Home Hemodialysis

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13.1 Introduction

Home hemodialysis (HHD), though novel and maybe even intimidating for many nephrologists, is not a new option for renal replacement therapy (RRT). First utilized in Japan in 1963 [1], HHD was the predominate dialysis modality until after the 1972 amendment to the Medicare Social Security Act created the financial impetus to develop in-center hemodialysis (HD). Though a significant number of patients remained on HHD, fewer and fewer patients utilized this treatment until a rejuvenated interest at the beginning of this millennium stimulated new growth. The driving force was the efforts of a few nephrologists who were determined to improve outcomes in HD patients by increasing time and frequency of dialysis treatments. Short daily hemodialysis (SDHD) was initially described in 1969, but was not financially viable and was abandoned until revived in the 1990s [2]. More frequent home nocturnal hemodialysis (NHD) was first introduced by Dr. Uldall in 1994 after obtaining a grant from the Ministry of Health, Province of Ontario [3]. Improvement in dialysis equipment and a decrease in cost of supplies made "daily" dialysis more financially attractive, yet still more expensive than thrice-weekly dialysis. However, the major cost–saving was performing dialysis at home with a patient functioning as a nonpaid dialysis technician. Finally, for HHD to be attractive for patients, novel dialysis equipment had to be developed that was unobtrusive in the home (small), simple to use, financially sound, and, ideally, portable. Industry has responded to these needs and we can expect even more innovative dialysis platforms in the future. Thus, more frequent HD at home evolved and was suddenly a very attractive option for many patients.

In this chapter, we review the benefits of HHD acknowledging that, as is true for most clinical subjects in nephrology, rigorous and scientifically sound data is limited. However, we need to recognize that the patients we treat today cannot afford to wait 5 or 10 years for the possibility that more studies will be done. Potential complications of HHD as well as solutions to manage the complications are outlined. We also describe appropriate dialysis prescriptions using traditional and more novel dialysis platforms. Finally, we review strategies to build a successful HHD program that includes an approach for discussion of modality selection options with patients.

13.2 Clinical Outcomes

Over the past decade, many observational studies and a few randomized control trials (RCTs) have been published examining a range of clinical outcomes for HHD patients. Although the studies encompass a variety of study designs, evaluate a number of outcomes, and are not all consistent with each other, the overwhelming take-away message from this growing body of literature is that more frequent dialysis (typically performed in the home) offers favorable clinical outcomes for patients. However, it is important to realize that this is largely observational data and thus we must interpret with caution. In addition, it is important to note that the general term "home hemodialysis" includes both SDHD and NHD. For the purpose of this chapter, "home hemodialysis" refers to "more frequent" or "daily" HD options performed at home. Both modalities offer overall more time on dialysis per week and are typically performed in the home, but are different from each other in prescription and should not be lumped together when discussing clinical outcomes. In this section, we will discuss the major clinical outcomes described in the literature and end with some special cases in which HHD may be a particularly attractive modality.

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13.2.1 Randomized Control Trials

There are two key RCTs that evaluate clinical outcomes in HHD. The Frequent Hemodialysis Network (FHN) trial was a multicenter RCT with both an SDHD arm (6 days per week) [4], which included 245 subjects, and an NHD arm (6 nights per week) [5], which included 87 subjects, compared with conventional in-center thrice-weekly dialysis (CHD). The primary composite outcomes at 12 months were (1) death or 1-year change from baseline in left ventricular (LV) mass, and (2) death or 1-year change in physical health based on a RAND health survey. There were a number of secondary outcomes that were evaluated and many ancillary studies have been subsequently performed. The SDHD trial showed statistically significant improvement in both co-primary outcomes ($p<0.001$, $p=0.007$, respectively) although the NHD trial showed no difference in primary outcomes from the conventional arm. The FHN trial had a number of limitations, including, notably, the low enrollment in the NHD trial and the fact that many of the controls in the NHD trial were actually doing traditional thrice-weekly HD at home instead of in-center, but it is one of only a few RCTs we have to evaluate HHD and so it is important to review.

The other RCT, by Culleton et al., randomized 52 subjects to 6 days per week NHD versus CHD and subjects were followed for 6 months [6]. The primary endpoint was change in LV mass, as measured by cardiovascular magnetic resonance imaging (MRI), and prespecified secondary outcomes included self-reported quality of life, blood pressure, mineral metabolism, and medication usage. In this study, frequent NHD significantly improved LV mass ($p=0.04$) and had favorable impact on systolic blood pressure (SBP) control, mineral metabolism, and some measures of quality of life.

13.2.2 Quality of Life

Performing dialysis at home, either as SDHD or NHD, affords the patient significantly more flexibility and freedom to tailor treatments around their daily lives. It allows patients to remain employed, spend more time with family and friends, and gain more freedom to do what they choose. In addition, patients generally report fewer intradialytic symptoms and shorter recovery time post-dialysis. The increased time on dialysis overall allows for smaller quantities of fluid removal and less extreme solute fluctuations in a given time period. In the Following Rehabilitation, Economics and Everyday-Dialysis Outcome Measurements (FREEDOM) study, a prospective cohort study of SDHD patients, improvement in quality of life was demonstrated using the SF-36 survey at initiation of SDHD and then subsequently at 4 months and 12 months [7]. The percentage of patients with depressive symptoms, using the Beck Depression Scale, significantly decreased during 12 months of follow-up as well [8]. Furthermore, there was a significant drop in post-dialysis recovery time at 12 months from 8 h in the thrice-weekly HD patients to only 1 h in the SDHD patients. Lockridge described his experience with NHD patients in Lynchburg, Virginia, and using patients as their own controls, he showed that the hospital admission rate dropped by 42% and the number of hospital days by 60% following initiation of NHD [9]. In addition, he found that his patients had statistically significant improvement in both the physical and mental components of the SF-36 scores after transitioning to NHD. Finally, in a cohort of 12 patients converted from CHD to NHD, Jassel demonstrated improvement in cognitive functioning on a battery of neuropsychiatric tests performed at baseline and after 6 months on NHD. The most impressive improvement was in attention and working memory, which improved by 32%. Patients' own perception of their cognitive function also improved significantly [10].

