Home Hemodialysis: Core Curriculum 2021

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In the early days of dialysis, because of a lack of existing in-center infrastructure, home hemodialysis (HHD) was frequently used to expand dialysis programs. Recently, HHD has been thrust into the spotlight of kidney care programs once again. Patients and policymakers are demanding more choices for the management of kidney failure while controlling for cost. Perhaps it is not surprising that the kidney community's interest in HHD has been revived, especially during the COVID-19 pandemic. To meet this increased interest and demand, nephrologists and dialysis providers must embrace new technologies and improve their understanding of HHD systems. This installment of *AJKD*'s Core Curriculum in Nephrology seeks to inform the reader about factors that can improve success in the training and retention of HHD patients. Benefits, pitfalls, and challenges of HHD are outlined. The features of novel and commonly used HHD equipment are also summarized. Examples of prescriptions and prescription adjustments to meet the needs of patients will also be reviewed. Finally, considerations related to medical management of HHD patients and their dialysis access at home are also included. HHD is an important tool for the management and rehabilitation of patients with kidney failure, which allows for patient-centered care and increased patient choice.

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Introduction

Since the early days of dialysis treatment for kidney failure, clinicians recognized that they could reach more patients in a less costly and more efficient manner if the patient was willing and able to assume some of the responsibility for the delivery of their care. Early dialysis programs developed robust outpatient home hemodialysis (HHD) systems that were eventually supplanted by the increase of in-center dialysis, which resulted in a subsequent decrease in the number of patients treated at home. The use of HHD in other countries is robust, and the uptake of HHD has increased substantially in the United States during the past several years. Even so, the number of patients who use this therapy still lags far behind in-center hemodialysis (HD) numbers. In the United States, in 2016, only 1.8% of prevalent patients were treated with home dialysis and only 0.3% of patients who began dialysis started with HHD. Among other benefits, HHD gives patients greater freedom from rigid schedules currently mandated in modern HD centers, allows for more frequent and customizable delivery of therapy to meet individual patient needs, and has demonstrable quality-of-life benefits. However, despite these benefits, several barriers still remain for patients and providers interested in using HHD therapies.

Factors That Contribute to HHD Success or Failure

Case 1: *Ms D is a 64-year-old woman with longstanding chronic kidney disease (CKD) secondary to type 2 diabetes mellitus with significant diabetic retinopathy. She began HD on an urgent basis in the hospital after presenting with kidney failure. She has mild visual impairment as a result of diabetic retinopathy. There is a mature fistula in her upper arm that was created several months ago. She is discharged to the outpatient dialysis center, and you meet her there for unit rounds. She reports to you that she is miserable undergoing dialysis and feels "washed out" after the treatments. She heard that home dialysis is an option that may not cause as many symptoms after dialysis. She believes this will free her schedule so she can go back to work. She also states she has significant support at home if needed to initiate alternative forms of dialysis.*

Question 1: Based on the above case scenario, is this patient a good candidate to initiate HHD?

For the answer to the question, see the following text.

Kidney replacement therapies are inherently expensive, and their use is largely dependent on the resources available to support patients and their care providers. Past events created a "perfect storm" that led ultimately to the demise of HHD treatments in the United States. In countries where payment policies favor home therapies and allow for caregiver support or assisted home dialysis, the number of patients who have access to these therapies is much higher. When highly specialized therapies are underused, a subsequent "brain drain" occurs such that nursing and physician expertise is lost or not maintained.

The Core Curriculum aims to give trainees in nephrology a strong knowledge base in core topics in the specialty by providing an overview of the topic and citing key references, including the foundational literature that led to current clinical approaches.

Without a local champion who generates interest from patients and providers or robust financial backing, there is no incentive for dialysis organizations to invest in infrastructure for home dialysis programs. Additionally, training programs for kidney doctors, particularly in the United States, frequently do not have mentors with home dialysis expertise available, and trainee patient panels at many academic centers do not include HHD patients. On the contrary, with proper investment in training, appropriate reimbursement, and creation of efficient dialysis center infrastructure, home dialysis programs can thrive and lower the cost of care over time. Common obstacles patients and providers must traverse are listed in Table 1.

One of the most important factors that determines success in HHD is patient motivation. Patients who are strongly motivated to perform dialysis at home are often the most successful. Motivation to embrace home dialysis is modifiable through direct patient education, appropriate counsel from physicians, and attention to patient concerns. Another important factor in HHD success is motivation of the dialysis provider and the support system of the dialysis unit. Entrenched, dogmatic home dialysis programs that attempt to select candidates for the therapy based on preconceived notions of successful patient characteristics are doomed to languish with low numbers and continue to shunt the bulk of their patient population to in-center treatment. Alternatively, nimble programs with out-of-the-box thinking and can-do attitudes will build innovative systems of home dialysis care to meet their patients' needs.

In the case above, the path of least resistance would be to have the patient continue in-center dialysis and not pursue home dialysis training. The patient-centered approach would employ the entire interdisciplinary team to troubleshoot the limitations that challenge her, assess her resources at home, and develop strategies for her to be successful in the home. Family members or caregivers can play an important part in assisting patients at home. Patients who will have a living transplant donor available may be better suited to peritoneal dialysis rather than HHD. Patients with limited vision or blindness will need the full support of family members or others to be successful with HHD. Those with significant dementia, stroke, poor short-term memory, or an uncontrolled seizure disorder may not be good candidates for HHD without significant in-home care resources. Self-care HD in a dialysis center may be useful for those without stable housing. With proper guidance from the dialysis center interdisciplinary team, motivated patients can often find ways to be successful. Thus, the answer to question 1 is that this patient, who is elderly and has mild diabetic retinopathy and diabetes mellitus, but has significant family support, is a viable candidate for HHD.

