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# Doppler Ultrasound Assessment of Well-Functioning Native Hemodialysis Access: Comparison with Sufficient Dialysis

**Background/Objective:** Malfunction of vascular accesses is a common cause of morbidity in hemodialysis patients. The purpose of the present study was to evaluate the flow volume and the diameter of the feeding artery in asymptomatic, well-functioning hemodialysis access with Doppler ultrasound.

**Patients and Methods:** From March 2006 to February 2007, we examined the functioning mature arteriovenous fistula (AVF) of 69 hemodialysis patients by Doppler ultrasound in Imam Reza hospital, Mashhad. The measured flow volume, primary renal disease, AVF type and location, and the demographic data were recorded. All statistical analyses were performed with the Chi square test, the *Student's t* test and one-way ANOVA. Pearson correlation coefficient was also calculated.

**Results:** Of the 69 patients, 30 (43%) had an antecubital AVF. Overall, the mean±SD flow volume was 1665±554 mL/min. The majority of accesses (n=52) had normal flow volume (500-1200 mL/min), 15 patients had high-flow fistulas (>1200 mL/min) and 4 had critical flow rates of <500 mL/min. The flow volume was significantly higher in the antecubital AVF than that placed in more distal positions. The mean diameter of the feeding artery at the measurement site was 6.0 mm. There is a linear correlation between the diameter of the feeding artery and the mean flow rate ($r=0.76$, $p<0.001$). No significant difference was observed between the type of anastomosis and the flow rate ($p=0.14$).

**Conclusion:** There is a high level of abnormalities, especially high flow volume, in well-functioning mature AVFs. Color Doppler ultrasonography makes early detection of the patients with a higher risk possible and it can also guide the surgeon to select the surgical procedure.

Keywords: Hemodialysis Access, Access Blood Flow, Dialysis, Arteriovenous Fistula, Color Doppler Ultrasound

## Introduction

With the increasing number of hemodialysis patients, the creation and maintenance of a patent and well-functioning arteriovenous fistula (AVF) has become a real challenge to nephrologists and vascular surgeons.[1] Malfunction and complications of hemodialysis vascular accesses are common causes of frequent and costly morbidity in patients with chronic renal failure.[2] The most serious complications are fistula failure and high-output heart failure.[3] Access blood flow of at least 500 to 800 mL/min is necessary to allow sufficient removal of uremic toxins from a patient within a reasonable time. A reduction in fistula blood flow to less than that range is usually caused by the occurrence of stenosis in the arterial or venous branch of the fistula.

Decreased hemodialysis access flow to <400 mL/min is associated with an increased risk of access stenosis and fistula failure, and an increased flow >1200 mL/min, especially >1500 mL/min, is associated with problems in the cardiac output.[4]

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A way of measuring dialysis adequacy is the Kt/V. In this measurement, (K stands for the dialyzer clearance (mL/min), t: time, Kt: is clearance multiplied by time, V: volume of water in the patient's body. The studies generally showed that patients with lower Kt/V (<1.2) had more health problems and a higher risk of death.[3]

Although abnormal hemodynamics in access fistulas are usually detected during hemodialysis, early detection of access dysfunction and subsequent specific intervention before worsening of the condition may help to reduce the rate of access-related morbidity.[5] Access blood flow measured by color flow-Doppler ultrasound is a reliable indicator of subsequent risk for fistula failure or cardiac overload.[2]

Numerous reports exist of patients with clinically presumed AVF complications. Nonetheless, only limited data are available about the asymptomatic AVFs.[3] The purpose of the present study was to evaluate the flow volume and the diameter of the feeding artery in asymptomatic native AVFs with color Doppler ultrasound to describe the characteristics of our well-functioning fistula and assessment of the causes affecting it.

## Patients and Methods

We examined 78 hemodialysis patients with a functioning mature (*i.e.*, older than two months) AVF at Imam Reza hospital in Mashhad with Doppler ultrasound from March 2006 to February 2007, in a cross-sectional study. We studied almost all hemodialysis patients with an AVF in an unselected group of patients, ensuring that an appropriate spectrum of patients was studied.

Well-functioning fistula had the following criteria: 1) no difficulties with hemodialysis (as reported by nurses); 2) normal venous diastolic blood pressure (BP) of <150 mm Hg at monthly evaluation; 3) normal urea clearance; 4) blood cell count, plasma electrolytes, and liver function tests at monthly evaluation. These four criteria were taken to denote a well-functioning fistula.

