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Early inadequate venous flow volume after technically successful balloon angioplasty of radiocephalic arteriovenous fistula: causes and follow-up results

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Abstract. – OBJECTIVE: The objective of this study was to investigate the causes of inadequate venous flow volume, which may lead to re-dysfunction in the early period after technically successful percutaneous transluminal angioplasty (PTA), and the results after one-week follow-up with or without medical treatment.

PATIENTS AND METHODS: This prospective case-control study included dysfunctional radiocephalic arteriovenous fistula (AVF) cases treated with PTA between December 2021-2022. After PTA, a residual stenosis of less than 30% was considered technically successful. Based on venous flow volume measured 1-2 hours after angioplasty, post-procedural doppler ultrasound (DUS) classified patients as cases (≤400 mL/min) or controls (>400 mL/min). Between groups, pre-post and control DUS parameters were compared. The correlation between fistulography lesion measurements and DUS values was investigated. The pre-procedural DUS resistive index (RI) cut-off value was determined to discriminate groups.

RESULTS: A total of 42 patients, 21 cases and 21 controls, were included in the study. Before PTA, 67% of cases had total venous thrombosis, and 71% of controls had stenosis. Lesion measurements and residual stenosis were similar between groups ($p>0.05$). After PTA, 48% of cases had a free-floating thrombus in the vein, and 10% had a peri-vein hematoma. In pre-procedural DUS, flow volume was the only spectral analysis parameter paired between groups ($p=0.057$). In post-procedural and control DUS, controls had higher peak systolic velocity (PSV), end-diastolic velocity (EDV), and flow volume, whereas cases had a higher RI ($p<0.05$). Lesion length and degree of stenosis correlated positively with pre-procedural RI in both groups ($p<0.05$). The pre-procedural RI cut-off of 0.76 discriminated groups with 76% sensitivity, 67% specificity, 70% positive predictive value (PPV), and 74% negative predictive value (NPV).

CONCLUSIONS: Low venous flow after PTA has been primarily associated with free-floating thrombi. Routine post-procedural DUS detects low venous flow, high RI, and small thrombi, providing evidence to initiate medical treatment that may prevent early AVF re-dysfunction.

Key Words:
Arteriovenous fistula, Flow volume, Doppler ultrasonography, Hemodialysis, Balloon angioplasty, Percutaneous transluminal angioplasty.

Introduction

The arteriovenous fistula (AVF) is recommended as the vascular access method of choice for hemodialysis patients. However, the long-term viability of an AVF remains problematic, as 36% are abandoned within two years of its creation[1]. Hemodynamically significant stenosis and subsequent thrombosis are the most common causes of AVF dysfunction[2]. The presence of a problem can be detected by routine physical examination and/or by symptoms of dysfunction manifesting during dialysis. However, a doppler ultrasound (DUS) is required to determine the location, morphology, and severity of the lesion.

In recent years, percutaneous transluminal angioplasty (PTA) has been recommended[3] as first-line therapy for vascular access stenosis and occlusion because it is safe, effective, and minimally invasive compared to surgical revision. PTA can restore blood flow to occluded vessels with an 80-100% success rate[4]. It is a well-established treatment for stenosis in AVFs and can significantly increase the duration of fistula patency[5,6]. However, PTA has limited durability, with 12-month patency rates ranging from 26% to 64%, and recurrent stenosis often requires repeated interventions, with an average of 3.1-3.5 before the access is ultimately abandoned[4,5,7]. Several previous reports[5,8-10] have investigated

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the clinical, anatomical, technical, and biochemical variables that can affect PTA patency, but the conclusions have been inconsistent or even contradictory. There are also very limited quantitative data on early AVF hemodynamic changes after PTA, which may have a significant impact on patency duration.

Flow volume is frequently considered a function of the access and can be obtained during the DUS examination. Low values are linked to higher thrombosis risk and increased blood recirculation, with a subsequent decrease in the dialysis dose (Kt/V). A well-functioning fistula has a blood flow between 700 and 1,300 mL/min. Less than 500 mL/min or a 25% decrease in basal flow are signs of impending failure[11]. In native AVFs, flow volume is usually calculated in the brachial artery because the drainage vein has an irregular diameter, side branches, and is easily compressed by the ultrasound probe. However, this technique does not completely correlate to the drainage vein flow volume, especially in native radiocephalic AVFs. Therefore, some centers measure the flow volume from the drainage vein[12,13].

The objective of this study was to determine the causes of inadequate drainage venous flow volume despite technically successful radiocephalic AVF balloon angioplasty, the control results after one week of follow-up with or without treatment, and the relationship between DUS blood flow parameters and pre-procedural lesion characteristics.

