Shunt-angiography, evaluation of A-V Cannula Malfunction in Clotting

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Short arterio-venous cannula survival, with multiple surgical procedures and attendant patient anxiety, continues to be the major problem in maintenance haemodialysis. The causation of most cannula failures and the reasons for exceptional longevity of some cannula systems are unknown (Pendras & Smith, 1966). The present study was conducted in an attempt to define the normal and abnormal radiographic flow and anatomic patterns in patients with cannula malfunction.

METHODS

In the initial few angiographic studies undiluted Conray\textsuperscript{R}-400 (Meglumine lothalamate 600 mg/ml) [Mallinckrodt Chemical Works, Second and Mallinckrodt Streets, St. Louis, Missouri, USA] was used as contrast medium. Rapid infusion of undiluted Conray\textsuperscript{R}-400 produced severe burning pain on arterial injection and in subsequent angiograms the osmolality of the Conray\textsuperscript{R}-400 was reduced by combining 8 ml of Conray\textsuperscript{R}-400 with 6 ml of saline and 2 ml of Procaine. Using this technique, there was little to no patient discomfort on arterial injection. Angiograms were performed and evaluated as described in a recent communication (De Palma et al, 1969).

RESULTS

Eighty-two angiographic studies were performed in 30 maintenance haemodialysis patients. Sixteen patients were dialyzed with a 2 layer modified Kiil dialyzer and 14 patients with the Travenol Twin Coil\textsuperscript{R} 1.9 m\textsuperscript{2} or Ultra-Flo\textsuperscript{R} 1.45 m\textsuperscript{2} coil dialyzers with blood pump. Blood flow rate through the Kiil dialyzer was measured either by 'air-bubble time' or an ultrasonic blood flow meter.

Blood flow rates of 125 ml or less during dialysis with the Kiil in the absence of hypotension or clinical hypovolaemia were considered an indication
TABLE I. Reason for shunt-angiogram

1. Blood flow through Ktil haemodialyzer of 125 ml/min or less, or blood flow through coil haemodialyzer of less than 200 ml/min or coil outflow pressure of 100 mm Hg, or greater with blood flow of 200 ml/min 56%

2. Cannula clotting episode 29%

3. Bleeding + mass at cannula exit sites 12%

4. Septicaemia without evidence of cannula infection 3%

for angiogram. Cannula malfunction during coil dialysis was felt to exist when a blood flow rate of 200 ml/min or more could not be obtained without collapsing the pre-pump arterial line (at the beginning of dialysis) or a coil outflow pressure gauge measurement of 100 mm Hg or greater existed at the same blood flow rate. Fifty-six per cent of the angiograms were performed for decreased blood flow through the dialyzer. Twenty-nine per cent of shunt angiograms were performed for cannula clotting episodes. Angiograms were usually performed within a few hours after the cannula system was declotted. Cannula clotting frequently occurred after gradual reduction of blood flow rate through the artificial kidney over a period of weeks despite the frequent

TABLE II. Radiographic findings of shunt-angiograms

<table>
<thead>
<tr>
<th></th>
<th>Artery</th>
<th>Vein</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 'Beadings'</td>
<td>20</td>
<td>-</td>
</tr>
<tr>
<td>2. Vessel wall calcification</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>3. Stenosis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. &lt;1.2 mm diameter</td>
<td>-</td>
<td>29</td>
</tr>
<tr>
<td>b. &gt;1.2 mm diameter</td>
<td>-</td>
<td>11</td>
</tr>
<tr>
<td>4. Filling defect at vessel-teflon tip junction</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>5. Transverse lucency at vessel-teflon tip junction</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>6. Clot at vessel-teflon tip or more proximally</td>
<td>7</td>
<td>6</td>
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<tr>
<td>7. Vessel-teflon tip angulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Mild</td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>b. Severe</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>8. Extravasation of contrast medium from vessel</td>
<td>4</td>
<td>-</td>
</tr>
<tr>
<td>9. False aneurysms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. &lt;0.6 cm diameter</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>b. &gt;0.6 cm diameter</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>10. Number of findings</td>
<td>80</td>
<td>79</td>
</tr>
<tr>
<td>11. Number of angiograms</td>
<td>69</td>
<td>77</td>
</tr>
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</table>
use of Warfarin. Cannula clotting occurred in several instances without previous evidence of poor dialysis blood flow rates. In the latter instances, clotting was usually related to trauma to the cannulated leg, a clotted artificial kidney, post-dialysis hypotension, and in one instance from walking in the snow in a patient who had a leg cannula system. Excessive bleeding from a cannula exit site with or without subcutaneous mass near the cannula tip or exit site, accounted for 12% of the angiograms in this series. Two patients had angiograms performed because of positive arterial cannula and peripheral vein blood cultures for Staphylococcus aureus in one and Staphylococcus epidermidis in the second. Angiograms were performed in these instances to exclude occult cannula infection from arterial or venous intimal lesions.

