The Clinical Importance and Prediction of Steal Following Femoro-femoral Cross-over Bypass: Study of the Donor Iliac Artery by Intravascular Ultrasound, Arteriography, Duplex Scanning and Pressure Measurements


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Objectives: to evaluate the clinical significance of the steal phenomenon following femoro-femoral bypass, and whether the addition of intravascular ultrasound (IVUS) to the established examinations of the donor iliac artery can improve the prediction of patients who will develop steal.

Design: prospective study.

Material and methods: twenty-eight patients, aged 73 (50±81) years, scheduled for femoro-femoral bypass surgery in the period from 1994 to 1997, had the donor iliac artery examined by single-plane arteriography, duplex scanning, IVUS and femoral-artery blood pressure measurements (FABP) + papaverine. Three patients were excluded due to simultaneous thromboendarterectomy (TEA) of the donor iliac artery. The clinical stage and the ankle-brachial index (ABPI) were measured pre-, postoperatively and prospectively 1, 6, 12 and 24 months after discharge.

Results: two patients developed clinical steal, while an additional five had a measurable (>0.1) decline in the donor ABPI postoperatively, but no symptoms (subclinical steal). The clinical stage of the donor limb did not deteriorate further during the follow-up period (median 8 months) in these seven patients. The decline in donor ABPI correlated with the FABP and the IVUS measurements, but not to duplex scanning or arteriography. FABP after papaverine injection and IVUS examination showed equal sensitivities and specificities.

Conclusion: a clinical steal phenomenon following femoro-femoral bypass surgery seems relatively uncommon, although a subclinical steal is more frequent. Both can be predicted by FABP or IVUS. Further follow-up is required to evaluate whether subclinical steal has any consequences in the long term.

Key Words: Steal phenomenon; Femoro-femoral bypass; Intravascular ultrasound.

Introduction

Ever since the introduction of the femoro-femoral cross-over bypass by Vetto in 1962,1 the importance of the donor iliac artery, regarding the development of symptoms of steal in the donor leg, has been discussed. Several papers have dealt with the problem, so far without any final conclusion, and the clinical importance of the steal phenomenon is still debated.2-14 A critical issue has been the lack of methods to discern precisely those patients who will develop a steal phenomenon. This may have discouraged surgeons from using this low-morbidity bypass procedure. So far, the evaluation of the donor iliac artery has been based primarily on arteriography, femoral-artery blood pressure (FABP) and pulse-quality assessment. In this prospective study, we supplemented arteriography and FABP with duplex scanning and intravascular ultrasound (IVUS), in an attempt to identify patients who develop the steal phenomenon. To our knowledge systematic evaluation of the donor iliac artery with intravascular ultrasound has not been reported previously.

Material

From September 1994 to October 1997, we studied 28 patients with unilateral iliac occlusive disease. The nine women and 19 men, median age 73 (range 50-81) years, were scheduled for femoro-femoral cross-over bypass. Patients who previously had undergone balloon dilatation or reconstructive surgery of the donor

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iliac artery were not included. Three patients underwent retrograde thromboendarterectomy (TEA) of the donor iliac artery in addition to the cross-over bypass procedure. Consequently, these three patients were excluded from the study. The indications in the remaining 25 patients were claudication in 10 (40%) patients and critical limb ischaemia in the remaining (rest pain in seven (28%) and ulcer/gangrene in eight (32%) patients). Eighteen (72%) patients had no symptoms from the donor limb, five (20%) had claudication and two (8%) patients had ulceration. Twenty-two (88%) patients were smokers or claimed to have stopped recently, while three patients (12%) were non-smokers. There were three (12%) diabetics. Nine (36%) patients had ischaemic heart disease. Eleven (44%) patients had had previous vascular surgery performed: aortic tube graft in one, revascularisation of the now occluded iliac artery in six, TEA of the donor iliac or femoral artery more than five years ago in two, and infrainguinal bypass in two. Informed consent was given by all the patients, and the study was approved by the local ethical committee (j.nr KF 01-379/93).

Methods

The patients were examined before surgery with arteriography and duplex scanning of the donor iliac artery, and the ankle–brachial index (ABPI) was measured on both limbs before and after Lewis’ exercise test. During surgery the donor iliac system was examined with IVUS and intra-arterial FABP. Postoperatively and 1, 6, 12 and 24 months after discharge the duplex scanning and the ABPI measurements were repeated. After at least 10 min of rest, the brachial arterial blood pressure was related to the ankle pressure measured by the use of a Doppler probe placed over a pedal artery. Then the Lewis test was performed, consisting of one minute of extension–flexion of the ankle joint at a rate of approximately one per second, followed by renewed measurement of the ABPI. This was performed for one leg at a time.