Patients and Methods

Study Population and Design

Prospectively, the patients who underwent balloon angioplasty for dysfunctional native radiocephalic AVF between December 2021 and December 2022 were included in this case-control study. The Local Ethics Committee approved this study (protocol No.: E-53043469-050.04.04-347502). Based on the results of DUS performed within 1 to 2 hours after PTA, the patients with a drainage venous flow volume ≤400 mL/min were included in the case group, and the patients with a drainage venous flow volume >400 mL/min were included in the control group. The following inclusion criteria were applied to a total of 42 patients, consisting of 21 cases and 21 controls. The flow diagram of the study is shown in Figure 1.

Inclusion Criteria

1. All patients should have a dysfunctional native radiocephalic AVF; evidence of increased venous pressure during dialysis and/or decreased blood flow.
2. PTA should be technically successful with residual stenosis lower than 30%.
3. Each patient should have three DUS examinations: before, after, and one week after PTA.
4. No patient should have known or suspected central venous stenosis (facial or arm edema).
5. The cephalic vein should not have abnormal tortuosity, dilation, or aneurysmal enlargement.
6. In the case group, the AVF should not be used until the control DUS examination after the PTA.

After a PTA, patients are usually kept in the observation room of our department for about four hours. Previously, a physical examination was conducted for bleeding and trills prior to discharge, and DUS was only performed if an abnormal trill (weak, intermittent, etc.) was detected. Over

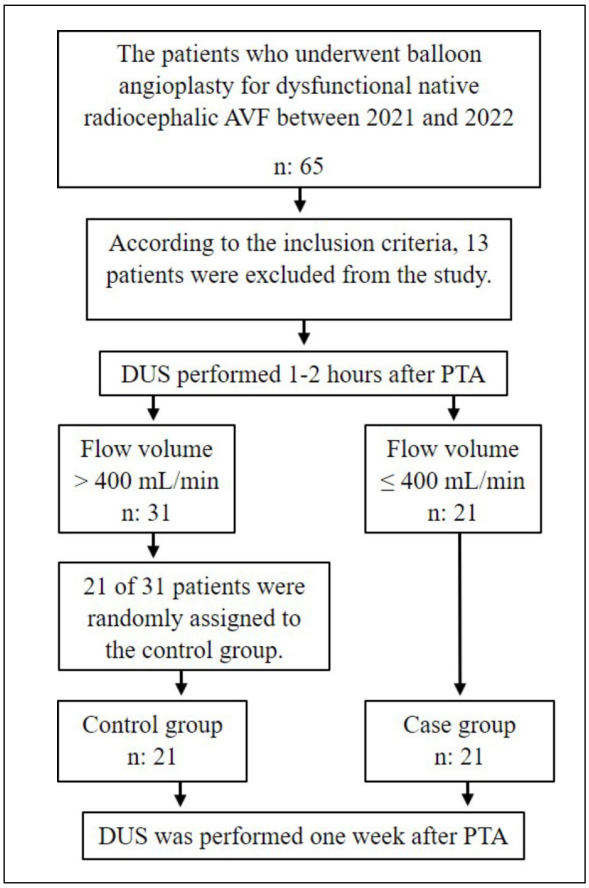

Figure 1. The study flow diagram is shown.

time, post-procedural DUS began to be performed on all patients, and it was observed that the flow volume in some patients was inadequate for dialysis despite the presence of a normal trill. As a result, our department's recent routine operation is as follows: even if the balloon angioplasty procedure is technically successful (residual stenosis lower than 30%), if the post-procedural DUS flow volume is lower than 400 mL/min, a control DUS is performed 1 week later with or without medical treatment. In this process, if a free-floating venous thrombosis is detected in the post-procedural DUS, the patient is administered enoxaparin sodium (150 IU/kg) *via* subcutaneous (SC) injection once a day for a total of 5 doses and low-dose aspirin (100 mg daily). In the absence of a thrombus, only general fistula exercises are performed. As a temporary femoral central venous catheter is routinely placed in these patients before PTA day, they are advised not to use the AVF for dialysis until the control DUS. If the flow in the control DUS is more than 400 mL/min and there are no other complications, the dialysis physician is informed that the AVF can be used.

Firstly, demographic information, fistulography lesion measurements, and DUS parameters such as AVF grayscale findings and spectral analysis values were recorded for each patient and compared between groups. The correlation between fistulography lesion measurements and DUS spectral analysis values was investigated. Finally, the cut-off value of the resistive index (RI) in pre-procedural DUS was determined to differentiate the groups. A single experienced interventional radiologist performed all endovascular treatments and DUS examinations.

