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Proactive monitoring of pediatric hemodialysis vascular access: Effects of ultrasound dilution on thrombosis rates

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Background. Hemodialysis vascular access thrombosis (VAT) is a significant cause of morbidity for hemodialysis patients and results, in part, from decreased access flow potentially caused by venous outflow stenosis. We have previously shown ultrasound dilution (UD) to be a practical and reliable predictor of venous outflow in children receiving hemodialysis.

Methods. The current study is the first to our knowledge to assess the impact of a proactive UD monitoring program upon VAT in pediatric patients. Nine patients experienced 18 VAT over the two-year study. Mean values for variables potentially associated with VAT were compared to values from a size-matched seven patient group without VAT during the study period. VAT rates were compared between the year-before (pre-UD era) and year-after (UD era) UD was initiated. During the latter half of the UD era (rapid referral period), patients with VA flow rate (Q_{Acorr}) <650 mL/min/1.73 m^2 were referred for balloon angioplasty within 48 hours.

Results. Mean Q_{Acorr} was lower for patients with subsequent VAT (562 ± 290 mL/min/1.73 m^2) versus patients without VAT (1005 ± 372 mL/min/1.73 m^2; P = 0.02). The VAT rate was significantly lower in the UD era (4.1 VAT/100 patient-months) versus the pre-UD era (11.0 VAT/100 patient-months; P = 0.03). The decrease in VAT rates was caused predominantly in the rapid referral period, where the VAT rate dropped to 0.96 VAT/100 patient-months ($P < 0.001$). Cost of vascular access management was 65% higher ($1264 vs. $765/patient-month) in the pre-UD era, reflecting the increased cost for treatment of VAT.

Conclusions. Monthly Q_{Acorr} <650 mL/min/1.73 m^2 is predictive of imminent VAT in children receiving hemodialysis. Prompt referral for angioplasty of VA with Q_{Acorr} <650 mL/min/1.73 m^2 leads to decreased VAT rates in children.

Provision of adequate hemodialysis depends upon a properly functioning hemodialysis vascular access. While permanent vascular access in the form of an arteriovenous fistula (AVF) or graft (AVG) is preferred over indwelling catheters, stenosis of the venous outflow tract can lead to decreased access flow and increased recirculation, preclude delivery of adequate dialysis and predispose to vascular access thrombosis (VAT) [1–3].

Ultrasound dilution (UD) is a simple, non-invasive bedside test for monitoring vascular access flow (Q_A) for patients receiving hemodialysis. A month-to-month decrease in access flow of greater than 15% [4] or an absolute access flow of less than 650 mL/min [5] as measured by UD is associated with an increased risk of VAT in adults. Prospective study using UD to monitor for a 20% decrease in vascular access flow or an absolute QA <600 mL/min to lead to prompt referral for angioplasty demonstrated decreased VAT rates in adult patients [6]. Another adult study demonstrated decreased VAT rates and dialysis unit cost when UD was used for referral to angioplasty [7].

No published studies exist to our knowledge with respect to permanent vascular access monitoring in children. As a result of the dearth of data, the NKF-DOQI Vascular Access Work Group could not make any recommendations with respect to pediatric permanent vascular access management [8]. Recently, we showed UD to be a reliable predictor of venous stenosis in children receiving hemodialysis [9]. Our study demonstrated that if vascular access flow by UD was corrected for patient size (Q_{Acorr}, mL/min/1.73 m^2), a value <650 mL/min/1.73 m^2 was both 100% sensitive and specific for venous stenosis >50% as measured by contrast venography.

We have been performing routine monthly UD monitoring of Q_{Acorr} in all permanent vascular access in our pediatric hemodialysis unit since April 2000. The aims of the current study were to determine if monthly UD measurement can decrease VAT rates by leading to expeditious referral for angioplasty, and to assess the effect of proactive vascular access management practice using UD on the cost of vascular access management in a pediatric hemodialysis program.

Key words: childhood ESRD, venous stenosis, angioplasty, adequacy of dialysis, arteriovenous grafts.

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METHODS

Monthly UD was performed prospectively (HD01^{plus} Hemodialysis Monitor; Transonic Systems, Ithaca, NY, USA) to evaluate access flow in all children with an AVF or AVG who had been receiving chronic hemodialysis for at least two months in the Texas Children's Hospital Renal Dialysis Unit, Houston, Texas from April 2000 to April 2001 (UD era). VAT rates, double-pool Kt/V, and dialysis unit cost for providing vascular access management were compared between the UD era and the immediate one year prior (pre-UD era) to when routine monthly UD measurement was instituted. Double-pool Kt/V was estimated using the logarithmic extrapolation method of Goldstein and Brewer [10]. Kt/V measurements were performed within two weeks of UD measurement. There were no technical problems that prohibited routine monthly UD measurement during the study period.

