Noninvasive Interventions to Decrease Hospitalization and Associated Costs for Pediatric Patients Receiving Hemodialysis

STUART L. GOLDSTEIN,* CAROLYN M. SMITH,† and HELEN CURRIER‡
*Department of Pediatrics, Baylor College of Medicine, Houston, Texas; †Decision Support Services, Texas Children’s Hospital, Houston, Texas; and ‡Texas Children’s Hospital Renal Dialysis Unit, Houston, Texas

Abstract. Minimal pediatric data describe hospitalization causes and associated costs for children who receive maintenance hemodialysis, and no data exist to evaluate methods to decrease hospitalization. In 1999, two common causes of hemodialysis patient hospitalization at Texas Children’s Hospital were fluid overload/hypertension (FO/HTN) and vascular access thrombosis (VAT). Evaluated is the effect of two noninvasive monitoring programs, monitoring of hematocrit-guided ultrafiltration algorithm and vascular access flow using ultrasound dilution vascular access flow technology, on FO/HTN and VAT in the pediatric maintenance hemodialysis population. This prospective observational study reviewed all hospitalization data for all 51 patients who received maintenance hemodialysis from January 1999 through December 2001 obtained from unit monthly performance improvement meeting records. Hospitalization rates and related costs for FO/HTN and VAT were tracked before and after institution of the noninvasive monitoring programs. Application of the noninvasive monitoring of hematocrit-guided ultrafiltration algorithm since January 2000 significantly decreased hospitalization for FO/HTN (64 total days in 1999, 4 total days in 2000 and 2001 combined) while maintaining acceptable patient BP control and minimizing antihypertensive medication requirements. The vascular access monitoring program using ultrasound dilution vascular access flow technology to direct referral for angioplasty instituted in January 2001 led to a significant decrease in hospitalization for VAT (45 d in 2000 and 21 d in 2001). It is suggested that application of noninvasive technologies to assess patient target dry weight and access flow can significantly decrease pediatric maintenance dialysis patient morbidity and health care cost.

Although recent pediatric data describe causes of mortality and a link between poor growth and hospitalization for children with ESRD (1–6), no published data evaluate potential therapeutic interventions addressing causes and costs for hospitalization for children who receive hemodialysis. Hospitalization interferes with a child’s quality of life by interrupting family routines and preventing school attendance and normal socialization with peers (7–12). Practices that decrease pediatric hemodialysis patient hospitalization rates should improve aggregate health-related quality of life.

In 1999, we prospectively gathered hospitalization data for all children who were receiving maintenance hemodialysis at Texas Children’s Hospital (Houston, TX) and found that two of the most common hospitalization causes were fluid overload/hypertension (FO/HTN; 41% of hospitalizations) and vascular access thrombosis (VAT; 41% of hospitalizations). Our center has previously reported improved fluid management and ultrafiltration (UF) practice guided by noninvasive monitoring of hematocrit (NIVM) during the hemodialysis treatment (13) and decreased VAT rates using an ultrasound dilution-guided proactive vascular access management protocol (14,15) for children who receive maintenance hemodialysis. The aim of the current study was to evaluate the effects of NIVM-guided ultrafiltration and ultrasound dilution-guided vascular access management practices on hospitalization rates and costs for children who receive maintenance hemodialysis.

Materials and Methods
All prevalent patients who received maintenance hemodialysis for at least 2 consecutive months in the Texas Children’s Hospital Renal Dialysis Unit from January 1, 1999, through December 31, 2001, were identified. Hospitalization data were then obtained via a systematic review of dialysis unit monthly performance improvement meeting records, which detail the primary hospitalization causes for the previous month.

Hospitalization Categories
Each hospitalization was assigned on the basis of the primary diagnosis leading to hospitalization: (1) FO/HTN and (2) VAT and other. Categorization was based on the initial reason for hospital admission. Because the same pediatric nephrologists care for Texas Children’s Hospital Dialysis Unit patients in the outpatient and inpatient settings and attend the monthly performance improvement meetings, hospitalization category assignment was reviewed and agreed on...
by the entire medical team each month. Hospitalizations were fol-
lowed through January 2, 2002, when the final patient with FO/HTN
was discharged from the hospital.

