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Vascular access blood flow monitoring reduces access morbidity and costs

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Background. Vascular access morbidity results in suboptimal patient outcomes and costs more than $8000 per patient-year at risk, representing approximately 15% of total Medicare expenditures for ESRD patients annually. In recent years, the rate of access thrombosis has improved following the advent of vascular access blood flow monitoring (VABFM) programs to identify and treat stenosis prior to thrombosis. To define further both the clinical and financial impact of such programs, we used the ultrasound dilution method to study the effects of VABFM on thrombosis-related morbid events and associated costs, compared with both dynamic venous pressure monitoring (DVPM) and no monitoring (NM) in arteriovenous fistulas (AVF) and grafts.

Methods. A total of 132 chronic hemodialysis patients were followed prospectively for three consecutive study phases (I, 11 months of NM; II, 12 months of DVPM; III, 10 months of VABFM). All vascular access-related information (thrombosis rate, hospitalization, angiogram, angioplasty, access surgery, thrombectomy, catheter placement, missed treatments) was collected during the three study periods.

Results. During the three study phases, graft thrombosis rate was reduced from 0.71 (phase I), to 0.67 (phase II), to 0.16 (phase III) events per patient-year at risk ($P < 0.001$ phase III vs. phases I and II). Similarly, hospital days, missed treatments, and catheter use related to thrombotic events were significantly reduced during phase III compared to phases I and II. Hospital days related to vascular access morbidity and adjusted for patient-year at risk were 1.8, 1.6, and 0.4 and missed dialysis treatments were 0.98, 0.86, and 0.26 treatments per patient-year at risk for phases I, II, and III, respectively ($P < 0.001$ for phase III vs. phases I and II). Catheter use was also significantly reduced during phases II and III, from 0.29 (phase I) to 0.17 and further to 0.07 catheters per patient-year at risk, respectively ($P < 0.05$ for phase III vs. phase I). Percutaneous angioplasty procedures increased during phases II and III from 0.09 to 0.32 to 0.54 procedures per patient-year at risk for phases I, II, and III, respectively ($P < 0.01$ for phase III vs. phase I). When the total cost of treatment for thrombosis-related events for grafts was estimated, it was found that during phase III, the adjusted yearly billed amount was reduced by 49% versus phase I and 54% versus phase II to $158,550. Similar trends in reduced thrombosis-related morbid events and cost were observed for AVFs.

Conclusions. VABFM for early detection of vascular access malfunction coupled with preventive intervention reduces thrombosis rates in both polytetrafluoroethylene (PTFE) grafts and native AVFs. While there was a significant increase in the number of angioplasties done during the flow monitoring phase, the comprehensive cost is markedly reduced due to the decreased number of hospitalizations, catheters placed, missed treatments, and surgical interventions. Vascular access blood flow monitoring along with preventive interventions should be the standard of care in chronic hemodialysis patients.

The rapid growth of end-stage renal disease (ESRD) programs in the United States has been accompanied by a notable increase in hemodialysis vascular access-related morbidity. A recent report from the United States Renal Data System (USRDS) estimated that the average cost of access morbidity is $7871 per patient per year at risk and that the annual global cost to Medicare represents 14 to 17% of total spending for dialysis patients per year at risk [1]. Recent data also suggest that the cost associated with vascular access care may be accelerating [2].

Given the magnitude of the problem, significant efforts have focused on improving understanding of the pathophysiology and appropriate treatment for vascular access morbidity. One of the important achievements in this field included understanding the need to monitor access function prospectively in order to detect incipient access malfunction [3]. Schwab et al initially proposed dynamic venous pressure monitoring (DVPM) for the purpose of predicting stenosis in 1989 [4]. Subsequent to the Schwab studies, Besarab et al utilized static venous pressure monitoring (SVPM) to predict stenosis [5]. The predictive

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capability for access stenosis was greatly advanced with the development of the ultrasound dilution technique of vascular access blood flow (VABF) measurement during the hemodialysis treatment [6]. Recent studies by our laboratory and others have shown that vascular access flow measurement was a significant and better predictor for stenosis as well as thrombosis compared with other techniques [7–11].

While prospective monitoring of the vascular accesses predicts probable stenosis with a high degree of sensitivity and specificity, an important issue that has not been clarified is the cost-effectiveness of prospective vascular access blood flow monitoring combined with a treatment algorithm for the resolution of the stenosis. The present study has been carried out to compare thrombosis rates, hospitalizations, and related costs over three periods of vascular access management. Our hypothesis was that VABFM using the ultrasound dilution method results in a decrease in thrombosis rate, access-related morbidity, and associated costs when compared with either no monitoring or with a program of DVPM.