The same nurse (A.A.) performed all UD measurements during the first 60 minutes of the dialysis session. The technique employs two reusable sensors one of each attached to the venous and arterial line while the patient is receiving hemodialysis. After the lines are temporarily reversed (to create recirculation), a 20 mL bolus of saline is injected quickly into the venous line. The sensors are attached to a computer that interprets the changes in Doppler velocity as the hematocrit changes in relation to dialyzer blood flow. The manufacturer provided software to adjust for caliber difference between adult and pediatric sized blood tubing.

Ultrasound dilution reports access flow (Q_A) results in mL/min. To adjust for patient size, raw Q_A was corrected for body surface area and reported as Q_{Acorr} in mL/min/1.73 m^2. After analysis of our previous UD data up through November 2000 demonstrated Q_{Acorr} <650 mL/min/1.73 m^2 predicted >50% luminal stenosis with 100% specificity and sensitivity, patients with Q_{Acorr} <650 mL/min/1.73 m^2 were referred for outpatient contrast venography performed by an interventional radiologist at an adjacent adult care hospital. Patients with >50% luminal stenosis received balloon angioplasty of the stenosis. To determine the effectiveness of balloon angioplasty on Q_{Acorr}, UD was performed during a hemodialysis treatment within one week after angioplasty. Patients with VAT underwent surgical thrombectomy performed by a pediatric surgeon under general anesthesia at Texas Children's Hospital.

Cost data were available for all patients. The cost of providing vascular access management was compared for the one year before (pre-UD era) and after (UD era) routine monthly UD measurement was instituted as part of our practice. Cost data accounted for thrombectomy/access revision costs (operating room and hospital stay expenses) and balloon angioplasty cost (radiologist and radiology suite expenses). Adjustments were made for item cost price increases over each fiscal year during the study period. Cost data do not include the one-time charge for UD equipment purchase. There are no disposable costs associated with UD monitoring. All cost data are reported based on an adjusted 2001 fiscal year basis. Total cost data also were adjusted for patient census by dividing the total cost by the aggregate patient census for the pre-UD era (109 patient-months) and UD era (147-patient months).

Table 1. Comparison of clinical variables for patients with and without VAT

	VAT	No VAT	*P*
Patient weight *kg*	47.8 ± 14.6	45.5 ± 10.0	NS
Q_{Acorr} *mL/min/1.73 m*^{2}	562 ± 290	1005 ± 372	0.02
Double-pool Kt/V	1.22 ± 0.18	1.22 ± 0.14	NS

Abbreviations are: VAT, vascular access thrombosis; Q_{Acorr}, vascular access flow rate; Kt/V, dialysis dose.

Statistical analysis

Potential associations between double pool Kt/V, Q_{Acorr} and VAT were evaluated by independent *t* test comparing patients with VAT to a size-matched seven-patient group without VAT during the study period. To determine if a decrease in double-pool Kt/V occurred prior to VAT, monthly double-pool Kt/V changes were recorded for the two months prior to VAT. We instituted our policy of rapid referral for venogram with balloon angioplasty for all accesses with Q_{Acorr} <650 mL/min/1.73 m^2 in November 2000. To determine the extent to which rapid referral contributed to the decrease in VAT during the UD era, VAT rates from April 2000 to November 2000 (pre-rapid referral) and from November 2000 to April 2001 (rapid referral period) were examined separately. Comparison of VAT rates (expressed as number of VAT episodes per patient month) between the pre-UD era and UD era was performed using chi-square analysis. A *P* value <0.05 was considered significant.

RESULTS

Twenty-one patients received 222 UD measurements during the UD era. Nine patients (mean weight 47.7 ± 14.6 kg, range 23.7 to 69.2 kg) experienced 18 VAT episodes (7 AVG, 1 AVF) over the two-year course of study. Mean values for variables potentially associated with VAT were compared to values obtained in the same month from a size-matched seven-patient group (mean wt 45.4 ± 9.6 kg, range 32 to 60 kg; 4 AVG, 3 AVF) without a VAT during the study period.

Vascular access flow rate (Q_{Acorr}) was the only clinical variable associated with subsequent development of VAT in the following month (Table 1). Mean Q_{Acorr} was significantly lower for patients with subsequent VAT (562 ± 290 mL/min/1.73 m^2) versus patients without VAT (1005 ± 372 mL/min/1.73 m^2; $P = 0.02$).