AVFs were considered to have inadequate dialysis filtration rates (malfunctioning) when they could not deliver sufficient blood flow to permit a hemodialysis treatment and a Kt/V <0.5.[3] Of the 78 patients studied, impairment of AVF function (Kt/V<1.2) was detected in nine fistulas and were thus excluded from the study. Because BP is known to influence the hemodynamic parameters, studies were not performed during the last hour of hemodialysis or during periods of significant hyper- or hypotension.[6,7]

Ultrasound examination was carried out using ultrasound color flow scanner (EUB-525 Hitachi unit) with a 7 MHz linear-array transducer. The fistulas were screened from the brachial artery in the mid-arm via anastomosis and upward to the upper arm. The flow measurement of the feeding artery (supplier proximal artery to the shunt) was taken two cm above the fistula.

Since precise determination of the maximum velocity and velocity ratio (the rate of peak systolic velocity (PSV) in the anastomotic area and proximal to it) in the anastomotic area due to the limitations of ultrasound examination and the lack of proper angle correction, was very difficult, as mentioned by other investigators,[8] we measured the flow volume in the brachial and feeding artery of the shunt to evaluate the AVFs.

For the evaluation of access flow, the diameter and cross-sectional area of the feeding artery were determined by a B-mode sonography in a transverse plane from the inner edge to the inner edge and tracing the luminal outline.

At the same site, Doppler spectra were obtained in a longitudinal plane with an insonating angle maintained as far as possible at ≤60° (45°–65°) for calculation of time averaged velocity (TAV). The sample volume size must be sufficiently large to include the entire luminal cross section (Fig 1). Access flow was determined by equipment software using the formula below:[3]

$$\text{Flow volume}_{(\text{mL/min})} = TAV_{(cm/\text{sec})} \times \pi \cdot {}^{2}(\text{cross-sectional area in } cm^2) \times 60$$

To reduce errors to an acceptable level, we carried out the measurements twice and used the mean results. If the second measurement varied by >10%, then a third measurement was performed and the mean of the two closest measurements were recorded.

For the steal syndrome, Doppler ultrasound was diagnostic if it showed a retrograde flow in the distal artery to AVF, but clinically, steal syndrome is de-

fined by the induction of extremity pain during hemodialysis. The studies were performed by one radiologist who was not aware of the clinical, laboratory or hemodialysis status when performing the ultrasound examination.

### Statistical Analysis

Comparisons between groups were performed by $\chi^2$, *Student's t* test and one-way analysis of variance (ANOVA) as appropriate. Correlation was assessed by Pearson correlation coefficient. SPSS, ver 13 for Windows® (SPSS Corporation, Chicago, Illinois) was used for statistical analysis. P<0.05 was considered statistically significant.

## Results

Sixty-nine patients with well-functioning accesses (31 women and 38 men) were studied. They had a mean±SD age of 40±17 (range: 12–82) years. AVFs were placed in the antecubital (n=30), snuff box (n=21), mid-forearm (n=9), and the distal forearm (n=9).

The two most common types of anastomosis were side vein to side artery (n=27) in the wrist and end vein to side artery (n=7) in the elbow. The mean±SD duration of hemodialysis was 3.1±4.4 years. The mean±SD time interval between AVF placement and first vein puncture was 3.7±1.1 months.

The mean±SD flow volume in 69 patients with well-functioning fistulas in the feeding artery of access was 1665±554 mL/min (range: 314–4080 mL/min). In the brachial artery (mid-arm) it was 1826±1551 mL/min (range: 500–6140 mL/min). Table 1 shows the flow volume in accesses with normal functioning stratified by the site of placement. There was a significant difference between the site of the fistula and the mean flow volume in the feeding artery of shunts. It was significantly higher in the upper arm fistulae (p = 0.001).

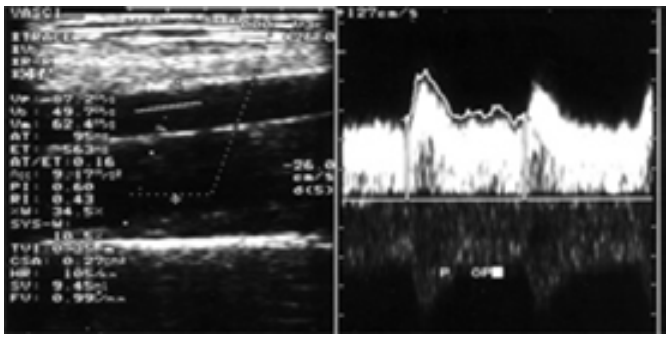

**Fig. 1.** A 65-year old woman with an antecubital arteriovenous shunt: A Doppler spectrum was obtained in a longitudinal plane of feeding artery of the shunt with an appropriate insonating angle of 63° and the entire luminal cross section was included in the sample size. Flow volume of the shunt is 990 mL/min.

