

Accuracy of first-generation methods in the detection of stenosis in native arteriovenous fistulae

Francisco Javier Rubio-Castañeda¹, Manuel Fernández-Núñez², Ana Isabel Sierra-Sánchez², María Amaya Mateo-Sánchez², Víctor Cantín-Lahoz¹, Emilia Ferrer-López¹

¹ Instituto de Investigación Sanitaria de Aragón (IISA); Haemodialysis and Kidney Transplant Unit, Hospital Universitario Miguel Servet de Zaragoza, Zaragoza, Spain

² Haemodialysis and Kidney Transplant Unit, Hospital Universitario Miguel Servet de Zaragoza, Zaragoza, Spain

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Corresponding author:

Francisco Javier Rubio Castañeda
fjrubio.due@gmail.com

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ABSTRACT

Objective: To determine the accuracy of first-generation methods in detecting stenosis in native arteriovenous fistulas.

Material and Method: Retrospective observational study. Sample: Patients with functioning native arteriovenous fistulas. First-generation methods include physical examination, manual tests, pulse increase test and arm elevation test, indirect methods, Kt/V, and arteriovenous fistula recirculation. The diagnosis of stenosis was confirmed by Doppler ultrasound. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy of first-generation methods based on Doppler ultrasound were calculated.

Results: Sample 39 patients, 79.48% male. Ultrasound detected 19 stenoses, nonsignificant. Physical examination: sensitivity 31.5%, specificity 80%, PPV 60%, NPV 55.1%, accuracy 56.4%. Pulse rise test: sensitivity 5.2%, specificity 90%, PPV 33.3%, NPV 50%, accuracy 48.7%. Arm elevation test: sensitivity 52.6%, specificity 70%, PPV 62.5%, NPV 60.8%, accuracy 61.5%. Indirect methods: sensitivity 15.7%, specificity 55%, PPV 25%, NPV 40.7%, accuracy 35.9%. Kt/V: sensitivity 10.5%, specificity 75%, PPV 28.5%, NPV 46.8%, accuracy 43.5%. AVF recirculation: sensitivity 10.5%, specificity 100%, PPV 100%, NPV 54.1%, accuracy 56.4%.

Conclusions: All first-generation methods have high specificity and low sensitivity. The degree of stenosis (significant or non-significant) could influence the sensitivity of the physical examination but not the specificity. The arm

elevation test is the most accurate first-generation method of detecting stenosis.

Keywords: native arteriovenous fistula; doppler ultrasound; complications; haemodialysis.

RESUMEN

Precisión de los métodos de primera generación en la detección de estenosis en fístulas arteriovenosas nativas

Objetivo: Determinar la precisión de los métodos de primera generación en la detección de estenosis en fístulas arteriovenosas nativas.

Material y Método: Estudio observacional retrospectivo. Muestra: Pacientes con fístulas arteriovenosas nativas funcionantes. Métodos de primera generación: exploración física, test manuales: test de aumento del pulso y test de elevación del brazo, métodos indirectos, Kt/V y recirculación de la fístula arteriovenosa. El diagnóstico de estenosis fue confirmado mediante ecografía doppler. Se calculó sensibilidad, especificidad, valor predictivo positivo (VPP), valor predictivo negativo (VPN) y precisión de los métodos de primera generación basándose en la ecografía doppler.

Resultados: Muestra 39 pacientes, 79,48% hombres. El ecógrafo detectó 19 estenosis, ninguna significativa. Exploración física: sensibilidad 31,5%, especificidad 80%, VPP 60%, VPN 55,1%, precisión 56,4%. Test aumento del pulso:

sensibilidad 5,2%, especificidad 90%, VPP 33,3%, VPN 50%, precisión 48,7%. Test elevación del brazo: sensibilidad 52,6%, especificidad 70%, VPP 62,5%, VPN 60,8%, precisión 61,5%. Métodos indirectos: sensibilidad 15,7%, especificidad 55%, VPP 25%, VPN 40,7%, precisión 35,9%. Kt/V: sensibilidad 10,5%, especificidad 75%, VPP 28,5%, VPN 46,8%, precisión 43,5%. Recirculación de la FAV: sensibilidad 10,5%, especificidad 100%, VPP 100%, VPN 54,1%, precisión 56,4%.