Table 1. Common HHD Obstacles and Solutions

Obstacle	Solution
Inadequate training/education about modality options	Early education about kidney replacement therapies, especially HHD
Myths and misconceptions propagated by other patients, health care providers	Additional classes on the benefits of HHD therapy and patient testimonials
Lack of nursing or physician expertise	Physician champion and dedicated HHD nursing staff
Patient ability to self-cannulate	In-center training while receiving in-center hemodialysis
Unavailable dialysis center infrastructure	Dedicated HHD team
Economic disincentives	Dedicated home dialysis program that integrates PD and HHD; payment for HHD helpers
Patient anxiety/fear of being home alone/lack of confidence	Increased education, "buddy system," telemedicine home monitoring
Patient or caregiver burnout	Regular dedicated in-center respite care
Concern over "medicalization" of the home	Home visit and efforts to incorporate patient-centered approach to HHD
Lack of adequate space, stable housing	Social services may help establish better HHD access; in-house self-care programs may allow patients to initiate their own dialysis with patient-friendly machines

Abbreviations: HHD, home hemodialysis; PD, peritoneal dialysis.

Additional Readings

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Improving Patient Access to HHD

Patient lack of awareness of the modality options available to them, as mentioned previously, is a significant barrier to additional uptake of HHD in certain regions. Strategies have been implemented that have shown an improvement in uptake of HHD and include multidisciplinary CKD clinics with dedicated nurse educator and nurse navigator programs for patients, in-hospital CKD and dialysis modality education, and early education about available HHD modalities. Education should be early and often, with a focus on meeting patients where they are with regard to socioeconomic and caregiver resources. Systems that provide reimbursement for home dialysis care nursing or technician support tend to have more patients undergoing home therapies.

Telehealth programs are also finding new and innovative ways to deliver dialysis care to patients and reduce burden of therapy, particularly to those who live at a distance from their dialysis provider or physician. Remote monitoring systems can help the interdisciplinary care team recognize potential problems the patient may be encountering at home before they develop into more serious issues. Routine visits or checkups with the physician can be conducted via telehealth to decrease patient burden of travel and save time. Additionally, providers can be more readily available to troubleshoot acute complications with access or mechanical complications via a video connection at home. Unfortunately, significant disparities exist in access to reliable internet and cell phone coverage in certain areas, particularly rural settings.

Additional Readings

➢ Chan C, Wallace E, Golper TA, et al. Exploring barriers and potential solutions in home dialysis: an NKF-KDOQI conference outcomes report. *Am J Kidney Dis.* 2019;73(3):363-371. ★ESSENTIAL READING

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Potential Benefits of HHD

The patient in case 1 reports a very common and often debilitating symptom of in-center HD: severe fatigue or "washed-out" feeling after the treatment. This common problem for dialysis patients is not well described scientifically, and the practicing nephrologist has few tools in hand to address it. HHD has been reported to mitigate some of these symptoms and improve quality of life. The exact reason for improvement is unclear but may be related to the speed at which the internal chemistry of the body is altered or the rate of ultrafiltration. HHD allows for a gentler correction of the metabolic milieu with more frequent and lower-volume ultrafiltration, which is likely to promote more stability during the dialysis treatment and lower symptom burden. In addition, 2-day breaks from dialysis treatments, also known as the deadly "dialysis weekend," can be avoided at home with more frequent treatments. Box 1 lists some potential benefits of HHD versus in-center dialysis that have been observed in the literature. Special patient populations who do not fit within the typical thrice-weekly dialysis regimen may also benefit from home dialysis. Some examples include pregnant patients who benefit from more frequent dialysis, patients with refractory hyperphosphatemia, and patients with hemodynamic instability or cardiovascular disease who require low ultrafiltration rates and extended treatment times to maintain blood pressure during dialysis treatments.

Box 1. Associations of Benefit With Home HD Versus In-Center HD

- Improvement in blood pressure control
- Regression of left ventricular hypertrophy
- Superior phosphorus control
- Better quality of life
- Fewer symptoms of fatigue, less washed-out sensation following dialysis
- Lower medication burden
- Improved pregnancy outcomes

Abbreviation: HD, hemodialysis.

In this case, it would be reasonable to have the patient try HHD treatments on an in-center basis for 1 week to see if the symptoms improve with more frequent, "gentler" dialysis. So-called transitional or self-care dialysis units are well positioned to offer patients this type of trial.

