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Investigations

Doppler Ultrasound: A Powerful Tool for Vascular Access Surveillance

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ABSTRACT

National Kidney Foundation Kidney Disease Outcomes Quality Initiative (NKF KDOQI) guidelines recommend Doppler ultrasound (DU) for surveillance of vascular access (VA), but trials have not been unanimous about its benefit on VA patency. The aim of this study was to evaluate the accuracy of DU for patency, as well as to highlight additional data provided by this method. A transversal study was conducted to evaluate DU method in correlation with BTM using paired *t*-test and Pearson test. Ultrasonography evaluation was performed with a Siemens Acuson X150 Ultrasound device and BTM-Qa with the Blood Temperature Monitor BTM®. Access blood flow (Qa) values were correlated with several factors by nonparametric tests. Fifty hemodialysis patients were included, with mean age of 64.5 ± 13.7 years; durations of hemodialysis and VA were 51.4 ± 47.3 and 47.6 ± 42.1 months, respectively. The mean difference between DU and BTM flows was 20.5 ml/minute (p 0.624). Pearson correlation was 0.851 ($p < 0.001$). DU-Qa values varied significantly with several factors: type of VA, reason for DU referral, the presence of artery stenosis, and the location and number of stenosis. BTM-Qa values only varied significantly with the presence and number of stenosis. Various silent abnormalities were detected with DU. DU provides accurate anatomic and hemodynamic data to further knowledge regarding the etiology of stenosis and other abnormalities that compromise VA well functioning.

Complications of vascular access (VA) for hemodialysis (HD) are a major cause of morbidity and mortality in end-stage renal disease patients (1). The pathogenic mechanisms for arteriovenous dysfunction are not completely understood, but it is thought that thrombosis resulting from stenosis due to neointimal hyperplasia is the main cause, which eventually leads to access failure (2–5).

Under the paradigm "prevention is better than cure", the National Kidney Foundation Kidney Disease Outcomes Quality Initiative (NKF KDOQI) recommends that accesses should be monitored regularly for the detection of the development of stenosis, and, if detected, it should be treated with elective percutaneous transluminal angioplasty or surgery prior to thrombosis (6).

The currently available tools for monitoring include clinical and physical examination of the VA (7,8). The surveillance methods are measurement of access blood flow (Qa), intra-access venous/arterial pressure, recirculation, and other physiologic parameters. Qa is one of the most powerful predictors of VA failure. Even without any additional risk factors, patients with flows <500 ml/minute have a higher risk of subsequent VA failure (9). Qa can be measured using several methods. Direct measurement such as with Doppler ultrasound (DU) (6), and indirect such as ultrasound dilution (6) are the current *standard of reference* techniques. KDOQI Guidelines recommend DU as the preferred method for Qa surveillance in arteriovenous fistulas (AFVs) and grafts (AVGs) (evidence A) (6).

According to previous trials, DU surveillance does not have adequate evidence to prolong access lifespan (10), but this finding has been reviewed (11–13).

Malik et al. (14) performed the largest randomized controlled trial, where they concluded that DU surveillance significantly improved VA patency and this benefit remained significant for more than 2 years. In their last work (15), they established additional criteria to distinguish borderline stenosis from those with clear indication to treat and showed that delaying endovascular interventions in the first cases can be safe using a watch-and-wait strategy.

DU correlates closely with other imaging modalities, and Qa-DU has been shown to be comparable

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TABLE 1. Categorical variables