Conclusiones: Todos los métodos de primera generación presentan alta especificidad y baja sensibilidad. El grado de estenosis (significativa o no significativa) podría influir en la sensibilidad de la exploración física, pero no en la especificidad. El test de elevación del brazo es el método de primera generación más preciso en la detección de estenosis.

Palabras clave: fístula arteriovenosa nativa; ecografía doppler; complicaciones; hemodiálisis.

INTRODUCTION

Vascular access is the most important factor determining the success or failure of chronic haemodialysis (HD) programmes¹. Vascular-access failure leads to a high number of hospital admissions and is a major cause of morbidity in patients on HD². For these reasons, HD units are recommended to implement protocolised surveillance programmes for arteriovenous fistulae (AVF)^{1,3}. These programmes include both the early diagnosis of significant stenoses using various screening methods and their pre-emptive correction to prevent thrombosis and increase AVF survival^{1,3,4}. Stenosis—narrowing of the normal vessel diameter—is caused by a combination of impaired remodelling, shear stress, and venous neo-intima formation^{3,5}. Stenosis is the leading cause of vascular-access thrombosis^{1,3,5}. Access thrombosis results in loss of the access and the need for central venous catheters (CVCs); CVC use has been associated with numerous complications that translate into high morbidity and mortality^{1,3,5,6}.

Monitoring is the examination and assessment of vascular access to detect physical signs suggestive of stenosis². Monitoring methods are grouped into first- and second-generation methods. Both first- and second-generation methods are effective for surveillance, monitoring, and reducing the incidence rate of thrombosis in native AVF^{3,7}. These monitoring methods are complementary rather than mutually exclusive and can be used simultaneously to improve the yield of surveillance programmes³. However, only second-generation methods allow calculation of vascular access blood flow (QA). Among second-generation methods, Doppler ultrasound (DU) is the imaging test of choice to confirm, locate, and quantify AVF stenoses^{3,8,9}.

There are several first-generation methods for AVF monitoring. Physical examination is the foundation of all

vascular-access monitoring: periodic inspection, palpation, and auscultation of the AVF. It is easy to learn and perform, time-efficient, and low cost. Detecting any change from baseline in the thrill, bruit, or pulse enables diagnosis of a stenosis and may help localise it^{3,6}. Manual tests are the principal bedside tests used during the physical examination of an AVF; 3 tests are used to detect stenoses and collateral veins^{3,6}. Indirect methods—also described as “problems during the HD session”—are indirect signs of AVF stenosis when they occur persistently in relation to recent HD sessions^{3,6}. Kt/V is the amount of plasma cleared of urea during the HD treatment time relative to the patient’s age- and sex-appropriate urea distribution volume; it is obtained from HD monitors. An unexplained decrease in Kt/V can be an indirect sign of vascular-access dysfunction^{3,6}. AVF recirculation occurs when a portion of already-dialysed blood exiting the venous needle re-enters the dialyser through the arterial needle⁵. With a significant stenosis, the percentage of recirculation during HD increases; however, this monitoring method does not enable early detection of stenoses. Recirculation can be measured by urea recirculation or by the blood temperature monitor (BTM) module built into HD monitors^{3,6}.

Although first-generation methods have lost some prominence with the advent of dilutional methods and the incorporation of DU into HD services, their role in early stenosis detection is indisputable because they rapidly, simply, and effectively provide a large amount of information. Despite this, the accuracy of most of these monitoring methods compared with DU has not been studied. Therefore, the aim of this study was to determine the accuracy of physical examination, manual tests, indirect methods, Kt/V, and AVF recirculation for detecting stenoses in native AVF vs Doppler ultrasound.

