Relative risk of home hemodialysis attrition in patients using a telehealth platform

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Abstract

Introduction: Home hemodialysis (HHD) facilitates increased treatment frequency, which may improve patient outcomes. However, attrition due to technique failure limits the clinical effectiveness of the modality. Nx2me Connected Health is a telehealth platform that enables ongoing assessment of HHD patients using NxStage equipment, and that may reduce patient burden. We aimed to assess whether use of Nx2me was associated with risk of HHD attrition.

Methods: We compared risks of all-cause attrition, dialysis cessation (i.e., death or transplant), and technique failure in Nx2me users and matched control patients, using a retrospective cohort study. We also compared the likelihood of HHD training graduation in patients who initiated use of Nx2me during training with the likelihood in matched control patients. Matching factors included date of HHD initiation, NxStage treatment duration at initiation of follow-up, and prescribed treatment frequency. We used stratified Fine-Gray and Cox regression to compare risks, with adjustment for demographic factors and vascular access modality, and stratification by matched cluster.

Findings: We identified 606 Nx2me users; 49.5% initiated use of Nx2me in < 3 months after initiation of HHD with NxStage equipment. Adjusted hazard ratios (AHRs) of all-cause attrition, dialysis cessation, and technique failure were 0.80 (95% confidence interval, 0.68–0.95), 1.10 (0.86–1.41), and 0.71 (0.57–0.87), respectively, for Nx2me users vs. matched controls. AHRs were similar in patients who initiated use of Nx2me in < 3 months after initiation of HHD. The AHR of HHD training graduation was 1.61 (1.10–2.36) in patients who initiated use of Nx2me within 2 weeks of training initiation vs. matched controls.

Discussion: Use of Nx2me was associated with lower risk of all-cause attrition, lower risk of technique failure, and higher likelihood of HHD training graduation. Further studies are needed to identify the mechanisms by which use of a telehealth platform may improve clinical outcomes and reduce patient burden.

Key words: Home hemodialysis, technique failure, telehealth, training

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INTRODUCTION

Home hemodialysis (HHD) facilitates delivery of more than 3 sessions per week. Higher treatment frequency likely reduces left ventricular mass, blood pressure, serum phosphorus, and post-dialysis recovery time. Between the ends of 2004 and 2013, the number of HHD patients in the United States increased from 1800 to 8507, although year-over-year growth has slowed recently. Continued growth of home dialysis, including both HHD and peritoneal dialysis, requires recruitment and successful training of new patients and retention of existing patients. A portion of home dialysis attrition is due to kidney transplant, which is associated with improved outcomes, relative to dialysis. However, most attrition is due to death and technique failure, or conversion from either HHD or peritoneal dialysis to another dialytic modality, almost always in-center hemodialysis. Because HHD is associated with lower mortality than in-center hemodialysis, primary emphasis on efforts to improve outcomes, relative to dialysis. A recent US study reported that the cumulative incidence of technique failure was 25% at 1 year after HHD training graduation and 35% after 2 years.

Nx2me Connected Health (NxStage Medical, Lawrence, MA, USA) is a telehealth platform that collects NxStage System One cycler data and patient factors (e.g., blood pressure, weight), transmits data to providers after each dialysis session, and enables providers to regularly review data in the Nx2me Clinician Portal. In contrast, usual care involves monthly review of patient-completed session records on paper. Better communication between patient and provider on a telehealth platform may improve the quality of care, thereby reducing the risk of technique failure and ultimately improving HHD retention. In this retrospective cohort study, we compared risks of all-cause and cause-specific HHD attrition in Nx2me users and matched control patients. We also compared the incidence of training graduation in patients who initiated use of Nx2me during HHD training to that of matched control patients.

