Intraoperative Monitoring of Penile and Buttock Blood Flow During Endovascular Abdominal Aortic Aneurysm Repair


Second Department of Surgery, Hamamatsu University School of Medicine, 1-20-1 Handayama, Hamamatsu, Shizuoka 431-3192, Japan

Objective. The purpose of this study was to assess the pelvic circulation during endovascular abdominal aortic aneurysm repair (EVAR) with a new monitoring system measuring penile and buttock blood flow.

Methods. We measured penile brachial pressure index (PBI) during EVAR by pulse-volume-plethysmography (PWV/ABI™). We also measured bilateral gluteal tissue oxygen metabolism with near-infrared spectroscopy to provide a gluteal tissue oxygenation index (TOI). Twenty-two men who underwent aortouni-iliac stent graft with crossover bypass for exclusion of abdominal aortic aneurysm were studied. Twelve patients underwent aorto-uni-common iliac artery stent graft (CIA) and ten underwent aorto-uni-external iliac artery stent graft (EIA).

Results. In all patients, there was an immediate reduction in PBI during the EVAR procedure. After revascularization of the ipsilateral limb of the stent graft, the recovery of PBI was significantly less in EIA group. After the completion of crossover bypass, PBI in both groups recovered to the baseline values. In both groups there was a bilateral reduction in gluteal TOI during malperfusion of the internal iliac artery. After revascularization of ipsilateral limb of the stent graft, the ipsilateral TOI recovered to the baseline level in CIA patients, but recovery was incomplete in EIA patients. In contrast, contra-lateral TOI remained low in both groups after revascularization of ipsilateral limb of the stent graft. Only after completion of crossover bypass did the contra-lateral TOI recover to baseline level in both groups.

Conclusions. Both TOI at the buttocks and PBI are a sensitive reflection of pelvic haemodynamics. Penile blood flow and bilateral gluteal blood flow are supplied via different circulations and both should be monitored for full assessment of the pelvic circulation.

Keywords: Abdominal aortic aneurysm; Stent graft; Internal iliac artery; Impotence; Penile pressure; Near-infrared spectroscopy.

Introduction

The internal iliac artery (IIA) and inferior mesenteric artery (IMA) often are occluded as an adjunct to endovascular abdominal aortic aneurysm (AAA) repair (EVAR) and this can cause pelvic ischaemic morbidity, such as vascular impotence, buttock claudication, and bowel ischaemia.1–7 For those with bilateral common iliac artery (CIA) aneurysms (CIAA), open surgery with reconstruction of the IIA is recommended to preserve pelvic circulation.18–20 Recently, endovascular alternatives such as external iliac artery (EIA)-IIA bypass or endograft in combination with a contra-lateral aortouni-iliac stentgraft have been proposed.1–7 During open repair of aorto-iliac aneurysm, various studies such as measurement of stump pressure in the IIA, assessment of intestinal viability by Doppler ultrasound, or intramural oxygen saturation in the colon have been proposed to aid the intra-operative decision about IIA reconstruction.21–24 However, no such monitoring is available during EVAR.

This study tested a new monitoring system to assess the pelvic circulation, which can be applied during EVAR in the operating theatre. We focused on gluteal and penile blood flow, because tissue in both areas is supplied from the IIA and malperfusion will cause buttock claudication or vascular impotence. We monitored penile blood flow by the oscillometric technique and measured gluteal tissue oxygen metabolism with near-infrared spectroscopy (NIRS) before, during and after EVAR.
Materials and Methods

Patients

Between September 2003 and July 2005, 30 patients with aortic and aorto-iliac aneurysms underwent elective EVAR at our department. Among them, 28 patients were monitored for penile and gluteal blood flow. Prior to the entry into the study each patient was informed fully of the nature, the aim and expected and possible side effects of this study, with informed consent obtained from all participating patients. All patients underwent preoperative contrast-enhanced spiral computed tomography. Twenty-two men (mean age 78.7 ± 5.9 years) were selected for this study, since they did not have evidence of peripheral artery occlusive disease and patent bilateral IIAs and IMA were confirmed on angiogram. Maximum aortic diameter ranged from 4.5 to 7.1 cm (mean 5.8 ± 0.8 cm). This series included six patients with unilateral CIAA. The Japanese government has not yet approved the import of commercial endovascular grafts. Therefore, custom-made aortouni-iliac stent grafting, with crossover bypass, was performed under general anesthesia in all patients. The stent graft comprised a Gianturco Z-stent (Cook Inc., Bloomington, IN, USA) and a spiral Z-stent (Medico’s Hirata Inc., Osaka, Japan) being tapered and sutured to woven polyester graft (UBE Corp., Ichihara, Japan). The stent graft was delivered via a 22 Fr sheath (Medikit Co., Ltd, Hyuga, Japan). The crossover bypass was performed using 8 mm knitted Dacron graft (Vascutek Gelsoft ERS™; Vascutek, Ltd, Renfrewshire Scotland, UK). Aorto-uni-CIA stent graft was deployed in twelve patients (group CIA). Aorto-uni-EIA stent graft was deployed in ten patients (group EIA), in which the ipsilateral IIA was embolized at its proximal site with a coil in six patients with ipsilateral CIAA, while four patients had unexpected EIA landing of the stent graft. Since there was no aneurysm in the any of these patients, coil embolization of the CIA was performed to prevent retrograde flow from the crossover bypass. In all patients, the contra-lateral IIA was preserved.