MATERIAL AND METHOD

We conducted an observational, retrospective study from December 1st through December 31st, 2022 in the Haemodialysis and Renal Transplant Unit of *Hospital Universitario Miguel Servet* (Zaragoza, Spain).

All patients on a periodic haemodialysis programme with functioning native AVF as of December 1st, 2022 were included. Patients with functioning native AVF who were dialysed through another vascular access were not included.

From the electronic health record we collected sociodemographic variables (age and sex) and AVF variables (type of AVF and access vintage). Indirect methods, Kt/V, and AVF recirculation were retrieved from the Nefrolink® v4.5 system. The remaining variables were obtained by DU (stenosis, percentage reduction in vessel diameter [RVD], peak systolic velocity [PSV] ratio, and QA) and by physical examination.

The first-generation methods used were physical examination, manual tests, indirect methods, Kt/V, and

AVF recirculation. Two nurses in our unit assessed native AVF with first-generation methods. Physical examination and manual tests were performed on 5–6 December 2022 (the first dialysis day of the week) before patients were connected to the HD monitor. Indirect methods, Kt/V, and AVF recirculation were recorded between 5 and 10 December at the end of each HD session.

Physical examination: Thrill, bruit, and pulse were evaluated at the anastomosis and along the mid and distal segments of the native AVF. Thrill was assessed with the palm, bruit with a Littmann Classic III stethoscope, and pulse with the fingertips. The physical examination was considered positive for stenosis if at least one suggestive sign was present: diminished thrill and/or bruit at the anastomosis; systolic-only thrill; increased thrill over the lesion; high-pitched (“whistling”) bruit over the stenotic lesion; hypopulsatility at the anastomosis; or hyperpulsatility over the stenotic lesion^{3,7,10}.

Manual tests: We used the pulse augmentation test and the arm elevation test; the sequential occlusion method was excluded because it is designed to detect collateral veins rather than stenoses. For the pulse augmentation test, the arterialised vein several centimetres above the anastomosis was transiently occluded with one hand while simultaneously assessing pulse strength with the other. A normal test was defined as an increased pulse distal to the occluding finger (between the finger and the anastomosis); hypopulsatility during the test suggested stenosis. For the arm elevation test, the AVF limb was raised above heart level to observe whether the arterialised vein collapsed. A normal test was defined as collapse of the native AVF on arm elevation. In the presence of a stenosis, only the segment proximal to the lesion collapses, whereas the segment distal to the stenosis does not; excessive collapse of the native AVF was also considered suggestive of stenosis^{3,6}. The accuracy of each test was calculated separately.

Indirect methods: Indirect indicators were difficult cannulation; aspiration of clots during cannulation; increased pre-pump arterial negative pressure; failure to reach the prescribed blood-pump flow (QB); increased venous pressure; and prolonged haemostasis time in the absence of excessive anticoagulation. Indirect methods were considered positive for stenosis if at least one occurred persistently over 3 consecutive HD sessions. Prolonged haemostasis time (without excessive anticoagulation) was defined as > 20 minutes to haemostasis in patients not anticoagulated with acenocoumarol (Sintrom[®])^{3,4,6}.

Kt/V: The Online Clearance Monitor (OCM) integrated into Fresenius 5008 HD monitors was used to obtain this parameter. The OCM calculates effective mean urea clearance (K) and the urea distribution volume (accounting for weight, height, age, and sex); with these and the treatment time, the dialysis dose (Kt/V) is calculated in real time¹¹. Kt/V was measured over three consecutive HD sessions and averaged. Stenosis was considered present if Kt/V was < 1.15^{3,6}.

AVF recirculation: Recirculation was measured using the Blood Temperature Monitor (BTM) in Fresenius 5008 HD monitors. The monitor generates a thermal bolus by changing dialysate temperature by 2 °C; the change is first detected by the venous-line temperature sensor, and, based on the subsequent change detected in the arterial line, the percentage recirculation is calculated. Recirculation was measured over 3 consecutive HD sessions and averaged. Stenosis was considered present if recirculation was >15%^{3,6,12}.