Since the majority of VAT occurred in AVG, the analysis was repeated only for AVG. Q_{Acorr} in AVG was lower for patients with subsequent VAT (562 ± 290 mL/min/1.73 m^2) versus AVG without VAT (990 ± 349 mL/min/1.73 m^2), although the difference did not reach statistical significance ($P = 0.09$). Once again, none of the other clinical variables demonstrated a statistically significant difference between AVG with and without VAT.

No difference in mean double-pool Kt/V (1.20 ± 0.16 vs. 1.22 ± 0.16) was noted between the pre-UD era and the UD era. In addition, no difference was noted between double-pool Kt/V for patients with VAT versus patients without VAT (1.22 ± 0.18 vs. 1.22 ± 0.14). Mean double-pool Kt/V did not differ for vascular accesses with Q_{Acorr} values lower or higher than 650 mL/min/1.73 m^2.

The mean change in double-pool Kt/V from the two months prior to VAT was -0.03 ± 0.13 (range -0.42 to 0.30). The mean percent change double-pool Kt/V from the two months prior to VAT was $-2.3\% \pm 9.8\%$ (-27.6 to 22.9%). Sixty percent of patients had a decrease in Kt/V in the two months prior to VAT.

All but one patient with VAT had a preceding monthly Q_{Acorr} <650 mL/min/1.73 m^2. The other patient had an episode of severe dehydration that preceded his VAT event.

The unit VAT rate was significantly lower in the UD-era (6 thromboses in 147 patient-months, 4.1 thromboses/100 patient-months) versus the pre-UD era (12 thromboses in 109 patient-months, 11.0 thromboses/100 patient-months; $P = 0.03$). After November 2000, we instituted a policy of referral within 48 hours for contrast venography with possible angioplasty for all accesses with Q_{Acorr} <650 mL/min/1.73 m^2. We observed a VAT rate of 9.8/100 patient-months in the pre-rapid referral period. The VAT rate in the rapid referral period (0.96/100 patient-months) was significantly lower than the rates observed in both the pre-UD era ($P = 0.001$) and the pre-rapid referral period ($P = 0.02$) of the UD era.

Thirteen patients received 28 surveillance venograms in the pre-UD period during which 13 angioplasty procedures were performed for >50% luminal stenosis. Seven patients received 8 angioplasty procedures for Q_{Acorr} <650 mL/min/1.73 m^2 during the UD era. Angioplasty resulted in a significant improvement in Q_{Acorr} from 393 ± 155 to 850 ± 215 mL/min/1.73 m^2 ($P < 0.001$) in the UD era. No patient in either era developed a VAT in the month following angioplasty.

Cost data were available for all patients during the study period. Total venogram/angioplasty costs adjusted for inflation were $23,055 for the pre-UD era and $34,039 for the UD era. Venogram/angioplasty cost adjusted for patient census was $212/patient month in the pre-UD era versus $232/patient-month for the UD era. Total costs adjusted for inflation for treatment of VAT, including hospitalization, were $114,619 for the pre-UD era and $78,454 for the UD era, respectively. When adjusted for patient census, the VAT treatment cost was $1052/patient-month for the UD era versus $533/patient-month for the UD era. Total cost for vascular access management (angiography, operating room and hospitalization expense) was $1264/patient-month in the pre-UD era and $765/patient-month in the UD era, respectively. Cost data are listed in Table 2.

Table 2. Comparison of cost data between the pre-ultrasound dilution (pre-UD) and UD eras

	Pre-UD era	UD Era
1. Venogram/angioplasty total cost *$*	23,055	34,039
2. Mean venogram/angioplasty cost per patient *$/patient-month*	212	232
3. Total VAT treatment cost *$*	114,619	78,454
Total VAT treatment OR cost *$*	50,725	46,197
Total VAT treatment hospitalization cost *$*	63,894	32,257
4. Mean VAT treatment cost per patient *$/patient-month*	1,052	533
Overall total cost for vascular access management *$* (line 1 + line 3)	137,674	112,493
Overall mean cost per patient for VA management *$/patient-month* (line 2 + line 4)	1,264	765

All cost data were adjusted for inflation and reported in fiscal 2001 terms. Mean cost per patient was determined by dividing total cost by patient census during the pre-UD era (109 patient-months) and the UD era (147 patient-months).

