ORIGINAL ARTICLES

Nocturnal Hemodialysis in Australia

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Background: Because home hemodialysis has long been a common Australian support modality, the advent of home-based nocturnal hemodialysis (NHD) in Canada stimulated the extension of our existing home- and satellite-based conventional hemodialysis (CHD) programs to NHD. As a result, the first government-funded, home-based, 6-nights-per-week NHD program in Australia began in July 2001.

Methods: Sixteen patients have been trained for NHD: 13 dialyzed at home 8 to 9 hr per night for 6 nights per week, whereas 3 preferred to train for NHD at home using an 8- to 9-hr alternate-night regime.

Results: The program experience to March 1, 2003, was 655 patient-weeks. Two patients had withdrawn for transplantation and 2 for social reasons, although 1 continues on alternate-night NHD. There have been no deaths. Ten patients have dialyzed without partners. All patients ceased phosphate binders at entry. Thirteen of 16 discontinued all antihypertensive drugs. There were no fluid or dietary restrictions. Phosphate was added to the dialysate to prevent hypophosphatemia. Pre- and postdialysis serum and phosphate levels were broadly within the normal ranges. All patients reported restorative sleep; similarly partners reported stable sleep patterns and noted improved mood, cognitive function, and marital relationships in their NHD partners. Preliminary cost analyses show that whereas consumables had doubled, and epoetin and iron expenditures had risen by 28.9%, other pharmaceutical costs had fallen by 47%, and nursing wage costs were 48% of the notional cost had these patients remained on CHD. Three patients on NHD were retired, 7 worked full-time, 3 worked part-time, and 3 drew disability support, whereas previously on CHD, 3 were retired, 3 had worked full-time, 3 had worked part-time, and 7 had drawn disability support.

Conclusion: We believe that NHD is viable, safe, effective and well accepted with significant lifestyle benefits and improved outcomes. Although initial setup costs are significant, NHD cost advantage over CHD progressively accrues as program numbers exceed 12 to 15 patients.


Key words
Nocturnal hemodialysis, Australia, clinical outcomes, cost

Introduction

Home hemodialysis has been a permanent feature of the dialysis landscape in Australia. Owing both to the geography and to the concentration of the Australian population in relatively few urban areas, home hemodialysis has been a common “regional” support modality first pioneered by Blagg et al. [1] in Washington State in the late 1960s. The Australian and New Zealand Dialysis and Transplant Registry (ANZDATA) [2] recorded 247 patients (35.8%) on home therapies on March 31, 2003, from a total dialysis pool of 6909 patients throughout Australia and New Zealand. Of these, 757 were on home hemodialysis, 122 were on home continuous ambulatory peritoneal dialysis (CAPD), and 500 were using automated peritoneal dialysis (APD) systems at home. Of all home-based patients, home hemodialysis comprised 30.5%, whereas CAPD and APD accounted for 69.5%. Of the total hemodialysis population, 14.7% were on home-based therapy with the remainder spread between satellite/limited-care centers and in-center hemodialysis.

Uldall et al. and Pierratos et al. first pioneered nocturnal hemodialysis (NHD) in Toronto, Ontario, Canada, as a viable home therapy [3–5]. In particular, the safety of overnight, home-based hemodialysis has been confirmed [6,7]. Further, clear and resounding biochemical [8–10], lifestyle [11,12], social, and rehabilitation [13] benefits have repeatedly been shown for overnight hemodialysis. Concurrently, cost competitive
with in-center and satellite hemodialysis techniques has been documented [14,15]. By extending dialysis time to ~50 hr per week from "conventional" hemodialysis (CHD) treatment times of 12 to 15 hr per week, dietary, fluid, and daytime freedoms are restored. In addition, ultrafiltration rates (UFR) can be lowered dramatically, thereby removing the risk of intradialytic hypotension from the obligatory large-volume replacement that accompanies many CHD treatments.

The elimination of the risk of intradialytic hypotension has made NHD suitable to consider for patients without partners. Home hemodialysis has previously only been acceptable if a dialysis partner was present and alert during the procedure, primarily to administer a saline bolus if a high ultrafiltration rate led to acute hypotension. In our own unit, more than 20% of satellite patients do not have partners and are dialyzing in satellite centers primarily for this reason. Because of the low ultrafiltration rates in NHD, all of these patients would be potential candidates for home therapy with the advantages this brings. Although it is clearly recognized that home-based therapy is not suitable for all, we have seen many patients benefit from the self-determination and self-assurance that accompanies successful home dialysis.

We have established the first 8-hr-per-session, 6-nights-per-week NHD program in Australia [16,17]. It has long been a personal belief [18] that membrane contact time is the best index of dialysis adequacy, with blood and dialysate flow rates, membrane flux, and surface area being of lesser or secondary importance. Dialysis while asleep is the only practical way by which to significantly increase membrane contact time and, as such, appeared a logical step to take as we endeavored to improve the health and lifestyle of our patients.

In addition, hemodialysis as currently practiced is geared to the administrative convenience and scheduling requirements of dialysis staff. Dialysis should optimally be at the convenience of the patient and at times most appropriate for a full and normal patient lifestyle. Only home therapy is likely to achieve these goals. Although not suited to all, NHD adds a further dimension to dialytic treatment, and in our view should be offered to all patients. Diversity and choice of regimen, greater dietary, fluid and daylight-hour freedom, rehabilitation of both work and social relationships, and self-determination in both treatment and outcome should be the goals by which we judge effective dialysis. Current dialysis modalities largely ignore these important parameters. Our NHD program seeks to address and redress as many of these issues as possible.

Finally, and of interest to the Department of Human Services, Victoria (DHSV), who have generously supported our program, is the cost of the program within the Australian setting. At the request of DHSV, we have set out to compare the costs of NHD with CHD.

Methods

It is acknowledged from the outset that our initial patient selection has been from among our more "clinically stable," "psychologically sound," and "technically adept" patients. To establish the program, it would have been unwise to do otherwise. Clinical stability required a candidate patient to be hemodynamically and biochemically stable and well on dialysis for >3 months and be either already at home on CHD or in one of our self- or limited-care satellite dialysis facilities. Psychological stability required the candidate patient to have a stable and supportive home and/or relational environment and to have demonstrated a record of compliance with dialysis and medication regimens. Technical adeptness required a level of manual dexterity adequate for self-insertion of needles and a conceptualizing capacity sufficient to understand and master the principles of machine function, machine setup, the on/off procedure, and simple troubleshooting procedures.