We excluded the first-generation “access pressure” method because it is primarily useful for surveillance of prosthetic AVF and cannot be used to monitor distal native AVF^{3,5,6}.

Doppler ultrasound (DU): DU was the monitoring method used to confirm the diagnosis of stenosis. Examinations were performed between 12 and 30 December, 1 week after the first-generation measurements, by a single nurse expert in vascular-access ultrasound who did not participate in first-generation assessments. A Hitachi-Aloka F31 scanner was used. Scans were performed before the HD session with the patient supine and the AVF arm supported. The entire course of the native AVF was examined for stenoses. Where a stenosis was found, we measured the percentage RVD relative to the proximal native AVF segment (formula: original lumen – residual lumen / original lumen × 100); the PSV ratio (post-stenosis PSV divided by pre-stenosis PSV); and vascular-access flow (QA)—3 measurements at the brachial artery, averaged, in mL/min^{3,8}.

We applied the criteria of the Spanish Multidisciplinary Vascular Access Group (GEMAV) to define a significant stenosis: both main criteria (%RVD >50% and PSV ratio >2) plus at least 1 additional criterion (residual diameter <2 mm and/or QA <500 mL/min in native AVF)³. We did not apply the additional criterion “QA decrease >25% if QA <1000 mL/min” because prior QA measurements were unavailable.

All patients were informed in advance, received written information, and provided written informed consent. Institutional and regional research-ethics approvals were obtained (*Comité de Ética de la Investigación de la Comunidad Autónoma de Aragón* [CEICA]).

Statistical analysis: Analyses were performed with Jamovi v2.2.5. Quantitative variables were expressed as measures of central tendency (mean, median) and dispersion (standard deviation [SD], interquartile range [IQR]) according to distribution; normality was assessed with the Shapiro–Wilk test. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy of first-generation methods were calculated with MedCalc^{®13}, using DU as the reference standard; 95% confidence intervals (CI) were computed for all estimates. Associations between categorical variables were analysed with contingency tables and the chi-square test. Statistical significance was set at p<0.05.

RESULTS

The sample comprised 39 patients. Mean age was 63.27 ± 13.4 years; 79.48% were men ($n=31$) and 20.52% women ($n=8$). By AVF type, 61.5% were radiocephalic ($n=24$), 30.76% brachiocephalic ($n=12$), and 7.49% brachiobasilic ($n=3$). Mean access vintage was 106 ± 69.6 months.

Among the indirect methods assessed, only prolonged haemostasis time in the absence of excessive anticoagulation and failure to reach the prescribed QB occurred over 3 consecutive HD sessions.

Ultrasound detected 19 stenoses. Median RVD was 33.9% (IQR, 11.1–61); 21.05% of stenoses had RVD $>50\%$ ($n=4$). The PSV ratio was >2 in 5.26% ($n=1$), and mean QA was 1363 ± 856 mL/min. None of the stenoses detected met criteria for significance. Of the 19 stenoses detected by ultrasound, 26.3% were not detected by any first-generation method ($n=5$).

Stenoses detected by first-generation methods were as follows: physical examination, 10; pulse augmentation test, 3; arm elevation test, 16; indirect methods, 12; Kt/V, 7; AVF recirculation, 2.