Arteriography was performed as a single-plane procedure, with puncture of the donor side using the Seldinger technique. A radiologist (JGR), blinded to the results of the other examinations, subsequently reviewed the arteriograms and assessed the degree of stenosis (diameter reduction) and the run-off in both legs (patency of superficial and deep femoral artery). Duplex scanning of the donor iliac artery was performed, using a B & K scanner (Brüel & Kjaer Medical) with a 3.5-MHz curved transducer. The patients were examined in the supine position and were not routinely fasting, although examinations shortly after a meal were avoided. Doppler spectra were obtained routinely from four positions: the proximal and distal part of both the common and the external iliac artery. Further Doppler spectra were obtained if the colour map indicated pathological changes in-between these four positions. From the peak systolic velocity (PSV) measurements the presence of stenoses could be evaluated. A haemodynamically significant stenosis was defined by a doubling of the PSV in the same segment of the artery.

Intravascular ultrasound of the donor iliac artery was performed with a 20-MHz transducer mounted in the tip of an 8F catheter (CVIS Cardiovascular Imaging Systems Inc., Sunnyvale, CA, U.S.A.). Proximal to the transducer a rotating mirror reflected the ultrasound beam to 360 degrees of the vessel, producing trans-sectional images displayed on a monitor and stored on a S-VHS video recorder. The catheter was introduced through the arteriotomy which would subsequently be used for the cross-over bypass on the donor side, and then slowly advanced retrogradely into the iliac artery to the aortic bifurcation. In two patients, it was not possible to advance the catheter all the way into the aorta. The catheter was withdrawn from the aortic bifurcation, while noting any atherosclerotic lesions and their distance from the bifurcation or from the internal iliac artery. Neither guidewire nor fluoroscopy was used. The CVIS system enabled off-line measurements of the luminal area and the media-bounded area. The luminal area was defined as the area within the inner lining of the intima and the media-bounded area was defined as the area within the outer lining of the intima. If any lesions were detected, the degree of stenosis was calculated by relating these two areas.

Femoral-artery blood pressure (FABP) in the donor limb was measured directly using a cannula connected through a rigid tube to a pressure transducer. This measurement was compared to the brachial arterial pressure measured simultaneously with a cuff. It was assumed that the brachial arterial pressure was the same as the aortic pressure proximal to any disease in the donor iliac segment. The pressure difference was assessed before and after the intra-arterial injection of 30 mg papaverine. Measurements were repeated after the graft had been inserted. (In seven patients data on pressure measurements were lost, due to theft of a computer).

Operative technique: both common femoral arteries and their major branches were exposed through bilateral vertical groin incisions. A 6- or 8-mm diameter polytetrafluoroethylene (PTFE) graft with external
support was tunneled subcutaneously in the suprapubic position. The graft was sutured end-to-side to the common femoral arteries in an inverted-U configuration. All bypasses were successfully inserted. The duration of surgery was 2 hours (1.25–4), and blood loss was in the median 300 ml (50–1800). Additional procedures were performed in 13 patients: five donor-side and five recipient-side common-femoral-artery TEAs and three recipient-side infrainguinal bypasses.

Statistics: non-parametric statistical methods were used. Results are given as median and (range). Changes in one continuous variable were evaluated with the Wilcoxon matched-pairs test, correlation between two continuous variables with the Spearman test, and relation between a categorical and a continuous variable with the Mann–Whitney test. A p-value of less than 0.05 was considered significant. Sensitivities and specificities are visualised on a “receiver-operating characteristics” curve (ROC curve).

**Results**

The clinical status of the donor limb was unchanged after surgery in 22 (88%) patients (16 asymptomatic, four claudication, two ulceration), while two (8%) patients developed claudication, and one was relieved of claudication, probably due to a TEA of the donor common femoral artery performed during the procedure. The median ABPI, at rest as well as after the Lewis test, remained unchanged as did the decline in ABPI following Lewis’ test (Fig. 1). However, in seven (28%) patients the ABPI fell more than 0.1 compared to the preoperative level (Fig. 2). Two of these seven patients developed claudication, while five remained asymptomatic, indicating a subclinical steal syndrome. The preoperative Lewis’ test was unable to predict steal in these seven patients (Δ ABPI: 0.17 (0.03–0.20)). The run-off in one of the two patients who developed steal was in a totally patent peripheral arterial tree, while the other patient suffered from occlusion of two crural arteries, but had patent superficial, deep femoral artery and popliteal artery. The status of the run-off did not seem to influence the change in ABPI (p = 0.85).