Doppler Ultrasonography (DUS)

US examination was performed with a Samsung Medison RS80 EVO prestige ultrasonography system (Samsung Medison Co. Ltd., Seoul, Korea) using an L2-9A MHz linear array transducer. On the day of PTA, DUS was performed twice and referred to as "pre-procedural DUS" and "post-procedural DUS" in all patients. After one week, DUS was referred to as "control DUS".

During the pre-procedural DUS, the radial artery, radiocephalic anastomosis, and cephalic vein were first checked for thrombus and/or stenosis. Second, spectral analysis was used to calculate the peak systolic velocity (PSV), end-diastolic velocity (EDV), and resistive index (RI) from the radial artery 3-4 cm before the AV anastomosis line. RI was calculated by dividing the difference between PSV and EDV by PSV. Finally, at the end of the stenosis and/or thrombus, the flow volume (mL/min) in the cephalic vein was calculated using the formula [cross-sectional area ($\pi r2$) x time-averaged mean velocity (cm/s) x 60]. Flow volume was measured from the non-aneurysmatic or straight venous segment, and care was taken not to compress the vein with the probe. During post-procedural DUS, which was performed approximately 1 to 2 hours after PTA, the same spectral analysis parameters were calculated again. Thrombi, aneurysms, dissections, and hematomas that occurred after PTA were also examined during the post-procedural DUS. One week later, a control DUS was performed. During this time, the AVF was not to be used for dialysis in the case group. In the control DUS, the final status of post-procedural complications was also evaluated.

Endovascular Treatment Procedure

All endovascular procedures were initiated by puncture of the cephalic vein after local anesthesia. A 5-French introducer was inserted into the cephalic vein using the Seldinger method, and fistulography was performed. After heparin injection (2,500 IU), the lesion was crossed with a catheter (5F Kumpe; Cook Medical, Bloomington, IN, USA) and guidewire (0.035-inch hydrophilic coated; Terumo Corp., Tokyo, Japan; or 0.018-inch polymer jacket-hydrophilic coated; Asahi Intecc Co., Aichi, Japan). Patients with thrombosed AVFs received an additional injection of 2,500 IU heparin before balloon angioplasty. Pharmacomechanical thrombectomy was not performed because the thrombi were in a chronic stage. Fistulography was then repeated with the catheter positioned in the radial artery after the AV anastomosis line, and lesion measurements were taken before balloon angioplasty. The balloon size was chosen to be 0-1 mm larger than the adjacent non-stenotic vessel. Balloon inflation was maintained for 3 minutes. Dilatation was repeated 3-5 times in the case of resistant or early elastic recoil lesions. After balloon angioplasty, a digital subtraction angiography (DSA) image was taken to evaluate the outcome of the procedure. A high-pressure balloon and/or a cutting balloon were used in cases with more than 30% persistent residual stenosis. If any post-procedure complications were detected, additional procedures were performed. After the removal of the vascular sheath, hemostasis was achieved by manual compression.

At the first fistulography, the length of the lesion and the degree of stenosis were measured. In cases of total venous occlusion, the length of the lesion was determined by comparing the first and second fistulography. The degree of residual stenosis was assessed on DSA images. Residual stenosis was calculated by dividing the narrowest diameter of the lesion by the diameter of the healthy vein after the lesion.

Statistical Analysis

The Shapiro-Wilk test was used to test the normality of the data. Parametric values were presented as 'mean [standard deviation (SD)]' and non-parametric values as 'median (25^{th}-75^{th} percentile)'. Categorical variables were presented as numbers and percentages. The *t*-test was used for parametric data, and the Mann-Whitney U test for non-parametric data when comparing two independent groups. Spearman's correlation coefficient analysis was used to examine the relationship between two independent non-parametric variables. A two-tailed test was performed with a significance level of 5%. The correlation coefficient (r-value) was interpreted as follows: 0-0.3, no linear relationship; 0.3-0.5, a weak linear relationship; 0.5-0.7, a moderate linear relationship; 0.7, a strong linear relationship; and +, -, a positive or negative linear relationship. The receiver operating characteristic (ROC) analysis test was used to determine the optimal cut-off value and the sensitivity and specificity of the pre-procedural RI value in differentiating the groups, and a 2x2 table was used for the positive predictive value (PPV) and negative predictive value (NPV).

IBM SPSS version 26 for Windows (IBM Corp., Armonk, NY, USA) was used for statistical analysis. A p-value <0.05 was considered statistically significant.