METHODS

We analyzed data collected by NxStage Medical. Specifically, we identified US HHD patients who initiated use of the Nx2me Connected Health platform between the date of product launch and December 31, 2016. The date of Nx2me initiation was defined as the date of first submission of a digital hemodialysis flowsheet. For each patient, we recorded dates of birth, HHD training initiation, HHD training graduation, and HHD attrition; reason for HHD attrition; race; sex; vascular access modality; and prescribed number of hemodialysis sessions per week. We calculated age on the date of Nx2me initiation. Data regarding vascular access and treatment frequency were ascertained from the flowsheet on the date of Nx2me initiation. In addition, we identified candidate controls, comprising US patients who initiated HHD training with NxStage equipment between January 1, 2005, and December 31, 2016, and who never subsequently initiated use of the Nx2me Connected Health platform. For each patient, we identified dates of birth, HHD training initiation, HHD training graduation, and HHD attrition; reason for HHD attrition; race; sex; vascular access modality; and prescribed number of hemodialysis sessions per week. We calculated age on the date of HHD training initiation. Data regarding vascular access and treatment frequency were ascertained from the most recent HHD prescription on file.

We constructed 2000 cohorts of matched control patients. Within each cohort, we ordered Nx2me users by date of Nx2me initiation, heretofore the index date. For each Nx2me user, we identified the date of HHD training initiation, dialysis setting (i.e., in training or at home) on the index date, the number of days between training initiation and the index date, and prescribed number of dialysis sessions per week. If the Nx2me user was in training, we winnowed the set of candidate controls to those still in training after $d$ days. If the Nx2me was at home, we winnowed the set of candidate controls to those with the same prescribed number of dialysis sessions per week. To ensure that candidate controls were also contemporaries of the Nx2me user, we retained those candidate controls whose date of training initiation was within $k$ months preceding the date of training initiation in the Nx2me user. We iteratively increased $k$ from 1 to 2, 3, 4, 5, 6, 12, and 24, but stopped when we observed $\geq 3$ controls. We randomly selected 3 matched controls from this pool; variability induced by random selection was the rationale for 2000 cohorts. We used a greedy matching algorithm, so that matched controls were selected only once per cohort.

We followed each Nx2me user from his or her index date and respective matched controls from the date exactly $d$ days after his or her date of HHD training initiation, with $d$ defined as above; thus, prior HHD treatment duration was necessarily matched. We followed patients until the earlier of HHD attrition or December 31, 2016. The reason for HHD attrition was categorized as either...
dialysis cessation (death, kidney transplant) or technique failure (due to vascular access or health issues, burden or psychosocial issues, or other or unknown reasons).

Regarding statistical analysis, we used descriptive statistics to compare characteristics of Nx2me users and controls, both before and after matching. We calculated rates and cumulative incidence of all-cause and cause-specific attrition in Nx2me users and matched controls. We used Fine-Gray regression to estimate adjusted hazard ratios (AHRs) of all-cause and cause-specific attrition (i.e., dialysis cessation, technique failure, and their components) in Nx2me users vs. matched controls. Models were stratified by matched cluster and adjusted for age, race, sex, and vascular access modality. We estimated each summary hazard ratio from the exponential of the mean of log hazard ratios, and each associated variance from the sum of the mean of log hazard ratio variance estimates and the variance of log hazard ratio estimates (i.e., by the law of total variance). Finally, we used Cox regression to estimate the AHR of training graduation in patients who initiated use of Nx2me within 2 weeks following initiation of HHD training vs. matched controls.

All analyses were conducted in SAS, version 9.4 (Cary, NC, USA).

RESULTS

There were 606 patients who initiated use of Nx2me. Relative to the index date of the first Nx2me user, there were 75 (12.4%) new users in months 1 to 6 thereafter, 140 (23.1%) in months 7 to 12, 96 (15.8%) in months 13 to 18, 65 (10.7%) in months 19 to 24, 89 (14.7%) in months 25 to 30, and 141 (23.3%) in months 31 to 36. Nx2me users were at 55 centers; quartiles of Nx2me users per program were 3, 6, and 14. Patient characteristics of Nx2me users and candidate controls are displayed in Table 1. Relative to candidate controls, Nx2me users were slightly younger and more likely to be black. At initiation of Nx2me use, mean duration of HHD with NxStage equipment was 1.18 years, although duration was <3 months in almost half of patients. Most Nx2me users dialedyzed with an arteriovenous fistula or central venous catheter for 4 or 5 hemodialysis sessions per week. Among 2000 cohorts of matched controls, sample size varied between 1817 and 1818 patients. Matching successfully balanced both mean duration of HHD and prescribed number of sessions per week at initiation of follow-up (Table 1).