METHODS

The study was conducted at an outpatient dialysis facility. Institutional approval was obtained for the study procedures from relevant administrative offices where the study was conducted. Data were obtained through review of existing patient records.

A total of 132 chronic hemodialysis patients were enrolled throughout the three phases of the study, all from the same dialysis facility. Inclusion criteria for the study were all chronic hemodialysis patients with a permanent vascular access [native arteriovenous (AV) fistula or synthetic graft] treated at the dialysis facility during the study period. Patients with a catheter as the primary and only vascular access were excluded from the study population. During the course of the study period, patients were censored from the follow-up at the time of the dropout event. These were (*1*) percutaneous catheter placed as the primary and only access, (*2*) transfer out of the facility, (*3*) transplantation, and (*4*) death.

All patients were dialyzed three times per week on high-flux biocompatible membranes (F-80 Fresenius, Concord, CA, USA) on standard bicarbonate dialysate, using a volumetric-controlled dialysis delivery system (Fresenius 2008H) and 15-gauge fistula needles. Patients were anticoagulated by using systemic heparin, according to a facility protocol based on 50 U/kg predialysis bolus, and 1000 U/h continuous intradialytic infusion, which was discontinued during the last 30 minutes of treatment. Heparin doses and discontinuation time were adjusted based on goals of maintaining clot-free dialyzers and post-treatment access hemostasis time of less than 20 minutes.

Study design

This study was analysis of data from three phases of access thrombosis monitoring and treatment. The dates of the study periods were January 1, 1996, to November 30, 1996 (phase I), December 1, 1996, to November 30, 1997 (phase II), and December 1, 1997 to September 30, 1998 (phase III). Phase I consisted of 11 months of hemodialysis treatment without access monitoring [no monitoring (NM)]. Phase II was a 12-month period of dynamic venous pressure monitoring, and phase III was a 10-month period of vascular access blood flow monitoring. During phase II, dynamic venous pressure monitoring was carried out according to the Schwab method of VP measurement at QB of 200 mL/min during the first five minutes of dialysis each treatment as modified by National Kidney Foundation, Dialysis Outcomes Quality Initiative, Clinical Practice Guidelines for Vascular Access [4]. Patients with VP measurements that were above the baseline for three consecutive treatments were referred for fistulogram, followed by treatment with angioplasty or surgery, based on the judgment of the radiologist. Prior to phase II, all staff was prospectively trained in DVPM.

Phase III of VABFM was carried out according to the algorithm depicted in Figure 1. The access flow rate of all patients was measured at the start of phase III, monthly thereafter, and within one week following any access intervention. All measurements were done in duplicate, and any measurement that would trigger access intervention was repeated, before being referred for intervention. Based on flow measurement results, a fistulogram was done within one week for grafts if (*1*) flow rate was $<$600 mL/min, (*2*) flow rate reduced by 25% compared with previous month measurement, or (*3*) flow rate was 25% below baseline. For native AV fistulas, fistulogram was done if (*1*) flow was reduced by 25% compared with previous month measurement or (*2*) flow was 25% below baseline. Based on the judgment of the radiologist, patients with vascular lesions were treated by either percutaneous angioplasty (PTA) or surgery within one week from the fistulogram. Of note, the same radiology group consisting of two interventional radiologists was used throughout the three phases of the study. After intervention, a new baseline access flow measurement was done, and routine monthly flow measurements were resumed. Before implementation of phase III, multidisciplinary meetings were held to develop a treatment algorithm agreeable to all team members (renal nurse, nephrologist, surgeon, radiologist). In addition, three patient-care technicians were trained as experts in performing access flow measurements and tracking related data, in addition to their usual duties. The facility manager, who facilitated implementation of the treatment algorithm for each patient, supervised these technicians. During