13.2.3 Phosphorous Control

Improvement in the control of phosphorous levels has been shown in many studies with HHD. Phosphorous removal entails a two-phase model, with early phosphorous removal from the extracellular compartment related to the concentration gradient from the blood to the dialysate. The second phase of phosphorous removal requires much more time, to allow for mobilization of phosphorous from the intracellular compartment. This two-phase removal process is why NHD, with its relatively longer treatments, has more profound effects on phosphorous removal than SDHD [11]. Patients using NHD often require few, if any, phosphorous binders and can follow a much more liberal diet which includes phosphorous-containing foods.

A number of studies have evaluated phosphorous control in SDHD patients and showed overall a modest improvement in phosphorous levels and some reduction in phosphate binder use [11, 12]. However clinically, NHD provides better control of phosphorous. In the RCT by Culleton et al., 19 of 26 NHD patients decreased or discontinued phosphorous binders compared with only 3 of 25 in the conventional arm [6]. Similarly, 40 patients followed longitudinally by Lockridge required no phosphorous binders after initiating NHD [9]. Kim et al. described the case of a patient with extraosseous tumoral calcification which resolved after daily NHD. The calcium–phosphorous product dropped from 85 mg^2/dL^2 to <55 mg^2/dL^2 [13]. Finally, in the NHD FHN trial, not only did 73% of the 87 patients not require any phosphorous binders, 42% required supplemental phosphorous in the dialysate to maintain normal phosphorous levels [5].

In addition to the improvement in control of phosphorous, frequent dialysis has been shown to improve overall nutritional status. In a study of eight patients on SDHD, Galland demonstrated improvement in serum albumin, protein intake, and lean body mass [14]. Similarly, improvement in appetite, protein intake, and energy were seen in a study of 14 NHD patients. However, they cautioned that fat intake also increased and put patients at increased risk of becoming overweight [15].

13.2.4 Cardiovascular

End-stage renal disease (ESRD) patients in the USA have an annual mortality rate of approximately 20 % [16], and cause of death is overwhelmingly related to cardiovascular events. Patients using conventional dialysis have long 2–3-day interdialytic intervals in which they become relatively volume-expanded and have more hypertension. Patients using frequent dialysis have overall more stable blood pressure and volume status. In addition, they do not have large volumes of fluid removed over short intervals of time (lower ultrafiltration rate) and therefore have fewer episodes of myocardial stunning and regional wall motion abnormalities [17].

SDHD has been shown to lower blood pressure and reduce the number of anti-hypertensive medications that are required. Fagugli studied 12 patients who transitioned from conventional to SDHD and observed that average SBP dropped 20 mm Hg, use of anti-hypertensive medications decreased, and left ventricular mass index (LVMI), which has been independently associated with increased mortality in the ESRD population, decreased significantly [18]. In the SDHD FHN trial, patients on frequent dialysis had an average of 10 mm Hg decrease in SBP and significant reduction in the mean LV mass as well, compared with the CHD control arm [4].

Similar improvements in blood pressure control and cardiovascular outcomes are demonstrated in a number of studies of NHD. In the RCT of NHD patients by Culleton, there was a significant reduction in LV mass in the NHD group after 6 months of follow-up [6]. In addition, 16 of 26 patients on NHD stopped or reduced the number of blood pressure meds they were taking and concurrently the SBP in the NHD group dropped on average by 7 mm Hg. Chan et al. observed 28 patients who switched from CHD to NHD and found a reduction in SBP of more than 20 mm Hg, a reduction in the average number of blood pressure meds per person from 1.8 to 0.3, as well as a significant reduction in LVMI [19]. There was no change in extracellular volume concurrently, which suggests that more frequent dialysis improves blood pressure control not only because of improved volume control but also by decreasing peripheral vascular resistance. Indeed, endothelial dependent and independent vasodilation improved in NHD patients. Norepinephrine levels were also noted to be lower [19, 20]. NHD has also been shown to improve the cardiac ejection fraction and reduce the frequency of apneic episodes in patients with sleep apnea [21, 22].

13.2.5 Survival

Many, but not all, of the studies addressing survival in frequent dialysis suggest at least a modest mortality benefit for patients. Blagg et al. found that 117 SDHD patients had 61 % better survival than comparable CHD patients [23]. The largest observational study of SDHD to evaluate survival investigated 1873 SDHD patients matched 1:5 with a group of CHD from the United States Renal Data System (USRDS) and showed a modest improvement in survival among patients using SDHD [24]. Similarly, studies comparing NHD show improved survival as well [25, 26]. Nesrallah et al. compared an international group of 338 patients receiving intensive home dialysis treatments (average of 4.8 times per week, 7.4 h per session) with matched CHD controls from the Dialysis Outcomes and Practice Patterns Study (DOPPS) and found a 13 % mortality in the intense dialysis group versus 21 % mortality in the CHD group, during median follow-up of 1.8 years. Finally, patients using NHD have been shown to have comparable survival to recipients of deceased donor kidney transplants [27].