Follow-up statistics are displayed in Table 2. Nx2me users accumulated 541.6 patient-years (mean, 0.89 years per patient), during which 223 attrition events occurred (rate, 41.2 events per patient-year). Among 2000 iterations, matched controls accumulated 1590.6 patient-years (0.87 years per patient) and 667.2 attrition events (48.3 events per patient-year). Rates of dialysis cessation in Nx2me users and matched controls were 17.9 and 17.6 events per 100 patient-years, respectively, while rates of technique failure were 23.3 and 30.7 events per 100 patient-years. In patients with NxStage treatment duration <3 months, attrition rates in Nx2me users and matched controls were 47.1 and 62.1 events per 100 patient-years; almost all of that difference was due to a lower rate of technique failure in Nx2me users.

The cumulative incidence of all-cause attrition is displayed in Figure 2A (all matched patients) and B (patients with treatment duration <3 months). At 1 year, cumulative incidence was 34.6% in Nx2me users and 40.2% in matched controls. At 2 years, corresponding estimates were 56.0% and 58.5%. In patients with treatment duration <3 months, cumulative incidence at 1 year was 37.0% in Nx2me users and 47.2% in matched controls. The cumulative incidence of dialysis cessation was similar in Nx2me users and matched controls (Figure 3A,B), but the cumulative incidence of technique failure was lower in Nx2me users than in matched controls. In all matched patients, cumulative incidence of technique failure at 1 year was 21.6% in Nx2me users and 27.1% in matched controls (Figure 4A), and in patients with treatment duration <3 months, cumulative incidence of technique failure at 1 year was 24.7% in Nx2me users and 36.1% in matched controls (Figure 4B). Additional estimates of cumulative incidence are displayed in Table 3.

Adjusted hazard ratios of attrition for Nx2me users vs. matched controls are displayed in Table 4. The AHR of all-cause attrition was 0.80 (95% confidence interval, 0.68–0.95) and AHRs of dialysis cessation and technique failure were 1.10 (0.86–1.41) and 0.71 (0.55–0.87), respectively. AHRs of death, technique failure due to burden or psychosocial issues, and technique failure due to other or unknown reasons were <1, whereas AHRs of kidney transplant and technique failure due to vascular access or health issues were >1; only AHRs of technique failure due to other or unknown reasons and kidney transplant were statistically significant. In patients with treatment duration <3 months, the AHR of all-cause attrition was 0.71 (0.56–0.90). In this subset, AHRs of all-cause attrition were 0.62 (0.46–0.82, P = 0.002) during the first year of follow-up and 1.15 (0.47–2.77, P = 0.76) during the second year of follow-up. The pattern of AHRs of cause-specific attrition in this subset was similar to the pattern in all matched patients.
There were 209 patients in HHD training at initiation of Nx2me use; 94 (45.0%) initiated Nx2me use within 2 weeks following the initiation of training. In the subset of 94, cumulative incidence of training graduation at 8 weeks after initiation of Nx2me use was 94.8%; in matched controls, the corresponding

Table 1  Patient characteristics in Nx2me users and controls, before and after matching