	Frequency (%)
Gender	
Masculine	72.5
Feminine	27.5
First VA status	
First VA	67.5
Not first VA	32.5
Previous interventions	
Yes	20.0
No	80.0
DU request motive	
Qa reduction	22.5
Difficult puncture	27.5
Lab and/or pressure alterations	7.5
Surveillance	32.5
Clinical alterations	10.0
Type of VA	
Radiocephalic fistula	32.5
Humerocephalic fistula	40.0
Humerobasilic fistula	10.0
Humerobasilic prothesis	7.5
Proximal radiocephalic fistula	7.5
Humeroperforating fistula	2.5
Anastomosis	
No alterations	92.5
Hemodynamic meaning stenosis	5.0
No hemodynamic meaning stenosis	2.5
Artery	
No alterations	92.5
Hemodynamic meaning stenosis	7.5
No hemodynamic meaning stenosis	0.0
Vein	
No alterations	30.0
Hemodynamic meaning stenosis	37.5
No hemodynamic meaning stenosis	22.5
Central vein stenosis	10.0
Stenosis	
No stenosis	20.0
Hemodynamic meaning stenosis	55.0
No hemodynamic meaning stenosis	25.0
Stenosis location	
Anastomosis	6.3
Artery	6.3
Vein	81.3
> one location	6.3
Prothesis	
No PTFE	92.5
No alterations	5.0
Hemodynamic meaning stenosis	2.5
No hemodynamic meaning stenosis	0.0
N° stenosis	
0	20.0
1	65.0
2	10.0
3	5.0

to indirect methods (16,17). Despite this evidence, there are concerns about variability due to operator dependence (18), lacking of expertise, and poor reproducibility; it cannot be done intradialysis or repeated as often as indirect tests, and regarding AV patency improvement, studies remain controversial.

Regarding Qa indirect measurement, there are several techniques available such as differential conductivity (TD) (19), which results are consistent with the ultrasound dilution technique (20); however, it also has limitations. Changes in line insulation and room temperature will cause errors in the calculation of access temperatures (21), and accuracy in detecting falls in the fistula flow is lower at higher values (21).

This study, performed at our unit, evaluated the efficiency of Qa measurement with DU method in comparison with TD. The present study also tried to encounter other parameters related to vascular access that might affect Qa values, taking into consideration that reduced fistula flow adds predictive value for the detection of access stenosis, thrombosis, and loss of VA patency.

Patients and Methods

A cohort of 50 patients, on regular program of postdilutional online hemodiafiltration with 5008S Fresenius Medical Care® monitors, were included.

Demographic variables such as age, gender, dialysis duration, VA type and duration, first VA or sequential, previous interventions (endovascular or surgical), intra-access venous and arterial pressure and recirculation were recorded.

Echographic study was performed by a Siemens Acuson X150 Ultrasound device. Morphologic exam was executed, with cross section B-mode, from the artery and anastomosis, through the drainage vessels until central veins in the upper arm and chest (according to patient phenotype and technical conditions), followed by longitudinal visualization. Color and Doppler mode were used to assess hemodynamic pattern of the access. DU-Qa was evaluated in the humeral artery by measuring the vessel diameter (D) and the time average velocity (TAV) through the formula: Qa (ml/minute) = TAV (cm/second) $\times$ D (cm) $\times$ 60 (22).

The criteria of hemodynamically significant stenosis included >50% reduction in the diameter and more than twofold increase in peak velocity with maximum peak velocity in stenosis >400 cm/second (23).

In the same week, Qa was measured, during the first 30 min of dialysis session, with blood temperature sensor BTM® (Blood Temperature Monitor), Fresenius Medical Care, Bad Homburg, Germany, incorporated in the hemodialysis devices (BTM-Qa) (24). BTM is performed using a constant infusion of saline that promotes a variation in dialysate temperature, which will change the venous blood temperature returning to the patient (20). Two sensors, which hold the blood lines, recorded the temperatures of arterial and venous blood passing the measuring site (tube temperatures) which were calculated for a given insulation and environmental conditions using the extracorporeal blood flow measured by the dialysis machine, with a sampling period of 15 seconds (25).