**Table 1.** Flow Volume in Different Locations of AVFs

| Site | Mean(±SD) Flow Volume (mL/min) | 95% CI* for Mean (mL/min) |
|---|---|---|
| Upper forearm | 2430±820 | 2138-2722 |
| Mid-forearm | 1825±850 | 1270-2380 |
| Distal forearm | 1014±435 | 730-1298 |
| Snuff box | 940±655 | 661-1219 |
| Whole group | 1665±554 | 1534-1796 |

***CI:** Confidence Interval

In the antecubital area, there was no correlation between the type of anastomosis and the flow volume (p=0.14). The majority of accesses (n=52) had a normal flow volume (500–1200 mL/min); 15 patients had high-flow fistulas (>1200 mL/min); four had critical flow rate (<500 mL/min).

The mean±SD diameter of the feeding artery at the measurement site was 6.0±1.1 (range: 4.1–8.7) mm. There was a linear correlation between the diameter of the feeding artery and the mean flow rate (r=0.76, p < 0.001) (Fig. 2). The mean±SD flow volumes in arteries with 2.8–4 mm, 4–6 mm, and 6–8 mm in diameter were 492±250 mL/min, 1113±650, and 3250±980 mL/min, respectively (p< 0.001).

The mean±SD diameter of the veins was 8.9±4.4 (range: 3.6–20) mm. The mean flow in patients with an aneurysmal vein 2970 (range: 1950–3250) mL/min. Furthermore, in patients with steal syndrome it was 2820 (range: 1760–3220) mL/min. There was a statistically significant difference between the aneurysmal or tortuous vein and mean flow volume. It was significantly higher in the fistulas with aneurysms (p<0.001). All aneurysmal veins were located in the efferent vein close to the anastomotic region. The mean±SD diameter of aneurysms was 12.4 (range: 7–32) mm. There was sonographic steal syndrome in 42 of the accesses, but the clinical steal syndrome was seen in four of them. The brachial flow rate was significantly higher in those with steal syndrome (p<0.001).

The flow rate was not statistically different between

**Table 2.** Relationship Between Gender, Age and Fistula Age and Mean Flow Volume

| Parameter | Mean(±SD) Flow Volume (mL/min) | *p* Value |
|---|---|---|
| Sex | | |
| Male | 1670±670 | 0.95 |
| Female | 1640±659 | |
| Fistula Age (days) | | |
| >180 | 1620±685 | 0.45 |
| <180 | 1542±559 | |
| Age (years) | | |
| >65 | 1183±620 | 0.004 |
| <65 | 1818±706 | |

men and women (women: 1640±659, men: 1670±670 mL/min; p=0.95) and between those with fistula age less than or more than 180 days (time from creation to flow rate measurement <180 days: 1542±559, *vs* ≥180 days: 1620± 685 mL/min; p=0.45). The flow volume was significantly lower in patients aged >65 years. In patients older and younger than 65 years, the mean±SD flow volume was 1183±620 and 1818±706 mL/min, respectively (p = 0.004) (Table 2).

In four access sites, the peak systolic velocity (PSV), end-diastolic velocity (EDV), pulsative index (PI) and resistive index (RI) were numerically similar and had no significant differences. There were no abscesses, hematomas and venous occlusions. Only during the study performance, three of the patients with a high-flow rate were benefitted from the results of this study by surgical correction of the shunt.

## Discussion

A well-functioning AVF is essential for the maintenance of hemodialysis in patients with chronic renal failure. Although abnormal hemodynamics in access fistulas are usually detected during hemodialysis, sonographic evaluation at the time of initial dysfunction may reveal an underlying correctable abnormality, so that an appropriate therapy may be instituted before worsening of the condition.[9]

Using data from a series of patients with native vessel AVF, we evaluated the relationship between clinical characteristics and rates of blood flow access. We found that access location was independently associated with the flow volume and it is a significant predictor of the flow rate in the mature AVF. Access failure was detected in nine patients with low flow rate which shows complete agreement between the findings of color Doppler sonography and dialysis adequacy. Similar to some publications,[3] our experience shows that the flow volume is the best Doppler parameter for the evaluation of a shunt.