**Indications for Hospitalization**

In general, we hospitalized patients who were receiving hemodial-
isis for maintenance FO/HTN when pre- and posthemodialysis treat-
ment BP were greater than the 99th percentile for age and height for
more than 2 consecutive weeks. Patients with VAT were routinely
hospitalized for 24 h minimum after thrombectomy to ensure vascular
access patency. No changes in these practices were instituted over the
course of study.

**Definitions**

“Heemodialysis patient days” refers to the number of days that
maintenance hemodialysis was the designated ESRD treatment mo-
dality for a patient. Thus, a patient classified as a maintenance
hemodialysis patient from March 1, 2001, to April 1, 2001, would
contribute 31 hemodialysis days to the year 2001 total. “Patient
census” refers to the number of individual patients who received
maintenance hemodialysis as their maintenance ESRD treatment mo-
dality for 2 consecutive months during a given year.

**Technological Interventions**

In January 2000, we instituted a NIVM-guided UF practice to
adjust UF rates and target dry weight achievement on the basis of the
associations between NIVM monitor (Critline, Hemametrics,
Kaysville, UT), blood volume changes, and intradialytic symptoms
that we observed in our previous pediatric NIVM study (13). In that
study, (1) no patient demonstrated intradialytic symptoms with blood
volume change <8% per hour in the first 90 min of treatment, and (2)
71% of symptoms that occurred in the last hour of treatment were
associated with blood volume change of >4% per hour. Starting in
January 2000, all patients received half of the prescribed UF volume
in the first treatment hour up to a maximum blood volume change of
8 to 12% as depicted on the NIVM monitor. UF rates were then
adjusted to attain the second half of the prescribed UF volume over
the remaining treatment time (2 to 3 h). In the last treatment hour,
patients received UF until they had hypotension or a blood volume
change >4% per hour as noted by NIVM, at which point UF was
continued for 5 min. When the NIVM monitor demonstrated re-
filling of the intravascular compartment, UF was resumed until the
patient was symptomatic or a blood volume change of >4% per hour
was noted again. When no intravascular refilling was seen after 5 min,
the patient was determined to be at his or her target dry weight.

In January 2001, we instituted a policy of rapid referral for arte-
riovenous fistula or graft (permanent vascular access) angioplasty
using monthly ultrasound dilution (Transonic HD01, Ithaca, NY) to
assess vascular access flow. Children with a corrected vascular access
flow of <650 ml/min per 1.73 m² were referred for balloon angiop-
plasty within 48 h. We previously reported that this practice led to a
90% reduction in VAT rates and a 40% reduction in vascular access
management costs (including increased costs for angioplasty) com-
pared with our previous surveillance venography protocol (15).

**Data Analyzed**

For each hospitalization, data obtained included the length of
hospital stay (hospitalization days) and the hospitalization cost. To
determine hospitalization rates, we divided the aggregate hospitaliza-
tion days by the number of maintenance hemodialysis patient days for
each year. We chose to define hospitalization rates in this manner, as
opposed to the number of hospitalizations per year, because we
wanted to assess the impact of each hospitalization on patient quality
of life. Thus, the length of stay for each hospitalization and the
resultant disruption of routine activity is a better measure for the
current analysis.

Hospitalization cost data were available for all patients using the
Eclipsys (formerly Transition Systems Incorporated) Decision Sup-
port system. The cost accounting function uses expenses from the
general ledger, volume statistics from the Patient Accounting system,
and relative value unit (RVU) data for every charge item. The general
ledger expenses are grouped into cost types, and these expenses are
spread on the basis of the volume and RVU. On the basis of these
data, a cost is attached to each charge item associated with a patient’s
hospitalization. Cost data accounted for nondialysis nursing and allied
health professional support care, supplies, and operating room ex-
ences for thrombectomy/access revision and non–patient care–re-
lated overhead. Physician service costs were not included. Adjust-
ments were made for item cost increases over each fiscal year during
the study period. All cost data are reported based on an adjusted year
2001 basis.