After ethics committee approval and with informed consent, we enrolled a mixture of patients from our home (3 patients) and satellite (13 patients) programs. This included 10 patients without partners from our satellite units. The patients, who were already at home on home CHD were the first to be converted to NHD, because they were already self-sufficient, trained, and home-based. All patients had comprehensive one-on-one education sessions both with the unit medical staff and with the two home-training nurses. The potential benefits and risks were openly discussed, and we are confident that all patients entering the program did so without coercion and with the option of withdrawal without treatment compromise should they want to do so. Once NHD was established with the first 3 to 4 patients, we found that others were then encouraged to seek information and entry by those patients already in the program. This resulted in a patient-led "snowballing" effect on our recruitment process. Now that the program is well established, we are considering NHD for those patients who are volume-sensitive owing to poor cardiac tolerance of large interdialytic fluid weight gains—those intuitively most likely to maximally benefit from frequent, slow, gentle, and long dialysis.

Training began in our long-established 2-chair home training unit in our largest 20-chair limited-care satellite center. Home training protocols and practices (in line with those in standard use throughout Australia) were already familiar to our staff and patients. In addition, because limited or self-care is encouraged and supported within the satellite dialysis unit system in Australia generally and in Geelong in particular, all patients enrolled in the NHD program were already familiar with and
variously contributing to their own dialysis before entry into formal NHD training.

As soon as training places became vacant, patients were converted to the intensive training program and dialysis changed from the standard 3 days per week, 4- to 5-hr CHD to 5 days per week, 4 hr per session. Although most patients developed full competency and self-sufficiency within a 5- to 6-week training period, it is important to stress that training was conducted at an individualized pace. No training-time schedule was demanded nor enforced; patients were encouraged and supported throughout the training period until fully comfortable with all aspects of self-dialysis.

The training period included both education in machine management and safety techniques as well as instruction in self-needling. Buttonhole development (*vide infra*) was an important aspect of this period. Although the partners of patients were encouraged to become familiar with the machine, the dialysis process and the backup assistance program, this was not a requirement, and some spouses have taken more active roles than others have in dialysis training. This was left as a personal choice and was not “scripted” by the program protocols.

The 5- to 6-week intensive one-on-one daytime outpatient training period to the point of technical and dexterity competency was followed by nurse-available, overnight, in-center “sleepover” dialysis for 3 to 4 consecutive nights. At the commencement of this phase, all phosphate binders were discontinued, and phosphate was added to the dialysate using 20 to 40 mL of Fleet™ enema per 5 L (Fleet enema pack as sodium phosphate, CB Fleet Co., Braeside, Victoria, Australia). Nightly pre- and postdialysis blood samples were drawn throughout this period to monitor, in particular, the serum potassium and phosphate levels and to help judge the amount of phosphate to add to the dialysate concentrate.

Once confident of being able to self-manage overnight dialysis in a controlled setting with their primary nurse trainer on site, alert but noncontributory throughout the “practice in-center sleepover”—unless an acute problem demanded intervention—the patients were passed for NHD at home. This was not by formal examination, but was dependent on the accumulated experience of our home training staff to determine readiness for home, experience gained over 20 years of maintaining an effective and active CHD home training program. The primary nurse then visited the home for the first home treatment, remaining until the patient had successfully initiated NHD at home.

Subsequently, no further treatment-oriented home visits were made, unless requested by the patient. Subsequent review home visits were made, however, by both the home training nurses (quarterly) and the biomedical maintenance staff (monthly) at mutually agreed times to review the home work area, to service the machines and to identify any potential problems in equipment and plant.

Blood sampling for routine pre- and postdialysis biochemistries (urea, creatinine, electrolytes, magnesium, calcium and phosphate, full blood count) is standardized to the second consecutive nightly run of each 6-night cycle. Blood was sampled before and after dialysis once a week for 1 month, every 2 weeks for an additional 1 month, and then, in line with routine hemodialysis monitoring practices in Australia, every 6 weeks thereafter. Patients were instructed both in self-sampling techniques for pre- and postdialysis blood tests and in the use of a portable centrifuge (IEC Benchtop Medispin™ six-tube angle rotor centrifuge, Selby Biolabs, Melbourne, Australia) so that sampled blood could be spun and stored overnight while on NHD. The blood samples and the centrifuge were returned to the NHD training unit the following day so the centrifuge could be used by another patient.

Patient training began in July 2001 from a total hemodialysis pool of 89 patients, however over the subsequent 18 months, the total hemodialysis pool expanded to 103 patients. Sixteen patients were trained for overnight dialysis with the first full 6-nightly-per-week NHD patient dialyzing at home in August 2001. One of the 16 NHD patients had previously been dialyzed on alternate-night NHD for 8 months before the commencement of the 6-nightly-per-week NHD program.

Three patients were enrolled from our 4- to 5-hr, three-times-per-week home-based CHD program, while 13 entered from CHD in our satellite hemodialysis program. Seven of the patients were married and 9 were single. Ten have dialyzed without partners with 1 of the married patients dialyzing in a separate bedroom from his wife. Fifteen had functioning native arteriovenous fistulae (AVF) at program entry. These included 11 radiocephalic, 3 brachiocephalic, and 1 brachiobasilic. One patient initially used a tunneled double-lumen internal jugular (IJ) catheter, although later dialyzed through a subsequently fashioned superficialized brachiobasilic AVF. Two patients required temporary IJ catheters to bridge fistula reconstructive surgery for stenoses known to be present before entry into the NHD program. All patients using AVFs utilize the buttonhole technique using 15-gauge beveled back-eye Terumo™ steel needles (Terumo, Mount Waverley, Victoria, Australia).

All patients dialyzed on Fresenius B machines (Fresenius Medical Care, Milsons Point, New South Wales, Australia), equivalent in North America to the Fresenius H. Reverse osmosis was provided by a Gambro WRO 95 (Gambro, Mount Waverley, Victoria, Australia). All patients used 1.25-m² (three patients), 1.6-m² (five patients), or 1.8-m² (eight patients) Fresenius low-flux
polysulphone dialyzers. Blood flow rates averaged 210 to 250 mL/min (mean 225 mL/min) with dialysate flow rates fixed in all patients at 300 mL/min. The mean ultrafiltration rate was <250 mL/hr (range 160–310 mL/h).

