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Maturation of native arteriovenous fistulas: influence of inflammatory, biochemical and haematological factors

Francisco Javier Rubio-Castañeda[1], Manuel Fernández-Núñez[2], Ana Isabel Sierra-Sánchez[2], María Amaya Mateo-Sánchez[2], Johanna Chico-Guerra[1], Emilia Ferrer-López[1]

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

[2] Dialysis and Kidney Transplant Unit, Hospital Universitario Miguel Servet de 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 preoperative and postoperative inflammatory, biochemical, and haematological factors that influence the maturation of native arteriovenous fistulas.

Material and Method: We conducted a retrospective observational study. Two blood tests were performed—pre- and postoperative—analysing biochemical, haematological, and inflammatory parameters. Statistical analysis included descriptive statistics, Student's t test, Mann–Whitney U test, chi-square test, Wilcoxon test, and binomial logistic regression.

Results: The sample comprised 130 patients with a mean age of 68.3 years; 75.3% were men. Overall, 75.3% of fistulas matured. When comparing mature *vs* non-mature fistulas, the following findings were observed: Preoperative analysis: albumin (p=0.012) and PO_2 (p=0.007) were significantly higher, and C-reactive protein (CRP) (p=0.006) was significantly lower in mature fistulas. Postoperative analysis: CRP (p=0.004) and creatinine (p=0.002) were significantly lower in mature fistulas. Paired-sample analysis: in mature fistulas, there was a significant postoperative increase in PO_2 (p=0.049), leukocytes (p=0.021), and neutrophils (p=0.011), and a significant postoperative decrease in PCO_2 (p=0.042) and creatinine (p<0.001). In non-mature fistulas, a significant decrease in preoperative albumin was observed (p<0.001). Logistic regression: higher preoperative albumin (OR, 0.15; p=0.003) and PO_2 (OR, 0.54; p=0.002) were associated with a lower risk of maturation failure. Higher preoperative uric acid (OR, 1.58; p=0.005), and higher postoperative CRP (OR, 1.31; p=0.047) and creatinine (OR, 1.22; p=0.006) were associated with a greater risk of maturation failure.

Conclusions: Elevated uric acid, creatinine, and CRP levels increase the risk of fistula maturation failure, whereas higher preoperative albumin and PO_2 reduce this risk. After surgery, mature fistulas show increased PO_2, leukocyte, and neutrophil levels, together with a significant decrease in PCO_2 and creatinine.

Keywords: haemodialysis; native arteriovenous fistula; Doppler ultrasound; biomarkers.

RESUMEN

Maturation of native arteriovenous fistulas: influence of inflammatory, biochemical and haematological factors

Objetivo: Determinar los factores inflamatorios, bioquímicos y hematológicos pre-quirúrgicos y post-quirúrgicos que influyen en la maduración de las fistulas arteriovenosas nativas .

Material y Método: Estudio observacional retrospectivo. Se realizaron dos analíticas sanguíneas, pre-quirúrgica y post-quirúrgica, analizando parámetros bioquímicos, hematológicos, e inflamatorios. Análisis estadístico: Descriptivo. T-Student, U de Mann-Whitney y Chi cuadrado. Prueba de Wilcoxon y regresión logística binomial.

Resultados: Muestra de 130 pacientes, edad media 68,3 años. 75,3% hombres. 75,3% fístulas maduras. Al comparar las fístulas maduras frente a las no maduras observamos: Analítica pre-quirúrgica: albumina (p=0,012) y PO2 (≤0,007) significativamente mayores, y PCR (p=0,006) significativamente menor en fístulas maduras. Analítica post-quirúrgica: PCR (p=0,004) y creatinina (p=0,002) significativamente menores en fístulas maduras. Análisis de muestras apareadas: en fístulas maduras: incremento significativo de PO2 (p=0,049), leucocitos (p=0,021) y neutrófilos (p=0,011) post-quirúrgicos, y descenso significativo de PCO2 (p=0,042) y creatinina (p<0,001) post-quirúrgicas. En fístulas no maduras: descenso significativo de albumina pre-quirúrgica (p<0,001). Regresión logística: a mayor valor pre-quirúrgico de albumina (OR:0,15; p=0,003) y PO2 (OR:0,54; p=0,002) menor riesgo de fallos de maduración. A mayores valores pre-quirúrgicos de ácido úrico (OR:1,58; p=0,005), y post-quirúrgicos de PCR (OR:1,31; p=0,047) y creatinina (OR:1,22; p=0,006) mayor riesgo de fallos de maduración.