|                          | Before matching | After matching |
|--------------------------|-----------------|---------------|
|                          | Nx2me users     | Candidate controls | Nx2me users | Matched controls^a |
| Sample size (n)          | 606             | 29,391        | 606         | 1817.3             |
| Age (y)                  |                 |               |             |                    |
| Mean (SD)                | 52.4 (14.1)     | 54.6 (14.6)   | 52.4 (14.1) | 54.0 (14.4)        |
| Percentage               |                 |               |             |                    |
| <20 y                    | 0.8             | 0.6           | 0.8         | 0.4                |
| ≥20 and <45 y            | 31.2            | 26.6          | 31.2        | 28.4               |
| ≥45 and <65 y            | 47.2            | 47.3          | 47.2        | 46.9               |
| ≥65 and <80 y            | 19.1            | 21.8          | 19.1        | 21.2               |
| ≥80 y                    | 1.7             | 3.7           | 1.7         | 3.1                |
| Race (%)                 |                 |               |             |                    |
| White                    | 46.2            | 53.6          | 46.2        | 54.2               |
| Black                    | 32.3            | 20.8          | 32.3        | 21.7               |
| Asian                    | 1.8             | 2.0           | 1.8         | 1.9                |
| Native American or Hawaiian | 1.3         | 1.5           | 1.3         | 1.6                |
| Unknown race             | 18.3            | 22.2          | 18.3        | 20.5               |
| Sex (%)                  |                 |               |             |                    |
| Female                   | 35.0            | 34.1          | 35.0        | 34.9               |
| Male                     | 63.2            | 63.0          | 63.2        | 61.9               |
| Unknown sex              | 1.8             | 2.9           | 1.8         | 3.2                |
| NxStage treatment duration^b (y) |                 |               |             |                    |
| Mean (SD)                | 1.18 (1.94)     | 1.18 (1.94)   | 1.18 (1.94) | 1.18 (1.94)        |
| Distribution (%)         |                 |               |             |                    |
| <3 mo                    | 49.5            | 49.5          | 49.5        | 49.5               |
| ≥3 mo and <1 y           | 20.3            | 20.3          | 20.3        | 20.3               |
| ≥1 and <2 y              | 11.6            | 11.6          | 11.6        | 11.6               |
| ≥2 and <4 y              | 8.6             | 8.6           | 8.6         | 8.6                |
| ≥4 y                     | 10.1            | 10.1          | 10.1        | 10.1               |
| Vascular access modality (%) |             |               |             |                    |
| Arteriovenous fistula    | 64.9            | 58.2          | 64.9        | 62.5               |
| Arteriovenous graft      | 10.6            | 9.0           | 10.6        | 9.0                |
| Central venous catheter  | 24.6            | 18.1          | 24.6        | 17.1               |
| Other modality           | 0.0             | 1.1           | 0.0         | 1.9                |
| Unknown modality         | 0.0             | 13.6          | 0.0         | 9.6                |
| Prescribed number of sessions/wk (%) |           |               |             |                    |
| 2                        | 0.2             | 0.1           | 0.2         | 0.2                |
| 3                        | 1.3             | 0.9           | 1.3         | 1.3                |
| 3.5                      | 1.3             | 2.1           | 1.3         | 1.3                |
| ≥4 and <5                | 26.1            | 13.1          | 26.1        | 26.1               |
| ≥5 and <6                | 60.9            | 54.7          | 60.9        | 60.9               |
| ≥6 and <7                | 9.6             | 28.6          | 9.6         | 9.6                |
| 7                        | 0.7             | 0.4           | 0.7         | 0.7                |

^aAmong 2000 cohorts of matched control patients.
^bTime between initiation of home hemodialysis training and index date (in Nx2me users) or initiation of follow-up (in matched control patients).
SD = standard deviation.
estimate was 74.8% (Figure 4). Relative to the index date, which was 7.2 days after initiation of training, median time to training graduation was 22 days in Nx2me users and 29 days in matched controls. The AHR of training graduation for Nx2me users vs. matched controls was 1.61 (1.10–2.36, P = 0.02).

**DISCUSSION**

Attrition—specifically, technique failure—constrains the clinical effectiveness of HHD and may constitute a financial barrier to provision of the modality. Little research has assessed interventions that may reduce risk of HHD attrition. Novel strategies that leverage developing

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**Table 2** Attrition event counts and rates in Nx2me users and matched controls