Total hospitalization cost data for FO/HTN were adjusted for
maintenance hemodialysis outpatient census by dividing the total cost
by the aggregate Renal Dialysis Unit census (patient-years) for each
calendar year from 1999 through 2001. Total cost data for VAT
management were adjusted for patient census by dividing the total
VAT cost by the aggregate patient census (patient-years) that received
maintenance hemodialysis via a permanent vascular access for each
calendar year from 2000 through 2001.

**Statistical Analyses**

The primary outcome variable, hospitalization rates (number of
hospitalization days divided by outpatient maintenance hemodialysis
days), was compared before and after intervention (1999 versus 2000
and 2001 for noninvasive monitoring of hematocrit; 2000 versus 2001
and 2002 for ultrasound dilution access flow surveillance) using χ²
analysis. Potential associations between mean patient age, patient dry
weight, and calendar year were assessed by one-way ANOVA. P <
0.05 was considered to be significant.

**Results**

Data reflecting the number of hemodialysis patient days,
hemodialysis unit census, and patient demographics for each
study year are shown in Table 1. Both patient census and the
total number of hemodialysis days are fairly constant from

Fifty-one patients received maintenance hemodialysis in our
center for at least 2 mo from 1999 through 2001. Mean patient
weight (38.1 ± 15.4 kg) was not different between any of the
study years. Mean patient age increased over the study period
(P < 0.001), which reflects, in part, some patients being
maintained on hemodialysis for >1 yr during the study period.

**Aggregate Hospitalization Data**

The total number of hospitalization days for patients who
were receiving maintenance hemodialysis demonstrates a
steady increase over the study period (Table 2), which resulted
in a sixfold increase in hospitalization rates from 1999 (3.7
hospitalization days per hemodialysis outpatient year) to 2001
(24.9 hospitalization days per hemodialysis outpatient year; P
A trend toward increasing length of hospital stay (median 3 d in 1999 and 2000, 5 d in 2001) and hospitalization cost (median $4367 in 1999 to $11,024) was also observed. We observed a significant increase in patient hospitalization days and costs for malnutrition; two patients had three hospitalizations totaling 121 d in 2000, and four patients had six hospitalizations totaling 390 d in 2001.

Hospitalization and Cost Data for FO/HTN and VAT

Table 2 lists the hospitalization days and costs for FO/HTN and VAT. In 1999, seven patients were hospitalized for 64 total days at a cost of $114,850 for FO/HTN. After institution of the NIVM-guided UF protocol, only one patient was hospitalized from January 1, 2000, through December 31, 2001, for a total of 4 d. Review of monthly performance improvement records from 2000 and 2001 reveals that patient target dry weight was readjusted after three to six hemodialysis treatments during which the NIVM-guided protocol led to a posttreatment weight that differed from the prescribed target dry weight.

To determine whether decreased hospitalization for FO/HTN resulted from factors not related to NIVM, we assessed mean pre- and posttreatment BP and antihypertensive medication use in hemodialysis patients from April to June 2001. Mean patient pretreatment and posttreatment BP were 124/76 and 112/71, respectively, and only 7 of 21 patients received antihypertensive medication; 5 received solely an angiotensin-converting enzyme inhibitor or an angiotensin II receptor blocker. In addition, the number of additional outpatient HD treatments for FO/HTN decreased significantly from 1999 to 2000 and 2001.

In 2000, 11 patients were hospitalized for a total of 45 d at a cost of $98,028 for surgical and medical treatment of VAT. After initiation of the ultrasound dilution–guided angioplasty referral protocol in 2001, only six patients were hospitalized.
for 21 d at a cost of $60,707 for VAT, despite the fact that there were more vascular access days in 2001 compared with 2000. Hospitalization for FO/HTN and VAT comprised significantly lower percentages of patient hospitalizations in the years after initiation of the NIVM and ultrasound dilution protocols (Table 2).