13.2.6 Anemia

The effect of SDHD or NHD on anemia management is less clear. There have been a number of observational studies suggesting improved hemoglobin and reduction in dose required of erythropoietin-stimulating agents (ESA) as well as many studies which show no difference [28, 29]. The FHN trial, both SDHD and NHD arms, shows no difference in hemoglobin or ESA dose [30] nor does the RCT in NHD by Culleton et al. [6].

13.2.7 Special Uses of Home Hemodialysis

13.2.7.1 Pregnancy

Young women on dialysis are typically less fertile, often with impaired ovulation and even amenorrhea, and thus rates of pregnancy are lower than in the general population. For women who do conceive, pregnancy complications include intrauterine fetal death, preterm delivery, and more intrauterine growth restriction [31]. There have been a number of small studies suggesting that more frequent and intensive dialysis, delivered as NHD, is associated with improved fertility and better maternal and fetal outcomes [32, 33]. Gangji

et al. described a 31-year-old woman on CHD who began menstruating 8 months after transitioning to NHD and had a successful full-term pregnancy 2 years after using NHD. During her pregnancy, she received 7.5 h of dialysis seven nights per week [34].

13.2.7.2 Ascites

Patients with ascites, from any cause, can particularly benefit from NHD. Pauly et al. described two patients with ascites who did poorly on CHD with no improvement in ascites because of intradialytic hypotension, cramping, and difficulty removing fluid. Once each patient was transferred to NHD, they experienced resolution of the ascites [35].

13.2.8 Ventilators

Dialysis patients who require continuous or intermittent mechanical ventilation may have difficulty finding a dialysis unit which can accommodate them for in-center treatments. Sometimes, these chronically ill patients cannot sit upright in a chair and would require a bed for dialysis treatments. Oftentimes, the clinical staff at the dialysis unit is not trained and comfortable in handling routine or emergency ventilator care. Finally, it may simply be more cumbersome to transport a patient who requires a ventilator to dialysis thrice weekly. For all of these reasons, mechanically ventilated patients may benefit from HHD if they have the necessary space and someone who can help with their home treatments (personal experience).

13.2.9 Summary

In summary, the overwhelming evidence available suggests that HHD offers an array of improved clinical outcomes for patients, including improved quality of life metrics, improved blood pressure control and reduction in LV hypertrophy, improved phosphorous control, and likely improved survival. In addition to providing all patients with more flexibility and ownership over their own dialysis treatments, NHD in particular can be particularly favorable for certain patient populations such as pregnant women or patients with ascites or who like to have free time during the day to work or pursue other pleasures in life.

13.3 Complications of Home Hemodialysis

With proper training, HD can be performed safely in the home. When patients are selected to be appropriate candidates for this modality, spend weeks training with a nurse before dialyzing independently, receive retraining at specified intervals, and follow specified safety precautions consistently, the rate of complications is very low. One large HHD program in Canada reviewed their HHD population and performed a quality assurance (QA) analysis. From 2001 to 2012, the HHD programs in Edmonton and Ottawa, Canada, trained 190 patients. In total, they estimate 500 patient-years and 117,000 HHD treatments of experience. Over those 11 years, they had only one death (from exsanguination) and six life-threatening procedure-related adverse events, or an event rate of 0.06 per 1000 dialysis treatments. Five events were definitely and two events were possibly attributed to human error and failure to follow specified protocols [36]. Some programs have instituted home-monitoring for patients dialyzing at night. While this provides some patients with reassurance, data have not shown that this practice improves outcomes or reduces complications. The London Daily/Nocturnal Study suggested that home monitoring may be helpful for a period of 3 months, until the patient is completely comfortable with performing dialysis at home [37]. Out of 4096 patient treatments, there were 5351 alarms, 322 calls to patients' home because of slow or nonresponse, and zero calls to emergency medical services. At this time, most practices do not utilize continuous home-monitoring.

There are several preventable, though potentially dangerous, complications of HHD including major hemorrhage, vascular access complications, cardiovascular events during dialysis, equipment malfunction, and psychosocial stress. It is imperative to instruct patients regarding these potential complications during training to underscore the importance of careful attention to procedures and technique. Some patients and health-care providers are concerned about safety of dialyzing alone at home without a partner. Though most programs recommend a partner, there are no data examining this subject, and many physicians have confidence in the experience of their home dialysis team and allow patients to dialyze at home alone. For example, we have a very safe and successful 7-year experience with patients who perform nocturnal HHD alone.

Perhaps the most concerning potential complication of HHD is major hemorrhage. In order to prevent this major complication, patients are taught to meticulously secure the needles with tape and then pull on the tubing to make sure needles do not move. In addition, they are instructed to use blood leak sensors (enuresis alarms) wrapped around the access site and placed strategically on the floor around the machine, which sound an alarm if blood or leaking dialysate is detected.