Conclusiones: Valores elevados de ácido úrico, creatinina y PCR aumentan el riesgo de fallos de maduración; una mayor albúmina y P02 pre-quirúrgicas lo reducen. Tras la cirugía, en fístulas maduras se observa un incremento de PO2, leucocitos y neutrófilos, y un descenso significativo de PCO2 y creatinina.

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

INTRODUCTION

In patients undergoing haemodialysis (HD), the native arteriovenous fistula (nAVF) is the vascular access of choice[1]. However, more than 80% of these patients do not have a mature nAVF at the start of HD and therefore require a central venous catheter (CVC) to undergo dialysis, which increases the risk of mortality, morbidity and healthcare costs[2].

Maturation is a complex process that begins after creation of the arteriovenous anastomosis and ends when the nAVF is suitable for haemodialysis. During maturation, increased intravascular pressure and blood flow induce vascular remodelling and vessel dilatation[3-4]. In general, 4 to 6 weeks are required to achieve successful maturation; nevertheless, approximately 53% of nAVFs fail to mature adequately for use in HD[4].

Multiple factors negatively affect the maturation process, including age, sex, uraemia, inflammation and certain blood biomarkers[3,5,6].

Reduction in glomerular filtration in patients with kidney disease leads to accumulation of blood toxins, particularly uraemic toxins (urea and creatinine), giving rise to the so-called uraemic syndrome. This syndrome produces a state of inflammation and oxidative stress that damages the vascular endothelium and promotes nAVF maturation failure[2,3,7]. In addition to the systemic inflammation caused by uraemia, local inflammation occurs after nAVF creation. Together, these processes contribute to an exacerbated inflammatory state that favours neointimal hyperplasia[3,7-9].

Numerous blood biomarkers have been associated with nAVF maturation failure, including coagulation and haematological factors, blood lipids, various electrolytes, urea, creatinine, inflammatory markers and plasma proteins[5,10,11]. However, the role of these biomarkers in maturation failure remains poorly defined[12]. Moreover, there is no consensus regarding which blood biomarkers are most strongly associated with nAVF maturation failure[3,5,6,10,11], and there is a lack of literature simultaneously analysing the effects of both pre-operative and post-operative blood biomarkers on nAVF maturation.

Therefore, the aim of this study was to determine the pre-operative and post-operative inflammatory, biochemical and haematological factors that influence nAVF maturation and maturation failure.

MATERIAL AND METHOD

We conducted an observational study with retrospective data collection in March 2025 at the haemodialysis vascular access clinic of *Hospital Universitario Miguel Servet* (Zaragoza, Spain).

Population and sample: Patients attending the advanced chronic kidney disease (ACKD) clinic and the chronic haemodialysis programme who underwent creation of an nAVF at *Hospital Universitario Miguel Servet* between 1 January 2023 and 31 December 2024 were included.

Inclusion criteria: Patients aged ≥18 years who had an nAVF created between 2023 and 2024 at Hospital Universitario Miguel Servet.

Exclusion criteria: Prosthetic AVFs and thrombosed nAVFs.

Only one nAVF per patient was included in the study; patients who lost vascular access and required a new access or surgical repair of the original nAVF were not re-included.

Study variables

Sociodemographic: age (years), sex (male, female). Comorbidities: diabetes, hypertension. *Type of nAVF:* radiocephalic, brachiocephalic, brachiobasilic. *Ultrasound variables:* vein diameter (mm), vascular access flow (QA). *Laboratory parameters:* pH, PCO_2 (mmHg), PO_2 (mmHg), PTH (pg/mL), iron (µg/dL), C-reactive protein (mg/dL), urea (mg/dL), creatinine (mg/dL), uric acid (mg/dL), calcium (mg/dL), phosphorus (mg/dL), albumin (g/dL), leukocytes (10^3/µL), neutrophils (%), eosinophils (%), basophils (%), monocytes (%), lymphocytes (%) and haemoglobin (%)[6,10,13-16]. All variables, except ultrasound parameters, were obtained from the electronic health record.

Two blood tests were performed: one pre-operative and one post-operative. The pre-operative test was the closest to surgery, while the post-operative test was obtained 30 days after surgery.

Ultrasound variables were measured using Doppler ultrasound. A maturation ultrasound assessment was performed at 6 weeks in the vascular access clinic using a Hitachi-Aloka F ultrasound scanner. Venous diameter was measured 3 cm above the arteriovenous anastomosis, and QA was measured 3 cm above the bifurcation of the humeral artery. An nAVF was considered mature when venous diameter ≥4 mm and vascular access flow (QA) ≥500 mL/min at 6 weeks[4].

