The Use of the A-V Fistula in Overnight Home Haemodialysis in Children

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The successful use of the internal arteriovenous (A-V) fistula in overnight home dialysis in adults was reported in 1968 (Shaldon & McKay, 1968). Further follow up over three years has confirmed initial impressions that this access site offers a long term approach to the vascular compartment without need for further surgery, together with a significant reduction in medical complications resulting in a halving of the number of hospital back up dialyses required to support home dialysis (Shaldon, 1970a). Adult patient acceptability is now 100% in our experience, the principal attraction being the greater degree of physical freedom. Home haemodialysis in children has also been shown to be acceptable (Shaldon et al, 1969), but the limiting factor to physical rehabilitation was the external A-V shunt. It therefore seemed logical to evaluate the use of the A-V fistula in paediatric overnight home haemodialysis.

MATERIAL

Two children were trained with their mothers to use an internal A-V fistula (Table I): SG, now aged 12, started fistula dialysis in the home after 10 weeks training; JM, now aged 10, had previously dialysed with an A-V shunt in the home for 28 months, and was converted to fistula use after 4 weeks training.

Table I. Patient data

<table>
<thead>
<tr>
<th>Patient</th>
<th>Disease</th>
<th>Age (yr)</th>
<th>Sex</th>
<th>Weight (kg)</th>
<th>Home Dialysis (months)</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>SG</td>
<td>CP</td>
<td>12</td>
<td>F</td>
<td>35.0</td>
<td>5</td>
<td>0, Well at school</td>
</tr>
<tr>
<td>JM</td>
<td>GN</td>
<td>10</td>
<td>M</td>
<td>25.0</td>
<td>2, 28</td>
<td>Well at school</td>
</tr>
</tbody>
</table>

CP = Chronic pyelonephritis.  GN = Chronic glomerulonephritis
METHODS

SURGICAL

Side to side internal A-V fistulae (anastomotic size 0.5 cm) between the radial artery and the cephalic vein were created in both arms in SG and in the left arm of JM. Small collateral veins in the immediate area of the anastomosis were ligated. The anastomotic site was situated higher in the forearm than previously described in order to create an adequate below fistula access site. No attempt to use the fistula was made for at least 4 weeks.

DIALYSIS

The dialyser used was an 0.6m² 2 layered Kil"¹ with shallow grooves and a small dialysate dead space. The membrane was 11.5 µ cross grain wet stretched Cuprophan. The urea clearance of this dialyser averaged 100ml per minute with blood flow rates of 150 ml per minute and dialysate flow single pass of 500 ml per minute.

Special blood tubing sets² designed for A-V fistula dialysis (Shaldon, 1970b) incorporating (1) a thin walled collapsible vacuum monitor sac before the blood pump; (2) no Y or T junctions or rubber injection sites between the outflow needle and the pump, and (3) a twin inflow venous bubble trap for visualisation of blood flow on both layers of the Kil were used. Continuous heparinisation was achieved by pumping heparin from a plastic sealed reservoir into the venous bubble trap. The total extra corporeal blood volume was 180 ml at zero dialysate pressure (Kil 70ml; blood tubing set 110ml.) The dialyser and blood lines were reused, and the Kil was rebuilt on a weekly basis. All saline infusions were given from plastic containers without air inlets.

A specially designed 15 gauge needle and tubing set² (Figure 1) was used.

Figure 1. 14 gauge standard needle and tubing set; 15 gauge short needle and tubing set
for venepuncture. The shaft length of the needle was 25 mm and the internal diameter 1.5 mm. The needle was short bevelled and the steel highly polished and silicone treated. A plastic hub connector joined the shaft to a 70 mm silicone rubber tube with an internal diameter of 2.5 mm which was used for clamping after venepuncture. The silicone rubber tube ended in a nylon female luer coupling which could be connected to the male luer coupling of the blood line or a syringe.

The resistance to blood flow of this needle and tubing set was 17% less than the standard 14 gauge needle and tubing set\(^2\) (Figure 2). However, in vivo it was possible to increase the blood flow rate through this needle and

**COMPARATIVE RESISTANCE OF 15 GAUGE SHORT AND 14 GAUGE LONG NEEDLE AND TUBING SETS.**

![Diagram showing dimensions of needle and tubing](image)

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>15 Gauge</th>
<th>14 Gauge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Needle Length (mm)</td>
<td>25</td>
<td>38</td>
</tr>
<tr>
<td>Needle Diameter (mm)</td>
<td>1.5</td>
<td>1.7</td>
</tr>
<tr>
<td>Silicon tube Length (mm)</td>
<td>70</td>
<td>150</td>
</tr>
<tr>
<td>Silicon tube Diameter (mm)</td>
<td>2.5</td>
<td>2.5</td>
</tr>
</tbody>
</table>

1. \(F \propto D^4\) (Poiseuille's Law)
2. \(F \propto \frac{1}{R}\) \(F = \) flow; \(D = \) diameter of tube; \(L = \) length of tube and \(R = \) resistance to flow.
3. \(R \propto L\)