The dialysate sodium was set at 140 mEq/L. The dialysate potassium was set at 2 mEq/L, whereas the oral potassium intake was unrestricted. Other dialysate concentrations were 32 mEq/L bicarbonate, 1.5 mEq/L calcium, and 0.5 mEq/L magnesium.

The dialysate flow rate was set in all patients at 300 mL/min, allowing a 5-L bicarbonate-based concentrate container to sustain a dialysate session for between 8 and 9 hr.

Intravenous iron (IV Fe) as iron polymaltose complex (Ferrum H₆, Fawns and McAllan, Croydon, Victoria, Australia) was self-administered by our patients at home. IV Fe administration is regulated by a sliding-scale protocol where 100 mg of IV Fe is administered at variable intervals dependent on a weekly measurement of the serum ferritin. This protocol is 100 mg IV iron in 100 mL normal saline infused weekly during a NHD treatment for a serum ferritin <300 μg/L; 100 mg IV Fe fortnightly for a serum ferritin 300 to 400 μg/L; and 100 mg IV Fe monthly for a serum ferritin 400 to 650 μg/L. No IV Fe was given if the serum ferritin was >650 μg/L. All patients received their first IV Fe dose in center to ensure there were no adverse reactions.

Epoetin (Eporex, Janssen-Cilag, North Ryde, New South Wales, Australia) was self-administered as an intravenous injection into the venous blood line port in the first hour of dialysis. The route of administration changed from the subcutaneous to the intravenous route in mid-2002. Epoetin utilization was assessed at three time periods: 3 months before NHD, 4 months after conversion to NHD, and as of March 1, 2003. Only those patients who remained on 6 nights-per-week NHD >4 months were assessed for epoetin utilization.

We have taken several measures to ensure while-asleep dialysis safety. We utilized electrode impregnated “enuresis” mats under the machines to detect dialysate leakage (ZirconTM water detector, JAT Trading, St Ives, New South Wales, Australia). We also used a similar electrode-impregnated tape and alarm device (Dri-SleeperTM [flexible], Alpha Consultants, Nelson, New Zealand) loosely wrapped around the AVF arm or placed beneath the tunnelled IJ catheter connectors to detect blood leaks from the access devices. Although modem/Internet monitoring technology can be used to feed real-time machine data to a centralized monitoring console, after due consideration and in line with the experience of Lockridge et al. [19], we decided not to install modem monitoring.

Immediate and experienced assistance must be available at all times throughout the night while patients are undergoing dialysis. Although those patients undertaking 6-nights-per-week NHD have 1 free night per week, this is not mandated to any particular night of the week to optimize patient preference. As such, a 365-nights-per-year nurse-on-call roster drawn in rotation from the satellite and in-center services and the nocturnal training staff operated to provide immediate telephone assistance. Technical help was also available for machine issues and was provided by the biomedical engineering department.

When problems were identified through telephone contact, patients were asked to attend the NHD unit the following day, where the problems were discussed and rectified. At worst, the patient discontinued dialysis until contact with the NHD staff the following day.

**Results**

Although too early for detailed or extensive analysis, some results are available for both objective and subjective measures. The patient demographics are shown in Table I. Of the 16 patients enrolled (15 men, 1 woman; mean age 49.4 years, range 25–76 years), 14 were trained for 6-nights-per-week NHD. Two elected to undertake alternate-night NHD, and 1 of those trained for 6-nights-per-week NHD converted to alternate-night HD after 3 weeks of the more intensive NHD. All patients on NHD dialyzed between 8 and 9 hr per night.

Four patients withdrew from the 6-nights-per-week program. Two underwent renal transplantation after successfully performing full 6-nights-per-week NHD for 23 and 42 weeks, respectively. One patient withdrew after she was unable to sleep confidently throughout the night, although subsequently at her request, she returned to alternate-night NHD and is doing well on that modality. Only one patient failed the NHD program, a 76-year-old male and the oldest patient trained. He was desperately keen to try NHD but found that the isolation from the security of the dialysis unit provoked unacceptable anxiety. He returned to satellite CHD after a 3-week trial of home-based dialysis.

As of March 1, 2003, 497 patient weeks had been logged by the patients on 6-nights-per-week NHD (range 9–73 weeks). The alternate-night NHD patients had logged 158 weeks. The total NHD experience was 655 patient-weeks.

There were five hospitalizations for 11 inpatient bed days. There were no deaths. Although data are being collected on comparative rates of hospitalization between CHD and NHD, no additional interpretable data are available beyond this simple statistic.

Fistula cannulation using the buttonhole method proved safe and effective with no complications. Patients were encouraged to develop two arterial and two venous buttonhole sites. Patients used one arterial and venous site for three to four consecutive insertions and then rotated to the alternate arterial and venous buttonholes to rest the first pair. In our experience, this third to
### Table 1: Patient demographics and epoetin usage.