Additional Reading

➢ Miller BW, Himmele R, Sawin DA, Kim J, Kossmann RJ. Choosing home hemodialysis: a critical review of patient outcomes. *Blood Purif.* 2018;45(1-3):224-229. ★ESSENTIAL READING

Potential Challenges With HHD

There are many challenges in arranging for safe dialysis at home. Concerns can develop from patients regarding the safety of performing HD in the home while isolated from medical staff. Competence or ability to perform needle cannulation is often cited at the forefront of barriers to patient confidence. Burden of therapy, physical space or housing limitations, and availability of support to perform the treatments also can present potential roadblocks to success. Caregiver fatigue and patient and/or caregiver burnout are common and often go unrecognized by health care professionals. Physicians prescribing HHD need the full support of the interdisciplinary team to address the myriad social and technical obstacles that patients will encounter. Training can be onerous and resource-intensive for the patient, caregivers, and the dialysis provider. In-center respite care should be made readily available to avoid patient and care-partner burnout. Uncompensated time off from work is often necessary to participate in training programs. Much is expected of patients and dialysis providers to achieve success in the home. Although the initial investment is high from the patient and the dialysis unit, dividends are paid the longer the patient is able to continue in the home. Costs for HHD have been quantified internationally and indicate that costs for HHD are between those of peritoneal dialysis and in-center dialysis. Projected Medicare costs for home programs compared with in-center treatment indicate that significant cost savings could be obtained with minimal increases in peritoneal dialysis and HHD patient populations in the United States.

Additional Reading

➢ Seshasai RK, Wong T, Glickman JD, Shea JA, Dember LM. The home hemodialysis patient experience: a qualitative assessment of modality use and discontinuation. *Hemodial Int.* 2019;23(2):139-50. ★ESSENTIAL READING

HHD Technology

Ideally, HHD equipment is designed so it is simple to set up, has intuitive features including a patient interface that includes visual and audio prompts, and contains built-in remote monitoring and safety features. Unfortunately, currently commercially available HHD technology has lagged behind other technologies with regard to updates. The future holds much promise for the next generation of HHD technology; however, in the United States, there are currently 3 HHD systems that are approved by the Food and Drug Administration for use in the home, and 2 are now manufactured by a single company and have not had their technology substantially updated in years. We will discuss some of the features of these machines below.

Conventional Machine HHD

Dialysis can be performed at home with a conventional HD machine. One such machine is Food and Drug Administration–approved for home use, the Fresenius 2008K ("Baby K") HD machine. The features of this machine are essentially identical to those of a traditional in-center HD machine. The setup for a dialysis treatment involves stringing blood tubing and the typical saline solution prime procedure. In addition to the dialysis machine, a portable reverse-osmosis water treatment system is used for water purification. Dialysate concentrate is proportioned with the treatment water to provide large volumes of dialysate for the treatment. Dialysis prescriptions are often similar to in-center prescriptions or can be adjusted to fit patient needs with regimens such as short daily dialysis or nocturnal dialysis (Table 2).

Table 2. Typical Conventional Dialysis Machine Home Prescriptions

Parameter	Short daily	Nocturnal
Treatments per week	5-6	5-6
Time, h	2-3	6-8
Blood flow, mL/min	300-400	200-250
Dialysate flow, mL/min	500-800	300

NxStage System One

The NxStage system is designed to be more patient-friendly and simpler to use at home than traditional HD machines, although the analog patient display is quite outdated by current technological standards and essentially has not changed since its initial development. The setup includes a cartridge that contains tubing and filter "pre--strung"; this is inserted into the machine to engage with the various sensors and pumps. The circuit is closed, making the priming process fairly time-consuming and laborious to remove all the air from the system and clear the alarms. The NxStage system directly addresses one of the key limitations to HHD therapy: lack of access to a large volume of purified water. The machine relies on the concept of water-efficient dialysis, which occurs by slowing the ratio of dialysate flow (Qd) to blood flow (Qb), a ratio also known as the flow fraction (FF), and allowing the dialysate to become more saturated with toxins over time. This concept is fundamentally different than traditional dialysis, which relies on large-volume dialysate and fast Qd rates to increase diffusive gradient and improve dialysis efficiency from a toxin-clearance standpoint. The NxStage prescription is a bit nuanced because of this fundamental difference. For a given treatment, providers determine a dialysate volume, Qb rate, ultrafiltration rate, and FF. The machine will then run the treatment for the duration needed at the Qd rate needed to meet those parameters. Dialysate flow rates are typically in the range of 100-300 mL/min depending on the version of machine used. The System One maximum flow rate can reach 12 L/h or 200 mL/min, and the System One S maximum flow rate can reach 18 L/h or 300 mL/min. Dialysate can come from preformed bags or from a water purification system (PureFlow system).

Tablo HD Machine

The Outset Medical Tablo machine is the most recent addition to the HHD armamentarium and was approved for home use by the Food and Drug Administration in April 2020 after a multicenter safety trial. The Tablo machine is reported to be relatively easy to set up and has an incorporated reverse-osmosis system. During the initial trial, treatments at home occurred 4 times per week for 3.4 hours per session. Patients were able to meet adequacy targets set at Kt/V ≥2.1 with no difference in adverse events between in-center and home dialysis. The Tablo machine can be used more like a traditional HD machine, but Qd rate is limited to 300 mL/min. In addition, it has a heat disinfection system for daily disinfection, but requires a chemical cleaning once per week, which may be difficult for patients and is one of the drawbacks of the system.

Water Treatment Systems

Securing a large volume of purified water for HHD is one of the major limitations to expansion of traditional dialysis methods in the home. Typical conventional dialysis treatments for 4 hours require Qd rates of 500 mL/min, mandating ≥120 L of purified water. Dialysis centers can take advantage of economies of scale to produce this water with large water purification systems serving multiple patients at the same time. However, this type of water treatment is not efficient and is costly for HHD patients. Home plumbing was not built to support large flows needed for dialysis. Purification equipment and the sheer volume of water needed can prohibitively increase utility costs for patients. There is a risk of serious events in the setting of water system failure. Fortunately, water system failure is very rare, and the adverse event rate is low.