Approval was obtained from *Hospital Universitario Miguel Servet* and the Research Ethics Committee of the Autonomous Community of Aragón (CEICA), decision CI: PI24/032. The committee authorised exemption from informed consent. Clinical data were extracted from electronic records in anonymised format and provided by an external intermediary, in accordance with Spanish Organic Law 3/2018 on Personal Data Protection and Digital Rights and Regulation (EU) 2016/679 (GDPR).

Statistical analysis: Jamovi® version 2.3.28 was used. Descriptive analysis employed measures of central tendency (mean, median) and dispersion (standard deviation, interquartile range). Normality was assessed with the Shapiro–Wilk test. Quantitative variables were compared using Student's t test (normal distribution) or the Mann–Whitney U test (non-normal distribution). Qualitative variables were expressed as frequencies and percentages and analysed using chi-square tests. Paired samples were vs the Wilcoxon test. Binomial logistic regression was performed to examine the association between maturation outcomes and laboratory parameters.

RESULTS

The sample consisted of 130 patients with a mean age of 68.3±11.7 years. Of these, 75.3% were men (n = 98) and 24.7% women (n=32). Diabetes was present in 42.3% (n=55) and hypertension in 86.9% (n=113). Regarding the type of nAVF, 68.4% were radiocephalic (n=89), 23.8% brachiocephalic (n=31) and 7.8% brachiobasilic (n=10) **(table 1)**.

Overall, 75.3% of nAVFs matured successfully (n = 98), whereas 24.7% failed to mature (n=32). By access type, maturation occurred in 64% of radiocephalic fistulas (n=57), 90.3% of brachiocephalic fistulas (n=28) and 80% of brachiobasilic fistulas (n=8). At 6 weeks after surgery, mature fistulas showed significantly greater venous diameter (5 mm [IQR, 3.9–8.2] *vs* 4 mm [IQR, 2.2–6.1]) and higher access flow QA (834 mL/min [IQR, 441–2200] *vs* 369 mL/min [IQR, 195–605]) *vs* non-mature fistulas (both p<0.001) **(table 1)**.

In the pre-operative blood analysis, patients with mature fistulas had significantly higher albumin levels (4.1 g/dL [IQR, 2.9–4.7] *vs* 3.4 g/dL [IQR, 3.1–6.0]; p=0.012) and higher PO_2 (32 mmHg [IQR, 11–72] *vs* 25 mmHg [IQR, 15–51]; p=0.007) *vs* those with maturation failure. Conversely, CRP values were significantly lower in mature fistulas (0.3 mg/dL [IQR, 0.02–14] vs 0.74 mg/dL [IQR, 0.03–3.1]; p=0.006) **(table 2)**.

In the postoperative analysis, CRP (0.34 mg/dL [IQR, 0.03–6.8] *vs* 0.83 mg/dL [IQR, 0.02–7.9]; p=0.004) and creatinine (4.14 mg/dL [IQR, 2.7–12.3] *vs* 4.84 mg/dL [IQR, 2.3–7.8]; p=0.002) were significantly lower in patients with mature fistulas than in those with non-mature fistulas **(table 2)**.

Tabla 1. Descriptive analysis.

Variable	Total	Mature nAVF	Non-mature nAVF	p value
Sample size, n (%)	130	98 (75.3%)	32 (24.7%)	–
Age, years (mean±SD)	68.3±11.7	68.6±12.2	67.5±10.6	0.26[1]
Sex				
Male	98 (75.3%)	70 (71.4%)	28 (28.6%)	0.96[2]
Female	32 (24.7%)	23 (71.9%)	9 (28.1%)	
Diabetes	55 (42.3%)	35 (63.6%)	20 (36.4%)	0.08[7]
HTN	113 (86.9%)	85 (75.2%)	28 (24.8%)	0.05[2]
Type of fistula				
Radiocephalic	89 (68.4%)	57 (64.0%)	32 (36.0%)	0.017
Brachiocephalic	31 (23.8%)	28 (90.3%)	3 (9.7%)	
Brachiobasilic	10 (7.8%)	8 (80.0%)	2 (20.0%)	
Ultrasound variables[1]				
Vein diameter, mm	4.8 (IQR, 2.2–8.2)	5.0 (IQR, 3.9–8.2)	4.0 (IQR, 2.2–6.1)	<0.001[3]
Access flow (QA), mL/min	702 (IQR, 195–2200)	834 (IQR, 441–2200)	369 (IQR, 195–605)	<0.001[3]

Statistical tests: [1] Student's t test; [2] Chi-square test; [3] Mann–Whitney U test.
nAVF: native arteriovenous fistula.
HTN: hypertension.
[1] Ultrasound measurements obtained at 6 weeks after fistula creation.