HHD patients appear to have increased risk of vascular access complications but there is no difference seen in access loss. This result was seen in a number of studies, including both arms of the FHN trials [38]. There is debate in the literature about the best cannulation technique for patients with arteriovenous fistulas—the "rope ladder technique" versus

"buttonhole." The rope ladder technique is most commonly used in-center and uses sharp needles and rotating access cannulation sites. The buttonhole uses a blunt needle and uses the same track with each cannulation. Some literature suggests increased access survival, reduced complications, reduced aneurysms, pain, and infiltrations with the buttonhole technique. However, there is a suggestion of increased risk of staphylococcus infection with buttonholes because of the track that forms [38–41]. Recent experience suggests that the increasing use of topical mupirocin seems to reduce buttonhole-related infection rate. Furthermore, there may be opportunity to decrease vascular access infection in the home by developing "best demonstrated practices" for home dialysis access use. When patients and nurses were surveyed regarding vascular access cannulation, not a single patient or nurse reported performing all steps in accordance with general accepted practice for access cannulation [42]. This study suggests there is tremendous opportunity to improve home cannulation technique and training.

Intradialytic hypotension and dialysis-related symptoms are less common in HHD [43]. There are also reports of a decrease in episodes of myocardial stunning. Myocardial stunning can lead to a decrease in ejection fraction and ventricular arrhythmias during dialysis [17]. Improvement in the aforementioned parameters is probably related to decreased ultrafiltration rates that occur with more frequent sessions and increased overall dialysis time.

Patients who use conventional dialysis equipment need to rigorously follow water treatment and testing guidelines to avoid problems with water quality. It is quite safe to use water in the home for HHD with the portable reverse osmosis machines and carbon filter as long as the patient is meticulous and appropriate water testing and cultures are done at regular intervals. For patients who use NxStage therapy, the NxStage PureFlow system makes ultrapure water from tap water which is mixed with sterile dialysate concentrate. This process is automated and thus is less likely to lead to complications in water treatment.

Finally, HHD can have major psychosocial benefits as well as complications for patients. For the motivated patient with social support, HHD can offer increased independence to tailor treatments around other activities. Many patients report improved physical and mental functioning. However, "burnout" is a major issue, with the discontinuation rate within 1 year of starting HHD in the 25–30 % range [8, 24, 44]. HHD requires significant commitment, time, and energy, and can be difficult for patients as well as their families to maintain. Decreased compliance with treatment frequency can also become a problem in these cases [44].

13.4 Prescription Management

13.4.1 Introduction

There are three components of a home dialysis prescription: solute removal, fluid removal, and quality of life. Solute removal encompasses more than just urea and the physician needs to consider, for example, other small solutes and electrolytes, phosphate and middle molecules. Fluid removal is more complicated than just achieving dry weight because we have to adjust fluid removal to a patient's inherent "refill rate" of the intravascular space to avoid myocardial stunning and the increase in mortality rate-associated high ultrafiltration rates. Finally, if the prescription does not match the patient's lifestyle and will be difficult to adhere to, it will lead to patient dissatisfaction, burnout, and possible dropout from the home program.

There are several different options for HHD including SDHD, NHD, traditional thrice-weekly HD, and even a hybrid plan that enables patients to do different types of treatments according to their schedule. We have patients who do several NHD treatments intermixed with SDHD in a week that varies according to their work and travel schedule with the caveat that changes to prescriptions can be done only with the physician's approval. In order to prescribe HHD correctly, make appropriate changes when target solute and fluid removal is not met, and to develop novel prescriptions to meet the personal needs of the home patient, the physician needs to understand the theory and nuances of each dialysis platform. Though currently there are only two dialysis platforms approved for use in the home, Fresenius 2008K@home (Fresenius) machine and NxStage System One (NxStage), there are new machines in clinical trial and development that will utilize other technologies (e.g., sorbent technology) that will require the physician to learn even more. Typical dialysis prescriptions for current dialysis machines and different HHD modalities are summarized in Table 13.1.

Table 13.1 Hemodialysis prescriptions

	Conventional HD equipment			NxStage	
	HD	SDHD	NHD	SDHD	NHD
Treatments/week	3	5–6	5–6	5–6	5–6
Treatment time (h)*	4	2	6–8	2–3.5	6–8
Q_b (mL/min)	400–450	400–450	200–300	400–450	200–300
Q_d (mL/min)	600–800	600–800	300	100–300	60–100

* we recommend a minimum weekly treatment time of 12 hours
HD hemodialysis, *SDHD* short daily hemodialysis, *NHD* nocturnal hemodialysis

13.4.2 Kt/V

Appropriate solute clearance is difficult to define because we have few tools to measure solute removal and even fewer tools to define what optimal removal is. Kt/V_{Urea} (Kt/V) has become the standard for adjusting dialysis dose for thrice-weekly conventional HD treatments. Dialysis modalities with different levels of continuousness have different degrees of efficiency and therefore cannot be compared by spKt/V. Take, for example, peritoneal dialysis (PD) and continuous RRT modalities, in which the serum blood urea nitrogen (BUN) level does not vary significantly during the day, yet over the course of 24 hours, urea removal is significant. To address this and to have a tool to compare dialysis treatments with different frequencies and duration, the (weekly) standard Kt/V (stdKt/V) model was developed. This model expresses dialysis dose for each modality as an equivalent, normalized (theoretical) continuous clearance [45]. The stdKt/V is the same for all modalities that produce the same mid-week pre-dialysis BUN. Though this model has never been clinically validated as a predictor of clinical outcomes, Kidney Disease Outcomes Quality Initiative (KDOQI) guidelines suggest a stdKt/V of 2.1.