|                      | All patients | Treatment duration <3 mo<sup>a</sup> |
|----------------------|--------------|--------------------------------------|
|                      | Nx2me users  | Matched controls<sup>b</sup>         | Nx2me users  | Matched controls<sup>b</sup>         |
| Follow-up duration (patient-years) | 541.6        | 1590.6                               | 239.7        | 667.2                                 |
| Attrition events (n [%]) | 223 (100.0)  | 767.4 (100.0)                        | 113 (100.0)  | 413.9 (100.0)                        |
| Dialysis cessation     | 97 (43.5)    | 279.8 (36.5)                         | 38 (33.6)    | 106.5 (25.7)                         |
| Death                 | 45 (20.2)    | 164.6 (21.4)                         | 17 (15.0)    | 66.1 (16.0)                          |
| Kidney transplant      | 52 (23.3)    | 115.2 (15.0)                         | 21 (18.6)    | 40.5 (9.8)                           |
| Technique failure      | 126 (56.5)   | 487.7 (63.5)                         | 75 (66.4)    | 307.4 (74.3)                         |
| Vascular access or health issues | 39 (17.5) | 102.5 (13.3) | 18 (15.9) | 51.3 (12.4) |
| Burden or psychosocial issues | 60 (26.9) | 210.1 (27.4) | 39 (34.5) | 136.2 (32.9) |
| Other or unknown reasons | 27 (12.1)   | 175.1 (22.8)                         | 18 (15.9)    | 119.9 (29.0)                         |
| Attrition rate (per 100 patient-years) | 41.2        | 48.3                                 | 47.1         | 62.1                                  |
| Dialysis cessation     | 17.9         | 17.6                                 | 15.9         | 16.0                                  |
| Death                 | 8.3          | 10.3                                 | 7.1          | 9.9                                   |
| Kidney transplant      | 9.6          | 7.2                                  | 8.8          | 6.1                                   |
| Technique failure      | 23.3         | 30.7                                 | 31.3         | 46.1                                  |
| Vascular access or health issues | 7.2   | 6.4                                  | 7.5          | 7.7                                   |
| Burden or psychosocial issues | 11.1    | 13.2                                 | 16.3         | 20.4                                  |
| Other or unknown reasons | 5.0         | 11.0                                 | 7.5          | 18.0                                  |

<sup>a</sup>Patients with NxStage treatment duration <3 mo at initiation of follow-up.

<sup>b</sup>Among 2000 cohorts of matched control patients.

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**Figure 1** Cumulative incidence of all-cause attrition in Nx2me users and matched controls, in all patients (panel A) and in patients with NxStage treatment duration <3 mo at initiation of follow-up (panel B).
technology to improve communication between patient and provider and thereby enable timely assessment may reduce risk. In this retrospective cohort study, we assessed whether use of the Nx2me Connected Health platform was associated with risk of HHD attrition. We found that Nx2me users had 20% lower adjusted risk of HHD attrition, due to 29% lower risk of technique failure, and that patients who initiated use of Nx2me within roughly 3 months of HHD training initiation had 29% lower adjusted risk of attrition, due to 34% lower risk of technique failure. Furthermore, we found that patients who initiated use of Nx2me during HHD training were more likely to complete training and begin dialysis at home. These results suggest that use of Nx2me may greatly improve retention during the early course of HHD, an interval that is characterized by relatively high risk of attrition.

Several large studies have recently described the incidence of death and technique failure on HHD. Weinhandl et al. assessed both endpoints in a study of 4201 US HHD patients who used NxStage equipment for either 5 or 6 prescribed sessions per week. Patients were followed

Figure 2 Cumulative incidence of dialysis cessation in Nx2me users and matched controls, in all patients (panel A) and in patients with NxStage treatment duration <3 mo at initiation of follow-up (panel B).

Figure 3 Cumulative incidence of technique failure in Nx2me users and matched controls, in all patients (panel A) and in patients with NxStage treatment duration <3 mo at initiation of follow-up (panel B).
from the date of first treatment in the home. The cumulative incidence of death was 8% at 1 year, while the cumulative incidence of technique failure was 25% at 1 year and 35% at 2 years.13 Both studies show that the incidence of HHD technique failure is roughly 2 times higher during the first vs. the second year at home. Because the eras of both cohorts predate US regulatory clearance of NxStage equipment for nocturnal HHD,16 most patients likely underwent short-daily hemodialysis. In 247 Canadian patients on nocturnal HHD, the cumulative incidence of HHD attrition was 10% at 1 year, 22% at 2 years, and 49% at 5 years.17 Whether the relatively low incidence of attrition in that cohort reflects the effect of dialysis schedule, dialysis equipment, or country is uncertain. In Australia and New Zealand, incidence of the composite of death and technique failure on HHD has also been lower than in the United States.18,19 Some variability in HHD attrition among studies may be attributed to epidemiological methodology, including the definition of technique failure (e.g., is death included?) and the specification of censoring events (e.g., is transplant included?).

