Soluble Vascular Cell Adhesion Molecule as a Predictor of Arteriovenous Fistula Maturation: A Pilot Study

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Abstract

Background: Predicting arteriovenous fistula (AVF) maturation in patients with end-stage kidney disease remains challenging. Soluble vascular cell adhesion molecule (sVCAM) is involved in vascular remodeling, but its predictive value is not well established. This study evaluated whether sVCAM levels can predict AVF maturation 8 weeks after creation.

Methods: In this prospective pilot diagnostic study, 19 patients undergoing AVF creation were enrolled. sVCAM levels were measured preoperatively and 4 weeks postoperatively. AVF maturation was assessed at 8 weeks using ultrasonographic criteria.

Results: Twelve patients (63%) achieved AVF maturation. Those with mature AVFs had significantly higher baseline sVCAM levels than those without maturation (1505.9±383.1 vs. 1029.9±378.3 ng/mL, p = 0.018). The percentage change in sVCAM levels also differed significantly between groups (mature: −6.6±35.8% vs. non-mature: +19.4±10.8%, p = 0.035). A baseline sVCAM threshold of ≥985.9 ng/mL yielded 100% sensitivity and 71.4% specificity for predicting AVF maturation (AUC = 0.845, 95% CI: 0.632–1.000). Combining sVCAM levels with clinical parameters, including age <73 years and BMI <30 kg/m², further improved predictive accuracy, achieving the highest AUC of 0.935 (95% CI: 0.804–1.000).

Conclusions: Preoperative sVCAM level is a promising biomarker for predicting successful AVF maturation. Incorporating clinical parameters alongside sVCAM further enhances predictive performance.

Keywords: AV access; ESKD; kidney failure; hemodialysis; AVF patency; dialysis

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การศึกษาแบบนำร่องของโมเลกุลการยึดเกาะของเซลล์บุผนังหลอดเลือดในการทำนายการเจริญเติบโตของเส้นฟอกเลือดแท้

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บทคัดย่อ

บทนำ: การทำนายการเจริญเติบโตของเส้นฟอกเลือดแท้ (arteriovenous fistula) ในผู้ป่วยโรคไตเรื้อรังระยะสุดท้าย ยังเป็นไปได้ยาก และปัจจัยที่นำมาใช้ในการทำนายยังขาดความแม่นยำ โมเลกุลการยึดเกาะของเซลล์บุผนังหลอดเลือด (Soluble Vascular Cell Adhesion Molecule หรือ sVCAM) เป็นตัวชี้วัดการทำงานของหลอดเลือด แต่ปัจจุบันยังไม่มีข้อมูลในการทำนายความสมบูรณ์ของเส้นฟอกเลือดแท้ งานวิจัยนี้มีวัตถุประสงค์เพื่อประเมินความสามารถของระดับ sVCAM ในการทำนายความสมบูรณ์ของเส้นฟอกเลือดแท้ที่ 8 สัปดาห์ภายหลังการผ่าตัด

ระเบียบและวิธีวิจัย: การศึกษาเชิงวินิจฉัยแบบไปข้างหน้าในผู้ป่วย 19 รายที่เข้ารับการผ่าตัดทำเส้นฟอกเลือดใน โดยตรวจวัดระดับ sVCAM ก่อนการผ่าตัด และหลังผ่าตัด 4 สัปดาห์ โดยประเมินความสมบูรณ์ของเส้นฟอกเลือดที่ 8 สัปดาห์โดยใช้อัลตราซาวด์