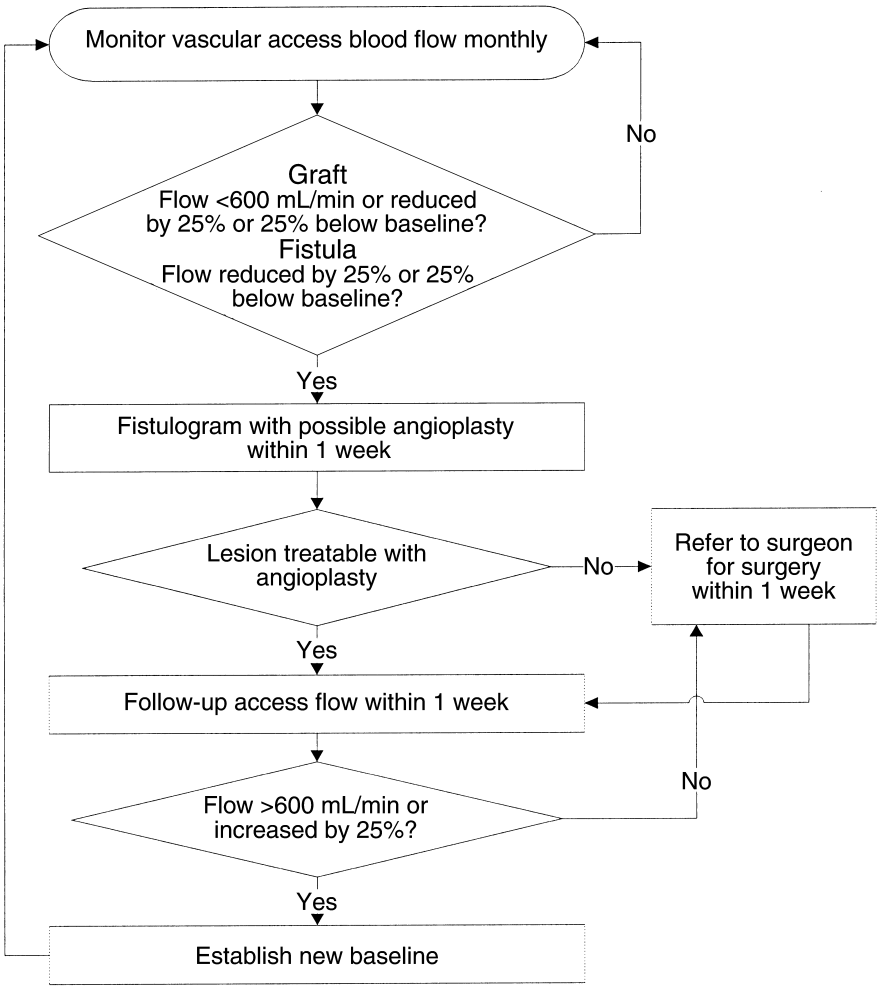

Fig. 1. Treatment algorithm for vascular access blood flow monitoring during phase III.

phase II and phase III, all patients were educated regarding the procedures.

The access management protocol was implemented in a prospective manner since the beginning of the study, which included extensive data collection from the beginning of phase I. The data were abstracted from the database for statistical analysis after the study was completed. Data abstraction for all patients included data for thrombotic events, PTA and surgical treatments, and all thrombosis-related events that included missed dialysis treatments, catheter placements, and hospitalization. The same study personnel did all the data abstraction, and the set of data items abstracted from the database was consistently the same throughout the study. All of these data items also were tracked routinely in the facility as part of the facility's continuous quality improvement program and focus on improvement of vascular access outcomes. For each treatment and thrombosis-related event, the associated expense information also was estimated. Specifically, an average charge per procedure was determined according to Vanderbilt University Medical Center financial information data system to calculate the adjusted yearly charges: $1000 per day for hospitalization, $200 per missed treatment, $750 per catheter placement, $6332 per new access/revision procedure, $5000 per thrombectomy, and $3000 per PTA.

VABF measurement technique

Hemodialysis VABF was measured by ultrasound velocity dilution technique using the Transonic HD01 hemodialysis monitor (Transonic Systems, Inc., Ithaca, NY, USA). The technique has been validated extensively and details can be found elsewhere [6]. In brief, the system uses two ultrasonic sensors attached to the lines of the hemodialysis tubing, one to the arterial and another to the venous line, approximately two to six inches distant from the connection of tubing to dialysis needles. Initially, blood recirculation is checked in the vascular access while the blood lines are in the normal position. Then, the blood lines are reversed and ultrafiltration is turned off. The blood pump flow is set at 300 mL/min. A bolus of saline (approximately 10 mL) is released into

Table 1. Characteristics of patient population during study phase I (no monitoring, NM), phase II (dynamic venous pressure monitoring, DVPM), and phase III (vascular access blood flow monitoring, VABFM)

Parameter	Phase I NM	Phase II DVPM	Phase III VABFM
N patients	104	103	98
N grafts	78	75	62
N fistulae	39	41	43
Age *average*	55.3 ± 17.4	56.6 ± 16.6	56.1 ± 16.9
Gender *% males*	51%	54%	59%
Race			
Caucasian	70.8%	69.9%	67.6%
African American	29.2%	30.1%	32.4%
Cause of ESRD			
HTN	43.7%	44.7%	46.5%
Diabetes	35.9%	35.9%	34.4%
Lupus	4.9%	2.9%	3.0%
GN	3.9%	4.9%	5.1%
Other	11.6%	11.6%	11.0%

the venous line, diluting the flow of blood in the access and resulting in changes of sound velocity, which is measured by the transducers on the lines. This change is calculated by the Transonic® software, giving the VABF in mL/min.