Accuracy of first-generation methods: **Physical examination:** sensitivity 31.5% (95%CI, 12.5–56.5%), specificity 80% (95%CI, 56.3–94.2%), PPV 60% (95%CI, 33.3–81.8%), NPV 55.1% (95%CI, 45.8–64.1%), and accuracy 56.4% (95%CI, 39.6–72.1%). **Pulse augmentation test:** sensitivity 5.2% (95%CI, 1.3–26.1%), specificity 90% (95%CI, 68.3–98.7%),

PPV 33.3% (95%CI, 4.7–83.5%), NPV 50% (95%CI, 45.5–54.5%), and accuracy 48.7% (95%CI, 32.4–65.2%). **Arm elevation test:** sensitivity 52.6% (95%CI, 28.8–75.5%), specificity 70% (95%CI, 45.7–88.1%), PPV 62.5% (95%CI, 42.9–78.6%), NPV 60.8% (95%CI, 47.2–73.1%), and accuracy 61.5% (95%CI, 44.6–76.6%). **Indirect methods:** sensitivity 15.7% (95%CI, 3.3–39.5%), specificity 55% (95%CI, 31.5–76.9%), PPV 25% (95%CI, 9.5–51.1%), NPV 40.7% (95%CI, 30.6–51.6%), and accuracy 35.9% (95%CI, 21.2–52.8%). **Kt/V:** sensitivity 10.5% (95%CI, 1.3–33.1%), specificity 75% (95%CI, 50.9–91.3%), PPV 28.5% (95%CI, 8.1–64.5%), NPV 46.8% (95%CI, 39.6–54.2%), and accuracy 43.5% (95%CI, 27.8–60.3%). **AVF recirculation:** sensitivity 10.5% (95%CI, 1.3–33.1%), specificity 100% (95%CI, 83.1–100%), PPV 100% (95%CI, 81.5–100%), NPV 54.1% (95%CI, 50.2–57.8%), and accuracy 56.4% (95%CI, 39.6–72.1%) (table 1).

There was a statistically significant association between DU findings and indirect methods (chi-square=3.9, $p=0.048$).

DISCUSSION

First-generation methods are key for early detection of stenoses on HD wards. Despite this, their accuracy has not been widely studied, which was the rationale for our study. However, a number of stenoses were not detected by first-generation methods, making it necessary to implement surveillance programmes that combine first- and second-generation methods to detect as many stenoses as possible.

Table 1. Accuracy of first-generation methods for detecting stenosis in arteriovenous fistulas compared with doppler ultrasound.

	Physical Examination	Pulse Augmentation Test	Elevation Test Arm	Indirect Methods	Kt/V	AVF Recirculation
Stenosis	10	3	16	12	7	2
True Positive	6	1	10	3	2	2
False Positive	4	2	6	9	5	0
False Negative	13	18	9	16	17	17
True Negative	16	18	14	11	15	20
Sensitivity % (95%CI)	31.5 (12.5–56.5)	5.2 (1.3–26.1)	52.6 (28.8–75.5)	15.7 (3.3–39.5)	10.5 (1.3–33.1)	10.5 (1.3–33.1)
Specificity % (95%CI)	80 (56.3–94.2)	90 (68.3–98.7)	70 (45.7–88.1)	55 (31.5–76.9)	75 (50.9–91.3)	100 (83.1–100)
Positive Predictive Value, % (95%CI)	60 (33.3–81.8)	33.3 (4.7–83.5)	62.5 (42.9–78.6)	25 (9.5–51.1)	28.5 (8.1–64.5)	100 (81.5–100)
Negative Predictive Value, % (95%CI)	55.1 (45.8–64.1)	50 (45.5–54.5)	60.8 (47.2–73.1)	40.7 (30.6–51.6)	46.8 (39.6–54.2)	54.1 (50.2–57.8)
Accuracy, % (95%CI)	56.4 (39.6–72.1)	48.7 (32.4–65.2)	61.5 (44.6–76.6)	35.9 (21.2–52.8)	43.5 (27.8–60.3)	56.4 (39.6–72.1)
Chi-square test	0.68	0.38	2.06	3.9	1.39	2.22
P value	0.40	0.579	0.15	0.048	0.23	0.13