The formula for stdKt/V is quite complex:

$$\mathrm{stdKt/V} = 168 * \left[1 - \exp\left(-\mathrm{eKt/V}\right)\right] / \mathrm{t} / \left[\left(1 - \exp\left(-\mathrm{eKt/V}\right)\right) / \mathrm{eKt/V} + 168 / \mathrm{N} / \mathrm{t} - 1\right] \quad [45]$$

Where: "eKt/V" is equilibrated Kt/V per treatment, "N" is treatments per week and "t" is time per treatment in hours. This formula can be used to generate a nomogram (Fig. 13.1) to estimate, for a given frequency of dialysis, the target per treatment spKt/V to achieve a stdKt/V of 2.0. For example, if a patient performs HD 5 days per week, then target per treatment spKt/V is about 0.6. Note that for thrice-weekly, 4 h HD treatments, a spKt/V of 1.2 is equivalent to a stdKt/V of 2.0.

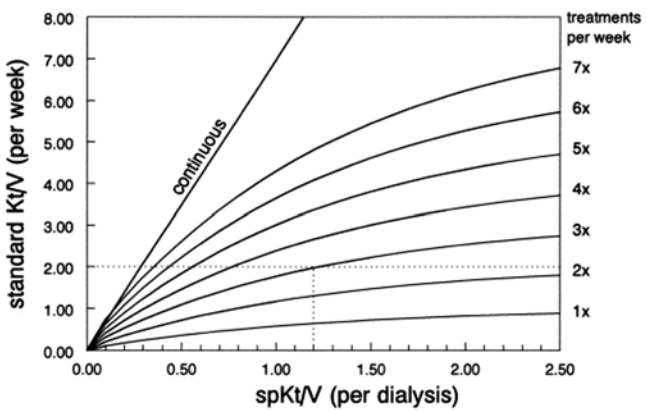

Fig. 13.1 Graph represents relationship between *spKt/V* and *stdKt/V* according to frequency of hemodialysis treatment [45]

The two dialysis machines approved for use in the home, Fresenius and NxStage, use different approaches to achieve target urea clearance and maintain electrolyte levels in the normal range.

13.4.3 Fresenius

Fresenius is a traditional dialysis machine that requires electrical and plumbing modification to the home to accommodate the dialysis machine and water treatment equipment (typically reverse osmosis). Prescription changes are fundamentally the same as using traditional dialysis equipment for in-center HD. SDHD is typically a 2 h treatment, at typical blood flow rates (Q_b) of 400–450 mL/min and typical dialysate flow rates (Q_d). If target spKt/V is not achieved then treatment duration, Q_b and Q_d can be adjusted in the same manner as in-center HD. Electrolyte content of dialysate is prescribed and altered according to blood tests. Ultrafiltration rates should be kept below 10–13 mL/Kg/h as is done for in-center HD patients [46]. For NHD, given the long duration of therapy, lower rates are used. Given lower Q_d rates overall, dialysate volumes are about the same and therefore dialysate electrolyte content is nearly the same as traditional HD. However, longer treatments will result in lower phosphate binder use and therefore, depending on the binder used, serum calcium levels may be lower resulting in higher parathyroid hormone (PTH) levels. In that situation, calcium supplementation or higher dialysate calcium may be required [47]. Occasional patients become hypophosphatemic and phosphate (0.7 mmol/L) is added to the dialysate [48].

13.4.4 NxStage

Patients prefer a simple, easy-to-use dialysis machine that requires minimal storage space, is energy and water efficient, and requires no significant electrical modification to the home. A low dialysate volume approach, though theoretically applicable to any dialysis machine, is a requirement for the NxStage. The hallmark of this machine is adjusting the relationship between Q_d and Q_b to maximize saturation of lower amounts of dialysate. In-center dialysis centers produce relatively large volumes of dialysate. At higher Q_d, urea clearance increases but relatively inefficiently, as noted by a plateau in clearance (Fig. 13.2). However, at low Q_d and relatively high Q_b, dialysate is highly saturated and therefore dialysate is used efficiently. The term "Flow fraction" (FF) is defined as Q_d/Q_b. When the FF is low, dialysate saturation is high (Fig. 13.3).

Part of the prescription for NxStage is selecting a maximum FF that is programmed into the machine. Setting a maximum FF sets minimum dialysate saturation. By fixing