Results

A total of 65 patients underwent PTA for dysfunctional radiocephalic AVF between December 2021 and 2022. Two patients with central venous stenosis, seven with cephalic vein aneurysms, and four who did not attend the control DUS one week later were excluded from the study. Of the remaining 52 patients, 21 had a post-procedural flow volume ≤400 mL/min and were included in the case group. Of the 31 cases with a flow volume >400 mL/min, 21 were randomized to the control group.

The demographic characteristics of the case group (16 males, age 60±10 years) and the control group (17 males, age 64±6 years) were matched (p>0.05). The most common pre-procedural DUS grayscale findings were cephalic vein thrombosis in the case group (n=14, 67%) and cephalic vein stenosis in the control group (n=15, 71%). Lesion length, pre-procedural degree of stenosis, and post-procedural residual stenosis as measured by fistulography were not matched but were similar between groups (p>0.05), (Table I). Among the

Table I. Demographic characteristics, pre- and post-procedural DUS grayscale findings, control DUS flow volume, and fistulography findings in the groups.

	Cases (n=21)	Controls (n=21)	*p*-value
Male/Female	16/5	17/4	0.214
Age	60±10	64±6	0.82
Radiocephalic AVF side (left)	95%	91%	0.55
Pre-procedural DUS			
Cephalic vein thrombosis	14 (67%)	4 (19%)	
Cephalic vein stenosis	5 (23%)	15 (71%)	
AV anastomotic stenosis	2 (10%)	2 (10%)	
Post-procedural DUS			
Free-floating thrombus	10 (48%)	2 (10%)	
Hematoma	2 (10%)	-	
Control DUS			
Flow volume (mL/min) ≤400	2 (10%)	-	
Flow volume (mL/min) >400	19 (90%)	21 (100%)	
Fistulography			
Lesion length (mm)	33±19	28±15	0.129
Pre-procedural degree of stenosis (%)	100 (63.5-100)	77±20	0.365
Post-procedural residual stenosis (%)	22±7	20±10	0.135

DUS, Doppler ultrasound, AVF, arteriovenous fistula.

Table II. Comparison of pre-procedural, post-procedural and control DUS spectral analysis values in the groups.

	Cases (n=21)	Controls (n=21)	*p*-value
Pre-procedural DUS			
PSV	59 (46-76)	102 (62-121)	0.002
EDV	3.9 (0-12,5)	21 (0-40)	0.026
RI	0.97 (0.79-1)	0.66 (0.60-1)	0.016
Flow volume (mL/min)	52 (26-115)	102 (43-219)	0.057
Post-procedural DUS			
PSV	101±32	205±75	<0.001
EDV	34±20	98±38	<0.001
RI	0.69±0.12	0.52±0.07	<0.001
Flow volume (mL/min)	283±74	690 (615-800)	<0.001
Control DUS			
PSV	128±36	145 (131-225)	0.013
EDV	61±34	124±53	<0.001
RI	0.54±0.18	0.32 (0.29-0.36)	<0.001
Flow volume (mL/min)	743 (336-875)	1,007±103	<0.001

PSV, peak systolic velocity (cm/s); EDV, end-diastolic velocity (cm/s); RI, resistive index.

pre-procedural DUS spectral analysis parameters, only flow volume was matched between groups (p=0.057); PSV and EDV were higher in the control group (p=0.002 and p=0.026, respectively), whereas RI was higher in the patient group (p=0.016), (Table II). Using a pre-procedural RI cut-off of 0.76 to differentiate the groups, sensitivity was 76%, specificity was 67%, PPV was 70%, and NPV was 74%, (Table III).

Post-procedural DUS grayscale showed free-floating thrombus in the cephalic vein in 48% and hematoma around the vein in 10% of the patient group, whereas only thrombus in the cephalic vein was detected in 10% of the control group (Table I). In the remaining 42% of the patient group, no DUS grayscale findings were found to explain venous flow volume ≤400 mL/min.

In both post-procedural and control, DUS, PSV, EDV, and flow volume were higher in controls, whereas RI was higher in patients (p<0.05, Table II). In control DUS, only 2 patients (10%) had a flow volume ≤400 mL/min. Both patients had recurrent total thrombus in the cephalic vein. In all other cases, it was above 400 mL/min. When the pre-procedural flow volume was compared with the control flow volume, an increase was found in both groups, more significantly in the patient group.

In both patient and control groups, there was a significant negative correlation between pre-procedural lesion length, degree of stenosis, and pre-procedural PSV, EDV, and flow volume and a positive correlation with RI (p<0.05). There was no correlation between post-procedural DUS spectral analysis parameters and pre-procedural lesion length or degree of stenosis (p>0.05, Table IV).