DISCUSSION

Provision of adequate hemodialysis depends upon a properly functioning vascular access. Vascular access morbidity costs total nearly $8,000 per patient-year in the adult hemodialysis patient population [8]. A recent adult study demonstrated decreased VAT rates and morbidity for patients who received monthly access monitoring by UD versus static venous pressure monitoring or no monitoring at all [6]. Pediatric patients have smaller vessel sizes and could theoretically be higher risk for venous stenosis and VAT. We have previously demonstrated the reliability of UD in predicting venous stenosis in our pediatric hemodialysis population [9]. The current study evaluates the effect of a prospective vascular access monitoring program on VAT rates and cost of vascular access management in children and adolescents.

Institution of UD monitoring was associated with a significant decrease in VAT rates (11.0/100 patient-months to 4.1/100 patient-months) over the entire study period. Further examination of the UD era revealed the decrease in VAT rates was made predominantly by combining UD with rapid referral to angioplasty. Prompt referral for angioplasty within 48 hours of monthly Q_{Acorr} <650 mL/min/1.73 m^2 resulted in a significant decrease in VAT rates (11 VAT/100 patient-months to 0.96 VAT/100 patient-months). The data suggest the decrease in VAT rates resulted from balloon angioplasty, since significant improvement in Q_{Acorr} was observed in the week after the angioplasty procedure. Prior to the use of monthly UD measurement, our center screened for access stenosis using a surveillance venography protocol. Well functioning accesses were screened every six months, while accesses with a history of previous stenosis were screened every 6 to 12 weeks. While extremely accurate in detecting stenosis, this invasive surveillance venography protocol was associated with a 10 times greater VAT rate than a protocol of monthly non-invasive UD monitoring and rapid referral for angioplasty when Q_{Acorr} <650 mL/min/1.73 m^2.

Decreasing clearance as measured by Kt/V has been advocated as a screening measure for poorly functioning accesses, since venous stenosis can lead to access recirculation and a reduction in Kt/V. The current data demonstrated no difference in double-pool Kt/V between accesses with Q_{Acorr} values lower or higher than 650 mL/min/1.73 m^2 or patients with and without VAT. Furthermore, 40% of patients actually had an increase in double pool Kt/V in the two months prior to VAT. These data suggest that Kt/V may be neither a sensitive nor specific indicator of venous stenosis.

Increasing vascular access recirculation also has been advocated as a marker for venous stenosis. However, our previous UD study did not demonstrate increased recirculation in patients with >50% stenosis seen on contrast venography [9]. As a result, we do not rely on recirculation measurement for detection of venous stenosis.

Mean Q_{Acorr} was the only clinical indicator studied associated with subsequent—supporting our previous conclusion that Q_{Acorr} <650 mL/min/1.73 m^2 is predictive of vascular access stenosis and imminent VAT in pediatric patients receiving hemodialysis.

Evaluation of cost data adjusted for patient census demonstrated a 65% higher cost for vascular access management in the pre-UD versus the UD era ($1264 vs. $765/patient-month). These savings reflect a nearly two-fold decrease in operating room and hospitalization expense for treatment of VAT in UD era ($533/patient-month) compared to the pre-UD era ($1052/patient-month). The current data demonstrate UD monitoring and rapid referral to angioplasty result in a 50% decrease in annualized cost ($12,624 to $6396) for vascular access morbidity (OR and hospitalization costs) per pediatric patient. The resultant value is lower than the $8000 per year associated with vascular access morbidity in adults receiving hemodialysis [8].

The UD era practice of early referral to angioplasty when Q_{Acorr} <650 mL/min/1.73 m^2 led to only a minor increase in venogram/angioplasty cost. A far greater increase in the UD era venogram/angioplasty cost might have been predicted, since UD could conceivably lead to more angioplasty procedures. The minor increase in observed venogram/angioplasty cost might result from the ability of UD to predict accesses at-risk for stenosis and help avoid unnecessary surveillance venography of well-functioning accesses.

Since we were comparing annual costs for vascular access management, which are costs that are expected to recur each year, we elected not to incorporate the one-time cost for purchase of the UD monitor in the current analysis. The manufacturer's list price is $12,330. In the current study, the total annual cost savings were $25,181, which is nearly double the list price of the UD monitor. There are no disposable items necessary to perform the UD procedure.

The results of the current study support the use of monthly vascular access monitoring by UD and for prompt referral for balloon angioplasty when Q_{Acorr} <650 mL/min/1. 73 m^2. Such practice lead to a decreased patient morbidity and pediatric dialysis unit cost during the time period studied. Further long-term study is needed to determine if such a proactive vascular access management program will result in prolonged AVG and AVF survival in children receiving hemodialysis.

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