Risk factors for HHD attrition necessarily reflect risk factors for each of death, transplant, and technique failure. Regarding technique failure, Seshasai et al. listed female sex; hypertension (vs. diabetes) as primary cause of end-stage renal disease; urban residence; diabetes; tobacco, alcohol, and drug use; and exclusion from the kidney transplant waitlist as nominally significant (P < 0.1) risk factors.13 Central venous catheter vs. arteriovenous fistula or graft for vascular access was associated with higher risk of technique failure in 2 studies.20,21

### Table 3 Cumulative incidence of attrition in Nx2me users and matched controls

|                      | N×2me users | Matched controls | N×2me users | Matched controls |
|----------------------|-------------|------------------|-------------|------------------|
| **All-cause attrition (%)** |             |                  |             |                  |
| 6 mo                  | 17.4        | 25.6             | 19.4        | 32.2             |
| 1 y                   | 34.6        | 40.2             | 37.0        | 47.2             |
| 2 y                   | 56.0        | 58.5             | 62.8        | 64.5             |
| **Dialysis cessation (%)** |             |                  |             |                  |
| 6 mo                  | 6.5         | 7.3              | 5.5         | 6.1              |
| 1 y                   | 13.0        | 13.1             | 12.3        | 11.2             |
| 2 y                   | 24.4        | 22.2             | 20.9        | 18.6             |
| **Technique failure (%)** |             |                  |             |                  |
| 6 mo                  | 10.8        | 18.4             | 13.9        | 26.1             |
| 1 y                   | 21.6        | 27.1             | 24.7        | 36.1             |
| 2 y                   | 31.6        | 36.3             | 41.9        | 45.9             |

*Patients with NxStage treatment duration <3 mo at initiation of follow-up.

*Among 2000 cohorts of matched control patients.
In 286 patients who underwent intensive hemodialysis, with >95% in the home setting, each 1-session increment in weekly treatment frequency was associated with increased risk of a vascular access event, and both incremental treatment frequency and occurrence of a vascular access event were associated with increased risk of technique failure; 60% of the vascular access events were categorized as infection, 15% as thrombosis, 10% as stenosis, 6% as aneurysm, and 9% as other issues. Thus, female sex, comorbidity, catheter dependence, and treatment frequency are putative risk factors for technique failure on HHD. Psychosocial characteristics are likely relevant risk factors as well. Intensive hemodialysis may increase caregiver burden, which is inversely associated with treatment adherence.

We found that use of Nx2me was associated with lower risk of technique failure, but not with risk of dialysis cessation. The Nx2me app that the patient uses on his or her tablet collects hemodialysis metrics from the cycler; measurements of blood pressure, temperature, and weight; information about administered medications; and other notes. Providers can review these data on the Nx2me Clinician Portal after each hemodialysis session ends. The Nx2me app also displays intradialytic parameters (e.g., arterial and venous pressures, ultrafiltration rate) and offers real-time troubleshooting of cycler alarms. These features, along with anecdotal evidence included in online supplemental material, suggest several mechanisms by which use of Nx2me may alter the course of HHD. Psychosocial characteristics are likely relevant risk factors as well. Intensive hemodialysis may increase caregiver burden, which is inversely associated with treatment adherence.