Discussion

Balloon angioplasty has been applied for many years in the treatment of dysfunctional AVF with a high technical success rate. After the procedure, <30% residual stenosis is considered a technically successful PTA[14,15]. Clinical success is defined as the resolution of clinical access malfunction and at least one adequate hemodialysis procedure after PTA[6]. However, even if the AVF can be used for dialysis after PTA, we believe that there is an important and partly ignored factor associated with its patency time and early re-dysfunction: post-procedural blood flow parameters. This study, using a methodology not previously seen in the literature, provided interesting results on 2 important issues. First, the DUS findings after technically successful PTA showed the true effectiveness of the treatment and preventable pathologies. Second,

Table III. ROC analysis results in differentiating case and control groups for pre-procedural RI.

Cases *vs.* Controls	
Pre-procedural RI	
Cut-off	0.76
Sensitivity	76%
Specificity	67%
PPV	70%
NPV	74%
AUC	0.711
95% CI	0.54-0.88

PPV, positive predictive value, NPV, negative predictive value, AUC, area under curve; CI, confidence interval.

Table IV. Correlation between pre- and post-procedural DUS spectral analysis values and fistulography lesion measurements in the groups.

	Lesion length (mm)				Pre-procedural stenosis degree (%)			
	Cases (n=21)		Controls (n=21)		Cases (n=21)		Controls (n=21)	
	r_s	*p*-value	r_s	*p*-value	r_s	*p*-value	r_s	*p*-value
Pre-procedural DUS								
PSV	-0.496*	0.022	-0.466*	0.026	-0.481*	0.027	-0.536*	0.012
EDV	-0.688**	0.001	-0.884**	<0.001	-0.438*	0.047	-0.947**	<0.001
RI	0.699**	<0.001	0.711**	<0.001	0.443*	0.044	0.884**	<0.001
Flow volume	-0.720**	<0.001	-0.614**	0.003	-0.715**	<0.001	-0.807**	<0.001
Post-procedural DUS								
PSV	-0.155	0.502	0.144	0.534	0.253	0.269	-0.018	0.938
EDV	-0.182	0.429	-0.177	0.443	0.196	0.395	-0.222	0.335
RI	0.085	0.713	0.255	0.265	-0.121	0.601	0.299	0.188
Flow volume	-0.064	0.782	0.195	0.322	0.323	0.153	0.152	0.512

r_s, Spearman's correlation coefficient; PSV, peak systolic velocity (cm/s); EDV, end-diastolic velocity (cm/s); RI, resistive index. ** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

the RI value, which is one of the DUS spectral flow parameters, appears to be an indirect marker that can be used to show AVF pathologies, treatment response and surveillance.

In this study, before PTA, 67% of cases and 19% of controls had cephalic vein thrombosis. After PTA, free-floating thrombus was found in 48% of cases and 10% of controls. The pre-procedural flow volume of the case group was similar to the control group (p=0.057) but was lower after the procedure and one week later (p<0.001). Also, in all DUS examinations, PSV and EDV were lower in the case group, while RI was higher (p<0.05). The absolute values of PSV and EDV are usually not remarkable on their own16 but tend to move inversely with RI as flow increases. The results of this study confirm this trend. Accordingly, RI and flow volume appear to be more prominent among the AVF blood flow parameters.

In this study, pre-procedural lesion length, stenosis degree, and post-procedural residual stenosis were similar between the groups (p<0.05). There was a moderately or strongly linear relationship between lesion length, stenosis degree, and pre-procedural DUS flow parameters in both groups (p<0.05), but there was no linear relationship between these variables and post-procedural DUS flow parameters (p>0.05). Based on these results, we were able to associate the lower post-procedural flow volume in the case group with two conditions: the presence of free-floating thrombus and hematoma. Before PTA, thrombus in the drainage vein was present in 67% of the case group and 19% of the control group. Due to the chronic stage of the thrombosis, it was not possible to perform aspiration. 10 cases (48%) had free-floating thrombi after PTA, prompting the initiation of medical treatment (enoxaparin sodium and aspirin). Large free-floating thrombi were detected on DSA images, and the balloon angioplasty procedure was repeated. However, small thrombi were only seen on post-procedural DUS and constituted evidence to start medical treatment. In the control DUS, the flow volume was insufficient in only two of these cases, and the thrombus regressed in the other cases almost entirely. One of these cases is presented in Figure 2. The presence of a thrombus before the procedure prolongs the duration and repetition of balloon angioplasty and increases the risk of complications; one of the two cases had a perforation of the drainage vein, and the other had a pseudoaneurysm in the AV anastomosis line. These complications were treated with additional interventions during the procedure, but a hematoma formed around the drainage vein. Instead of a free-floating thrombus, the low flow volume observed during control DUS in these two cases was due to a re-thrombosed lumen caused by the hematoma's external compression on the vein.