<table>
<thead>
<tr>
<th>Sex/race</th>
<th>Age (years)</th>
<th>Weight (kg)</th>
<th>Renal disease</th>
<th>Main comorbidities</th>
<th>Year of CHD start</th>
<th>Initial NHD mode</th>
<th>Current HD mode</th>
<th>Weeks of NHD</th>
<th>Before 4-month Jan, 03.</th>
<th>Epotin usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>M/Caucasian</td>
<td>29</td>
<td>75</td>
<td>IgA nephropathy</td>
<td>HT</td>
<td>1999</td>
<td>Alt-night NHD</td>
<td>Alt-night NHD</td>
<td>92</td>
<td>c</td>
<td>c</td>
</tr>
<tr>
<td>M/Caucasian</td>
<td>51</td>
<td>61</td>
<td>Focal glomerulosclerosis</td>
<td>IHD/CABG/2 prior RT HT/</td>
<td>1979</td>
<td>6x/week NHD</td>
<td>6x/week NHD</td>
<td>73</td>
<td>4,000</td>
<td>8,000</td>
</tr>
<tr>
<td>M/Caucasian</td>
<td>39</td>
<td>67</td>
<td>Alport’s syndrome</td>
<td>HT/1 prior RT</td>
<td>1991</td>
<td>6x/week NHD</td>
<td>6x/week NHD until RT</td>
<td>23</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>M/Caucasian</td>
<td>25</td>
<td>55</td>
<td>Congenital nephropathy</td>
<td>HT/2 prior RT HT/</td>
<td>1994</td>
<td>6x/week NHD</td>
<td>6x/week NHD</td>
<td>68</td>
<td>4,000</td>
<td>6,000</td>
</tr>
<tr>
<td>M/Caucasian</td>
<td>39</td>
<td>80</td>
<td>Neurogenic bladder metastases in lung</td>
<td>HT/2 prior RT HT/</td>
<td>1997</td>
<td>6x/week NHD</td>
<td>6x/week NHD</td>
<td>68</td>
<td>8,000</td>
<td>4,000</td>
</tr>
<tr>
<td>M/Caucasian</td>
<td>54</td>
<td>93</td>
<td>Bilateral renal carcinoma</td>
<td>Metastases in lung</td>
<td>2000</td>
<td>6x/week NHD</td>
<td>6x/week NHD</td>
<td>65</td>
<td>12,000</td>
<td>12,000</td>
</tr>
<tr>
<td>M/Caucasian</td>
<td>45</td>
<td>87</td>
<td>IgA nephropathy</td>
<td>HT/2 prior RT HT/</td>
<td>1987</td>
<td>6x/week NHD</td>
<td>6x/week NHD until RT</td>
<td>42</td>
<td>8,000</td>
<td>1,000</td>
</tr>
<tr>
<td>M/Caucasian</td>
<td>65</td>
<td>105</td>
<td>Polycystic kidney disease</td>
<td>HT/2 prior RT HT/</td>
<td>2000</td>
<td>6x/week NHD</td>
<td>6x/week NHD</td>
<td>51</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>M/Caucasian</td>
<td>76</td>
<td>71</td>
<td>Ischemic nephropathy</td>
<td>HT/CABG</td>
<td>2000</td>
<td>6x/week NHD</td>
<td>CHD (failed NHD)</td>
<td>3</td>
<td>c</td>
<td>c</td>
</tr>
<tr>
<td>M/Caucasian</td>
<td>69</td>
<td>72</td>
<td>p-ANCA+ vasculitis</td>
<td>IHD/TCC bladder</td>
<td>2000</td>
<td>6x/week NHD</td>
<td>6x/week NHD</td>
<td>44</td>
<td>0</td>
<td>6,000</td>
</tr>
<tr>
<td>F/Caucasian</td>
<td>49</td>
<td>60</td>
<td>Focal glomerulosclerosis</td>
<td>HT/IHD</td>
<td>1996</td>
<td>6x/week NHD</td>
<td>Alt-night NHD</td>
<td>8</td>
<td>c</td>
<td>c</td>
</tr>
<tr>
<td>M/Caucasian</td>
<td>50</td>
<td>61</td>
<td>Alport’s syndrome</td>
<td>HT/IHD</td>
<td>2001</td>
<td>Alt-night NHD</td>
<td>Alt-night NHD</td>
<td>25</td>
<td>c</td>
<td>c</td>
</tr>
<tr>
<td>M/Caucasian</td>
<td>58</td>
<td>73</td>
<td>Diabetic nephropathy</td>
<td>HT/1 prior RT HT/</td>
<td>2001</td>
<td>6x/week NHD</td>
<td>6x/week NHD</td>
<td>21</td>
<td>6,000</td>
<td>4,000</td>
</tr>
<tr>
<td>M/Caucasian</td>
<td>48</td>
<td>92</td>
<td>IgA nephropathy</td>
<td>HT/cardiomyopathy HT/</td>
<td>2001</td>
<td>6x/week NHD</td>
<td>6x/week NHD</td>
<td>21</td>
<td>4,000</td>
<td>16,000</td>
</tr>
<tr>
<td>M/Caucasian</td>
<td>38</td>
<td>99</td>
<td>Diabetic nephropathy</td>
<td>HT/1 prior RT HT/</td>
<td>1986</td>
<td>6x/week NHD</td>
<td>6x/week NHD</td>
<td>9</td>
<td>0</td>
<td>&lt;4</td>
</tr>
<tr>
<td>M/Caucasian</td>
<td>56</td>
<td>78</td>
<td>IgA nephropathy</td>
<td></td>
<td>2002</td>
<td>6x/week NHD</td>
<td>6x/week NHD</td>
<td>9</td>
<td>2,000</td>
<td>&lt;4</td>
</tr>
</tbody>
</table>

*All subcutaneous epoetin.
*All intravenous epoetin.
*Denotes data not provided in patients not on 6x/week NHD.

CHD = conventional hemodialysis; NHD = nocturnal hemodialysis; IgA = immunoglobulin A; HT = hypertension; IHD = ischemic heart disease; CABG = coronary artery bypass graft; RT = renal transplantation; TCC = transitional cell carcinoma; p-ANCA = perinuclear antineutrophil cytoplasmic antibody.

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Fourth treatment access rotation helped to avoid access site inflammation from repetitive punctures and overnight needle dwells.

Blood seepage from the AVF was rare and minor. The DRI-Sleeper blood leak detector tape and alarm system initially proved too sensitive, being triggered through the night by skin moisture. This was rectified by the simple insertion of a layer of gauze under the tape.

Pierratos (personal communication) cautioned of the potential for machine malfunction to lead to dialysate leakage during overnight dialysis, one such significant episode of dialysate leakage from a faulty connection occurring early in his experience. Although we continue to use a Zircon mat under the machine to detect this unlikely occurrence, no dialysate leakage occurred in our program.

Thirteen patients ceased all antihypertensive therapy within the first month of NHD. Three remained on angiotensin-converting enzyme inhibitors, not for blood pressure control but to benefit cardiac function.

Rehabilitation was assessed for the whole NHD group. Before NHD, of the 16 patients, 3 were working full-time, 3 were in part-time work, and 3 were retired whereas 7 were drawing disability support. Followin conversion to NHD, 7 were in full-time work and were in part-time work, whereas 3 remained retired. Importantly, only 3 drew disability support.
TABLE II  Pre- and postdialysis biochemistries (mean ± SEM) of 10 patients undergoing conventional hemodialysis (CHD) and after 3 months of nocturnal hemodialysis (NHD).