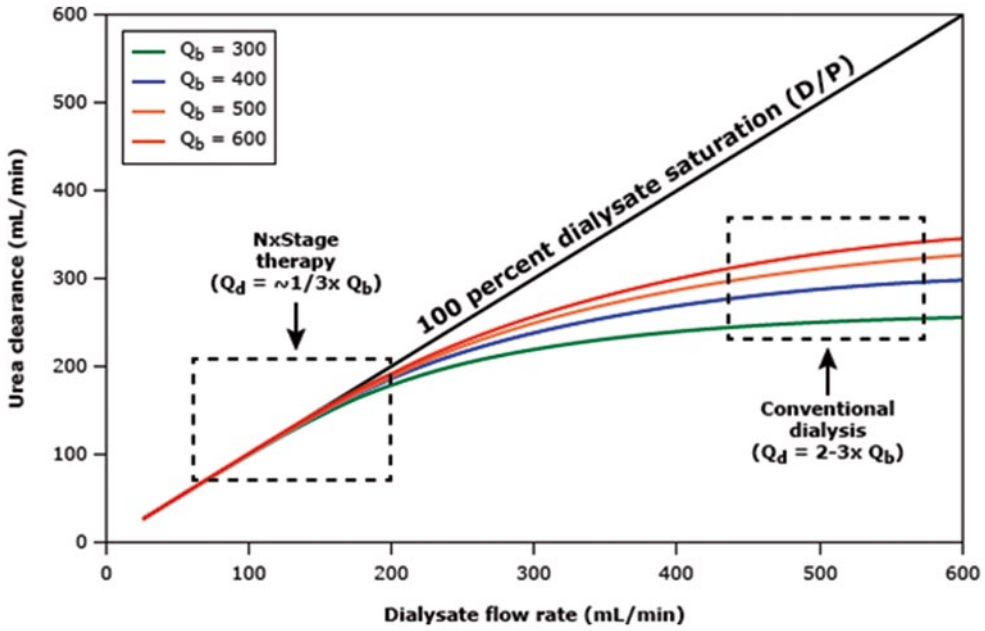

Fig. 13.2 Urea clearance is depicted as a function of dialysate flow rates *(Q_d)* at different blood flow rates *(Q_b)*. At slower Q_d, dialysate is nearly 100 % saturated with urea. NxStage therapy uses low Q_d to maximize dialysate saturation whereas conventional dialysis uses higher Q_d with lower dialysate saturation. (Data reproduced with permission from NxStage Medical, Inc. Copyright © 2012)

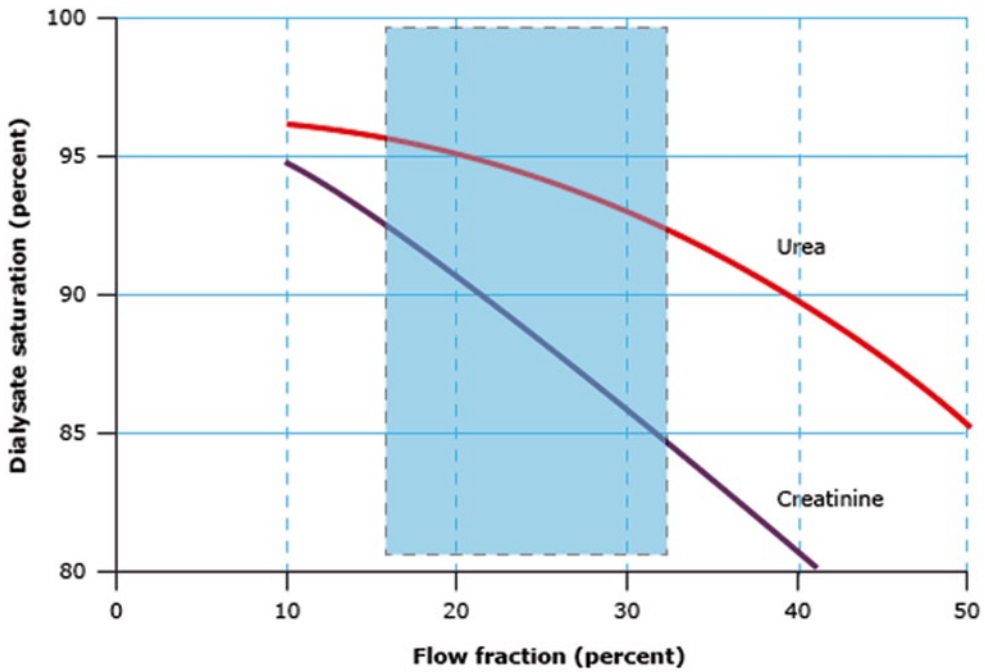

Fig. 13.3 Graphs represent dialysate saturation in relationship to flow fraction (FF). At lower FF, dialysate saturation is higher. (Data reproduced with permission from NxStage Medical, Inc. Copyright © 2012)

the minimum saturation (saturation can be higher but not lower during a treatment), the patient will receive their target Kt/V as long as they complete their treatment with the prescribed amount of fluid. The methodology to measure stdKt/V is exactly the same as any HD treatment; a urea reduction ratio (URR) is obtained and converted to a spKt/V which is converted to a stdKt/V as previously described in this chapter.

However, to appropriately adjust the prescription to achieve target Kt/V, it is useful to conceptually consider Kt/V for HD just as we do for PD. In PD, the volume of PD dialysate drained multiplied by D/P urea (percent saturation

of PD fluid relative to plasma) will equal the amount of drained dialysate that is completely (100%) saturated (Kt). Then Kt is divided by an estimate of V. This is represented by the formula:

$$Kt / V = \left(D / P_{Urea}\right)\left(\text{Dialysate drain volume}\right) / V.$$

For NxStage, therapy (D/P_{Urea}), or percent saturation, is determined by the FF (Q_d/Q_b). To increase percent saturation, we decrease FF, which invariably means Q_d will be lower. If Q_d is lower, it will take longer to process the fixed amount of dialysate and treatment time will be longer. Similarly, if the prescribed dialysate volume is increased, at the same FF (same Q_d), the treatment will be longer. Finally, because Kt is equal to the product of percent saturation and dialysate volume, one could generously increase dialysate volume and modestly decrease percent saturation and still achieve a higher Kt/V.