Statistical analysis

The Generalized Linear Model–Poisson loglinear statistical procedure was carried out for testing the statistical associations between the study variables, that is, thrombosis rate, hospitalization, missed treatments, new access, and catheter placement rates for the three study phases. The Poisson loglinear model extends the traditional linear model to encompass responses such as proportions or incidence. For the Poisson loglinear model, the probability distribution is the Poisson distribution, and the maximum likelihood estimators are obtained through iterative reweighted least-squares algorithms. The mixed-effect model was used to adjust the intracorrelation effect for the patients who had more than one clotting event during the study. For patients with more than one access during the study, the statistical model for the crossed-nested design was applied for the data analysis. All tests of significance were two sided, and differences were considered statistically significant when P value <0.05. All data were expressed as means ± SD. SAS version 8.0 was used for all analyses.

RESULTS

Patient characteristics

The characteristics of the patient population for each study phase are found in Table 1. For the 132 patients studied, 104 patients were included in phase I, 103 patients were in phase II, and 98 patients were in phase III. There were no significant differences among the study phases for any of the parameters listed in Table 1.

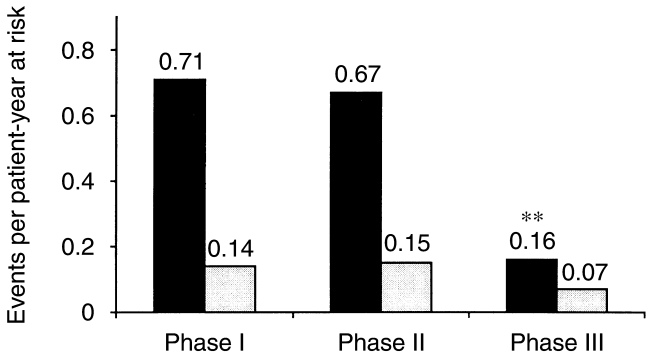

Fig. 2. Thrombosis rates of grafts and arteriovenous (AV) fistulas during study phases I, II, and III. Symbols are: (■) grafts; (▒) fistulas; $^{**}P < 0.001$ vs. phases I and II.

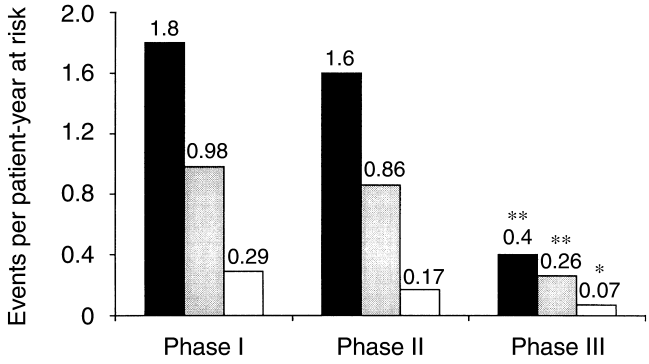

Fig. 3. Access-related event rates for hospitalization (■), missed treatments (▒), and catheter placement (□) for phases I, II, and III; grafts only. $^{*}P < 0.05$ vs. phase I; $^{**}P < 0.001$ vs. phases I and II.

Thrombosis rates

The thrombosis rates during the three phases of the study are shown in Figure 2. Grafts thrombosed at a rate of 0.71 events per patient-year at risk during phase I of no access monitoring. During phase II of DVPM, the rate decreased marginally to 0.67 events per patient-year at risk. This reduction in thrombosis rate in phase II was not statistically significantly different compared to phase I. During phase III of VABFM, thrombosis rates for grafts decreased to 0.16 events per patient-year at risk. This reduction in thrombosis rate during phase III was highly statistically significantly different compared with either phase I or phase II ($P < 0.001$ vs. both phases I and II). This reduction represented a 77% decrease in thrombotic events compared with no monitoring and 76% decrease compared with DVPM; indeed, the thrombosis rate of PTFE grafts during phase III approached the thrombosis rate observed in native fistulae. The native fistula thrombosis rate followed a similar pattern, with 0.14, 0.15, and 0.07 events per patient-year at risk for phases I, II, and III, respectively. However, the 50% reduction in thrombosis rate observed during phase III was not statistically significant compared with phases I or II.