Monitoring of penile blood flow during EVAR

To assess penile blood flow, penile blood pressure (PBP) was repeatedly measured with an oscillometric cuff placed on the patient’s penis. The penile brachial pressure index (PBI: as the ratio of PBP divided by brachial systolic blood pressure) was automatically calculated with the recently developed device Form PWV/ABI (Colin Medical Technology, Ltd, Komaki, Japan). Form PWV/ABI™ and its small air cuff originally were designed for measurement of toe blood pressure. The cuffs were connected to a plethysmographic sensor that determined volume pulse details and an oscillometric pressure sensor. We have previously demonstrated that the PBI values obtained by the device significantly correlated with the data obtained by Doppler ultrasound measurement. Preliminary measurement also demonstrated that the Foley catheter in the urethra did not affect the data (data not shown). With this method, we could repeatedly measure PBI without manual manipulation during EVAR. To evaluate the reproducibility of PBI measurement, PBI in ten patients without vascular diseases was measured twice: the coefficient of variation and correlation coefficient were 10.9% and 0.95, respectively.

Monitoring of bilateral gluteal flow during EVAR

We assessed gluteal blood flow using two NIRS probes positioned on each side of the buttocks. NIRS is a noninvasive light-based technique that can assess tissue oxygen metabolism. The NIRS instrument, NIRO-300 (Hamamatsu Photonics KK, Hamamatsu, Japan) was used in this study. We monitored tissue oxygenation index (TOI), which was calculated as a ratio of oxygenated hemoglobin to total hemoglobin in tissue. Because TOI is a relative value at the buttock, it was expressed as percent changes compared to the baseline values at the starting time-point. To distinguish each side of the buttocks, we defined the side ipsilateral to the aortouni-iliac stentgraft as Ips-side and the contra-lateral side as cont-side.

Monitoring time point of pelvic hemodynamics during EVAR

We recorded data at the following five time points (Fig. 1).

A The start of the operation.
B Five minutes after stent graft deployment. The delivery sheath was still inside the iliac artery just distal to the stent graft. Bilateral IIAs flow was blocked in group EIA, while some amount of ipsilateral IIa flow existed in group CIA (because the delivery sheath system did not cover completely the IIA orifice).
C Five minutes after the completion of proximal anastomosis of crossover bypass and revascularization of the ipsilateral limb. Ipsilateral IIA flow recovered in group CIA, while bilateral IIAs flow remained occluded in group EIA.

D Five minutes after completing distal anastomosis of the crossover bypass and revascularization of the contra-lateral limb. The contra-lateral CIA was embolized before the anastomosis. At this time point, bilateral IIA flow was maintained in group CIA, while only contra-lateral IIA flow was maintained in group EIA.

E End of surgery.

Statistical analysis

Patients’ demographics and surgical parameters were expressed as the mean ± SD, while PBI and TOI data are expressed as the mean ± SE. Student’s t-test was used to assess patients’ demographics as well as surgical parameters between group CIA and group EIA. One way analysis of variance (ANOVA) followed by Tukey’s test was performed to test the differences in the mean values of PBI and TOI between group CIA and group EIA. For the comparison of PBI or TOI at different time points within each group was analyzed by repeated-measures ANOVA. \( p < 0.05 \) was considered significant.

