key words

Elective repair of abdominal aortic aneurysms (AAA) by conventional surgery is associated with a mortality of 5–10 %, although particular factors such as age and extent of co-existing systemic disease may place patients at much greater risk, even to the extent of denying them surgery. Myocardial infarction (MI) is responsible for 40–70 % of this mortality,1 with infarction within the 6 months preceding surgery and the presence of congestive cardiac failure representing the two most consistent preoperative predictors of perioperative cardiac morbidity. Endovascular repair of AAA is a technique developed to allow exclusion of the aneurysm from the circulation by means of a transfemoral approach. Early experiences with endovascular graft insertion have been reported from Nottingham and other centres.2–4 This technique offers several potential advantages over conventional (open) repair, including a surgical approach via groin incisions rather than laparotomy, avoidance of retroperitoneal dissection and a much briefer period of abrupt aortic occlusion during placement of the graft. These theoretical advantages are likely to be of benefit to the patient only if they are accompanied by a reduction in the haemodynamic and metabolic stresses imposed by surgery, although the association between these intraoperative improvements and a reduction in postoperative morbidity and mortality may only become apparent by studying large numbers of patients.

We have compared specific intraoperative haemodynamic and metabolic variables in two groups of patients undergoing repair of infra-renal AAA by either open or endovascular surgical techniques.

Patients and methods

After obtaining approval from the hospital Ethics Committee, we studied 20 consecutive adult patients undergoing repair of an infra-renal AAA. Ten patients were selected for insertion of a bifurcated “Chuter” graft by the endovascular technique (endovascular group), with the other 10 patients undergoing conventional graft insertion (open group). Selection into the endovascular group was based primarily on radiographic criteria using calibrated aortic angiography and spiral computed tomograms.5 This was to ensure that the aneurysm morphology was suitable for the technique, that is a maximum aneurysm proximal neck diameter of 2.5 cm and common iliac diameter of 1.5 cm, minimum
neck length of 1.5 cm from the origin of the more
distal renal artery and relatively non-tortuous iliac
artery to permit introduction of the 22-Fr delivery
system. Preoperative assessment was standard in
both groups, including height, weight, cardiac and
pulmonary function and risk factors, hepatic and
renal function, and diabetic status. All patients
underwent transthoracic echocardiography and
spirometry, and had measurement of arterial blood-
gas tensions while breathing room air.

All patients were premedicated with temazepam
20 mg orally. A standard anaesthetic technique was
used for both groups: i.v. induction with etomidate
0.3 mg kg⁻¹, maintenance with isoflurane and 66 %
nitrous oxide in oxygen, vecuronium to facilitate
traumatic intubation and subsequent ventilation of the
lungs, and repeated increments of fentanyl 1–3 µg
kg⁻¹ for analgesia. No regional anaesthetic tech-
nique was used during the intraoperative period.
Monitoring included continuous 5-lead electrocar-
diogram with ST-segment analysis on lead II, and
continuous inspired and expired gas analysis for
measurement of oxygen, nitrous oxide, carbon
dioxide and isoflurane concentrations. Direct con-
tinuous measurement of arterial pressure was under-
taken via a radial artery cannula, and a pulmonary
artery catheter was sited to measure central venous
and pulmonary artery wedge pressures. Cardiac
output (CO) and systemic vascular resistance (SVR)
were calculated at 30-s intervals and displayed on a
Baxter Vigilance Monitor (Model VMS) attached to
the pulmonary artery catheter.

For the endovascular procedure both common
femoral arteries were exposed and heparin 10 000 u.
administered i.v. before making bilateral arteri-
otomies to gain access to the lumen. At this stage both
femoral arteries were cross-clamped. A transfemoral
catheter was introduced from the left femoral artery and
pulled out of the right femoral arteriotomy with
the assistance of a stone retrieval basket. The
delivery system comprising an inner shaft and an
outer sheath containing the graft and stent was intro-
duced via the right femoral arteriotomy. Particular
care was required in deploying the top stent between
the renal artery and the aneurysm neck, which was
achieved by withdrawing the outer sheath while the
inner shaft was stabilized in the correct position
assessed by angiographic screening. Complete with-
drawal of the outer sheath exposed a catheter
attached to the left limb of the graft, which was sub-
sequently sutured to the transfemoral catheter. The
left graft limb was guided into the left iliac artery as
the transfemoral catheter was withdrawn out of the
left femoral arteriotomy. After deployment of both
graft limbs, Wallstents (Schneider Ltd) were used to
provide additional support. At this stage the femoral
artery cross-clamps were removed sequentially and
haemostasis secured.