Although assessment of clinical and Doppler parameters such as gender, fistula age, PSV, EDV, PI and RI had no additional diagnostic value for the detection of stenosis and the assessment of hemodynamic parameters,[3,10] Belli, et al, found them predictive.[11] In the present study, age >65 years was apparently associated with lower flow rate in AVFs. Lin, et al, and Tonelli, et al, also had the same results.[7,12] Begin, et al, investigated the relationship between blood flow and age.[13] They did not find a relationship between age and flow volume, but there was a trend towards a lower flow in the younger age group.

We also found a wide variation in the range of flow rate in patients whose AVF was clinically stable. The flow rate was documented as low as 314 mL/min and as high as 4080 mL/min. In the majority of publications the mean flow volume was reported as 500-1200 mL/min,[7,14,2,10] but Nonnast, et al, mentioned the figure of 1525 mL/min.[15] While the range of flow seen in our study is not new, the overall mean flow volume of 1826 mL/min in normally functioning fistulas is higher than that previously reported, especially for the antecubital AVFs. This may be due to the fact that about half of our fistulas had a high location in the upper extremity (*e.g.*, antecubital) or due to the type of surgical procedures. In another study, most of the fistulas (about 70%) were on the wrist and forearm area.[3]

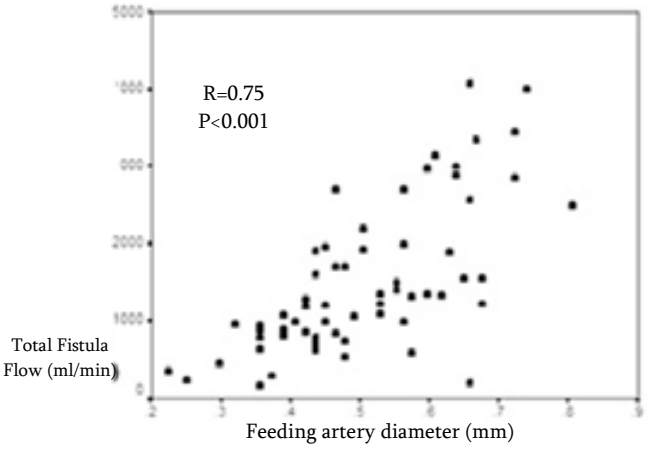


**Fig. 2.** Correlation between diameter of the feeding artery and the mean flow rate.

We found the diameter of the feeding artery and the site of the fistula as two very useful parameters because there is high correlation between them and the hemodynamic parameters (flow volume and dialysis filtration rate) and clinical conditions. These results are in contrast to the findings of Tonelli, et al, who found no evidence of correlation between the flow volume and the AVF location.[7]

Diameter of feeding artery and site of fistula has consistently been demonstrated to be important predictors of AVF flow rate[16] According to our results; the mean flow volume in was higher than brachial artery feeding artery of access. In addition, there is strong correlation between flow volume with aneurismal or dilated vein and steal syndrome. Also, a variable portion of fistula flow may be supplied by the distal collateral arteries via the palmar arch (steal syndrome). Subsequently, we believe that real flow rate via native vessel arteriovenous fistula (AVF) in patients who had aneurismal or dilated vein or steal syndrome and in patients who had higher flow volume in brachial artery were significantly higher than measured flow rate in feeding artery of shunt and measurements in the feeding artery can underestimate AVF flow rate. Then, flow rate in feeding artery of shunt alone isn't an accurate indicator of shunt function.

Although we believe that they are unlikely to have affected our conclusions, a vulnerable limitation of our results is measurement errors due to the unit used or the operator. Although color Doppler ultrasound allows assessing AVFs very precisely, the question about the clinical value of these results and whether or not this should lead to treatment of high-flow fistulas in routine practice and asymptomatic patients still remains unanswered. However, a long-term clinical trial would be necessary to assess this hypothesis.

Another note was made of the patients' pulse rate during the Doppler study which indicated that it is better to evaluate and rule out transient tachycardia or changes in the heart rate in our patients but we did not record it.

We conclude that there was a high level of abnormalities present in well-functioning mature AVFs. Color Doppler sonography enables early detection of the abnormalities and helps the surgeon select the appropriate surgical procedure.

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