Two studies were found that assess the accuracy of physical examination for detecting stenoses in native AVF^{7,10}, while 3 others were excluded because they evaluated physical-examination accuracy in prosthetic AVF¹⁴⁻¹⁶. Asif et al.¹⁰ reported sensitivity and specificity of physical examination for detecting outflow stenoses of 92% and 86%, respectively, and 85% and 71% for inflow stenoses. Methodologically, however, that study differs from ours in that it used fistulography to detect stenoses, classified stenoses by location, relied only on morphological criteria to define stenoses, and did not indicate whether stenoses were significant. By contrast, the study by Campos et al.⁷ is methodologically similar to ours. Those authors reported sensitivity and specificity of physical examination for detecting significant stenoses of 96% and 70%, respectively. Campos et al.⁷ identified fifty significant stenoses by DU, whereas we found none. Both studies used the two main GEMAV criteria to determine whether a stenosis was significant³, although in our case an additional criterion also had to be present to deem a stenosis significant. The higher number of significant stenoses found by Campos et al.⁷ could explain the high sensitivity of physical examination in their study, suggesting that the sensitivity of physical examination may depend on stenosis severity—being higher for significant stenoses. In contrast, specificity in that study is similar to ours, which may indicate that specificity is not influenced by whether or not stenoses are significant.

The arm-elevation test was the method that detected the most stenoses, yielded the highest number of true positives, and had the greatest sensitivity, NPV, and accuracy. In contrast, the pulse-augmentation test was the second-least sensitive method and produced the fewest true positives. These data are novel because the accuracy of the manual tests for detecting stenoses had not previously been studied, despite their being part of the physical examination. Studies on the accuracy of physical examination have only assessed changes in thrill, bruit, and pulse in AVF^{7,10}.

We found no literature on the accuracy of indirect methods for detecting stenoses. The absence of such studies may be due to the lack of reference values to interpret some of these methods properly—for example, how much arterial or venous pressure must rise to consider a stenosis present, what constitutes a prolonged haemostasis time, or which medicines should be considered excessive anticoagulation³. We defined prolonged haemostasis time as >20 minutes, in line with the GEMAV guideline³, and considered acenocoumarol (Sintrom[®]) use to represent excessive anticoagulation in the absence of studies or guidelines clarifying this point. Indirect methods were the second-best performer in terms of number of stenoses detected and the only method showing a statistically significant association with DU. Nonetheless, indirect methods produced the highest number of false positives, and therefore the number of stenoses detected may be overestimated, influencing the results obtained.

The accuracy of Kt/V for detecting stenoses has not been previously studied. We did, however, find one study on the accuracy of AVF recirculation measured by the BTM sensor.

In that study, Wang et al.¹⁷, reported that BTM-derived recirculation values >15% provided high sensitivity (81.8%) and specificity (98.6%) for identifying native AVF requiring elective intervention. In our study, by contrast, AVF recirculation showed low sensitivity and high specificity; these results are consistent with Ibeas et al.⁵, who stated that AVF recirculation is a highly specific but poorly sensitive method. The paucity of literature on the accuracy of AVF recirculation and Kt/V may be due to the many factors that affect their measurements⁶. Moreover, neither method is useful for the early detection of stenoses³; indeed, Kt/V does not change until there is a high percentage of recirculation^{6,18}. Furthermore, if a stenosis lies between the two needles, it will not cause recirculation and thus will not be detected³. All of this may explain why AVF recirculation was the method that detected the fewest stenoses in our study and why AVF recirculation and Kt/V have not been rigorously studied⁶.

The main limitation of this study is methodological. The sample size is small, which widens confidence intervals and therefore reduces the precision of parameter estimates; our confidence intervals are wider than in other studies with larger samples⁷. In addition, the scarcity of studies on the accuracy of first-generation methods limits comparisons.

In light of these results, we conclude that, for detecting non-significant stenoses, first-generation methods have low sensitivity and high specificity; stenosis severity (significant vs non-significant) may influence the sensitivity—but not the specificity—of physical examination; and the arm-elevation test is the most accurate first-generation method for detecting stenoses.

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