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We found that use of Nx2me was associated with lower risk of technique failure, but not with risk of dialysis cessation. The Nx2me app that the patient uses on his or her tablet collects hemodialysis metrics from the cycler; measurements of blood pressure, temperature, and weight; information about administered medications; and other notes. Providers can review these data on the Nx2me Clinician Portal after each hemodialysis session ends. The Nx2me app also displays intradialytic parameters (e.g., arterial and venous pressures, ultrafiltration rate) and offers real-time troubleshooting of cycler alarms. These features, along with anecdotal evidence included in online supplemental material, suggest several mechanisms by which use of Nx2me may alter the course of HHD. First, in contrast to usual care, which is characterized in the United States by monthly review of paper flowsheets during appointments with the nephrologist and HHD nursing staff, ongoing assessment on a telehealth platform may enable timely response to changes in treatment (e.g., shortened sessions, missed sessions, low ultrafiltration volume) and health status (e.g., increases in blood pressure, temperature, and post-dialysis weight). Incident HHD patients exhibit high prevalence of cardiovascular comorbidity, including heart failure, and may be sensitive to worsening volume status. Infection control is also a challenge in the home setting; providers may be able to diagnose and treat vascular access infections by serially assessing variability in body temperature. Although we found that use of Nx2me was not associated with risk of technique failure due to vascular access or health issues, we did find that the pooled rate of death and technique failure due to vascular access or health issues was modestly lower in Nx2me users vs. matched controls (with attrition events per 100 patient-years at 15.2 vs. 16.7, respectively). Second, elimination of paper flowsheets, online troubleshooting of alarms, and the mere knowledge of provider monitoring may increase patient confidence. Interviews of 19 HHD patients in the United Kingdom revealed that most patients felt scared or worried during the early course of HHD, and that patients and nurses found paper manuals to be impractical tools for troubleshooting. Cañezo et al. reported that conventional hemodialysis patients had greater interest in nocturnal HHD when treatment was accompanied by remote monitoring. Interviews revealed that remote monitoring serves as surrogate nursing care, thereby alleviating caregiver stress. Nx2me is not a real-time remote monitoring tool, but the connection that it fosters between patient and provider may be similar. However, any monitoring tool can offer disadvantages. Patients may have difficulty with a tablet or consider monitoring to be intrusive, while providers may find that reviewing data inefficiently consumes nursing hours.
Surprisingly, attrition during HHD training has not been widely quantified. In a Canadian single-center series of 177 HHD patients, 24 (14%) patients failed to complete training, whereas in 142 patients who completed training, only 8 (6%) technique failures occurred during the first year at home.\textsuperscript{28} Most frequently cited factors contributing to training failure were inappropriate residence (17%), deterioration in medical status (13%), inability to cope with the burden of HHD (13%), nonadherence (13%), and failure to pass training tests (13%). In an English single-center series of 166 HHD patients, 12 (7%) patients failed to complete training, with 4 failures due to lack of confidence, 3 to lack of motivation, 2 to stress, and 3 to other issues.\textsuperscript{29} Obviously, neither study included US patients. We observed that roughly 1 in 4 matched controls failed to complete training after 10–12 weeks, and that introduction of Nx2me during the early phase of training increased the probability of training graduation and shortened the median time to train. Relative to reliance on paper flowsheets, incorporation of familiar technology (e.g., tablet) may reduce the perceived difficulty of training and of the burden of HHD. That introduction of Nx2me was associated with shorter time to train contrasts with an earlier study of simulation-based teaching, which was not associated with shorter time to train.\textsuperscript{30} More research is necessary to understand the role of technology aids during HHD training.\textsuperscript{31}

This study has several limitations. First, it is an observational study, so all comparisons between Nx2me users and matched controls may suffer from residual confounding. Although we exactly matched patients by NxStage treatment duration and prescribed treatment frequency, we did not adjust for factors other than demographic characteristics and vascular access modality. Data about comorbidity are not collected on HHD prescription forms; it is possible that Nx2me users were generally healthier than matched controls. Centers that deployed Nx2me may have had lower HHD attrition than other centers, as high-performing centers may have deployed Nx2me relatively early. Second, information error may have induced bias. We reported missing data regarding race and vascular access modality. Additionally, while 12% of attrition events in HHD were due to other or unknown reasons, 23% of attrition events in matched controls were similarly categorized. If ongoing assessment of Nx2me users resulted in more accurate ascertainment of the cause of HHD attrition, then AHRs of technique failure due to vascular access or health issues and burden or psychosocial issues may be upwardly biased. Thus, associations of Nx2me use with cause-specific technique failure should be interpreted cautiously. Third, some patients who initiated use of Nx2me during HHD training may have already been identified by providers as likely to complete training. Such reverse causality may have upwardly biased the AHR of training graduation for Nx2me users vs. matched controls. Finally, no aspect of this study may be applicable to HHD with equipment that uses a high volume of dialysate per session.

Home hemodialysis requires an upfront investment in training, and transfers the work of dialysis from health care professionals in facilities to patients in homes. Strategies and tools that can improve the quality of HHD training, improve communication between patient and provider, and ease the patient burden of HHD may address clinical and psychosocial factors leading to HHD attrition.\textsuperscript{32} In other countries, periodic home visits by nursing staff and remote monitoring are employed to support HHD, but in the United States, these practices are uncommon. Because NxStage equipment is widely used for HHD in the United States, the Nx2me Connected Health platform is a practical tool that may be useful for reducing risk of HHD technique failure in the United States, particularly when utilization begins shortly after initiation of HHD, and increasing likelihood of training graduation. Future studies should assess how the use of this platform and others like it alter health trajectories and patient outcomes.

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