Intravascular volume was supplemented if
required with 0.9% sodium chloride solution and
modified 4% gelatin solution, volumes administered
being guided by reference to the pulmonary artery
wedge pressure. If estimated blood loss exceeded
20% of the calculated blood volume, red cell prepa-
rations were transfused to replace further losses.
Neither group received i.v. mannitol, dopamine or
any specific vasoconstrictors, vasodilators or other
inotropic support during surgery. The endovascular
group received 300–500 ml of non-ionic contrast
medium during surgery to allow digital subtraction
imaging which ensured accurate deployment of the
prosthesis.

Baseline haemodynamic values were obtained
after general anaesthesia had been established,
before any surgical intervention. Haemodynamic
data were collected also throughout surgery with
particular reference to a number of critical events:

<table>
<thead>
<tr>
<th>Table 1: Patient data (mean (range) or number of patients)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
</tr>
<tr>
<td>Weight (kg)</td>
</tr>
<tr>
<td>Sex (M/F)</td>
</tr>
<tr>
<td>Cardiovascular pathology (see below)</td>
</tr>
<tr>
<td>Respiratory pathology</td>
</tr>
<tr>
<td>Renal impairment (serum creatinine &gt; 150 µmol litre⁻¹)</td>
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</tbody>
</table>

**Cardiovascular pathology** (Goldman’s risk factors in bold)¹⁵

Each patient is listed numerically. Concurrent cardiovascular medication is shown in parentheses

**Open group**

1. **Echocardiograph:** segmental wall dyskinesia, but overall, left ventricular function reasonable

2. **Paroxysmal supraventricular tachycardia** (flecainide)

3. **Coronary artery bypass grafts (CABG) 3 months previously**

4. **Hypertension** (atenolol)

**Endovascular group**

1. **Atrial fibrillation (AF), hypertension, CABG 3 years previously** (atenolol)

2. **AF, controlled congestive cardiac failure (CCF),** myocardial infarct (MI) 3 years previously, angina, hypertension (isosorbide mononitrate (ISMN), diltiazem, GTN patch, enalapril, frusemide)

3. **MI 1 year previously, angina, echocardiograph:** segmental wall dyskinesia, but overall left ventricular function good (ISMN, nifedipine, atenolol)

4. **Hypertension** (atenolol)

5. **MI 5 years, hypertension** (atenolol)

6. **Hypertension** (nifedipine)
and after aortic occlusion, and before and after reperfusion of the first and then the second limb. Blood lactate concentrations were measured in both groups at the same times, with samples obtained in sodium fluoride/potassium oxalate bottles and refrigerated until analysis. Haemodynamic variables and blood lactate concentrations were compared within each group during the course of surgery using ANOVA and Student’s paired \( t \) test \((P < 0.05)\). Comparison of blood lactate concentrations was also made between the groups using the Student’s unpaired \( t \) test \((P < 0.05)\).

## Results

Patient data for the two groups are summarized in table 1. Details of the duration of surgery, aortic occlusion time, femoral artery clamp time and blood loss are shown in table 2. No patient in the endovascular group required conversion of the technique to an open procedure.

Changes in haemodynamic variables during surgery are shown in figures 1–3. On cross-clamping of the aorta in the open group, there were significant decreases in MAP from 115 (94–166) mm Hg, and SVR from 2280 (196) to 2485 (240) dyn s cm\(^{-1}\) related to occlusion of blood flow through both femoral arteries. Femoral artery occlusion did not result in significant changes in MAP or CO.

On reperfusing the first limb, the open group demonstrated significant decreases in MAP from 89 (4) to 61 (3) mm Hg, and SVR from 2327 (146) to 1686 (153) dyn s cm\(^{-1}\), without significant changes in CO. Reperfusion of the second limb caused a further significant decrease in SVR from 1919 (182) to 1586 (152) dyn s cm\(^{-1}\), while MAP and CO remained relatively stable. The only significant changes in the endovascular group were a decrease in SVR from 2104 (167) to 2160 (184) dyn s cm\(^{-1}\) when reperfusing the first limb, with a more marked decrease in SVR from 2039 (227) to 1673 (209) dyn s cm\(^{-1}\) when the second limb was reperfused. Blood lactate concentrations did not change significantly in either group before reperfusion of distal tissue (fig. 4).