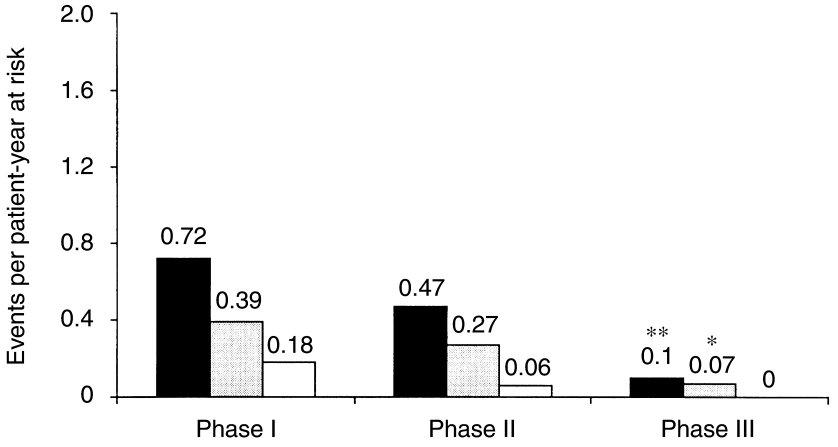

Fig. 4. Access-related event rates for hospitalization (■), missed treatments (▩), and catheter placement (□) for phases I, II, and III; native fistulas only (*$P <$ 0.05 vs. phase I; **$P <$ 0.05 vs. phases I and II).

Access-related hospitalization, missed treatments, and catheter placement

The rate of occurrence of morbid events directly related to access events and procedures was determined for hospitalization, missed treatments, and catheter placement. These rates for polytetrafluorolethylene (PTFE) grafts are shown in Figure 3. Thrombosis-related hospitalization was reduced significantly from 1.8 hospital days per patient-year at risk and 1.6 hospital days per patient-year at risk in phases I and II, respectively, to 0.4 days per patient-year at risk in phase III ($P < 0.001$ vs. phases I and II). Similarly, missed treatments were reduced significantly from 0.98 events per patient-year at risk in phase I and 0.86 events per patient-year at risk in phase II to 0.26 events per patient-year at risk in phase III ($P < 0.001$ vs. phases I and II). The need for catheter placement was also reduced from 0.29 events per patient-year at risk in phase I and 0.17 events per patient-year at risk in phase II to 0.07 events per patient-year at risk in phase III. The reduction in catheter placement events during phase III was statistically significantly less than phase I only ($P < 0.05$ vs. phase I).

Figure 4 depicts the same information on hospitalization, missed treatments, and catheter placement for native fistulas. During phase III, hospitalization was significantly reduced to 0.1 days per patient-year at risk versus phases I and II (0.72 and 0.47 days per patient-year at risk, respectively, $P < 0.05$). Missed treatments were reduced from 0.39 missed treatments per patient-year at risk during phase I to 0.27 missed treatments per patient-year at risk during phase II and to 0.07 missed treatments per patient-year at risk during phase III ($P <$ 0.05 for phase III vs. phase I). A reduction in catheter placement was not statistically significant during the three phases of the study, although there were no catheters placed during phase III of the study.

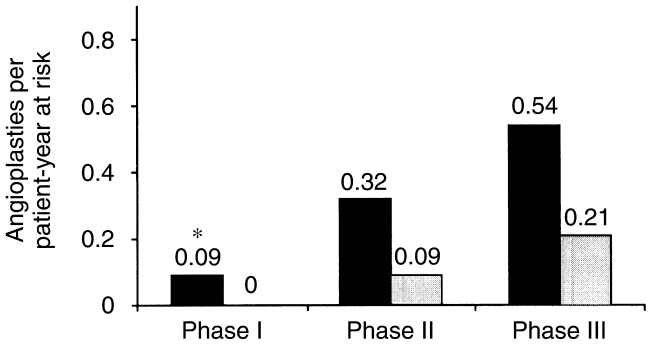

Fig. 5. Angioplasty rates of grafts (■) and AV fistulas (▩) during study phases I, II, and III (*$P <$ 0.01 vs. phases II and III).

PTA and surgical procedures

We further examined the rate of interventional procedures during the three phases of the study. There were substantial increases in angioplasty rates for both PTFE grafts and native fistulas during phase II and phase III (Fig. 5). These rates for PTFE grafts were 0.09, 0.32, and 0.54 PTA procedures per patient-year at risk for phases I, II, and III, respectively ($P < 0.01$ for phase I vs. phases II and III). For AVFs, there were 0, 0.09, and 0.21 PTA procedures per patient-year at risk for phases I, II, and III, respectively (P = NS).