Home water can be from municipal sources or, if the patient lives in a rural area, the water can come from a well or a surface source. The contents of the water being used has an impact on the HHD water treatment system. If well water has a high ionic content, it may require a prefiltration system including a water softening process and/or additional filtration to protect or increase the longevity of the dialysis water treatment system and filters. Patients will need to have their home assessed for the appropriateness of HHD and will need to have their source water and treated water tested to assure they meet the standards of the Association for the Advancement of Medical Instrumentation at least annually or upon any changes to the water supply by municipal authorities. In addition, monthly testing of the purified water for colony count and endotoxin is recommended. Chlorine tests need to be performed every time dialysate is produced at home.

The slower Qd rates used with NxStage technology allow for smaller and more compact water treatment systems; the PureFlow system is most commonly used at home for dialysate preparation in this context. This system uses deionization, among other filters, for purification of water (Fig 1). The purified water combines with concentrate to form the final dialysate, which is delivered to the dialyzer. Production of a full batch of dialysate with the PureFlow system requires approximately 8 hours. Therefore, many patients have to set up their PureFlow system to produce dialysate 1 day in advance of the dialysis treatment. This means that, if they are undergoing short daily dialysis, patients often need to work to set up their dialysate production for the next day immediately after they finish a dialysis treatment. A single batch of water can be used for multiple treatments or if the prescribed dialysate volume is low; otherwise, the water needs to be generated after each treatment (dialysate concentrate comes in 40-, 50-, and 60-L volumes). The burden of work involved in this process is not insignificant to most patients.

With conventional dialysis machines, water must be pretreated with a separate mobile water purification system in the home. The systems most commonly used are similar to those used in most hospitals for portable dialysis at the beside, and include a backflow preventer, pretreatment ultrafilter, 2 carbon tanks for redundancy of chlorine and chloramine removal, and a portable reverse-osmosis system. The portable water purification system requires regular maintenance, monitoring, and routine disinfection, which adds to the patient burden of treatment and the complexity of HHD.

The Tablo system has its own internal water treatment system, which can be thought of as a miniaturized water treatment system and is similar to conventional water treatment systems. It is contained within the machine itself and not separate from the device that performs the dialysis therapy. Given the Tablo system's scaled-down size, water production does not occur as quickly as with the conventional machine; therefore, there is a limitation in Qd rates with the Tablo machine compared with conventional HD. Also, if the source water has a high sediment content, additional filters may be needed for the machine to perform dialysis properly.

Additional Readings

➢ Young B, Chan C, Blagg C, et al. How to overcome barriers and establish a successful home HD program. *Clin J Am Soc Nephrol*. 2012;7(12):2023-2032.

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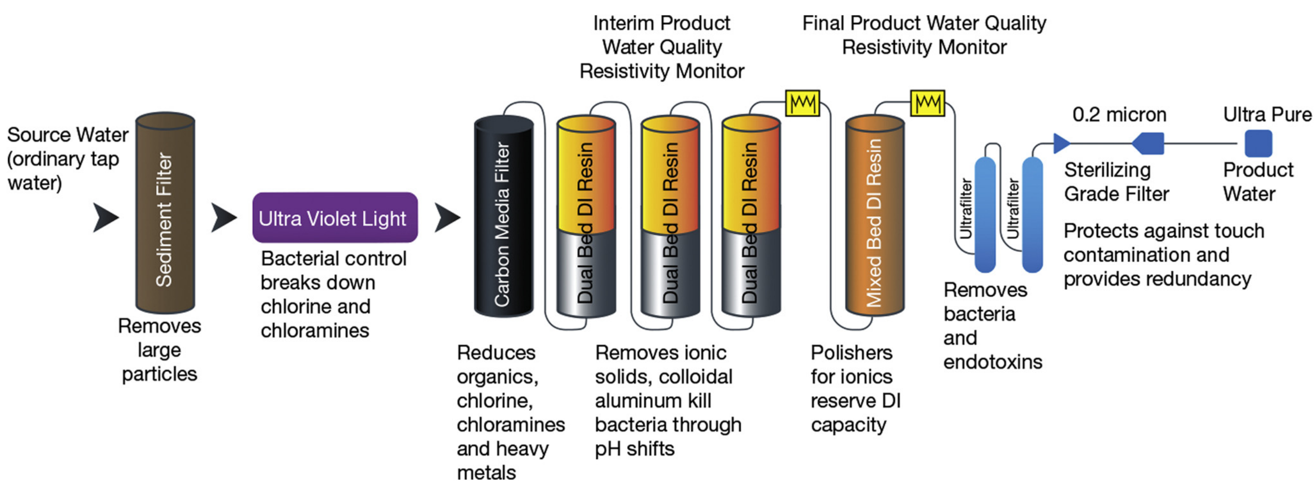

Figure 1. NxStage PureFlow Purification Pack water purification system. Image ©2019 NxStage Medical, Inc; reproduced from *Therapy Handbook: NxStage Hemodialysis Treatment* with permission of the copyright holder.

outcomes over 1 year in home hemodialysis patients using 2008K@home or NxStage System One. *ASAIO J.* 2016;62(2):182-189. ★ESSENTIAL READING

➢ Damasiewicz MJ, Polkinghorne KR, Kerr PG. Water quality in conventional and home haemodialysis. *Nat Rev Nephrol.* 2012;8(12):725-734. ★ESSENTIAL READING

➢ Plumb TJ, Alvarez L, Ross DL, et al. Safety and efficacy of the Tablo hemodialysis system for in-center and home hemodialysis. *Hemodial Int.* 2020;24(1):22-28. ★ESSENTIAL READING

➢ Liu F, Walton S, Leipold R, Isbell D, Golper TA. Financial implications to Medicare from changing the dialysis modality mix under the bundled prospective payment system. *Perit Dial Int.* 2014;34(7):49-57.