Statistical Analysis

Resulting data were analyzed using SPSS 20.0 software for Windows (SPSS, Inc., Chicago, IL). Continuous variables were expressed as mean, median, standard deviation, minimum and maximum

TABLE 2. Continuous variables

	Mean	Median	SD	Min	Max
Age (years)	64.50	65.00	13.68	32.00	84.00
Time of dialysis (months)	51.35	33.00	47.30	0.00	155.00
Time of vascular access (months)	47.60	34.00	42.11	2.00	154.00
Thermodilution Qa (ml/minute)	1012.00	885.00	492.97	270.00	2000.00
Doppler Qa (ml/minute)	1032.55	997.00	468.75	297.00	2230.00
Average venous pressure (mmHg)	208.50	200.00	31.64	139.00	272.00
Average arterial pressure (mmHg)	−182.20	−189.50	31.53	−226.00	−98.00
Recirculation (%)	11.65	11.00	3.12	6.00	20.00

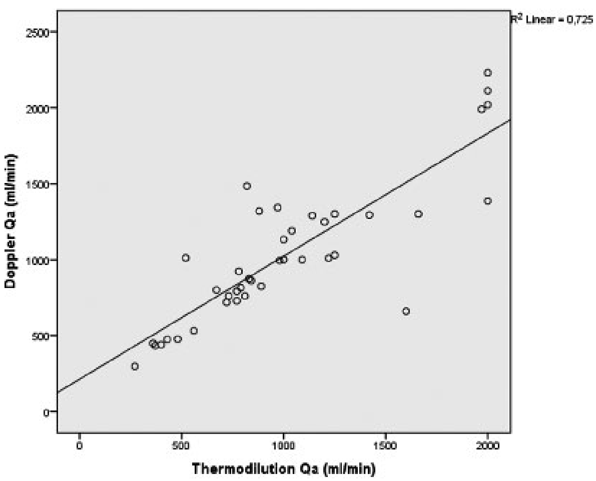

FIG. 1. Simple scatter plot DU-Qa vs. BTM-Qa.

values; and rejected null hypotheses of no difference if *p*-values were less than 0.05.

Qa measurements (BTM and DU) were both compared and evaluated their correlation using the paired *t*-test and Pearson coefficient, respectively. Nonparametric tests were used to analyze if Qa values varied significantly with other VA-related factors.

TABLE 3. Kruskal–Wallis and Mann–Whitney test

	p-value	
	TD Qa (ml/minute)	DU-Qa (ml/minute)
DU request motive	0.076	0.006
First VA	0.036	0.199
VA type	0.079	0.021
Time of VA (threshold 48 months)	0.112	0.061
Previous endovascular procedure	0.509	0.478
Venous pressure (threshold 200 mmHg)	0.203	0.155
Arterial pressure (threshold −185 mmHg)	0.028	0.015
Recirculation (threshold 10%)	0.145	0.266
Anastomosis characteristics	0.103	0.076
Artery characteristics	0.538	0.048
Vein characteristics	0.208	0.844
Presence of stenosis	0.039	0.038
Stenosis location	0.087	0.031
Stenosis hemodynamic meaning	0.290	0.935
Number of stenosis	0.012	0.034

Results

Fifty patients were evaluated during regular program of HD with a mean age of 64.5 ± 13.7 years; average time on HD was 51.4 ± 47.3 months and of VA was 47.6 ± 42.1 months. Categorical and continuous variables are recorded in Tables 1 and 2, respectively.

Overall, mean DU-Qa was 1032.5 ± 468.7 mL/minute, and mean BTM-Qa was 1012.0 ± 492.9 mL/minute. Paired *t*-test between BTM and DU methods revealed a mean difference of 20.5 ml/minute, with a *p*-value of 0.624 (>0.05). Pearson correlation coefficient was 0.851, *p*-value 0.000 (<0.05) (Fig. 1).

DU-Qa measurements differed significantly with VA type ($p = 0.021$), reason for DU referral ($p = 0.006$), mean arterial pressure intra-access ($p = 0.015$), artery characteristics/stenosis ($p = 0.048$), as well as, the presence ($p = 0.038$), location ($p = 0.031$), and number of stenosis ($p = 0.034$). On the other hand, BTM-Qa values only varied significantly with mean arterial pressure intra-access ($p = 0.028$), and the presence ($p = 0.039$) and number of stenosis ($p = 0.012$) (Table 3).