The number of thrombectomy procedures for PTFE grafts was not significantly changed from phase I to phase II (0.51 procedures per patient-year at risk vs. 0.36 procedures per patient-year at risk, P = NS); however, during phase III, thrombectomies were reduced significantly to 0.05 procedures per patient-year at risk ($P <$ 0.05 vs. phases I and II). Of note, there were no thrombectomies performed for AV fistulas throughout the entire study period. The rate of new surgeries (access placement and revisions) for PTFE grafts was not significantly different among the three phases (0.20 procedures per patient-year at risk for phase I, 0.31 procedures per pa-

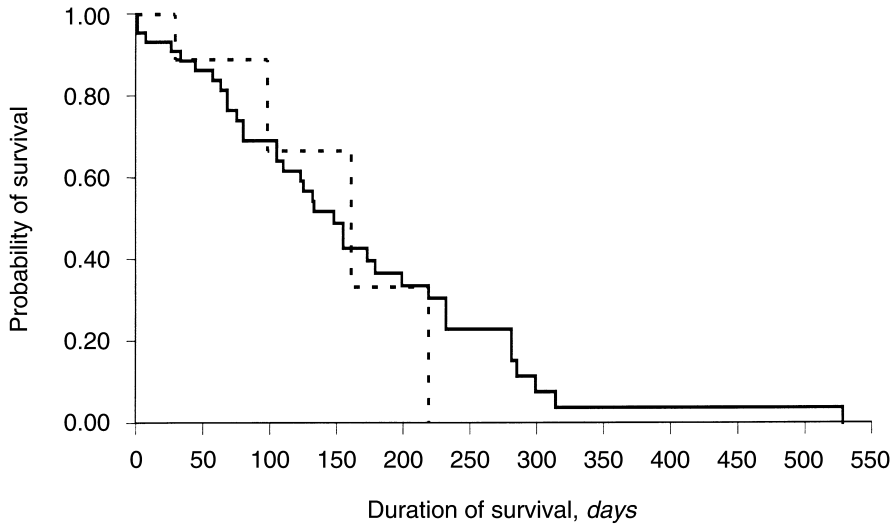

Fig. 6. Survival curve for angioplasty patency for grafts (solid line) and native AV fistulas (dashed line). Angioplasty half-life in grafts was 148 days ($N = 44$) and fistulas was 161 days ($N = 9$).

Table 2. Adjusted yearly charges for thrombosis-related access care for patients with grafts and fistulas

	Grafts			Fistulae		
Cost item	Phase I NM	Phase II DVPM	Phase III VABFM	Phase I NM	Phase II DVPM	Phase III VABFM
Hospitalization	$ 87,275	$ 82,000	$ 20,400	$21,820	$16,000	$ 3,600
Missed treatments	9,600	9,000	2,650	2,400	1,800	480
Catheters	10,650	6,750	2,700	4,090	1,500	0
New access/revisions	62,170	101,312	38,000	41,450	50,656	15,200
Thrombectomy	125,450	95,000	12,000	0	0	0
Angioplasty	13,100	51,000	82,800	0	9,000	21,600
Adjusted yearly cost	$308,245	$345,062	$158,550	$69,760	$78,956	$40,880

tient-year at risk for phase II, and 0.14 procedures per patient-year at risk for phase III). For AV fistulas, there were again no new accesses placed during phase III, while the new access placement rate was 0.18 procedures per patient-year at risk during phase I and 0.07 procedures per patient-year at risk during phase II ($P < 0.001$ for phase I vs. phase III).

Angioplasty patency

To evaluate the primary patency of the vascular accesses that underwent angioplasty during the whole study period, angioplasty patency was measured from each PTA to time of repeat PTA, surgery, or clotting event. Figure 6 depicts the survival curve for angioplasties done during the study. As can be seen, the overall primary patency for those accesses was less than 40% at six months.

Overall cost

The cost of access-related morbidities was examined in regard to estimated billed amounts, and is shown in Table 2. When the charges of all morbid events and treatment procedures were combined, the adjusted yearly billed amount for access-related morbidity for PTFE grafts was $308,245 for phase I. The billed amount increased during phase II to $345,062, primarily due to an increase in surgical and angioplasty procedures. During phase III, the adjusted yearly billed amount was reduced by 49% versus phase I and 54% versus phase II to $158,550. Although total billed amounts for native fistulae were only 22 to 26% of the billed amounts for grafts during each study phase, the trend in cost reduction was similar. For fistulae, the adjusted yearly billed amount was reduced during phase III by 41% versus phase I and by 48% versus phase II.

DISCUSSION

The results of this study strongly suggest that vascular access blood flow monitoring for early detection of vascular access malfunction coupled with preventive intervention reduces the vascular access thrombosis rate as well as associated charges when compared with no monitoring or dynamic venous pressure monitoring in chronic hemodialysis patients. The overall benefit from this approach provides an overall cost cutting of 49% compared with no monitoring and 54% compared with dynamic ve-

nous pressure monitoring. The beneficial effects also are observed as decreases in the total number catheters inserted, thrombectomies, new accesses placed, and missed treatments, suggesting additional medical advantage to the patients. To our knowledge, this is the first study that systematically evaluates the effects of an early detection and intervention protocol for vascular accesses on thrombosis as well as hospitalizations and associated costs.