Crafting an HHD Prescription

Case 2: *Mr Y is a 60-kg man with polycystic kidney disease who has decided he would like to pursue home dialysis. He has a well-functioning access, is experienced with in-center self-cannulation, and typically undergoes in-center dialysis 4 times per week because of large fluid gains. He wants to improve his quality of life and control over his schedule by transferring to HHD. He reports to the clinic for evaluation with you to get a better idea of what his options are for HD treatment at home. You review the prescriptions with him that would be suitable to achieve adequate dialysis.*

Question 2: The most reasonable initial home dialysis prescription for Mr Y would be:

a) NxStage, 3 times weekly, Qb of 250, volume of 30 L, FF of 20%
b) Baby K, 2 times weekly, 5 hours, Qb of 400, Qd of 800
c) NxStage, 5 times weekly, Qb of 300, volume of 30 L, FF of 40%
d) Baby K, nocturnal, 12 hours every day, Qb of 400, Qd of 800
e) Tablo, 3 times per week, 3.4 hours, Qb of 400, Qd of 300

For the answer to the question, see the following text.

Conventional HHD (Baby K)

HHD with a conventional machine can be prescribed similarly to how it is prescribed in a dialysis center (Table 2). Alternatively, prescriptions can be modified to meet patient needs. Short daily dialysis or nocturnal dialysis is an option for patients for whom there is concern for persistent volume overload or a need for increased solute clearance. Dialysis can be performed every other day to avoid the typical in-center 2-day break (ie, dialysis weekend), which is associated with sudden cardiac death. Schedule flexibility is a major benefit of conventional home dialysis.

NxStage

The NxStage prescription requires a different thought process than a typical dialysis prescription. The machine uses slower Qd rates and fixed dialysate volumes, so the prescription is written in a way that is unique to the technology and is, at times, confusing to providers who are most familiar with conventional HD. The prescription calls for a total volume of dialysate to be used (similar to peritoneal dialysis), Qb rate, ultrafiltration rate (similar to HD), and FF (unique to NxStage). Based on those parameters, the Qd rate and time of treatment are determined by the machine. FF is simply the ratio of dialysate compartment flow to Qb rate, ie, FF = (Qd + ultrafiltration rate)/Qb.

To understand the prescription, it makes sense to think about the adequacy of the treatment in terms of urea and single-pool Kt/V (spKt/V). This is not to suggest that dialysis can be simplified into just urea clearance—certainly, many more toxins, molecules, and electrolytes are cleared or delivered during a dialysis session—but it makes sense to think about this as a construct to understand the prescription. Kt/V is the clearance (K) per time (t) divided by the volume of distribution (V). In the case of urea, the volume of distribution is the total body water (TBW). Clearance and volume of distribution of urea are units of volume. Urea is distributed throughout body water (ie, V). Clearance is defined as the volume from which a substance has been completely removed over time. Therefore, the Kt/V can be simply thought of as the number of times that a volume the size of the TBW has been completely stripped of urea per unit of time. In other words, the Kt/V is dimensionless, or without units, and a Kt/V of 1 would be equal to clearing the TBW of urea once. Per-treatment spKt/V can be described in an equation as follows:

$$\text{Per-treatment spKt/V} = [D_{urea}/P_{urea} \times (\text{dialysate drain volume})]/\text{TBW}$$

where D_{urea} is dialysate urea concentration, P_{urea} is plasma urea concentration, and TBW also represents the volume of distribution of urea.

Now recall the method in which the NxStage system is most efficient at removal of urea while sparing water. To achieve the greatest water conservation, we would prefer that the dialysate is completely saturated with urea, such that the urea concentration in the blood is equal to the urea concentration in the dialysate effluent. How do we achieve complete dialysate saturation? The Qd rate needs to be sufficiently slow relative to the Qb rate to allow for complete diffusive equilibration of urea across the membrane from the blood compartment to the dialysate compartment of the dialyzer. Typically, an FF <30% will accommodate near-complete saturation of dialysate, providing the most water-efficient situation. Because more frequent treatments, such as those that would take place in the home, lead to a lower clearance on a per-treatment basis compared with in-center treatments, we need a construct to evaluate adequacy other than the per-treatment spKt/V. The standard Kt/V (stdKt/V) is the solution to this problem. Although prescriptions can be designed to target a per-treatment Kt/V, adequacy of the treatment is usually assessed on a weekly basis with the stdKt/V measurement. Table 3 gives a listing of the expected stdKt/V by number of weekly treatments by per-treatment spKt/V needed to meet the commonly cited goal of stdkt/V >2, while Fig. 2 is a nomogram that shows the difference between stdKt/V and spKt/V and frequency of dialysis.