In the control DUS, the final mean flow volume of the control group was higher than that of the case group, representing a well-functioning AVF. This is probably because the fibrosis that occurs during thrombus regression reduces the elasticity of the vessel wall. For this reason, we expect the duration of patency in the case group to be shorter than in

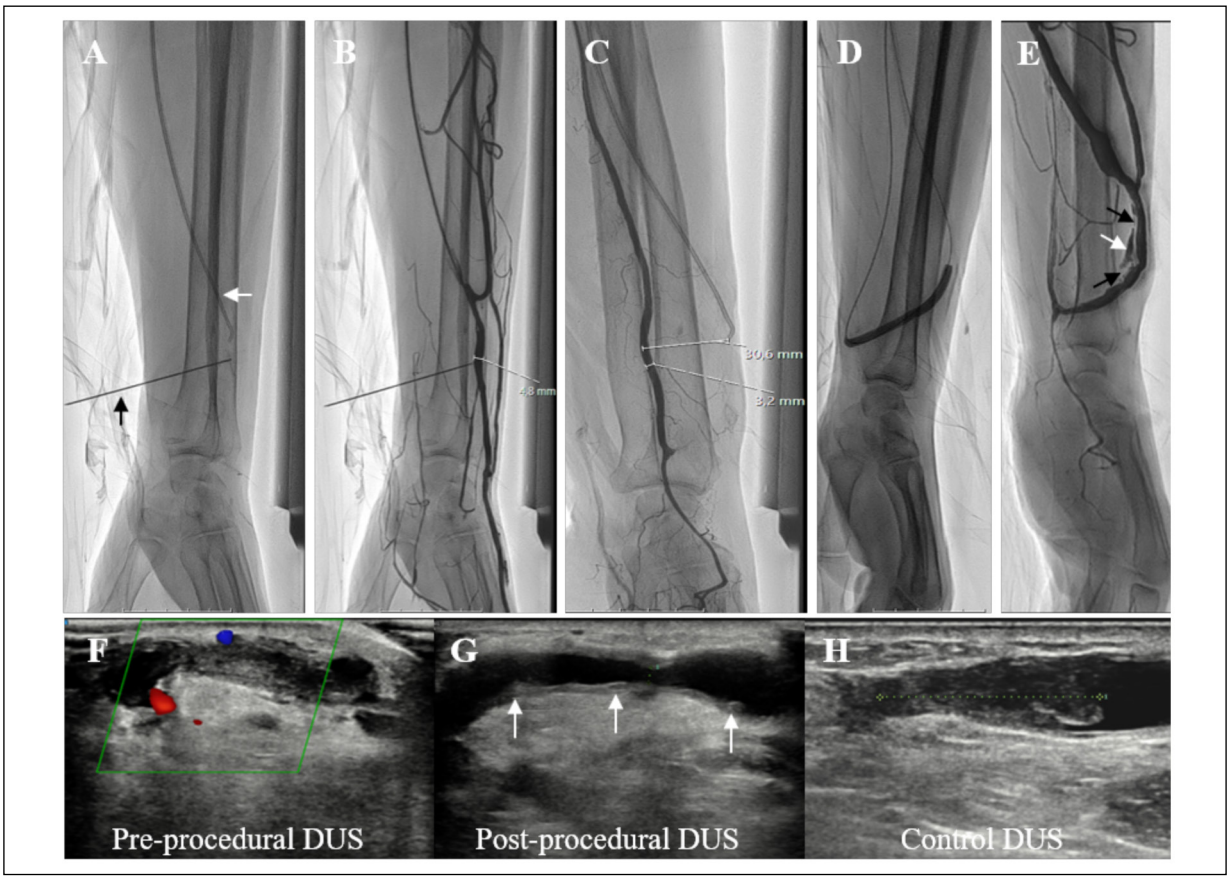

Figure 2. In a 58-year-old male case, the balloon angioplasty procedure and DUS findings for the dysfunctional AVF are shown. **A**, A 5F Kumpe catheter positioned in the cephalic vein (white arrow) and an external marker located on the AVF anastomosis line (black arrow). **B**, After contrast injection via the cephalic vein, total occlusion was demonstrated on the drainage side of the AVF anastomosis. **C**, After contrast injection via the brachial artery, the lesion length was measured to be 30.6 mm. **D**, The balloon angioplasty procedure was applied by passing the occlusion with a guidewire, as shown. The residual stenosis was 29%. **E**, After the procedure, leakage due to perforation of the cephalic vein (white arrow) and free-floating thrombi (black arrows) were observed. **F**, The pre-procedural DUS showed a chronic thrombus in the cephalic vein. The spectral analysis parameters were flow volume 105 mL/min, PSV 56 cm/s, EDV 0 cm/s, and RI 1. **G**, The post-procedural DUS confirmed a free-floating thrombus adjacent to the vein wall (white arrows) and luminal opening. The spectral analysis parameters were flow volume 280 mL/min, PSV 102 cm/s, EDV 13 cm/s, and RI 0.87. **H**, In the control DUS, the venous lumen was found to be thrombosed again. The spectral analysis parameters were flow volume116 mL/min, PSV 100 cm/s, EDV 6 cm/s, and RI 0.94.

the control group despite the fact that the flow volume was adequate for dialysis. There may be a second indirect reason for the lower post-procedural flow volume in the case group; the hemodynamics of AVF blood flow are not solely dependent on mechanical causes. Blood flow can be reduced in conditions such as heart failure and dehydration. However, as this study was a control group comparison, these factors were not taken into account.