While it is known that vascular access-related morbidity represents a major portion of the ESRD related costs, recent data also suggest that this cost associated with vascular access care may be accelerating. Feldman, Kobrin and Wasserstein reported that, while access-related morbidity accounted for approximately 15% of hospital stays prior to 1989, more recent evidence suggests that access-related morbidity accounts for at least 25% of all hospital stays and in the first year of dialysis may constitute up to 50% of all patient care costs [2]. These data become even more relevant to nephrology practice in the face of a major interest by Medicare and some Health Maintenance Organizations (HMOs) to capitate medical care to ESRD patients.

In addition to this enormous financial burden, for patients, dialysis staff, nephrologists, and surgeons, the frequency and unpredictability with which hemodialysis vascular access thrombosis develops are immense frustrations. Vascular access-related morbidity also contributes significantly to a reduction in the delivered dose of dialysis (a major factor in the high relative risk of mortality of chronic hemodialysis patients) through the use of temporary catheters or reduced blood flow; importantly, this access-related morbidity leads to a significant reduction in the quality of life of dialysis patients.

The results of our study clearly indicate that prospective monitoring of vascular access blood flow coupled with early intervention significantly reduces thrombosis rate. This reduction in thrombosis rate was almost 4½-fold in PTFE grafts and twofold in AV fistulas during the VABFM phase compared with phase I. Earlier studies by our laboratory and others have already indicated that VABFM is the best predictor for future thrombosis [7, 8, 11–13]. The novel finding in this study is the fact that when the vascular access at risk for future malfunction is detected with VABFM, early intervention by angioplasty or surgery significantly reduces the thrombosis chance in that specific vascular access. Indeed, the thrombosis rate for the PTFE grafts during phase III of the study was as low as 0.16 events per patient-year at risk, which is similar to our native AV fistula thrombosis rate without any monitoring. This rate observed in PTFE grafts is actually almost half of what has been recommended for native AV fistulas by the NKF-DOQI Clinical Practice Guidelines [14]. The beneficial effect of early intervention also was detectable for AV fistulas. However, the decrease in the AV fistula thrombosis rate did not reach statistical significance, most likely secondary to the low number of thrombotic events. It is also important to note that a similar approach for preventive intervention utilizing dynamic venous pressure monitoring did not result in any improvement either in PTFE grafts or AV fistula thrombosis rates. This finding is consistent with the recent studies suggesting that DVPM is not sensitive as an early predictor of vascular accesses at risk for malfunctioning [8].

The significant reduction in thrombosis rate during phase III for the study translated into significant improvements in vascular access-related morbidity. Specifically, there was a fourfold decrease in vascular access-related hospital days during this phase of the study. As expected, the decrease in hospital days greatly reduced the total hospitalization charges. Yearly adjusted hospitalization charges (PTFE grafts and AV fistulas) during phase III of the study were as low as $24,000 for the whole study patients. Improvement in hospitalization cost was not the only financial advantage observed during the study. Indeed, there was a significant reduction in the number of missed treatments due to vascular access malfunction during the VABFM phase of the study. Overall, there was $8870 more revenue available by reducing missed treatments during phase III of the study.

In addition to financial benefits, there were important medical advantages of early intervention. Specifically, there was a significant reduction in number of central venous catheters placed during the VABFM phase of the study compared with the other two phases. Given the potential adverse effects of temporary and permanent central venous catheters, such as risk of infection and delivery of inadequate dialysis, the medical benefits of early intervention are clear [15]. In addition, during the VABFM phase of the study, there was a remarkable reduction in the number of new accesses created. It is evident that preservation of potential access sites in CHD patients is critical [3, 16]. Vascular access blood flow monitoring seems to provide CHD patients a crucial medical benefit by preserving future access placement sites. These benefits were most noteworthy for AV fistulas such that there were no catheters and/or new accesses placed for these patients during the VABFM phase of the study.

A notable finding of our study was that prospective monitoring of vascular accesses either with DVPM or VABFM coupled with early intervention significantly increased angioplasty rates and associated costs. This is an expected finding, since the treatment algorithms used involved referral for angiogram during phases II and III. Early detection of vascular accesses at risk with monitoring would prompt more frequent arteriograms and this would in return result in more angioplasties, since there is a tendency to perform angioplasty at the same session once a clinically significant stenosis is determined by arteriograms. This resulted in an increase in utilization of

PTA procedures during phases II and III compared with phase I. However, the increased number of angioplasties translated to an improvement in thrombosis rates only during the VABFM phase but not during the DVPM phase of the study. Furthermore, in spite of increased cost of angioplasties, there was a significant reduction in surgery-related costs during the VABFM phase of the study, attenuating the increased cost of angioplasties.