Table II is a summary of the arterial and venous radiographic findings of these 82 shunt-angiogram studies. An irregular outline of the arterial wall proximal to the teflon tip, 'beading', was seen in 20 studies. This finding was not reproducible in the same individual on repeat angiograms and seemed to occur more frequently when undiluted ConrayR 400 was used or the patient experienced pain (probably from a too rapid injection of the contrast medium). This finding is illustrated in Figure 1. Vessel wall calcification appears radiographically identical to 'beading' but the irregularity of the vessel wall is consistent on repeat angiogram and plain films of the extremities show the

Figure 1. Arterial 'beading'
Figure 2. Arterial wall irregularity from vessel wall calcification. Arrow points to area of vessel calcification.

Figure 3. Stenosis, at vein-telfon tip junction with severe angulation at the vessel-telfon tip junction.
vessel outlined by calcium. An example of this particular finding is seen in Figure 2. Stenosis with a minimal diameter less than 1.2 mm of the vein was seen in 29 studies and greater than 1.2 mm diameter, usually 1.5 to 2.0 mm, was seen in 11 studies. No arterial stenoses were seen. The venous stenotic segments began at the teflon tip of the vein or from one to six cm proximal to the teflon tip. Figure 3 illustrates a venous stenosis at the teflon tip with the additional finding of severe angulation of the vessel-terlon tip junction.

Filling defects at the vessel-terlon tip junction were seen 13 times and were either wedge shaped or irregularly linear. A finding similar to a filling defect, seen 19 times, was the presence of a very fine transverse lucency at the vessel-terlon tip. Figure 4 illustrates this finding in an angiogram which was taken immediately after successful surgical revision of an arterial cannula. Mild vessel-terlon tip angulation was seen 29 times. Severe angulation as seen in Figure 3 was observed 10 times.

Extravasation of contrast medium around the vessel tip occurred in 4 arterial studies. In all 4 studies excessive bleeding with or without a subcutaneous mass was present and particular care was taken to exclude the contamination of contrast material on the gauze dressing which might mimic the extravasation of dye. In 2 instances the arterial injection revealed a 'stain' of contrast material from the subcutaneous tissue. Figure 5 strikingly

Figure 4. Arterial transverse lucency
Figure 5. Arterial-teflon tip area dye extravasation

illustrates extravasation of dye about the cannula tip. It is thought that there is no subcutaneous dye 'stain' in this study because the patient had stopped bleeding and clotted the bleeding area.

The presence of intravascular clots at the vessel-teflon tip junction or more proximally were seen following declotting procedures except in one instance where they were associated with decreased blood flow. These clots were distinguished from air bubbles by their constancy of position, size, and shape on repeat injection of the vessel.

False aneurysms were seen in 6 studies. In 2 patients where the greatest diameter of the aneurysms was 2.5 and 1 cm respectively the arterial cannula was revised. In 3 instances where the greatest diameter of the aneurysms was 0.6 cm or less, there was no evidence on subsequent angiograms of progression in size of these aneurysms. Most interestingly, a venous aneurysm, 2 cm in diameter, was discovered during angiogram for a subcutaneous vessel tip mass. Because of the size of the venous aneurysm this cannula limb was revised. There was no clear difference of frequency or kind in arterial or venous lesions in those patients dialyzed with a Kii dialyzer from those maintained on coil haemodialyzers.

Indications for surgical revision
In 31 studies, 16 patients, surgery was not performed following angiogram because:
1. In 22 studies though there was evidence of partial obstruction to the arterial and/or venous system, the findings were thought not severe enough to warrant surgery and the patient was placed on Warfarin or intermittent subcutaneous heparin.

2. In 5 studies the shunt angiograms had no significant anatomical flow abnormalities.

3. In 4 studies, either the arterial or venous angiogram was not performed and no diagnosis was made at that time.

Venous stenosis of 1.2 mm diameter or less usually with evidence of decreased blood flow rate through the artificial kidney or an episode of clotting was the most common reason for surgical revision. In the 29 angiographic vein studies where the stenosis was 1.2 mm or less, surgical revision was performed in 27 instances either immediately or from 7 to 21 days thereafter because of continued poor dialyzer blood flow rate or higher outflow gauge pressure or recurrent clotting. In 2 instances, one patient (K.B.) was placed on Warfarin and had good blood flow for four months. Cannula revision was then performed because of delayed treatment of an arterial cannula infection and not for venous stenosis. The other patient (H.R.) continued to have poor dialyzer blood flow, angiogram showed increasing stenosis and surgical revision was required 31 days post initial venous angiogram. In 11 instances where venous stenosis was greater than 1.2 mm diameter, usually 1.5 to 2.0 mm in diameter, immediate surgical correction was performed 4 times. In the remaining 7 instances, the patients were placed on Warfarin and no cannula failures occurred within the next 30 days.