Discussion
The current pediatric study assesses the impact of technology driven ultrafiltration and vascular access surveillance practices on an important outcome measure, hospitalization rates. Application of two noninvasive technology-based clinical management protocols led to significant decreases in hospitalization rates for FO/HTN and VAT. The noninvasive monitoring of hematocrit-guided ultrafiltration protocol not only led to decreased hospitalization rates but also was associated with acceptable maintenance BP control, low antihypertensive medication requirement, and a decrease in additional outpatient hemodialysis treatments for FO/HTN in our pediatric hemodialysis population. Thus, the decrease in hospitalization rates secondary to FO/HTN observed from 1999 to 2000 and 2001 seems to be related to NIVM-guided target dry weight adjustments and did not come at the expense of chronic patient hypertension or result from multiple antihypertensive medication administration. Since the NIVM protocol clearly reduced the short-term morbidity of hospitalization, we suggest that the NIVM protocol could have a beneficial effect on the long-term cardiovascular disease, which has recently been shown to be the most common cause for mortality in children with ESRD (16).

The ultrasound dilution-guided angioplasty referral protocol led to a significant decrease in patient hospitalization rates for VAT management. Our center recently reported permanent vascular access survival rates similar to those published for adults (17). The significantly decreased VAT rates observed with our ultrasound dilution-guided angioplasty referral protocol could conceivably be associated with prolonged permanent vascular access functional survival and ultimately reduce the need for chronic catheter use for children who receive hemodialysis.

Hospitalization data from our center compares favorably to rates from adult hemodialysis patients reported from the United States Renal Data System (USRDS) (18). All-cause hospitalization rates from the USRDS in 1998 to 2000 were 14.2 d per patient year, whereas hospitalization rates in our center were 3.7, 12.1, and 24.9 d per patient year for 1999, 2000, and 2001, respectively. The increase in hospitalization rates seen in our study resulted from a more aggressively defined hospitalization practice for patient malnutrition, which we instituted in 2000. With respect to cause-specific hospitalization data, the USRDS reports a rate of 12.7 d per patient-year for hypertension, whereas our observed rates for FO/HTN were 2.7, 0, and 0.2 d per patient-year over the time course studied. The USRDS provides no similar specific data for VAT (only vascular procedures are reported). McCrory et al. (19) noted a reduction in hospitalization rates for VAT from 1.8 to 0.4 d per patient-year at risk as a result of their ultrasound dilution protocol. We noted a reduction from VAT hospitalization rates from 3.6 to 1.5 d per patient-year after institution of our ultrasound dilution protocol. Pediatric VAT rates might be conceivably higher secondary to their relatively small vessels, although one might expect higher rates in adults secondary to diabetes-associated peripheral vascular disease.

It was not the purpose of the current study to report all-cause hospitalization rates for pediatric patients who receive maintenance hemodialysis, because such single-center data could be skewed by our local practice: all-cause data would be more applicable from registry data including the USRDS or the North American Renal Transplant Cooperative Study. Rather, we aimed to assess the impact of the application of two noninvasive technologies on two of the most common hospitalization causes observed previously in our program. Data from the current study demonstrate that pediatric hemodialysis patient morbidity and health care costs from hospitalization can be significantly reduced by application of the noninvasive methods in the manners described herein. These advances led to fewer missed school days, less separation from family and peers, and fewer invasive procedures. Additional research is required to determine whether these measures result in long-term improvements in patient health-related quality of life.

Acknowledgments
We thank Rebekka A. Kears, B.B.A, for diligent maintenance of Texas Children’s Hospital Renal Dialysis Unit patient census and hospitalization data.

References
7. Brownbridge G, Fielding DM: Psychosocial adjustment to end-stage renal failure: Comparing haemodialysis, continuous ambu-


Access to UpToDate on-line is available for additional clinical information at http://www.jasn.org/