Table 2. Pre- and post-operative laboratory parameters according to final Outcome

Parameter	Mature nAVF	Non-mature nAVF	p value
Preoperative laboratory tests			
PO_2, mmHg	32 (IQR, 11–72)	25 (IQR, 15–51)	0.007
CRP, mg/dL	0.30 (IQR, 0.02–14.0)	0.74 (IQR, 0.03–3.1)	0.006
Albumin, g/dL	4.1 (IQR, 2.9–4.7)	3.4 (IQR, 3.1–6.0)	0.012
Postoperative laboratory tests			
CRP, mg/dL	0.34 (IQR, 0.03–6.8)	0.83 (IQR, 0.02–7.9)	0.004
Creatinine, mg/dL	4.14 (IQR, 2.7–12.3)	4.84 (IQR, 2.3–7.8)	0.002

Statistical analysis: Mann–Whitney U test.
nAVF, native arteriovenous fistula.
CRP, C-reactive protein. **PO_2,** partial pressure of oxygen.

Paired-sample analysis showed that patients with mature fistulas exhibited a significant postoperative increase in PO_2 (32 mmHg [IQR, 11–72] *vs* 37 mmHg [IQR, 11–60]; p=0.049), leukocytes (7.1×10^3/µL [IQR, 3.6–13.6] *vs* 7.5×10^3/µL [IQR, 3.5–21]; p=0.021) and neutrophils (62.6% [IQR, 2.5–85] *vs* 65.4% [IQR, 44–89]; p=0.011), together with a significant reduction in PCO_2 (45 mmHg [IQR, 32–57] *vs* 43.6 mmHg [IQR, 33–58]; p=0.042) and creatinine (4.6 mg/dL [IQR, 2.6–11.8] *vs* 4.14 mg/dL [IQR, 2.7–12.3]; p<0.001). In contrast, patients with non-mature fistulas showed a significant post-operative decrease in albumin (3.4 g/dL [IQR, 3.1–6.0] *vs* 3.1 g/dL [IQR, 2.8–4.8]; p<0.001) **(table 3)**.

Binomial logistic regression demonstrated that higher preoperative albumin (OR, 0.15; p=0.003) and PO_2 (OR, 0.54; p=0.002) were associated with lower risk of maturation failure. Conversely, higher pre-operative uric acid (OR, 1.58; p=0.005) and higher post-operative CRP (OR, 1.31; p=0.047) and creatinine (OR, 1.22; p=0.006) were associated with increased risk of maturation failure **(table 4)**.

DISCUSSION

In this cohort, 24.7% of nAVFs failed to mature. These findings are consistent with published vascular access guidelines, which report failure rates between 28% and 53%[4,17]. Radiocephalic fistulas exhibited higher failure rates than humeral-based fistulas, likely due to their smaller vessel diameter[4]. Our results align with previous studies showing maturation failure rates ranging from 5–37% for radiocephalic, 8–16% for brachiocephalic and 2–23% for brachiobasilic fistulas[18].

In our study, consistent with the published literature, we found an association between elevated levels of creatinine[5,15,18,19], uric acid[11,18,20] and CRP[9,14,16] and AVF maturation failure. It should be noted that although several studies have reported an association between creatinine levels and AVF maturation failure[5,15,18],we did not identify any studies that specifically analysed the independent vascular and inflammatory effects of creatinine. Instead, the available literature examines this effect within the broader framework of the uraemic syndrome, which is defined as a condition caused by elevated blood levels of urea and creatinine[3,7,15,21,22]. Consequently, the term uraemia is used to describe the relationship between creatinine, inflammation and vascular damage.

Table 4. Binomial logistic regression analysis.

	Odds ratio	95% Confidence Interval	p value
Preoperative laboratory parameters			
Albumin	0.15	0.04 – 0.52	0.003
PO_2	0.54	0.43 – 0.81	0.002
Uric acid	1.58	1.14 – 2.19	0.005
Postoperative laboratory parameters			
C-reactive protein (CRP)	1.31	0.91 – 1.45	0.047
Creatinine	1.22	0.95 – 1.55	0.006

Reference outcome: Non-maturation of native arteriovenous fistulas (nAVF).