Results

There was no significant difference in patient demographics and peri-operative parameters between patients who underwent aorto-uni-CIA stentgraft (group CIA) and aorto-uni-EIA stentgraft (group EIA). In group CIA and group EIA, seven and five patients, respectively, had erectile dysfunction pre-operatively (Table 1). Those patients remained impotent postoperatively. No other patient developed postoperative erectile dysfunction. No patients complained of buttock claudication postoperatively.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Group CIA</th>
<th>Group EIA</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>12</td>
<td>10</td>
<td>( p )</td>
</tr>
<tr>
<td>Age (year)</td>
<td>80.6 ± 5.4</td>
<td>76.5 ± 5.7</td>
<td>NS</td>
</tr>
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<td>Maximum aortic diameter (cm)</td>
<td>5.7 ± 0.7</td>
<td>5.9 ± 0.9</td>
<td>NS</td>
</tr>
<tr>
<td>Erectile dysfunction before surgery</td>
<td>7</td>
<td>5</td>
<td>NS</td>
</tr>
<tr>
<td>Buttock claudication after surgery</td>
<td>0</td>
<td>0</td>
<td>NS</td>
</tr>
<tr>
<td>Operation time (min)</td>
<td>227.9 ± 42.2</td>
<td>245.7 ± 42.8</td>
<td>NS</td>
</tr>
<tr>
<td>Blood loss (ml)</td>
<td>346.9 ± 234.7</td>
<td>429.0 ± 232.1</td>
<td>NS</td>
</tr>
<tr>
<td>Intraoperative ( \text{PaO}_2 ) (mmHg)</td>
<td>257.9 ± 32.5</td>
<td>209.3 ± 51.0</td>
<td>NS</td>
</tr>
</tbody>
</table>

NS, not significant; \( \text{PaO}_2 \), partial pressure of arterial oxygen.
Monitoring of penile blood flow

At the start of surgery (time point A), there was no significant difference in PBI between patients in group CIA and group EIA (0.83 $\pm$ 0.04 and 0.86 $\pm$ 0.03, respectively, $p=0.62$) (Fig. 2). At time point B, PBI in both groups significantly decreased to 0.42 $\pm$ 0.07 and 0.17 $\pm$ 0.07 (group CIA and group EIA, respectively, $p<0.001$). PBI in group EIA was significantly lower than that in group CIA ($p=0.017$). At time point C, PBI recovered in both groups to 0.76 $\pm$ 0.04 and 0.38 $\pm$ 0.07 (group CIA and group EIA, $p=0.35$ and $p<0.001$, respectively). The PBI in group CIA at this time point was still significantly higher than that in group EIA ($p<0.001$). At time points D and E, the PBI in both groups had recovered to the baseline values (time point A).

Monitoring of bilateral gluteal flow during EVAR

Group CIA (Fig. 3(A))

At time point B, gluteal TOI decreased sharply from the baseline values on both sides ($p<0.001$). However, the fall of TOI on the Ips-side (the ipsilateral side of aorto-uni-CIA stentgraft) was greater than cont-side (the contralateral side of the stentgraft) TOI (-9.18 $\pm$ 2.93 and -20.79 $\pm$ 3.90%, Ips-side and Cont-side, respectively, $p=0.026$). At time point C, Ips-side TOI recovered to the baseline value ($p=0.56$), while Cont-side TOI remained low (-14.61 $\pm$ 3.58%, $p<0.001$ versus baseline). At time points D and E, TOI had returned to near baseline values bilaterally.

Group EIA (Fig. 3(B))

At time point B, bilateral TOI decreased to almost 65% of the baseline values, $p<0.001$. Then, at time point C, revascularization of the ipsilateral limb increased TOI on the Ips-side, while the Cont-side TOI remained low (-13.02 $\pm$ 3.43 and -30.56 $\pm$ 6.73%, $p=0.014$ and $p<0.001$, respectively). After completion of crossover bypass (time points D and E), TOI returned to the baseline values bilaterally.

Discussion

To evaluate pelvic circulation with this monitoring system, we selected AAA patients, with or without CIAA, in which bilateral IIAs and IMA were confirmed patent on preoperative angiography. We divided the patients into two groups according to the landing artery (CIA or EIA) of the stent graft because aorto-uni-EIA stent grafts sacrifice the ipsilateral IIA while aorto-uni-CIA stent grafts do not affect IIA patency. Currently, aortouni-iliac stent grafts are used less frequently than bifurcated grafts. However, the aortouni-iliac stent graft has the advantage in situations of unilateral iliac arterial kinking or stenosis. Moreover, it is applicable to cases with iliac artery aneurysm and has been reported to have a satisfactory patency rate when combined with crossover bypass.

In EVAR, IIA often becomes occluded as an adjunct to this procedure. The frequency of IIA occlusion was reported to be 2–3 times higher than for open surgery. Several studies have reported that
from 26 to 41% of patients complained of persistent buttock claudication after IIA interruption during EVAR.\textsuperscript{9–14} The incidence of new onset impotence after IIA interruption during EVAR ranges between 4 and 12%.\textsuperscript{9,10,15} However, there is no intra-operative monitoring system available to assess pelvic haemodynamics to provide an alert of such complications.