Two patients in the open group had episodes of fast atrial fibrillation (ventricular response greater than 120 beat min\(^{-1}\)) in the first 24-h postoperative period, each requiring pharmacological intervention. There was no significant cardiac morbidity in the first 30 days after operation in the endovascular group.

### Table 1

<table>
<thead>
<tr>
<th>Duration of surgery (min)</th>
<th>Open group</th>
<th>Endovascular group</th>
<th>(P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>First limb</td>
<td>52.1 (40–80)</td>
<td>112.5 (85–160)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Second limb</td>
<td>73.5 (53–100)</td>
<td>119.5 (94–166)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Blood loss (ml)</td>
<td>1403 (680–2400)</td>
<td>515 (300–750)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Fluids administered (ml)</td>
<td>Crystallid 2200 (2000–3000)</td>
<td>1690 (1500–2000)</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>Colloid 950 (500–1000)</td>
<td>550 (0–1000)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>Red cell preparations 1190 (0–2800)</td>
<td>245 (0–1050)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Contrast media Nil</td>
<td>350 (300–500)</td>
<td></td>
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</table>

### Table 2

<table>
<thead>
<tr>
<th>Intraoperative details (mean (range)). Data were compared between groups using the unpaired Student’s ( t ) test. *Open group: time from placement of the aortic cross-clamp until subsequent reperfusion via each femoral artery clamp; endovascular group: time from placement of each femoral artery clamp until its subsequent release after placement of each femoral artery clamp. **Open group: time from placement of the aortic cross-clamp until subsequent reperfusion via each femoral artery clamp; endovascular group: time from placement of each femoral artery clamp until its subsequent release after prosthetic graft insertion.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration of surgery (min)</td>
</tr>
<tr>
<td>----------------------------</td>
</tr>
<tr>
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### Figure 1

Intraoperative changes (mean, SEM) in mean arterial pressure (MAP) in the open (○) and endovascular (●) groups. Point A = baseline value for each group; A = before and after femoral artery clamping (no data point before A in the open group); C = D = before and after aortic flow occlusion; E = F = before and after reperfusion of the first limb; G = H = before and after reperfusion of the second limb. * \(P < 0.05\) compared with previous datum point (“within-group comparison” using paired Student’s \( t \) test).

### Figure 2

Intraoperative changes (mean, SEM) in cardiac output (CO) in the open (○) and endovascular (●) groups. Legend and X axis categories are the same as in figure 1.
groups. Legend and X axis categories are the same as in figure 1.

**Discussion**

We have demonstrated that endovascular exclusion of infra-renal AAA is associated with fewer acute haemodynamic and metabolic changes in the intraoperative period compared with conventional surgery. Cardiovascular and metabolic variables are known to alter significantly during open repair because of abrupt occlusion of blood flow via the aorta caused by cross-clamping, and again when perfusion to the distal tissues is re-established.

Previous studies examining the haemodynamic changes during open repair of AAA have identified aortic cross-clamping as one of the critical intraoperative events, producing up to a 35% decrease in cardiac index and stroke volume, a significant increase in MAP, and a 40% increase in SVR. Similar changes were observed in patients in our open group, with SVR increasing by nearly 11%, MAP increasing by 19% and CO decreasing by 21%. The equivalent stage of surgery in the endovascular group was taken to be during deployment of the proximal end of the graft and stent within the aorta. This produced occlusion to aortic flow until the ipsilateral leg was re-opened, but this period of complete occlusion lasted for a mean of 9.2 min, significantly less than the 32.1 min during open procedures.

Patients in the endovascular group showed greater haemodynamic stability during this period, with predictable but non-significant changes in all variables measured. Several reasons for this may be suggested, in addition to reduction in complete occlusion time. The action of aortic occlusion may have been associated with less notable changes in cardiac output because these patients had already been subjected to prior application of bilateral femoral artery clamps, after which a 22-Fr delivery system was present constantly within the distal aorta and common iliac artery, producing an increase in resistance to blood flow. At the time of proximal graft/stent deployment, we conclude that the endovascular technique resulted in a less profound increase in myocardial afterload and a less marked reduction in preload, both of which have been implicated in the changes seen with aortic cross-clamping during conventional surgery.