Among other anomalies than those recorded on Tables 1 and 2, we found four patients with mural thrombus, three with pseudoaneurysm, one with a hemodynamic stenosis-like behavior conditioned by a twisting of the basilic vein, one with peri-PTFE abscess, one with colateral veins unrelated with stenosis. Intimal hyperplasia was seen in several patients, although not specifically recorded.

Discussion

The goal of this new technique is early detection of AVF or AVG dysfunction and preemptive correction by angioradiologic or vascular surgical techniques without placement of a central venous catheter.

Depending on each center and its resources, the first evaluation after physical exam, can be ultrasound performed by nephrologist who plays a main role in the vascular access care multidisciplinary team. Ultrasonography skills can be achieved with experts and widely validated through randomized trials.

Surveillance methods determine access blood flow rate and are important tools for assessing hemodialysis access; however, they require technical equipment and cannot substitute the clinical importance of physical examination (26). Considering BTM a widely accepted method in our unit, mainly because of its convenience (without delaying sessions and requiring no more staff), we found that DU-Qa measurement represented an excellent direct method of flow evaluation. However, we found that flows varied differently with several factors. DU-Qa varied significantly with patient referral, reflecting the accuracy of the complementary methods of monitoring (mainly physical examination and indirect techniques). As found by Monroy-Cuadros et al. (9), DU-Qa was significantly lower in distal AVF, probably related with the smaller size of the vessels at this location. In contrast to anastomosis and vein, artery characteristics were determinant to DU method, which could be explained by the fact that the artery is the vessel that feeds the access.

Stenosis presence, number, and location had a significant impact on DU-Qa, which is in agreement with the most frequent pathogenic mechanism of VA dysfunction.

With regard to BTM method, as well as DU, Qa values varied significantly with mean intra-access arterial pressure. Patients with their first VA had higher values, probably because a second VA reflects a previous failure (primary or not), in association with an increased impact of risk factors.

Although Qa values for both methods were higher when VA duration was <12 months, no significant difference was noticed between them. In spite of a lack of statistical significance, only the DU method found inferior values in patients with venous stenosis with hemodynamic significance comparing to those who did not meet this criteria. Only three patients had intra-anastomosis stenosis with hemodynamic significance, and despite the fact they all had lower Qa in both methods, values were inferior with DU.

This study confirmed that in addition to Qa measurement, DU detected and characterized stenosis as to their location, residual diameter, and hemodynamic significance. It also clarified stenosis etiology (intimal hyperplasia, parietal thrombus, postpuncture scarring, pressure of surrounding structures, twist vein) (23). Asymptomatic changes without blood flow decreasing were also diagnosed (arterial calcification, pseudoaneurysms, vessels duplications, and others).

All this additional information can be crucial in the future because not all dysfunctional VA have stenosis and are at risk for thrombosis (23,27,28), in which premature endovascular manipulation can increase the stimulus for neointimal hyperplasia and restenosis. On the other hand, some VA with high blood flow and silent alterations like a thrombus can suddenly stop, and a late intervention may lose an access forever.

Adding to these advantages, patients who did an angiography after performing Doppler ultrasound, had shorter procedures, fewer complications, and less material waste.

Research into more determinants for vascular failure is essential and will have direct implications in patient care. It will permit potential identification of subgroups of patients at higher risk of VA failure and to consider modifying surveillance accordingly for a risk group stratification that may result in cost savings for the healthcare system.

Conclusion

Our study demonstrated that besides strong correlation with other methods, ultrasound has several advantages over these. Adding its high accuracy in measuring access flow, it provides a more concise explanation of stenosis etiology and detects several other abnormalities enabling earlier interventions without unnecessary invasive interventions with high morbidity, high cost, and low benefit.

To the best of our knowledge, this study showed that Doppler ultrasound is the only accurate, noninvasive, portable tool that provides both anatomic and hemodynamic data. As it stands, it should be part of the regular surveillance of vascular access.

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