<table>
<thead>
<tr>
<th>Parameter (normal value)</th>
<th>CHD Before dialysis</th>
<th>CHD After dialysis</th>
<th>NHD Before dialysis</th>
<th>NHD After dialysis</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urea (2.5–7.5 mM)</td>
<td>26.2 ± 1.7</td>
<td>8.9 ± 1.1</td>
<td>10.2 ± 0.7</td>
<td>1.9 ± 0.3</td>
<td>0.001</td>
</tr>
<tr>
<td>Creatinine (30–120 μM)</td>
<td>953 ± 76</td>
<td>370 ± 71</td>
<td>439 ± 25</td>
<td>134 ± 14</td>
<td>0.02</td>
</tr>
<tr>
<td>Potassium (3.5–5.0 mM)</td>
<td>5.3 ± 0.16</td>
<td>3.7 ± 0.1</td>
<td>4.5 ± 0.12</td>
<td>3.5 ± 0.07</td>
<td>NS</td>
</tr>
<tr>
<td>Hemoglobin (125–175 g/L)</td>
<td>—</td>
<td>119.8 ± 5.6</td>
<td>—</td>
<td>119.0 ± 6.5</td>
<td>NS</td>
</tr>
<tr>
<td>Ferritin (20–300 μg/L)</td>
<td>—</td>
<td>273 ± 46</td>
<td>—</td>
<td>340 ± 68</td>
<td>NS</td>
</tr>
<tr>
<td>Albumin (32–50 g/L)</td>
<td>35.3 ± 0.9</td>
<td>38.3 ± 2.7</td>
<td>38.3 ± 0.7</td>
<td>35.6 ± 1.9</td>
<td>0.02</td>
</tr>
<tr>
<td>Corrected calcium (2.15–2.55 mM)</td>
<td>2.58 ± 0.03</td>
<td>2.26 ± 0.09</td>
<td>2.55 ± 0.04</td>
<td>2.64 ± 0.02</td>
<td>NS</td>
</tr>
<tr>
<td>Phosphate (0.85–1.40 mM)</td>
<td>1.61 ± 0.11</td>
<td>0.90 ± 0.11</td>
<td>1.47 ± 0.08</td>
<td>0.84 ± 0.07</td>
<td>0.04</td>
</tr>
<tr>
<td>Parathormone (0.5–8.0 pM)</td>
<td>—</td>
<td>45.8 ± 13.7</td>
<td>—</td>
<td>26.0 ± 11.2</td>
<td>0.04</td>
</tr>
</tbody>
</table>

For the remaining data, only those patients who maintained full 8-hr-per-night, 6-nights-per-week NHD for > 12 weeks are included in result analyses. Thus, only 10 of the 16 patients have been assessed: 3 were excluded for alternate-night therapy and 2 for < 12 weeks’ exposure. One failed the NHD program and returned to satellite CHD.

The 10 assessable patients generated a mean total call rate of two calls per week. No home visits by the nursing staff were required; all calls were managed over the phone. Although patients were instructed to discontinue the dialysis session in the event of machine malfunction or other difficult-to-rectify events, aborted dialysis sessions were rare.

Clear biochemical improvement was evident. Table II shows before and after values for both CHD and NHD for a range of biochemical measurements. Mean pre- and postdialysis biochemistry appears significantly better on NHD than that recorded by the same patients on CHD before entry into the NHD program.

Of particular interest, however, are the albumin data. As seen in Table II, CHD postdialysis albumin levels rose by 7.8% to 38.3 ± 2.7 g/L when compared to predialysis levels of 35.3 ± 0.9 g/L—as might be expected during the rapid volume contraction that accompanies CHD. Conversely, during long, slow NHD, serum albumin levels fell by 7% from 38.3 ± 0.7 to 35.6 ± 1.9 g/L.

Subjectively, all patients reported complete food and fluid freedom and could eat and drink what they wanted, when they wanted. Three patients even required brief potassium supplementation to maintain their serum potassium levels until they had gained sufficient confidence to again eat high-potassium-containing foods after years of rigid potassium restriction.

All 10 patients had serum phosphate levels within the normal range (see Table II), the mean predialysis NHD phosphate level was 1.47 ± 0.08 mM, and the mean postdialysis NHD phosphate level 0.84 ± 0.07 mM (normal range 0.85–1.40 mM). This was despite that all patients had permanently discontinued phosphate binders on entry and all patients required supplemental phosphate via the dialysate. These values contrast with pre- and postdialysis CHD mean phosphate levels of 1.61 ± 0.11 and 0.90 ± 0.11 mM, respectively, when phosphate binder agents were in use. The mean CHD phosphate binder usage for the group before NHD conversion was 600 mg of calcium carbonate (Caltrate®. Whitehall Consumer Healthcare Pty Ltd, Baulkham Hills, New South Wales, Australia), two tablets three times daily, and 600 mg of aluminum hydroxide (Alutabs®. 3M Pharmaceuticals Pty Ltd, Thornleigh, New South Wales, Australia), two tablets twice daily. Sevelamer hydrochloride is generally unavailable in Australia.

Two of the 10 assessable patients had small reductions in epoetin dosage (see Table I). It had no change, and 5 required an increased dose. There was a significant mean increase in epoetin dosage for the group as a whole, the mean dose rose from 4600 to 6600 units per week after 4 months of NHD when compared to epoetin doses at 3 months before 6-nights-per-week NHD entry. Iron utilization was not altered.

All except one patient reported an improved sleep pattern. Most patients required 3 to 6 weeks to adjust to the sounds of the machine pump and the reverse osmosis (RO) unit. Some patients “dial-watched,” but covering the dial with a cloth resolved this. One patient had ongoing sleep-depriving anxiety which led her to request alternate-night therapy. Since doing so, she has regained her confidence and now sleeps soundly on nights both on and off NHD, though she remains on alternate-night therapy by preference. One patient, the oldest trained at 76 years of age, failed to cope in the isolation of home-based therapy and, although he had no specific dialysis-related complications, transferred back to the satellite unit CHD program after 3 weeks. All patients report improved sleep quality while spouses verbally reported a significant reduction in patient snoring and restlessness. This is subjective confirmation of
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the report from Hanly and Pierratos [20] of the correction of sleep apnea by NHD.