Since there was a substantial increase in the number of angioplasties during the phases II and III of the study, we further evaluated primary patency of the vascular accesses that underwent angioplasty during the study. The overall primary patency for those accesses was less than 40% at six months. This finding suggested that while early intervention with angioplasty decreases thrombosis rates in PTFE grafts and AV fistulas, this improvement is accompanied by a significant increase in cost and trivial postponement until the next need for intervention. Therefore, it is essential that treatment algorithms based on radiologic findings of the stenotic lesion include alternative approaches such as surgery for vascular accesses at risk. Studies of outcomes would further identify the most efficacious and cost-effective treatment that provides the greatest benefit in access survival.

In spite of the intriguing results presented herein, one should also consider several pitfalls of the study when interpreting these results. Most importantly, this study design is not a randomized design, but utilizes data obtained from prospective cohorts for comparison. Indeed, the only available prospective randomized study failed to prolong the primary patency of PTFE grafts by prophylactic balloon angioplasty [17]. It is possible that the recognition of the importance of vascular access-related morbidity and associated costs over the recent years might provide a potential bias during the final phase of the study favoring the results for that period. Additionally, there is a possibility that the accesses entering the final phase of the study are "fitter." This is due to the possibility that the reservoir of access abnormalities that were manifest in phases I and II were treated, leaving behind a fitter set of accesses entering phase III. While this assumption may be true, there are several indications that the set of accesses entering phase III were not actually statistically a "fitter" set. First, there is no statistically significant change regarding thrombosis rate, hospital days, missed treatments, and catheter use for both grafts and fistulas from phase I to phase II. Furthermore, the rate of angioplasty actually increased during phase III compared with phase II of the study. Therefore, we believe that the accesses in the third phase of the study were not different as compared with phase I and phase II, and that the robust improvement in vascular access outcomes during phase III are clinically significant, and have resulted from the specific intervention. Nevertheless, the design used in this study is limited in the sense that the strategies were not implemented in a different order at the beginning of the study; this limitation can only be overcome through the implementation of appropriately designed clinical trials.

There have been recent changes in vascular access care due to financial restrictions by Medicare and private insurance companies. Specifically, vascular access procedures are more commonly done at outpatient setting without hospitalization, unless medically required. This might create an advantage for hospitalization rates during the final phase of the study. However, there was a planned multidisciplinary team approach for vascular access management at the initiation of our study with an awareness for the most appropriate care for the patient. The only significant change during the study period was the availability of additional screening techniques. Furthermore, even if the hospitalization is excluded from analysis, the improvement in other outcome measures (that is, thrombosis rates, missed treatments, catheter placement, revisions, and thrombectomy) during phase III is 47% compared with phase II. Therefore, we believe that the robust findings presented in this study are more than just related to time and selection bias. It should also be noted that the cost data presented in this study are primarily for illustrative purposes and do not reflect the actual billed and collected amounts. While there may be differences between the billing amounts for these events among institutions, the payment amount by Medicare is usually fixed for each charge and the costs used were uniform for all three phases. Accordingly, the cost associated with morbid events will be directly related to frequency of those events.

Another potential drawback in the study is that the interventions were decided by the judgment of the radiologist, which may introduce subjectivity in the study. However, the same radiology and surgery groups were utilized during the entire study period, which should minimize this potential bias. The patient population also varied during the three phases of the study, albeit a small percentage. However, the statistical methodology used in this article—a generalized linear model—accounted for such differences in patient population as well as possible recurrent events in the same patient. Finally, an important issue that has not been clearly delineated by this study is the optimal frequency of sequential screening in order to detect the access at risk. While in this study measurements of vascular access blood flow were made every month, other studies suggested that less frequent monitoring, such as every other month or quarterly, might be as efficient [7, 13]. Since most dialysis centers do not have personnel dedicated for VABF measurements, this would create a substantial noncapital costs depending on the frequency of the measurements. Therefore, further studies are needed to define the optimal interval between measurements that provides early detection of increased

risk of thrombosis without generating high operational costs of detection that, at present, are not subject to reimbursement by Medicare.

In summary, the results of this study strongly suggest that vascular access blood flow monitoring for early detection of vascular access malfunction coupled with preventive intervention reduces thrombosis rates in both PTFE grafts and native AV fistulas in this relatively small number of chronic hemodialysis patients. While there is a significant increase in the number of angioplasties done during flow monitoring, the overall cost is markedly reduced due to the decreased number of hospitalizations, catheters placed, missed treatments, and surgical interventions. A similar approach with venous pressure monitoring failed to provide any medical or financial benefit compared with no monitoring. We conclude that vascular access blood monitoring along with preventive interventions should be the standard of care in chronic hemodialysis patients.

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