In this study, IIA occluded in six patients with CIAA and in four other patients in whom aorto-unilateral EIA stent grafts were deployed (group EIA). Therefore, only the contralateral IIA remained patent in group EIA patients, while both IIAs were patent in group CIA at completion of surgery.

With our new monitoring system for pelvic haemodynamics, we repeatedly measured both penile blood flow and gluteal perfusion. With regard to monitoring penile blood flow, the PBI was measured by just pushing the start button without direct penile manipulation, once a small air cuff was placed at the penis. The data obtained with this oscillometric method were almost identical with that obtained with Doppler ultrasound technique.\textsuperscript{25} Unlike the Doppler technique, the oscillometric method does not interfere with surgical manoeuvres and does not carry any risk of contaminating the operative field. Moreover, the plethysmographic technique reflected the contributions of all vessels at the root of the penis. NIRS has been clinically applied to monitor tissue oxygenation in the cerebrum and skeletal muscles utilizing good transparency of the biologic material in the near infrared region of the spectrum.\textsuperscript{33–36} With the device, we can continuously measure tissue oxygenation and/or deoxygenation changes. Moreover, using two probes placed bilaterally on the buttocks, we could assess gluteal blood flow separately on each side. During surgery, NIRS signals gradually changed after each procedure and reached a plateau within 5 min. These changes sensitively reflect tissue ischaemic conditions.

Shortly after stent graft deployment (time point B) is likely to be the time when pelvic blood flow is minimal. At that time, both PBI and bilateral TOI showed the lowest values in both the CIA and EIA groups. After completion of cross-over bypass (time point C), PBI in group CIA had almost recovered, while in group EIA PBI remained low, suggesting that ipsilateral IIA and limb revascularization was sufficient to maintain penile blood flow. Later PBI in group EIA recovered, suggesting that patent contra-lateral IIA and bilateral limb revascularization were also sufficient to maintain penile blood flow. Our results suggest that unilateral IIA is sufficient for maintaining penile blood flow for patients.

For gluteal blood flow, TOI in group CIA recovered to the baseline level after ipsilateral IIA and limb revascularization (time point C), while TOI remained low on the contra-lateral side. This suggested that, unlike penile blood flow, ipsilateral IIA and limb revascularization are not sufficient to maintain contra-lateral gluteal blood flow. However, in group EIA, ipsilateral TOI partially recovered to baseline levels after ipsilateral limb revascularization (time point C). Therefore, ipsilateral collateral flow from the limb (i.e. via deep femoral artery or common femoral artery, etc.) is not sufficient to maintain ipsilateral gluteal blood flow. In group EIA, TOI was similar bilaterally at time point C, suggesting that the amount of collateral flow from contra-lateral limb circulation to the buttock might be very scarce. TOI returned to the baseline levels bilaterally after revascularization of both contra-lateral IIAs and bilateral limbs in group EIA (time point D). Therefore, the ipsilateral IIA could be sacrificed while maintaining bilateral gluteal blood flow for patients with bilateral patent IIAs at the start of the procedure.

We demonstrated that penile blood flow and bilateral gluteal blood flow are maintained differently during EVAR. Therefore, we should monitor penile blood flow and bilateral buttock blood flow separately to provide a warning system for the development of postoperative vascular impotence or buttock claudication. However, this study did not indicate the threshold values for concern. With regard to vascular impotence, a previous study reported that patients with vascular impotence generally exhibit a PBI less than 0.6, with an overlap in the range between 0.6 and 0.8 measured with Doppler ultrasound.\textsuperscript{37} PBI measured oscillometrically in this study was almost identical to that measured by Doppler ultrasound. Therefore, it may be better to maintain the PBI above that range to avoid vascular impotence. With regard to buttock claudication, although few studies have measured the recovery time of oxygenated hemoglobin and deoxygenated hemoglobin at buttocks with NIRS\textsuperscript{21,38} previously no study has measured TOI at the buttocks. Further study is needed to set the thresholds for avoidance of vascular impotence and/or buttock claudication during EVAR. If clear thresholds can be described, we would be able to judge whether or not to reconstruct IIA in combination with EVAR intra-operatively. The same threshold values might also be applicable for open surgical repair of aortoiliac aneurysms.

In summary, we utilized the oscillometric method to measure penile blood flow and NIRS to assess gluteal blood flow during EVAR. Both methods sensitively reflected changes in blood flow at each stage of
the surgery. These results suggested that blood flow in each region is supplied via different circulatory routes and should be monitored separately for proper assessment.

References

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