Uraemia and elevated uric acid levels cause vascular injury and exacerbate the inflammatory process, thereby promoting arteriovenous fistula maturation failure[3,7,18,20-24]. High uric acid levels directly damage the vascular endothelium[11,20,23,24]. In addition, uraemia not only impairs endothelial function but also induces vascular fibrosis, promotes smooth muscle cell infiltration, and increases vascular calcification[3,7,11,13,19,21,22]. Furthermore, inflammation negatively affects AVF survival by altering vascular permeability[2,16]. Both uraemia[3,7,13,21] and elevated uric acid levels[20,23,25] intensify systemic inflammation in patients with kidney disease through the release of inflammatory cytokines that further contribute to maturation failure[20].

CRP is a widely used biomarker for assessing inflammation in patients with kidney disease and has been associated with nAVF dysfunction[8,9,14,16,20,26,27]. In our study, patients with maturation failure exhibited significantly higher CRP levels both pre- and post-operatively. However, we found no previous studies that asses-

Table 3. Paired sample analysis.

	Preoperative laboratory test	Postoperative laboratory test	p value
Mature nAVF			
PCO_2, mmHg	45 (IQR, 32–57)	43.6 (IQR, 33–58)	0.042
PO_2, mmHg	32 (IQR, 11–72)	37 (IQR, 11–60)	0.049
Creatinine, mg/dL	4.6 (IQR, 2.6–11.8)	4.14 (IQR, 2.7–12.3)	<0.001
White blood cell count, $\times10^3$/µL	7.1 (IQR, 3.6–13.6)	7.5 (IQR, 3.5–21.0)	0.021
Neutrophils, %	62.6 (IQR, 2.5–85)	65.4 (IQR, 44–89)	0.011
Non-mature nAVF			
Albumin, g/dL	3.4 (IQR, 3.1–6.0)	3.1 (IQR, 2.8–4.8)	<0.001

Statistical analysis: Paired Wilcoxon signed-rank test.
nAVF: native arteriovenous fistula. **PO_2:** partial pressure of oxygen. **PCO_2:** partial pressure of carbon dioxide.

sed CRP levels after AVF creation; in the available literature, CRP is measured exclusively in the preoperative period[8,27].

Our findings also indicate that higher preoperative PO_2 and albumin levels promote nAVF maturation.

Hypoalbuminaemia in patients with kidney disease results from systemic inflammation secondary to uraemia[12]. Low serum albumin levels are associated with reduced nAVF survival[12], and preoperative hypoalbuminaemia is a recognised predictor of maturation failure[5,6,12,16,28]. Accordingly, our results are consistent with existing evidence in showing that higher preoperative albumin levels protect against maturation failure.

We found no studies examining the relationship between preoperative PO_2 levels and nAVF maturation failure. The literature exclusively focuses on the role of hypoxia in nAVF maturation. Previous authors have reported an association between hypoxia and maturation failure[1,15,19]. as hypoxia induces vascular cellular dysfunction, ultimately leading to intimal hyperplasia and impaired maturation[15,21].

To date, no studies have simultaneously analysed pre- and postoperative blood biomarkers. In the systematic review by Morton et al., no consensus was found regarding the optimal timing of blood sampling, with some studies collecting samples before fistula creation and others after fistula failure[10]. Notably, in our study, leukocyte and neutrophil counts increased significantly one month after fistula creation. Following surgery, local tissue hypoxia and inflammation develop due to macrophage and neutrophil infiltration at the surgical site[3], which likely explains this postoperative rise in white blood cell counts. In our cohort, this increase was associated with successful fistula maturation. Nevertheless, no published studies have evaluated neutrophils or leukocytes in isolation as predictors of nAVF maturation. The only haematological indices previously associated with nAVF maturation failure are the neutrophil-to-lymphocyte ratio[30] and the monocyte-to-lymphocyte ratio[13,31].

The principal limitation of this study is methodological. The small number of female participants resulted in wider confidence intervals and reduced parameter precision. Furthermore, the absence of studies simultaneously evaluating pre- and postoperative biomarkers limits direct comparison of our findings with those of other authors.

Based on our results, elevated preoperative uric acid levels and increased postoperative CRP and creatinine levels indicate the presence of an exacerbated inflammatory process that promotes nAVF maturation failure. Conversely, higher preoperative albumin and PO_2 levels increase the likelihood of achieving a mature fistula.

Finally, comparison of pre- and postoperative analyses revealed that in mature fistulas there is a significant postoperative increase in PO_2, leukocyte count, and neutrophil percentage, together with a significant decrease in PCO_2 and creatinine.

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Conflicts of interest

None declared.

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