During the follow-up period, four patients remained asymptomatic, one patient with clinical steal remained a claudicant, while the other patient became asymptomatic (Fig. 2). The last patient was lost to follow-up, because the recipient limb was amputated due to an occluded infrainguinal bypass.

The median (and range) of the pre- or intraoperative evaluation of the donor iliac artery by arteriography, duplex scanning, Lewis’ test, IVUS and FABP can be seen in Table 1. The correlations between these measurements and the changes in the donor ABPI are also indicated. As can be seen, only IVUS and FABP correlated with the change in the donor ABPI. The sensitivity and specificity of these two methods were therefore compared using ROC curves (Fig. 3). As can be seen, the optimal IVUS value for predicting a decline in donor ABPI was 55%, while the optimal cut-off value of FABP after papaverine was 15 mmHg. Five out of the seven patients who developed steal had a stenosis of 55% or more as assessed by IVUS, while this was the case in only three of the remaining 18 patients (p = 0.03).

During follow-up (median 8 months, range 4 days to 3 years), two grafts occluded, after 11 and 242 days,
Table 1. Median and range of the different methods of pre- and intraoperative evaluation of the donor iliac artery, and the correlation between these measurements and the change in ABPI from pre- to postoperatively levels.

<table>
<thead>
<tr>
<th>Method</th>
<th>Number of observations</th>
<th>Median (range)</th>
<th>Correlation to change in donor ABPI</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arteriography, % stenosis (preoperative)</td>
<td>23</td>
<td>10 (0–60)</td>
<td>0.08</td>
<td>0.7</td>
</tr>
<tr>
<td>Duplex PSV ratio (preoperative)</td>
<td>22</td>
<td>1.54 (1–2.44)</td>
<td>−0.02</td>
<td>0.9</td>
</tr>
<tr>
<td>Lewis’ test % decline in ABPI (preoperative)</td>
<td>17</td>
<td>10 (0–20)</td>
<td>−0.33</td>
<td>0.2</td>
</tr>
<tr>
<td>IVUS % stenosis (intraoperative)</td>
<td>23</td>
<td>45 (0–85)</td>
<td>−0.53</td>
<td>0.009</td>
</tr>
<tr>
<td>Intra-arterial femoral pressure difference mmHg (intraoperative)</td>
<td>18</td>
<td>5 (−28–19)</td>
<td>−0.62</td>
<td>0.006</td>
</tr>
<tr>
<td>Intra-arterial femoral pressure difference + papaverine mmHg (intraoperative)</td>
<td>17</td>
<td>6.5 (−42–42)</td>
<td>−0.71</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Fig. 3. Receiver-operating characteristic (ROC) curves for intra-vascular ultrasound (IVUS) and pressure differences before and after papaverine injection. Each point on the curves represents one cut-off value. Ex 50% stenosis. The (x,y)-values represent (1-specificity, sensitivity) obtained for each specific cut-off value for predicting a decline in ankle-brachial index (ABPI). As can be seen, the sensitivity and specificity for 55% stenosis as evaluated by IVUS equals 15 mmHg pressure difference after papaverine.

importance and prediction of steal

patients with claudication or rest pain. At the one-month follow-up visit the ulcers in five out of eight patients had healed, one healed two months later, while two patients underwent amputation because of occluded infra-inguinal reconstructions despite patent cross-over bypasses. The ABPI increased from a median of 0.35 (range 0.13–0.69) before surgery to 0.73 (range 0.12–1.02) postoperatively (p<0.001) (Fig. 1). There was no significant difference in the increase in ABPI between the patients with an open superficial femoral artery (n = 16) and the patients with stenotic or occluded superficial femoral artery (n = 9) (p = 0.09). Better run-off in the recipient compared to the donor limb (n = 6) was not related to the change in donor ABPI postoperatively (p = 0.83).

No complications attributable to IVUS occurred. Superficial infection of the groin incision occurred in three patients, all treated successfully with antibiotics. One patient underwent repeat surgery two days postoperatively, due to intimal dissection of the superficial femoral artery on the recipient site which was compromising the run-off, although the graft was still patent.

Discussion

The magnitude and clinical importance of the steal phenomenon, defined as a decline in donor ABPI and aggravation of symptoms in the donor limb after insertion of a femoro-femoral cross-over bypass, is still debated. In our study only two out of 25 patients experienced a clinical steal, and these symptoms persisted in only one of the patients after one-month follow-up. Comparable low incidences of this phenomenon have been reported earlier.2, 3, 5-7, 9, 11, 12, 14. In only one study has the steal phenomenon been found
to be more frequent (25%). However, this study included only eight patients. The location of the atherosclerotic changes responsible for steal varies. Inflow disease, as well as compromised run-off in both the donor and the recipient limb, have been suggested as the responsible factor. The Veterans Administration (V.A.) study is one of the only studies with a considerable number of patients (n = 317) prospectively followed for three years. The study revealed an incidence of 4% of clinical steal and a further 12% of subclinical steal, which corresponds well with our results. This study was unable to relate the angiographic patterns of donor and recipient limbs to either form of steal events.