**COMPARATIVE RESISTANCE BASED ON DIAMETER**

<table>
<thead>
<tr>
<th>Diameter (mm)</th>
<th>(D^4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicone rubber</td>
<td>2.5</td>
</tr>
<tr>
<td>14 gauge needle</td>
<td>1.7</td>
</tr>
<tr>
<td>15 gauge needle</td>
<td>1.5</td>
</tr>
</tbody>
</table>

**COMPARATIVE RESISTANCE DERIVED FROM \(\frac{1}{D}\)**

<table>
<thead>
<tr>
<th></th>
<th>15 gauge set</th>
<th>14 gauge set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicone tube</td>
<td>70 / 7.7 = 9</td>
<td>150 / 7.7 = 19</td>
</tr>
<tr>
<td>Needle</td>
<td>25 / 1.6 = 34</td>
<td>38 / 1.7 = 41</td>
</tr>
</tbody>
</table>

15 gauge needle set has 17% less resistance to flow than 14 gauge needle set.

Figure 2. Calculation of comparative resistance to flow based on Poiseuille's Law between 14 and 15 gauge needle and tubing sets

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tubing set by 15% compared with the standard set without increasing the pressure drop to the vacuum monitor, similarly it was possible to reduce the return venous pressure by 10% when the 15 gauge small tubing needle set was compared with the standard 14 gauge long tubing set.

DIALYSATE SUPPLY MONITORING UNIT AND BLOOD PUMP (Figure 3)

(a)  
(b)

Figure 3. NKC1 Dialysate supply and monitoring unit illustrating (a) level control holding bubble trap in a vertically adjustable height clamp and (b) vacuum monitor

The NKC 1 machine with integral fistula monitoring for blood pump cut off was used. This unit incorporates an optical fast reacting venous pressure gauge, level detector on the bubble trap and a sensitive micro-switch vacuum monitor. The lamp voltage to the level head and mon-o-con gauge are DC and stabilised. The trigger circuits are all fail safe. The blood pump (MHRE 200) has a remote speed control for ease of patient operation during the night. Delay overriding of the low venous alarm allows correction of low venous alarms without the need to open the alarm contacts. Adjustment of the bubble catcher height relative to the venous manometer permits a constant venous pressure under resting conditions which permits presetting of the
venous alarms and their ultimate fixation. This increases the safety factor and at the same time allows a wider gap between the venous pressure and the alarm limits, as no patient obligation to reset the alarm is required. The use of these techniques has virtually eliminated false venous alarms during sleep and there is no requirement for the patient to move to the machine while resting in bed. Full operational control can be exercised from the remote control unit.

The other essential feature of the machine is an extremely efficient internal degassing system using a vacuum recirculating pump for the dialysate together with a curved plastic tube to enhance centrifugal bubble aggregation before the return of dialysate to the head vessel.

RESULTS

CLINICAL

The mothers in both instances were initially trained to venepuncture, the children assisting their parent. One child, JM, has recently started to self puncture. Both children preferred local anaesthesia which they introduced themselves. Security strapping of needles and tubing sets is vital to prevent accidental movement. No instance of accidental falling out of the needle from the vein has occurred in 150 overnight dialyses. Complete acceptance of the fistula was rapidly demonstrated when the children voluntarily requested removal of their perfectly functioning A-V leg shunts within two weeks of commencing use of the fistula. In fact the shunts were removed after 4 and 8

Figure 4. AG playing tennis
weeks respectively. The training and home dialysis requirement was for 4 dialyses per week, 8 hours on day training and then 10 hours at night per dialysis. Both children were able to sleep well without frequent alarms and there has been no requirement for medical assistance in venepuncturing. Parental sleep has also been remarkably good. The incidence of unsuccessful puncture was 10% in training but after 3 months in the home SG has not had an unsuccessful puncture in the last 30 dialyses (60 punctures). The skin at the puncture sites has healed well without excessive scar formation.

Physical rehabilitation has been the major benefit to the children enabling them to participate in sporting activities in their school lives (Figure 4).

**SIDE EFFECTS**

No increase in heart size has been observed and no alteration in limb size due to the fistula has yet been seen.

**BIOCHEMICAL AND HAEMATOLOGICAL** (Table II)

Blood flow rates of 150-200 ml per minute were achieved and small molecule nitrogen control in the blood has been good. The average pre-dialysis blood urea levels after 48 hours without dialysis was 75 and 70 mg/100 ml on a 50g daily protein intake.

<table>
<thead>
<tr>
<th>Table II. Diet, BP, biochemical and haematological data</th>
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<tbody>
<tr>
<td>Patient</td>
</tr>
<tr>
<td>---------</td>
</tr>
<tr>
<td>SG</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>JM</td>
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</tbody>
</table>

Haematocrit levels have risen slightly in the two children but are still low at 20 and 21% respectively. No transfusions have been given. IV iron has been given when iron deficiency was present. The calculated blood loss per week in the 4 dialyses in these children has been 50 ml, including blood samples, dialyser blood loss and venepuncture blood loss. Neither child has received testosterone.