NxStage Prescription

To determine the initial NxStage prescription, a dialysate volume must be chosen first. Larger patients will need a greater dialysate volume to achieve adequacy targets. Next, an FF should be chosen that will dictate the approximate amount of dialysate saturation that will occur. Table 4 lists approximate dialysate saturation by FF.

Then, the product of the volume prescribed and the percent saturation (as a decimal) is divided by the TBW, yielding the per-treatment Kt/V.

As an example prescription, consider the patient in case 2. For a 60-kg patient, TBW = 0.5 × 80 = 40 L. You choose 30 L of dialysate per treatment. Next, you choose an FF of 40%. At this FF, we expect 90% dialysate saturation, so spKt/V = (30 × 0.9)/40 = 0.675. With this information, you can reference Table 3 to determine how many treatments per week would be needed to meet an stdKt/V goal of >2. We would need to provide 5 treatments per week with this prescription.

Missing from our calculations thus far is time. The machine will run until all dialysate is used at the given FF. To calculate time of treatment, you can calculate the Qd rate and use the total volume to solve for time. Assuming a Qb rate of 300 mL/min and neglecting ultrafiltration:

$$FF = Qd/Qb$$
$$0.4 = Qd/300\ mL/min$$
$$Qd = 120\ mL/min$$

At a rate of 120 mL/min, our prescription of 30,000 mL (30 L) would take 250 minutes for the treatment, or approximately 4.2 hours.

We then go back to the patient and explain that the dialysis plan is for a little more than 4 hours 5 times per week, and that is the point at which the negotiations start to happen. The patient does not want to undergo dialysis for that much time. What are our options to reduce the dialysis sessions to 4 times weekly and still meet adequacy goals?

Table 3. Per-Treatment spKt/V Needed to Reach stdKt/V >2

	Treatments per week			
	6	5	4	3
spKt/V	0.5	0.6	0.8	1.2

Abbreviations: stdKt/V, standard Kt/V; spKt/V, single-pool Kt/V.

Table 4. Expected Dialysate Saturation by Flow Fraction

	Flow Fraction			
	50	40	30	20
Dialysate saturation of urea (approximate)	85%	90%	93%	95%

Decreasing HD Time

If the frequency of dialysis was reduced to 4 times weekly, it is most likely that the adequacy target of stdKt/V >2.0 would not be met with the per-treatment spKt/V of 0.67 (Table 3). To reach this goal of performing dialysis 4 times weekly, we will need to improve the efficiency of each treatment to a per-treatment spKt/V of approximately 0.8. To achieve more clearance of urea, one option would be to increase fluid volume. Recall that TBW is 40 L. If you increase your prescription to 50 L per treatment, the same FF of 40% would yield a dialysate saturation of 90% (Table 4), giving:

$$spKt/V = (50 \times 0.9)/40 = 1.1$$

Because we did not change the FF or the Qb rate, the Qd rate remains the same at 120 mL/min. To calculate treatment time, we divide 50,000 mL by 120 mL/min, obtaining 417 minutes, or 6.9 hours! This increase in volume without an adjustment in FF or Qb rate will give the patient a treatment time that is not likely to be acceptable to him as a short daily option but may work if nocturnal home dialysis is planned. Also note that, in the above scenario, one caveat is that the patient will no longer be able to perform 2 dialysis treatments with one 60-L PureFlow bag for dialysate. He will now need to produce dialysate for every session. This increases his workload and costs him time to set up and manage the PureFlow system more frequently.

Improving Kt/V

Another option to improve the per-treatment Kt/V is to adjust the FF to try to squeeze even more efficiency out of the 30-L volume. Recall that TBW is 40 L. You stick with 30 L per treatment, but lower the FF to 20%. Now the dialysate saturation will be 95%, yielding:

$$spKt/V = (30 \times 0.95)/40 = 0.71$$

Now we are slightly closer to meeting the stdKt/V goal, using the same volume of fluid and a lower FF. However, lowering the FF will slow the Qd rate, and this will cost the patient time per treatment. Assuming a Qb rate of 300 mL/min and neglecting ultrafiltration:

$$FF = Qd/Qb$$
$$0.2 = Qd/300$$
$$Qd = 60\ mL/min$$

With a volume of 30,000 mL, a Qd rate of 60 mL/min yields a treatment time of 8.3 hours! This option is also not acceptable to the patient, but again could work if nocturnal treatments were desired.

Because the fistula is working well, we could decide to increase the Qb rate from 300 mL/min to 450 mL/min:

$$0.2 = Qd/450$$
$$Qd = 60 \text{ mL/min}$$

With volume of 30,000 mL, a Qd rate of 90 mL/min gives a treatment time of 5.5 hours.

The patient mentions that this amount of time may be acceptable but still wants to know if it is possible to perform dialysis 4 times weekly at home while keeping time per treatment at approximately 4 hours and still meet adequacy targets. One option is to change the fluid volume per treatment and increase the FF at the same time. Recall that TBW is 40 L. You increase it from 30 L to 40 L per treatment and increase the FF from 40% to 50%. Now, per Table 4, the dialysate saturation will be 85%, giving:

$$spKt / V = (40 \times 0.85)/40 = 0.85$$

To calculate Qd rate and approximate time of treatment:

$$FF = Qd/Qb$$
$$0.5 = Qd/300$$
$$Qd = 150 \text{ mL/min}$$

For 40,000 mL, a Qd rate of 150 mL/min gives a treatment time of 267 minutes, or 4.4 hours.