For example, if we have a 76 kg patient who wants to do 5-day-per-week SDHD, we will need to target a per treatment spKt/V of about 0.6 (Fig. 13.1). Assuming his V is about 38 L, he will need a Kt of about 23 L (0.6 multiplied by 38 L). If we decided to use 25 L of fluid, it will need to be 92% saturated to yield 23 L of 100% saturated fluid. We can estimate the patient needs a flow fraction of about 0.3 to achieve a percent saturation of 92 (Fig. 13.3). Assuming Q_b is 400 mL/min, the Q_d will be about 120 mL/min. If we have to process 25 L of dialysate at a rate of 120 mL/min, the patient will have a treatment time of nearly 210 min. If we redo the calculation using 30 L of dialysate, we could use a FF of 0.5, achieve percent saturation of 85%, and Kt will be more than 25 L. Assuming Q_b of 400 mL/min, Q_d will be 200 mL/min and treatment time will be about 150 min. We are able to save the patient an hour of treatment time, improve quality of life, and achieve a higher Kt/V! Remember, regardless of our estimate of Kt/V for a given prescription, we measure URR to calculate stdKt/V.

There are limited options for altering the electrolyte content of the dialysate when using the NxStage system. Dialysate is available in pre-packaged 5 L bags, or generated by a self-contained dialysate generating system (PureFlow™ SL). PureFlow™ SL makes ultrapure water from tap water and then adds it to sterile dialysate concentrate to produce dialysate in 40, 50, or 60 L batches. The dialysate buffer is lactate which is metabolized in the liver to bicarbonate in a 1:1 ratio. The composition of dialysate currently available is:

- Lactate—40 or 45 mEq/L
- Potassium—1.0 mEq/L and for 2.0 for some of the batches
- Sodium—140 mEq/L
- Calcium—3.0 mEq/L
- Magnesium—1.0 mEq/L
- Chloride—105 mEq/L
- Glucose—100 mg/dL

Note that hypokalemia and hypercalcemia are unusual because of the relatively low volume of dialysate used [49].

13.4.5 Blood Pressure Management

Regardless of dialysis equipment used at home, most HHD patients require significantly less blood pressure medication. Blood pressure may fall even within days of beginning therapy and therefore it is very important to reduce the antihypertensive regimen *prior* to beginning SDHD or NHD by as much as 50% and monitor blood pressure closely to avoid hypotensive events. Initially, most patients will be able to achieve a lower estimated dry weight once they are dialyzing more frequently, and blood pressure medications often need to be reduced or discontinued as the dry weight is reduced. With time, many patients may gain body weight, blood pressures tend to decrease again, and dry weights need to be increased. Patients need education regarding the risk of hypotension at home and to report low blood pressures promptly to the HHD nurse. Eventually, if the prescription and dry weight are correct, most patients require no or just one anti-hypertensive medication.

13.5 Developing a Home Dialysis Program

Intentionally, we describe how to build a successful home dialysis program as opposed to just an HHD program because the many similarities between HHD and PD essentially dictate that these two programs live under one roof. Strategies to increase utilization of HHD will also increase utilization of PD. Teaching methods to improve training and retraining of patients are similar for HHD and PD. Programs to develop QA and continuous quality improvement (CQI) initiatives overlap for these two modalities. Finally, the goals, philosophy, and mission of PD and HHD programs are the same and should be clearly stated and practiced.

Our program's philosophy keeps it very simple: "It's all about the patient." That is, we practice "patient-centric" medicine and try to incorporate the patient's vantage point in every aspect of the program. For example: we typically present patients with options for prescription changes to make sure it is compatible with their lifestyle, and we organize comprehensive, multidisciplinary monthly clinic visits to minimize patient visits and allow us to address all of their needs at one time. Every project, miscue, and opportunity for improvement in the process of setting up a home program will turn into a success if the entire home dialysis team focuses on the patient's needs (and not necessarily ours).

There are three major components of a home dialysis program: the people, the physical infrastructure, and the policies and procedures that operate the clinic. For certain, the peo-

Table 13.2 The medical team

At least one person needs to be the program champion
Nurses
Physician
Social worker
Dietician
Administrator
Biomedical engineer
Administrative assistant
Patient care technician
Interventional radiologist
Surgeon (vascular and laparoscopic for PD)

PD peritoneal dialysis

Table 13.3 Sources and strategies to recruit patients

In-center hemodialysis
"Lobby days"
Chairside machine demonstrations
"Try it you will like it" programs
Patient support groups
CKD patients
CKD education
One-on-one meetings with home dialysis nurse
Acute start patients
In-hospital modality education
Maintain contact with patients interested but not ready to commit
Transplant patients
Develop relationships with transplant program

CKD chronic kidney disease

ple are most important and patients are paramount because without patients there is no program (Table 13.2). A home dialysis facility needs to project census prior to developing space and hiring staff. It is shortsighted to build a space that will be too small within a year or two or have to mothball because of inadequate utilization. Set a goal for projected census growth. Though there is limited literature, realistically, 5–10% of dialysis patients will embrace HHD. PD literature is much better defined. Given the opportunity to choose a dialysis modality, 35–40% of incident patients select PD [50]. Of course, there will be some variation according to demographics and some practices will have higher utilization. However, a beautiful home and a college education is not a requirement. We have single mothers with barely high school education succeeding tremendously on HHD and similarly we have octogenarians and functionally illiterate patients thriving while on PD.