Patients in the endovascular group showed a significant increase in SVR secondary to femoral artery clamping during the initial stage of surgery. Although there was an associated decrease in CO and increase in MAP, neither change was statistically significant. Subsequent to femoral artery clamping, an angiographic catheter was introduced to allow intraoperative identification of the aneurysm morphology. During this stage SVR returned to baseline values, implying that femoral artery clamping produced a transient effect on the haemodynamic profile, which was relatively non-significant in clinical terms. After positioning the angiographic catheter, the wide-bore co-axial delivery system containing the graft and stents was introduced unilaterally via the femoral and common iliac artery and fed into the aorta beyond the neck of the aneurysm. This stayed in place until the prosthesis was ready for deployment. No significant haemodynamic disturbance resulted from this procedure. No comparative data from the open group were available during this period because of the differences in surgical technique.

Re-establishment of blood flow to tissues distal to an arterial clamp site has two effects: first, decrease in SVR as a result of perfusion of a maximally vasodilated vascular bed; second, return to the circulation of vasoactive metabolic products which have accumulated within the ischaemic tissue. Patients undergoing conventional surgery in our study demonstrated marked haemodynamic changes when the distal tissues were reperfused. Re-establishment of blood flow through the first graft limb produced significant decreases in MAP and SVR, with a further decrease in SVR when the second limb was reperfused. Cardiac output increased during these events, although this was not significant, presumably to compensate to some degree because of maintenance of an adequate left ventricular preload during this period. There was a marked increase in blood lactate concentration in the open group on reperfusion of each limb; reperfusion of the second limb resulted in a 114% increase compared with the baseline value.

In contrast, patients in the endovascular group showed a small but significant decrease in SVR after release of the first femoral clamp, but with rapid recovery towards the pre-release value. A more marked decrease was apparent on release of the second clamp. Each occasion was associated with non-significant changes in MAP and CO. These results suggest that sequential reperfusion via each femoral artery re-opens a vascular compartment.
sufficient to decrease afterload significantly, but the patient is able to compensate by modest changes in CO₂, so preventing a clinically significant alteration in MAP. The endovascular group demonstrated no changes in blood lactate concentrations throughout surgery, implying that any “ischaemic” period did not cause a significant metabolic insult from imposed anaerobic metabolism. We suggest that the differences between the two groups related to reperfusion occurred because although the open group had apparently been subjected to a shorter overall period of tissue ischaemia, the quantity and location of tissue rendered ischaemic was significantly different. The endovascular technique used bilateral femoral artery clamps for the majority of surgery, but blood flow through internal iliac and deep femoral collaterals would have continued during this period of arterial clamping.

Haemodynamic stability during endovascular aortic surgery demonstrated in this study represents a potential improvement for patients requiring aortic aneurysm surgery. A significant proportion of this patient population have associated cardiovascular disease, notably previous myocardial infarction (40–50%), congestive cardiac failure (10–15%), ischaemic heart disease (20–30%) or hypertension (50–60%). Although debate continues on the combination of preoperative factors associated most reliably with perioperative cardiac morbidity or mortality, it seems reasonable to suggest that a more stable intraoperative haemodynamic profile without evidence of ischaemic metabolic insult may be beneficial during surgery of this type. The Chuter graft/stent system used in this study uses self-expanding modified Gianturco Z-stents, and requires neither deliberate haemodynamic manipulation by the anaesthetist nor balloon inflation at the time of proximal graft fixation, in contrast with other endovascular systems. Although the association between improved intraoperative haemodynamic stability and a reduction in significant perioperative cardiac events is intuitive, this study and others to date include insufficient numbers to make firm conclusions. This will rely on larger scale, prospective, date include insufficient numbers to make firm conclusions. It afterload significantly, but the patient is able to compensate by modest changes in CO₂, so preventing a clinically significant alteration in MAP. The endovascular group demonstrated no changes in blood lactate concentrations throughout surgery, implying that any “ischaemic” period did not cause a significant metabolic insult from imposed anaerobic metabolism. We suggest that the differences between the two groups related to reperfusion occurred because although the open group had apparently been subjected to a shorter overall period of tissue ischaemia, the quantity and location of tissue rendered ischaemic was significantly different. The endovascular technique used bilateral femoral artery clamps for the majority of surgery, but blood flow through internal iliac and deep femoral collaterals would have continued during this period of arterial clamping.

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References