The resistive index is one of the most commonly used vascular ultrasound indices because of its simplicity. The RI is proportional to both vascular compliance and vascular resistance. As a vessel narrows and resistance to flow increases, the RI will increase[17]. Several studies[18] have investigated the RI of the flow pattern in the feeding artery. It has been reported[19,20] that the mean RI in AVFs without stenosis is 0.33. Values above 0.6-0.7 indicate stenosis. These values are consistent with the pre-procedural and control DUS mean RI values (0.66 and 0.32) of the control group. However, the RI value was higher in all DUS examinations in the case group compared to the control group ($p<0.05$). We assumed that the pre-procedural RI value could be used to predict the post-procedural hemodynamics. In cases where the pre-procedural RI value was higher than 0.76, the post-procedural flow volume was ≤400 ml/min with a sensitivity of 76%, specificity of 67%, PPV of 70%, and NPV of 74%. The results could not be compared as there

was no similar study in the literature. In one study[21], a brachial artery RI of 0.52 was reported to discriminate between functional and non-functional AVF with 89% sensitivity and 88% specificity.

Limitations

There were several limitations to this study. Firstly, it was a single-center study with a small sample size. The method of calculating the flow volume from the drainage vein may be questionable, as protocols differ between centers. In most cases, the drainage vessel was nearly or totally occluded before PTA; therefore, the groups are not homogeneous, and the data may not reflect the overall population.

Conclusions

Pre-procedural lesion length, degree of stenosis, and degree of residual stenosis were not associated with post-procedural flow volume. Low flow volume was primarily associated with the presence of free-floating thrombus after the procedure and with complications during the procedure. Routine post-procedural DUS provided evidence for the initiation of anticoagulant therapy by demonstrating small thrombi as a detectable cause of low venous flow, which may lead to early dysfunction, even when PTA was technically successful and physical examination findings were normal. Future studies using DUS in larger case series are likely to be useful in defining the true efficacy of endovascular treatment of AVF and in establishing a patient-based early prevention and follow-up protocol.

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Ethics Approval

This study was approved by the Aydın Adnan Menderes University Ethics Committee (protocol No.: E-53043469-050.04.04-347502).

Informed Consent

Informed consent was obtained from all individual participants included in the study.

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Conflict of Interest

The author declares that there is no conflict of interest.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