Filling defects of either artery or vein which reduced the measured effect of diameter at the teflon tip to 1.0 mm diameter or less were surgically revised, usually within one week post angiogram. In 4 instances, small filling defects were seen, consistent with subintimal proliferation, and these were not surgically revised. No cannula failure occurred within the next month as a result of these lesions. Severe vessel-teflon tip angulation associated with decreased blood flow was seen in 10 instances, in 4 instances surgical correction was performed, in 5 instances where anticoagulation was used one patient required recannulation within 30 days. Only one instance of marked angulation with venous stenosis was seen and this is illustrated in Figure 3. This cannula limb was revised because of the venous stenosis. Extravasation of contrast media was an indication for surgical correction in all 4 instances. In these patients there was prior history of Staphylococcal infection at this cannula site which was successfully treated. The two false arterial aneurysms which required surgical repair also had a history of previous Staphylococcal infection. The venous aneurysm, however, occurred in a patient who had had no history of infection.

Clotting at the vessel-teflon tip or more proximally was seen 12 times.
In one patient both the artery and venous system evidenced clot at the teflon-tip vessel junctions with no evidence of other abnormalities. He was continued on Warfarin and a subsequent angiogram showed disappearance of these clots. A second patient had an arterial-thero Added tip large clot which was again radiographically seen some 4 months later without evidence of cannula failure. The rest of the instances of intravascular clotting were seen in angiograms done following a declotting procedure and associated with venous stenotic disease. Vessel wall calcification was seen in 5 instances and in 2 patients surgical revision was required because of poor arterial blood flow as a result of extensive intimal and medial calcification of the posterior tibial artery.

In 10 instances transverse lucency of the vessel-thero Added tip junction was unassociated with other abnormalities and surgical revision was not indicated for this finding. Indeed, one patient with arterial and venous cannula survival of 33 months each (G.M.) had transverse lucencies evident at both vessel-thero Added tip junctions. 'Beadiing' was seen 14 times without other significant abnormalities of the artery, and in these instances no early failure of the artery occurred, and no surgical correction was performed for this finding.

**DISCUSSION**

The results of this study are essentially descriptive in content. Our initial radiographic findings have led us to modify our surgical procedures for cannula insertion as well as the medical follow-up care of cannulae which evidence malfunction or clotting. It is our contention that the vessel-thero Added tip angulation is partially due to the use of long, 4 cm, teflon tips. It has been our more recent practice to use 2 to 2.5 cm teflon tips. The usual silastic cannulae which contain a 180 degree bend may also be implicated in causing vessel-thero Added tip angulation and we are increasingly using straight silastic cannulae.

The filling defects seen at the vessel-thero Added tip junction and the venous stenoses adjacent to the teflon tip may be related to excessive mobility of the teflon in the blood vessel causing frictional trauma to the intima of the blood vessel. The loss of intima immediately adjacent to the teflon tip in cannulated veins as reported (Glashan & Walker, 1968) adds support to this concept. The role of infection in cannula malfunction and failure seems to be clear in those instances of arterial false aneurysm with bleeding due to vessel wall disruption. The relation of infection to venous stenosis is unclear and is made more puzzling by the frequency with which the venous stenosis begins 1 to 6 cm proximal to the teflon tip. This would appear to be a less likely area to be infected than that directly adjacent to the teflon tip and more contiguous to the cannula exit sites. It is difficult to evaluate the role of infection in venous stenosis as most patients are treated for cannula infection promptly and for 30 days thereafter. The rapidity of treatment and prolonged antibiotic
use may allow a low-grade undetected infection to persist which may cause gradual scarring and stenosis.

We have increasingly used Warfarin as it seems to prolong cannula survival (Pendras & Smith, 1966), and at present it is difficult to obtain reliable data on the significance of minor angiographic lesions since all our patients without overt bleeding tendencies are placed on Warfarin when they have cannula malfunction. In several instances both vessels were diseased when only the arterial or venous cannula seem implicated. Because of this we routinely now inject both the arterial and venous cannulae sequentially in order to avoid missing a lesion on the unsuspected side. Our clinical impressions as to which limb of the A-V cannula system has been involved has too often been incorrect.

The transverse lucency at the vessel-teflon tip junction was initially confused with subintimal proliferation. This phenomenon is probably related to turbulence in the blood flow pattern when the contrast medium leaves the teflon tip and enters a larger diameter vessel. Intimal loss in this region (Glashan & Walker, 1968) might also produce this finding.

The irregular beaded appearance of the arterial wall probably is related to the use of hyperosmolar contrast material, intimal irritation and arterial spasm. The angiographic appearance is similar to that seen in the renal arteries in fibromuscular hyperplasia and in vessel wall calcification. 'Beading' should be distinguished from vessel wall calcification which is associated with senescence and secondary hyperparathyroidism. In vessel wall calcification, the blood vessel may or may not be able to dilate when the rest of the peripheral vascular bed dilates and because of its fixed resistance have a low blood flow when there is peripheral vaso-dilation. Secondly, the rigidity of the vessel wall would seem to enhance intimal damage at the vessel-teflon tip and allow angulation to occur more readily at this junction.

Shunt angiograms with sequential injections of both the arterial and venous cannulae is a relatively simple technique for studying the relationship of the vascular anatomy and flow patterns. Angiographic studies complement histological studies and in our experience have been the single most useful clinical manoeuvre in attempting to determine the aetiology and prognosis of cannula malfunction and clotting.

REFERENCES