Partner sleep patterns, while initially disturbed, have not been an issue except with one. Here, the issue was not NHD, but rather two individuals who had long been on different sleeping “time clocks!” Alarm-disturbed sleep was a concern for all patients. In reality, however, alarms are relatively few with the majority being low arterial pressure alarms. This commonly indicated a kinked line and was rapidly rectified. An average of 1.5 alarms occurred per 8-hr dialysis treatment.

None of the patients who remained on NHD would voluntarily return to CHD. Two cut short holidays, during which a return to CHD was required, feeling sufficiently ill at ease with CHD to want to return home to the well-being of their home-based NHD. All seven spouses subjectively reported improvements in patient mood, cognitive function, and interactivity, noting significant improvements in family structure and function. This information was obtained at interview. Although subjective global analysis data were being collected, insufficient data points have been accrued to report at this time.

It is still too early for a detailed cost analysis of our program. Despite this, the following simplified cost data are provided. It is presented in Australian dollars (AuS$), the conversion at the time of writing being Au$1.00 = US$0.60. Costs for NHD were assessed over a 3-month window after 3 months of stable home therapy and then annualized and compared with the annualized costs for CHD for the 3 months before entering training for NHD. In Australia, no reuse programs exist and single-use protocols for both dialyzers and bloodlines are routine, whether the patient is on CHD or NHD.

Mean annualized consumable costs for CHD in the 3 months before commencing NHD were AuS$8,780 per patient per year. For the 6-nights-per-week NHD program, consumable costs doubled to AuS$17,560 per patient per year. Consumables included Fresenius polysulfone low-flux dialyzers, Fresenius blood lines, and hemodialysis fistula packs (Neomedics, Mount Waverley, Victoria, Australia) utilizing Terumo steel 15-gauge needles for arterial and venous buttonhole access.

Drugs available under the Australian Federal Pharmaceutical Benefit Scheme (all drugs excluding epoetin and iron that are funded and recorded separately) reduced from a 10-patient mean of AuS$940 per patient per year during CHD to AuS$490 per patient per year after 3 months of NHD.

Epoetin and polymaltose iron (Ferrum H) were combined in cost analysis and increased from AuS$3045 per patient per year for CHD to AuS$4280 per patient per year for NHD. The difference in cost reflected the increase in epoetin expenditure as iron polymaltose dosages remained unaltered from CHD to NHD.

Machine and installation costs were small in comparison to other maintenance costs. Amortizing machine (AuS$15,000) and individual R/O (AuS$7500) costs over a 12-year expected equipment life span reduced equipment costs to ~AuS$2,500 per patient per year, whereas home installation (including building, plumbing, and redecorating as needed) averaged a once-off cost of AuS$3,000 per patient. These costs are offset by the significantly greater costs associated with progressive satellite and in-center unit expansion and the ever-present pressures for additional “bricks and mortar” additions to house an expanding CHD program. Although no additional dialysis stations have been added to our satellite or in-center services in the past 18 months, other nearby services have expanded their facilities. In one of these, it cost AuS$350,000 to renovate/convert a preexisting house into a 9-station facility used for two shifts per day, 6 days per week to provide CHD services for a maximum of 36 patients. This expenditure did not include the machines, the chairs, the R/O unit, or any other equipment. This rounds out to ~AuS$10,000 per patient for bricks and mortar expenditures alone (Kerr PG, Monash Medical Center, Melbourne, Australia, personal communication). These costs significantly exceed the one-time installation expenditure incurred in outfitting a home for NHD.

In Victoria, the DHSV allocates a reimbursement of AuS$250 for the water costs sustained by patients who undertake hemodialysis in the home. This amount is reimbursed directly to patients annually from the managing renal unit. There is no similar scheme for reimbursing the costs of electricity. To defray electricity costs, a power cost reduction meter (“Winner Meter,” Origin Energy, Melbourne, Australia) was provided to patients to reduce power costs. This meter reduced power costs to a night rate of 7.73 cents per kilowatt from 11 pm to 7 am from the standard power rate of 19.25 cents per kilowatt day and night. This meter cost AuS$15 and costs were borne by the NHD program as a one-off expenditure.

The major cost differential, however, is seen in staffing costs. In Australia, the average nurse-to-patient ratio in satellite and in-center dialysis units, although clearly varying state to state, is approximately one nurse per 3.5 patients. A rounded wage cost for a hemodialysis nurse (including on-costs, superannuation, holiday leave, and other salary costs) is AuS$60,000 per year. On a per-patient basis, this equates to a nurse wage of ~AuS$17,142 per patient per year. NHD nursing is undoubtedly more expensive as a full, overnight on-call system must be maintained 365 nights per year. This increases the wage costs per nurse by AuS$13,000 per nurse per year, the rounded-out full salary for a NHD nurse therefore increasing from AuS$60,000 per nurse per year to AuS$73,000 per nurse per year. In our program, the on-call responsibilities and reimbursements are shared between the two NHD nurses and nurses from
TABLE III  Comparative costs* in Australian dollars (Au$) between conventional hemodialysis and nocturnal hemodialysis.

<table>
<thead>
<tr>
<th></th>
<th>Conventional hemodialysis</th>
<th>Nocturnal hemodialysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS drugs</td>
<td>8,780/patient/year</td>
<td>17,560/patient/year</td>
</tr>
<tr>
<td>Epoetin and iron polyanthae</td>
<td>940/patient/year</td>
<td>490/patient/year</td>
</tr>
<tr>
<td>Nursing wage with on-costs</td>
<td>3,045/patient/year</td>
<td>4,280/patient/year</td>
</tr>
<tr>
<td>Estimated “bricks and mortar” expenditure/patient</td>
<td>17,142/patient/year</td>
<td>4,866/patient/year</td>
</tr>
<tr>
<td>(based on nurse/patient ratio of 1:3.5)*</td>
<td>(~10,000/patient)</td>
<td>(~3,000/patient)</td>
</tr>
<tr>
<td>Energy-saver “Winner Meter”</td>
<td>—</td>
<td>515/patient</td>
</tr>
<tr>
<td>Machine and R/O purchase (expected 12-year machine life span)</td>
<td>3,750/patient</td>
<td>22,500/patient</td>
</tr>
<tr>
<td></td>
<td>(~312.50/year over machine lifetime)</td>
<td>(~1,900/year over machine lifetime)</td>
</tr>
</tbody>
</table>

*Costs are preliminary; final costs cannot be determined until completion of the pilot program in late 2004.