References

1) Al-Jaishi AA, Oliver MJ, Thomas SM, Lok CE, Zhang JC, Garg AX, Kosa SD, Quinn RR, Moist LM. Patency Rates of the Arteriovenous Fistula for Hemodialysis: A Systematic Review and Meta-analysis. Am J Kidney Dis 2014; 63: 464-478.
2) Heye S, Maleux G, Vaninbroukx J, Claes K, Kuypers D, Oyen R. Factors influencing technical success and outcome of percutaneous balloon angioplasty in de novo native hemodialysis arteriovenous fistulas. Eur J Radiol 2012; 81: 2298-2303.
3) National Kidney Foundation. KDOQI Clinical Practice Guideline for Hemodialysis Adequacy: 2015 update. Am J Kidney Dis 2015; 66: 884-930.
4) Balamuthusamy S, Reddi AL, Madhrira MH, Sankarapandian B, Nguyen P, Vallurupalli A, Gabbard W, Jalandhara N, Yurvati A. Clinical predictors of recurrent stenosis and need for re-intervention in the cephalic arch in patients with brachiocephalic AV fistulas. J Vasc Access 2017; 18: 319-324.
5) Malka KT, Flahive J, Csizinscky A, Aiello F, Simons JP, Schanzer A, Messina LM, Robinson WP. Results of repeated percutaneous interventions on failing arteriovenous fistulas and grafts and factors affecting outcomes. J Vasc Surg 2016; 63: 772-777.
6) Suemitsu K, Shiraki T, Iida O, Kobayashi H, Matsuoka Y, Izumi M, Nakanishi T. Impact of Lesion Morphology on Durability After Angioplasty of Failed Arteriovenous Fistulas in Hemodialysis Patients. J Endovasc Ther 2017; 25: 649-654.
7) Elramah M, Boujelbane L, Yevzlin AS, Wakeen M, Astor BC, Chan MR. Dialysis access venous stenosis: Treatment with balloon angioplasty 30-second vs. 1-minute inflation times. Hemodial Int 2014; 19: 108-114.
8) Mortamais J, Papillard M, Girouin N, Boutier R, Cougnaud L, Martin X, Badet L, Juillard L, Rouvière O. Endovascular Treatment of Juxta-anastomotic Venous Stenoses of Forearm Radiocephalic Fistulas: Long-term Results and Prognostic Factors. J Vasc Interv Radiol 2013; 24: 558-564.
9) Neuen BL, Gunnarsson R, Baer RA, Tosenovsky P, Green SJ, Golledge J, Mantha ML. Factors Associated with Patency Following Angioplasty of Hemodialysis Fistulae. J Vasc Interv Radiol 2014; 25: 1419-1426.

10) Higashiura W, Takara H, Kitamura R, Yasutani T, Miyasato H, Tengan T. Factors Associated with Secondary Functional Patency After Percutaneous Transluminal Angioplasty of the Early Failing or Immature Hemodialysis Arteriovenous Fistula. Cardiovasc Intervent Radiol 2018; 42: 34-40.

11) Zamboli P, Fiorini F, D'Amelio A, Fatuzzo P, Granata A. Color Doppler ultrasound and arteriovenous fistulas for hemodialysis. J Ultrasound 2014; 17: 253-263.

12) Bae M, Jeon CH, Han M, Jin M, Kim HJ. Analysis of access flow using duplex ultrasonography and the ultrasound dilutional method. J Vasc Access 2021; 23: 286-294.

13) Khan T, Bhat M, Shah OA, Choh NA, Maqsood S, Shera TA. Percutaneous transluminal angioplasty of dysfunctional hemodialysis vascular access: Can careful selection of patients improve the outcomes? Indian J Nephrol 2022; 32: 233.

14) Zhu ZR, Zou L, Xing Y, Tan YC, Xu GJ, He ZJ, Cao JQ, Wu JY, Liang XX, Zhang HP, Tan YH, Luo CH. Predictors of primary patency after percutaneous balloon angioplasty for stenosis of Brescia-Cimino hemodialysis arteriovenous fistula. Br J Radiol 2020; 93: 20190505.

15) Aktas A, Bozkurt A, Aktas B, Kirbas I. Percutaneous transluminal balloon angioplasty in stenosis of native hemodialysis arteriovenous fistulas: technical success and analysis of factors affecting postprocedural fistula patency. Diagn Interv Radiol 2015; 21: 160-166.

16) Malik J, Lomonte C, Meola M, de Bont C, Shahverdyan R, Rotmans JI, Saucy F, Jemcov T, Ibeas J. The role of Doppler ultrasonography in vascular access surveillance—controversies continue. J Vasc Access 2021; 22: 63-70.

17) Wang C, Chen X, Wang L, Makihata M, Liu HC, Zhou T, Zhao X. Bioadhesive ultrasound for long-term continuous imaging of diverse organs. Science 2022; 377: 517-523.

18) Koseoglu K, Akar H, Eraslan C. Color Doppler US Evaluation of Feeding Artery after Balloon Angioplasty of the Drainage Vein in Dysfunctional Hemodialysis AVF. Ren Fail 2008; 30: 801-807.

19) Moreno Sánchez T, Martín Hervás C, Sola Martínez E, Moreno Rodríguez F. Value of doppler ultrasonography in the study of hemodialysis peripheral vascular access dysfunction. Radiología 2014; 56: 420-428.

20) Napoli M, Prudenzano R, Russo F, Antonaci AL, Aprile M, Buongiorno E. Juxta-Anastomotic Stenosis of Native Arteriovenous Fistulas: Surgical Treatment versus Percutaneous Transluminal Angioplasty. J Vasc Access 2010; 11: 346-351.

21) Çildağ BM, Köseoğlu KÖF. Discriminative Role of Brachial Artery Doppler Parameters in Correlation with Hemodialysis Arteriovenous Fistula. Clujul Med 2017; 90: 407-410.