Now the prescription will theoretically meet stdKt/V adequacy goals and is more compatible with the patient's lifestyle desires. The patient eventually goes home with this prescription and starts to experiment with his machine. He increases the Qb rate to 450 mL/min. Now, theoretically, the time to complete treatment changes as follows:

$$0.5 = Qd/450$$
$$Qd = 225 \text{ mL/min}$$

For 40,000 mL, a Qd rate of 225 mL/min leads to a treatment time of 178 minutes, or 3 hours. However, this theoretical example does not actually occur because the higher Qd rate is not compatible with the standard NxStage machine, especially when ultrafiltration is accounted for in the numerator of the FF equation. The maximum dialysate compartment flow rate for a standard System One NxStage machine is 12 L/h, or 200 mL/min. Therefore, the actual time (neglecting ultrafiltration) for this treatment is 40,000 mL divided by 200 mL/min, corresponding to 200 minutes, or 3.3 hours.

With the newer version of the NxStage machine (System One S), Qd rates as high as 18 L/h (300 mL/min) can be achieved, and the time can be shortened to closer to 3 hours as above.

This case example illustrates adequacy as it pertains to urea clearance targets. The above prescriptions are theoretical examples of how prescription changes can be made to meet adequacy targets and illustrate the thought process involved to generate a prescription. In actual practice, what is best for the patient may not be in line with adequacy goals or calculated prescriptions. Dialysis prescriptions should also take into account other features of the adequacy of the therapy such as volume balance, middle molecule clearance, and parameters such as acid/base, potassium, and phosphorus. Residual kidney function may also play a role in determining the amount of dialysis that is necessary to avoid uremic complications. Even though the patient is excited about the possibility of using the newer NxStage machine to achieve a regimen of 3 hours 4 times weekly, this may or may not be enough to achieve effective dialysis, particularly if the patient has anuria. Ultimately, it is the responsibility of the physician to work with the patient to find an appropriate prescription that will facilitate success with home dialysis while keeping the burden of therapy acceptable to the patient (Table 5).

Table 5. Typical NxStage Home Dialysis Prescriptions

Parameter	Short daily	Nocturnal
Treatments per week	4-6	4-6
Time, h	2-3	6-8
Blood flow, mL/min	300-400	200-250
Dialysate flow, mL/min	130-300	60-100
Flow fraction	35-40	20-30

Returning to question 2, the best answer is (c). Options (a) and (b) are probably not appropriate for this patient, who is struggling with fluid balance with in-center dialysis and needs to perform dialysis more frequently. Option (d) may deliver excessive clearance and may run the risk of electrolyte abnormality such as hypophosphatemia during dialysis. The Tablo system is now available for HHD but is not widely available for home dialysis programs nationally. In addition, using the Tablo system for 4 hours 4 times a week, not 3 times per week as in option (e), is more likely to yield the needed clearance and ultrafiltration for this patient.

Additional Readings

➢ Lockridge R, Cornelis T, Van Eps C. Prescriptions for home hemodialysis. *Hemodial Int*. 2015;19(suppl 1):S112-S127. ★ESSENTIAL READING

➢ Diaz-Buxo JA, Zeller-Knuth CE, Rambaran KA, Himmele R. Home hemodialysis dose: balancing patient needs and preferences. *Blood Purif*. 2015;39(1-3):45-49. ★ESSENTIAL READING

➢ Plumb TJ, Alvarez L, Ross DL, et al. Safety and efficacy of the Tablo hemodialysis system for in-center and home hemodialysis. *Hemodial Int*. 2020;24(1):22-28. ★ESSENTIAL READING

Medication Changes for HHD Patients

Many patients who perform HHD end up with prescriptions at home that offer more time undergoing dialysis, which results in greater clearance of solutes. Also,