All patients deserve the opportunity to learn about options for RRT without bias or prejudice of health-care providers. Our paradigm for presentation of options is straightforward. Patients who are interested in transplant are referred for transplant evaluation, and patients who may not benefit or are not interested in RRT are counseled on options for appropriate medical care. Patients who are interested in RRT are told they can have dialysis treatments done in the comfort of their own home or they come to a dialysis clinic 3 days per week. We then review home options (PD vs. HHD), as well as benefits and disadvantages of each modality. In-center thrice-weekly HD as well as NHD is also offered. After this relatively brief outline is presented, we refer every patient to one of our home dialysis nurse educators for a more detailed one-on-one meeting. During these meetings, patients have the opportunity to see home dialysis equipment and receive all the information they need to make an educated decision regarding RRT. Finally, prospective patients frequently speak directly with current home dialysis patients to get a different and insightful perspective.

There are several sources of patients. Robust chronic kidney disease (CKD) education programs for both outpatients and inpatients will help attract patients. For HHD, the largest source of patients is probably transfers from in-center HD. To recruit patients from your in-center program, consider "lobby days" where patients can receive educational materials and see HHD machines. For those patients who are great candidates, do an up-close machine demonstration while they receive in-patient HD. And for the patient who is highly motivated but not 100% confident, consider investing in a trial of SDHD training. If the patient likes it, they can complete training. If they don't feel any better (unlikely), they will return in-center. Finally, a relatively high proportion of our home dialysis patients have failed kidney transplants or developed renal failure as a consequence of chronic immunosuppression for other solid organ transplants. Develop programs to attract these patients (Table 13.3).

The medical staff needs at least one "leader" or "champion" and preferably two from different disciplines (e.g., physician and nurse), but everyone on the team needs to understand the special needs of the home patient. The physician needs to be the point person for patient recruitment but, along with the nurse champion, develop staff education programs, policies and procedures, program development, and QA and CQI projects. The day-to-day operation of the program rests on the shoulders of the nurse. Having a great nurse is the key to success so make sure to recruit the right nurses and invest in their education. Dietary restrictions for patients improve but do not disappear with home dialysis, so a dietician knowledgeable about home therapies is essential. The social worker is the key to provide support to patients and families, and identify potential changes in the home that may lead to patient burnout or dropout from the program.

The physical infrastructure includes the clinic space and layout as well as dialysis equipment. In keeping with the theme of "it's all about the patient," we strongly believe that the space needs to be beautiful, comfortable, warm, and appealing (Fig. 13.4 and 13.5). It is often difficult to retrofit existing space for home dialysis in most dialysis facilities because a storage closet converted to a multiuse training and exam room is rarely attractive and does not allow for growth.

Fig. 13.4 Home dialysis unit with a central nursing work area surrounded by training and exam rooms

Fig. 13.5 Two home hemodialysis rooms separated by a sliding pocket door allow a nurse to monitor two patients at once yet provide privacy when needed

A new program will focus primarily on training patients but eventually the nursing staff will spend a significant portion of their time with monthly, routine, and urgent clinic visits. A space that focuses only on training rooms and not the workflow of the staff during clinic visits will fall short of needs and will lead to tremendous inefficiencies and frustrations for the nurses. As an example, we elected to have a central nursing station with work spaces and rooms surrounding the nursing station. The nurses also have laptops with a wireless connection so they can document and enter orders easily in every room. We also like having two training rooms connected by sliding pocket doors so they can be used to take care of two patients at once during training yet also provide privacy when needed. We have designated clinic rooms that are not used for training but the training rooms can be used for clinic visits during those very busy days. The training rooms should obviously have appropriate drains for used dialysate, and if you plan to use the Fresenius 2008K@Home

machine, make sure there is appropriate water and electric connections. The NxStage machine does not require special plumbing and runs on standard electric outlets. It's size, simplicity, and portability makes it the machine of choice for almost all of our patients.

Developing policies and procedures is beyond the scope of this limited article. Suffice to say some policies are universal and apply to both in-center HD and HHD. But there need to be home dialysis-specific policies, procedures, and protocols. As previously noted, we believe in the multidisciplinary model of home dialysis care and schedule monthly patient visits at the home dialysis center with the nurse, physician, social worker, and dietitian all present. Some programs have a separate nursing visit at the facility and a physician visit at the physician's office or at the facility on another day. But we mandate that physicians participate in the multidisciplinary visit because we find that we are much more effective and thorough when the entire team sees the patient at the same time.

Finally, QA and CQI projects are especially important not only in the early, developmental phase of the program but also as the program matures. Identify quality indicators other than the usual Kt/V, anemia, and albumin for example, which the medical team feel are important and specific to the program such as dropout, blood pressure control, and adherence to treatments. If outcomes fall short of predetermined goals, develop projects and teams to fix them. The quality of the program helps increase the census of the program because dropout rates will be lower. But having a larger program will not guarantee better outcomes if the right staff, facility, and procedures are not developed. QA and CQI projects are a win-win situation: they improve patient care and the professional satisfaction of the whole dialysis team.

13.6 Conclusions

There are many options for RRT, and it is important for the nephrologist and patient to work together to figure out what the best dialysis modality is for the individual patient at a given time. Both the literature and the experience of established home dialysis programs suggest improved clinical outcomes and patient satisfaction with HHD. However, it is important that the patient and nephrologist are comfortable with managing a dialysis patient at home to reduce the risk of complications. The development of new technology has already made and will likely continue to make performing dialysis at home simpler and safer. It is our belief and hope that with proper education and training of patients and physicians, the prevalence of HHD use in the USA can grow, allowing us to provide dialysis care tailored to our ESRD patients.

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