An additional five patients had a measurable (>0.1) decline in the donor ABPI, indicating a haemodynamic, but subclinical, steal. Two patients with steal experienced a temporary improvement in donor ABPI at one-month follow-up (Fig. 2). This can be explained by the postoperative changes in flow through the donor iliac artery and the peripheral resistance of the recipient leg: immediately after surgery the flow in the donor iliac artery is relatively high, due to the still-low resistance in the recipient leg. The pressure gradient over a stenosis in the donor iliac artery will consequently increase, resulting in a decline in the donor-limb ABPI. However, as the peripheral resistance in the recipient limb normalises and the hyperaemia subsides, the flow through the donor iliac artery diminishes, thereby reducing the pressure-drop across the stenosis. As a consequence the donor ABPI improves. These considerations were described theoretically by Sumner and Strandness in 1972. In the long term the longer walking distance could lead to a further improvement of the circulation of the donor limb, while progression of atherosclerotic disease may limit this favourable effect. Criado et al. described a similar improvement of the donor ABPI, in some of their patients, at the follow-up visit compared to the postoperative level.

The changes in donor ABPI were significantly correlated to the FABP and to the IVUS but not to the preoperative Lewis' test, angiography or external duplex scanning. From the ROC curves (Fig. 3) it can be seen that the IVUS and FABP after papaverine injection correspond well. The methods seemed to have equal value in predicting a postoperative decline in donor ABPI. However, the material is too small to prove this point. The curve for FABP without papaverine seems slightly inferior to the other two curves for all cut-off values – indicating an increased accuracy by using papaverine injection in this setting. Archie reported on pressure measurements in the donor femoral artery before insertion of 94 femoro-femoral bypass grafts. He found similar low sensitivities and specificities of resting systolic pressures for predicting a decline in donor ABPI postoperatively, but no improvement of the results by injection of papaverine. The rather low sensitivity of both methods is due to the many sources of errors of the methods, but also a reflection of the complexity of the steal phenomenon. Even though the changes in the donor iliac artery may be the most important factor, infrainguinal disease and the distribution of this between recipient and donor limb may also have an impact on the problem. The fact that two of the IVUS examinations were incomplete may also have affected the sensitivity of this method. The more-or-less identical curves of IVUS and pressure difference after papaverine would lead most surgeons to use the less expensive method of FABP (the IVUS catheters are still for single use and quite costly). However, the FABP has its own drawbacks. The assumption that the blood pressure in the arm equals the aortic pressure can be erroneous in the presence of supra-aortic atherosclerotic disease. In our study, four patients had negative pressure differences, which could be attributed to this fact. Calibration errors, air-bubbles or kinking of the tube are other sources of errors which may affect the results. The attraction of the FABP with papaverine injection is that it mimics the haemodynamic state following insertion of the cross-over bypass, in which donor-iliac-artery flow is increased as a consequence of a lower peripheral resistance. IVUS, on the other hand, enables anatomical information providing the location and nature of the atherosclerotic changes. In studies of PTA, intravascular ultrasound has proven its superiority to arteriography in measuring the degree of stenosis in iliac arteries.

Regarding the lack of correlation between the decline in donor ABPI and arteriography, one should bear in mind that the material is selected, since only patients who, from the original arteriographic evaluation, have been found to be candidates for cross-over bypass surgery are represented. Nevertheless, the re-evaluation of the arteriograms by a radiologist did reveal a stenosis exceeding 50% in seven patients, and these lesions did not correlate with the decline in ABPI. As remarked earlier in the discussion, the same lack of correlation to the arteriographic patterns has been demonstrated also by the V.A. study. Arteriograms including orthogonal views and routine use of pull-back catheter pressure measurements, would lead to a better selection of patients. It would also provide the possibility of treating the patients with stenoses in the donor iliac artery with PTA in the angiography...
suite instead of the less favourable setting of the operating theatre.

In conclusion, a clinical steal phenomenon, defined as aggravation of symptoms from the donor limb after femoro-femoral bypass surgery, due to a decline in ABPI, seems to be relatively uncommon. A subclinical steal is more frequent and can be predicted by FABP or IVUS evaluation of the donor iliac artery. Further follow-up is required to evaluate whether subclinical steal has any clinical consequences in the long term.

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References


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