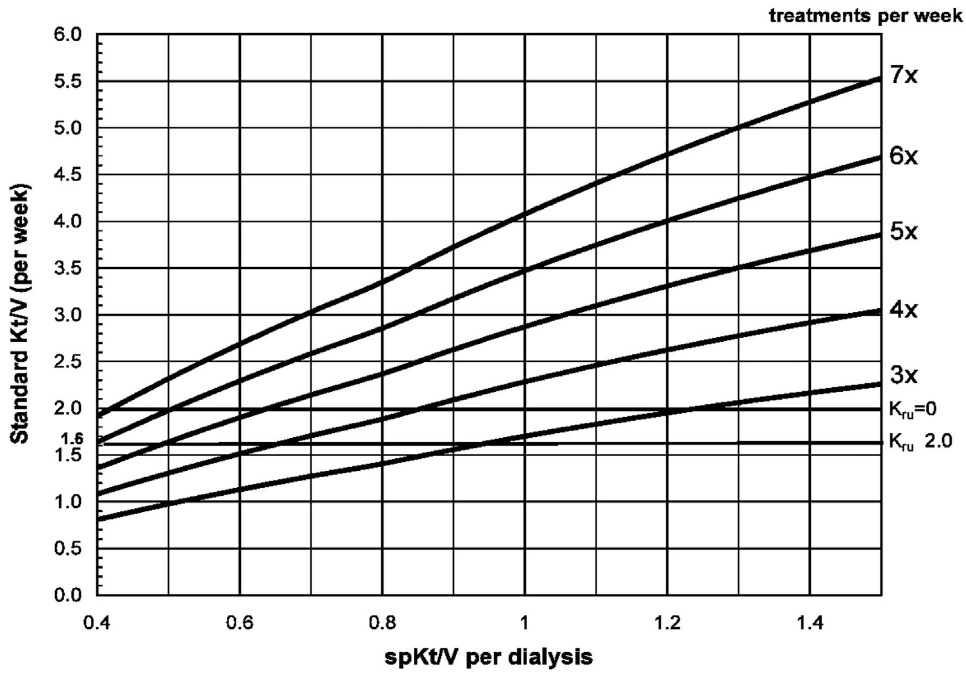

Figure 2. Single-pool versus standardized weekly Kt/V. Image ©2019 MedText, Inc; reproduced from *Hypertension, Dialysis, and Clinical Nephrology* with permission of the copyright holder.

because of the more frequent or extended nature of dialysis not constrained by traditional in-center schedules, superior fluid balance can be achieved in the home. This usually, but not always, means that patients require fewer medications to control blood pressure and phosphorus levels. Close attention should be paid to metabolic parameters after initiating more frequent home dialysis to facilitate timely reduction or discontinuation of antihypertensive agents as volume control is achieved. Often, phosphorus binder dosage can be adjusted downward as well. Studies show a potential decrease in erythropoietin dosage requirements and HHD.

Anticoagulation of the circuit during home dialysis is usually achieved through bolus dosing of heparin at the start of the dialysis treatment session. Given the relatively quick metabolism of heparin, patients undergoing extended dialysis treatments (>3-4 h) or nocturnal HD often will need more than the bolus dose of heparin to achieve circuit patency for the duration of the session. Options for extended anticoagulation include hourly infusion of heparin or longer-acting predialysis low molecular weight heparin. Low molecular weight heparin carries the risk of prolonged action and bleeding of vascular access upon treatment completion. Some home dialysis machines do not have heparin syringe pumps installed, and this requires setup and additional training for a separate intravenous infusion pump, adding to the complexity of dialysis treatments.

Additional Readings

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➢Bakris GL, Burkart JM, Weinhandl ED, McCullough PA, Kraus MA. Intensive hemodialysis, blood pressure, and antihypertensive medication use. *Am J Kidney Dis*. 2016;68(5 suppl 1):S15-S23. ★ESSENTIAL READING

Access Considerations for HHD

Of the most difficult hurdles to becoming proficient at HHD is access cannulation; successful HHD relies on a functional vascular access. For patients who are already undergoing in-center dialysis, learning to cannulate the access while undergoing routine in-center HD can allow a head start and less training burden when they present for instruction for the home dialysis unit. Tunneled HD catheters have been found by some groups to be an acceptable access type, especially for nocturnal HHD, with a lower risk of infectious complications than in-center HD catheters. Long-term catheters can be considered for those who cannot overcome the cannulation burden. Arteriovenous fistulas are the vascular access of choice, but special care must be applied to nocturnal HHD. Routine monitoring of dialysis access examinations and parameters of access function should be continued when patients are seen for their regular visits with the multidisciplinary HHD team.

Access cannulation technique, ie, buttonhole versus sharp cannulation, also needs to be considered in the HHD patient. Buttonhole cannulation is associated with increased infectious risk without clear evidence of improvement in cannulation pain. On the contrary, there is clear evidence to suggest that frequent cannulation of the fistula with sharp needles, which is necessary with frequent home dialysis, is associated with greater risk of access complications such as aneurysm and thrombosis. Buttonhole cannulation may allow for shorter training time and easier cannulation in certain patients. Fistulas with short workable segments, small diameter, or deep position are difficult to cannulate consistently without the buttonhole technique. The decision of buttonhole versus sharp cannulation requires careful attention to the risks and benefits of each approach, and an individualized approach to each patient access is recommended.

Management of access infections depends on the type of infection and clinical presentation of the patient. Fever and/or bacteremia should be treated with clinically appropriate antibiotic therapy for a minimum of 4 weeks and can be extended to 6 weeks for *Staphylococcus aureus* infections or if there are metastatic complications. Cellulitis or localized exit site infection can be treated with appropriate antibiotic therapy for 2 weeks or longer. Abscess should be treated with surgical intervention if warranted and with antibiotic therapy for 4 weeks or longer as clinically appropriate. Patients may need to be hospitalized or return briefly to in-center dialysis during assessment and/or treatment. Any access infection should be accompanied by retraining the patient and care partners on access cannulation to identify potential lapses in technique and reinforce sterile technique for cannulation.

Additional Readings

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Conclusion

Successful initiation and continuation of HHD requires a motivated patient, educated clinicians competent in HHD therapy, dedicated and well-educated HHD nursing staff, and supportive dialysis unit administrative personnel. In addition, it is important to assess patients and their support systems for the suitability of HHD and to recognize burnout so respite care can be scheduled to avoid complications and rapid return to in-center treatment. Physician training and comfort with HHD techniques still lags in most training programs but is still mandatory. With increased exposure of trainees to newer HHD machines and education of patients, such that they are more frequently offered these modalities, physician use and patient acceptance of the home modality will likely increase. Our hope is that the future will bring more dialysis options to the homes of patients with kidney failure.

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