**Mean dialysis unit nurse/patient ratio for the state of Victoria, Australia.

*Estimated nurse/patient ratio for nocturnal dialysis nurse training/administration. PBS = Australian Government Pharmaceutical Benefits Scheme; R/O = reverse osmosis equipment.

the satellite and in-center services who take after-hours call. This cost has been apportioned to the NHD program. Because we believe that two nurses can train and manage up to 30 NHD patients, this equates on a per-patient basis to ~Au$4866 per patient per year.

In the Australian setting, ~10 nurses (inclusive of administrative time) are needed for 30 in-center or satellite patients with resultant wages of ~Au$600,000 per year. This compares with wages of ~Au$146,000 per year for 2 nurses managing the same number of home-based NHD patients; this includes the 365-nights-per-year on-call wage component. These potential wage savings far outweigh the greater expenditure in consumables, epoetin and iron. Individual sector program costs are shown in Table III.

Extrapolated costs (Table IV) for a 30-patient CHD program suggest likely annual costs of ~Au$983,000. In comparison, a 30-patient NHD program predicts costs of ~Au$816,000 per year. This offers a potential ~Au$167,000 per year (17%) saving in comparative 30 patient programs.

Discussion

Our 18-month NHD experience of over 655 patient-weeks in 16 patients reassures us that NHD is a viable, safe, well-accepted, and effective therapy. It is, in our experience, suitable for both partnered and single patients. This latter group potentially exposes a large subpopulation of our satellite dialysis program to the potential for home therapy where it had previously been denied.

In Australia, the hemodialysis population is broadly divided into three separate groups. Those who require extensive or complete nursing care and assistance for dialysis are treated in in-center units. Those capable of self-care, who have available partners and are technically and manually capable, are offered and encouraged to undertake home dialysis and, nationally, education and training programs continue to support home hemodialysis. Satellite (or limited care) hemodialysis is offered to two main populations: those who need some help from nursing staff but who are generally clinically stable and can be managed with a lower nurse-to-patient ratio and those who would otherwise be considered as candidates for home dialysis but who live alone and do not have a ready dialysis partner available. It is this latter group in particular who could be considered as potential NHD candidates. In our service, > 20% of satellite patients dialyze in the satellite unit simply for the reason that they do not have a potential dialysis partner. Under conventional thinking and dialysis regimens, these patients must dialyze under nursing staff control primarily owing to the ever-present risk of intradialytic hypotension.

The risk of intradialytic hypotension most commonly results from the high UFR necessary to return from the 2- to 3-day volume expansion to dry weight in the short space of a 4- to 5-hr dialysis treatment. By doubling the treatment time to 8 or more hours and by doubling the frequency from three to six treatments per week, the UFR is potentially reduced by a factor of 4. This lowers the mean UFR on NHD to < 250 mL/hr (and commonly ~180 mL/hr), a UFR within the capacity of replacement from the extracellular fluid without a mean reduction in intravascular fluid volume.

This volume equilibration concept, interestingly, appears to be supported by our albumin data. The physiology of normal postural change shows that a significant rise in blood volume occurs in the supine position by, typically, 600 to 700 mL when compared to the erect posture in adults [21]. This leads to a rise in the blood albumin concentration as the upright posture is assumed and as the plasma volume contracts. Usually, this increase in plasma and blood volume is complete within 30 min of assuming a recumbent position whereas, conversely, volume contraction is complete within 10 min of resuming an upright stance. The mean fall in the erect
Nocturnal Hemodialysis in Australia

TABLE IV  Real and extrapolated total program cost estimates for conventional hemodialysis (CHD) versus nocturnal hemodialysis (NHD) in Australian dollars (Au$).

<table>
<thead>
<tr>
<th>Number of patients</th>
<th>CHD (Au$)</th>
<th>NHD (Au$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>98,295</td>
<td>212,990</td>
</tr>
<tr>
<td>6</td>
<td>196,590</td>
<td>279,980</td>
</tr>
<tr>
<td>9</td>
<td>294,885</td>
<td>346,970</td>
</tr>
<tr>
<td>12</td>
<td>393,180</td>
<td>413,960</td>
</tr>
<tr>
<td>15</td>
<td>491,475*</td>
<td>480,950*</td>
</tr>
<tr>
<td>18</td>
<td>589,770*</td>
<td>547,940*</td>
</tr>
<tr>
<td>21</td>
<td>688,065*</td>
<td>614,930*</td>
</tr>
<tr>
<td>24</td>
<td>786,360*</td>
<td>681,920*</td>
</tr>
<tr>
<td>27</td>
<td>884,655*</td>
<td>748,910*</td>
</tr>
<tr>
<td>30</td>
<td>982,950*</td>
<td>815,900*</td>
</tr>
</tbody>
</table>

*Extrapolated costs.

...serum urea and phosphate levels oscillate between the upper and lower limits of normal from before to after dialysis, the latter despite the withdrawal of all phosphate binding agents. Indeed, phosphate must be added to the dialysate concentrate to prevent hypophosphatemia.

Lockridge et al. [19] have reported an approximate 50% reduction in erythropoietin dose in an NHD program. We have not seen this fall in all patients; only 2-10 showed a reduction, whereas 3 showed no change at all required an increased dose, with an overall increase in epoetin costs of 28.9%. During 2002, our protocol for epoetin administration changed from the subcutaneous to the intravenous route. With this change, the epoetin dosage in our whole hemodialysis population broadly risen by 20% to 30%. We have maintained long-established iron administration protocol that has ensured that all patients entering the NHD program were fully iron replete and had stable hemoglobin levels within the 120 g/L range before entry (see Table II). This was little opportunity to gain an erythropoietin dosage advantage through improvements in iron administration, while introducing the NHD program. These factors are the likely explanation for the increase in dose of epoetin seen in more than half of our patients and the absence of the erythropoietin dosage reductions during NHD that have been reported by others.

Of primary importance to patient well-being and satisfaction has been the complete dietary and fluid freedom of NHD. In particular, so ingrained have been the dietary restrictions of potassium that three patients required oral potassium supplementation until they had adjusted to a free diet inclusive of bananas and citrus fruits. Subjective improvements in restorative sleep were also seen along with major additional freedoms in lifestyle rehabilitation and work capacity. These benefits to the individual patient appear profound and cannot be underestimated. Formal assessment of lifestyle and dietary outcomes is being undertaken using a modified quantitative subjective global assessment [24] and will be reported separately at the completion of our 3-year DHSV-sponsored pilot study.