**DISCUSSION**

The major risk of pumped haemodialysis is death from air embolus. The approach to this problem has been to avoid the introduction of air by using
blood tubing sets without inlets of any form between the patient and the blood pump, and by efficient internal degassing of the dialysis fluid to prevent the transfer of gas across the dialysing membrane. The absence of gas bubble coating of the membrane during dialysis may account for the high urea clearances obtained and their failure to drop with time on dialysis. The use of plastic containers without air inlets is another essential feature of safety. If saline is required during dialysis, the blood pump is switched off and the infusion is given directly into the venous bubble trap through the venous manometer air line connector. Heparin is also delivered continuously through a side arm directly into the venous bubble trap from a sealed plastic reservoir without an air inlet. The additional use of a monitor to detect vacuum conditions on the outflow line between the patient and the blood pump, together with a low resistance 15 gauge needle tubing set have permitted safe night dialysis at blood flow rates of up to 200 ml per minute.

The fast reacting optical venous pressure gauge with preset venous alarms which cannot be adjusted has produced undisturbed sleep with a greater feeling of security. The level detector on the venous bubble trap has never been activated by a genuine accumulation of air during dialysis, and its ultimate value when preventative measures to introduce air into the system are taken, requires further consideration.

The value of full physical freedom to the young child on long term haemodialysis is immeasurable and this is clearly the major benefit to the patient. The acceptance of repetitive venepuncture by children when performed by their parents requires time and understanding to achieve. Small needles are essential but no accidental dislodgement of the small needle has occurred to date. It may, however, be premature to generalise on the acceptability of the role of the A-V fistula as a routine access to the blood stream. In addition, the potential long term side effects on limb growth and the heart remain to be evaluated. However, our experience to date would suggest that all the benefits described in adults (Shaldon & McKay, 1968) can be achieved in children where the physical freedom role may be the most important.

**SUMMARY**

Two children have been trained with their mothers to use an A-V fistula in the home overnight. Experience to date is 7 patient months and suggests that the A-V fistula is a superior approach to the blood stream for children and can be done safely overnight, provided precautions against air embolus are taken by using preventative methods for the introduction of air as well as monitors. The benefit of physical freedom to children achieved with fistula dialysis was the greatest asset of the technique.
REFERENCES


SUPPLIERS
(see text)

(1) Meltec Ltd, 5b Cores End Road, Bourne End, Bucks.
(2) Avon Medicals, Hazelwell Mills, Stirchley, Birmingham 30.
(3) Dylade Co Ltd, Brindley 45, Astmoor Industrial Estate, Runcorn, Cheshire.
(4) Watson Marlow Ltd, Falmouth, Cornwall.

OPEN DISCUSSION

R BAILLOD (London): I think perhaps Dr Shaldon in his conclusion missed one important point, which is surely that if you are taking on children for dialysis you are thinking on a long term basis. Most people's results with ordinary A-V shunts are poor and these children rapidly lose their access sites. Therefore fistulae are very valuable in children, especially if you are thinking in terms of treating them with transplantation, dialysis, backwards and forwards over a period of twenty or more years.

SHALDON: I think this is a question of each individual fistula result. We believe that these fistulae will last as long as the children and we have no evidence in our own experience to doubt this. The earlier you get your fistula, the happier you are. We have never had a fistula fail after 3 months on 4 times a week use in something like 65 consecutive patients. Of course it is a question of how you make the fistula and then how you use it. These are our results, these are our beliefs, but I can't accept that you have to conserve fistulae for when you are an adult and deprive yourself of being a fit person while you are a child, or perhaps I misunderstood you?

BAILLOD: I think fistulae are ideal for children.

SHALDON: Oh, I am sorry. Well never mind, the message has got doubly through then.

D N S KERR (Newcastle): Dr Shaldon, you mention the value of good de-
aeration which is certainly a problem to us in the frozen north of Europe. Could you tell us which method of de-aeration you finally decided was the best one?

SHALDON: Well, for the last 18 months we have been using on our own equipment internal de-aeration using a vacuum pump with a curved centrifugal plastic tube before the pump, because theoretically vacuum de-aeration alone is not entirely acceptable. Small bubble formation is not the answer, you need large bubble aggregation in order to prevent small bubble return in the dialysate delivery system to the dialyser. We are really using a combined vacuum high resistance centrifugal plastic tube so that small bubbles aggregate before the pump into large bubbles, and then come back under positive pressure into a partitioned head vessel. The problem with this is that incorporating heat sterilisation into the cycle produces air locking in practically every pump one tends to use. For this reason we have a variable negative pressure valve on the system which requires manual operation during the heat sterilisation period. I don’t believe that with fixed orifice control you can achieve as effective vacuum de-gassing under dialysis conditions and still not air-lock your pumps. I think most systems other than this have not got a sort of pre-set valve — they either have a fixed orifice or they don’t heat sterilise. We get virtually no gas on our membranes at all, and our clearances for urea on KiIs that are fairly tightly made are about 30% higher than the published figures for the pyramidal support. Our mean urea clearances at about 150 ml/min blood flow are somewhere around 120 ml/min and they tend to rise further as you get up to 200 ml/min.