Cost containment is a vital issue in hemodialysis programs worldwide as growth in end-stage renal failure increasingly tests the capacity of funding systems. Although capital equipment is clearly costly, it can amortized over a number of years and does not represent the dominant cost of dialysis provision—indeed, the reverse is the case. Recurrent annual wage costs are a single greatest single cost burden in Australian programs, where hemodialysis nurse shortages create further stresses on service provision. From an economic perspective, a managed home hemodialysis is therefore an attractive proposition because it both reduces the wage burden and allows scarce nursing staff to be better utilized in areas of higher-dependency hemodialysis care.
There can be little dispute that the initial setup costs of NHD are high and unavoidable. From the outset, a home training program needs to be established—although in Australia, where home hemodialysis has long been a significant dialysis modality choice in most units, it has been relatively simple and cost-neutral to convert our home CHD training service to a nocturnal training program. In areas without strong and established home training programs, however, protocol manuals, procedures, and staff training would need to precede any thoughts of patient recruitment.

From the first patient, a one-on-one training program and a full after-hours nursing cover service must be in place. In addition, the cost of individual machines and reverse osmosis equipment along with home installation and plumbing appear at first prohibitive. The results of our early and admittedly simplified cost analyses suggest otherwise. Although NHD program longevity with sufficient patients enrolled for more than 2 consecutive years is required before detailed cost data can be provided with confidence, our experience to date suggests that progressive comparative cost efficiency to CHD is seen as NHD patient numbers increase. As CHD numbers rise, additional nursing staff must be added to the dialysis unit staff complement. With a mean nurse-to-patient ratio of 1 to 3.5, after 15 patients have been added to a CHD program, 4 to 5 additional nurse wages must be paid annually. After 30 additional patients, 10 additional nurse wages will be needed with one of these primarily assuming an administrative role. In addition, as a CHD program proliferates, our experience has been of repeated expenditure in bricks and mortar as unit expansion or relocation is regularly revisited.

It is recognized that our cost modeling is incomplete. The premise of our pilot program, supported as it has been by the state government through DHSV, has been to compile an accurate assessment of the costs and benefits of NHD against CHD. To produce meaningful data, it was agreed that a full 2-year survey of costs be obtained. None of our patients has yet completed 2 years in the program and two have been on NHD less than 4 months. Further detailed analysis is planned and required by DHSV before a "funding model" for NHD is established for other renal services. Nevertheless, we believe the preliminary data provided here suggest so far that, in the Australian setting, NHD program costs equate to CHD program costs somewhere between 12 and 15 patients. Thereafter, NHD costs progressively undercut those of CHD. The doubling of consumable expenditures in 6-nights-per-week NHD is more than offset by progressively diminishing comparative nursing wages and bricks and mortar costs as patients are located at home and with nurses on call only. We believe it quite feasible that two home-training nurses can comfortably train and care for up to 30 NHD patients, provided that an on-call nurse program can be funded to respond to after-hours phone calls. We believe that it is only by managing as many patients as possible at home that the burgeoning wage and facility costs currently associated with the expansion in hemodialysis can be affordable into the future. The initial setup funding, consumable expenditures, and equipment costs are, against these latter expenditures, relatively minor.

One economic benefit, which although difficult to quantify is at least intuitively significant, is the heightened capacity for patients on NHD to return to active employment. Our experience to date has shown a significant reemployment rate among our NHD patients and, from a government perspective, an equally attractive reduction in those seeking disability support. This "hidden" economic benefit may yet prove to be one of the most telling arguments of all in support of NHD.

Because home hemodialysis has sustained a strong presence in Australia since the mid-1960s, political obstacles to the introduction of NHD were few. Funding to support home dialysis has long been accepted as part of the dialysis landscape. As a result, few barriers were encountered beyond those of the setup costs. In Victoria, reimbursement models are in place for in-center and satellite hemodialysis with renal units being funded at Au$40,756 per in-center or satellite patient per year, whereas home hemodialysis is funded at the lower rate of Au$29,600 per patient per year. After negotiation with DHSV, NHD patients were allowed to be claimed for the duration of our pilot program at in-center/satellite reimbursement rates rather than those in place for standard home CHD. This differential of Au$11,156 has been sufficient to cover the additional training, consumable, reverse osmosis equipment, and installation costs. It is anticipated that, upon completion of the pilot program in the second half of 2004, an NHD program cost per patient per year will be determined—a cost that will be then converted to a new NHD mode reimbursement rate for other centers that may decide to proceed with an NHD program.

In our service, we now offer NHD as a formal dialysis choice to all patients in our predialysis education program. Although clearly not appropriate for all patients, home-based NHD along with short daily hemodialysis should be and are added to the choices we offer our patients. Greater flexibility in choice is a goal we have set for ourselves as we strive to offer optimal our dialysis patients.

Chertow [25], while acknowledging the circumstantial evidence for outcome benefit from NHD and other modes of dialysis that increase either frequency or time, correctly laments the lack of clinical trials in NHD. The same might be said for much of hemodialysis from its inception, where there is a dearth of basic trial evidence, not only in the comparison of treatment length and
frequency but even in trials to determine the appropriate level of residual renal function at which to instigate therapy. We agree that there is a clear need to dispassionately compare the multiple models of dialysis length and frequency before folklore yet again supersedes science in this area. Nevertheless, the conduct of true randomization trials of the different dialysis modes is, by the nature of the process itself, almost impossible. Thus unfortunately, the kind of trials needed to satisfy these criticisms will likely never be done.

Having said this, we believe NHD to be an exciting new dialysis modality within the funding reach of most dialysis services. It offers patients new horizons in choice and self-determination. Although not suitable for all, we believe that ~30% of all current hemodialysis patients are potentially suitable for this modality and that it should be freely available and fully funded for any patient who seeks quality of life in renal replacement therapy.

Acknowledgments

The authors thank the Department of Human Services (Victoria, Australia) for funding support. In addition, Fresenius Medical Care (Australia) has been generous, both in their equipment support and in their enthusiasm for the education of the Australian dialysis community in longer and more frequent dialysis techniques. Finally, the Rotary Clubs of the Geelong region have generously given both time and funds to assist with the home installation of plant and equipment.

References