ผลการวิจัย: พบผู้ป่วย 12 รายมีเส้นฟอกเลือดที่เติบโต (63%) ในผู้ป่วยที่มีเส้นฟอกเลือดเติบโตมีระดับ sVCAM ก่อนผ่าตัดสูงกว่าผู้ที่มีเส้นฟอกเลือดไม่เติบโตอย่างมีนัยสำคัญ (1505.9±383.1 vs. 1029.9±378.3 นาโนกรัม/มล., p=0.018) และพบการเปลี่ยนแปลงของระดับ sVCAM ที่ 4 สัปดาห์เปรียบเทียบกับก่อนการผ่าตัด แตกต่างกันอย่างมีนัยสำคัญระหว่างทั้งสองกลุ่ม (-6.6±35.8% vs. +19.4±10.8%, p=0.035) โดยค่าระดับ sVCAM ก่อนผ่าตัด ≥985.9 นาโนกรัม/มล. ให้ความไวร้อยละ 100 และความจำเพาะร้อยละ 71.4 ในการทำนายการเจริญเติบโตของเส้นฟอกเลือดโดยมีค่า AUC ที่ 0.845 (95% CI 0.632-1.000) การนำปัจจัยทางคลินิกอื่นได้แก่ อายุ <73 ปี และ ดัชนีมวลกาย <30 กก./ม.² มาร่วมในโมเดลจะช่วยเพิ่มประสิทธิภาพการทำนายได้ดียิ่งขึ้นโดยมีค่า AUC สูงถึง 0.935 (95% CI 0.804-1.000)

สรุป: ระดับ sVCAM ก่อนการผ่าตัดเป็นตัวบ่งชี้ทางชีวภาพที่มีศักยภาพในการทำนายความสำเร็จของการเจริญเติบโตของเส้นฟอกเลือดแท้ การผสมผสานค่าพารามิเตอร์ทางคลินิกร่วมกับ sVCAM จะช่วยเพิ่มความแม่นยำในการทำนายมากยิ่งขึ้น

คำสำคัญ: เส้นฟอกเลือด; เส้นฟอกเลือดตัน; เส้นแท้; ฟอกเลือด; ฟอกไต; ไตวายระยะสุดท้าย

Introduction

Patients with end-stage kidney disease (ESKD) have several options for vascular access. The 2019 Kidney Disease Outcomes Quality Initiative (KDOQI) clinical practice guidelines designate arteriovenous fistula (AVF) as the modality of choice due to its superior longevity and significantly fewer complications. Vascular outward remodeling is necessary for AVF maturation following AVF creation[1,2]. Additionally, endothelial function in proliferating endothelial cells and pericytes is vital in

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vascular remodeling. In the early phase of AVF maturation, soluble vascular cell adhesion molecule (sVCAM) interacts with proteins called integrin $\alpha 4\beta 1$ and consequently promotes close intercellular adhesion between endothelial cells and pericytes during vascular remodeling and the neovascularization process[3,4]—however, sVCAM level increases when AVF complication occurs in the late phase[5,6]. Hence, we hypothesized that sVCAM may predict AVF maturation early after surgery.

AVF maturation rate generally varies between 20-60% within approximately 4 to 8 weeks after creation[7]. According to the literature review in Thailand, the AVF maturation rate is 74.2-76.3% within 3 months after surgery[8]. Clinical risk factors are integrated into the predictor model in routine preoperative vascular assessment. For example, the CAVeA2T2 score is applied in a clinical predictor model for AVF maturation **(Table 1)**[9]. A score of at least 2 increases the risk of AVF non-maturation. However, the models for fistula maturation have fair discrimination, as indicated by the area under the receiver operating characteristic curve of 0.68[10]. There is still a lack of clinical studies using biomarkers such as sVCAM to predict AVF maturation. The present study offers an opportunity to investigate sVCAM levels as a predictor of AVF maturation, potentially establishing a preoperative predictive model for successful AVF development.

Table 1 CAVeA2T2 Score

Factors	Score
History of the central venous catheter placement	1
Age >73 years	1
Venous diameter <2.2 millimeters	1
History of vascular repair	2
Abnormal physical examination	2
Total score	7

Modified from Martinez LI, Esteve V, Yeste M, Artigas V, Llagostera S. Clinical Utility of a New Predicting Score for Radiocephalic Arteriovenous Fistula Survival. Ann Vasc Surg. 2017 May; 41:56-61.[9]

Methods

Study participants

We conducted a prospective pilot diagnostic study at Phramongkutklao Hospital from July to December 2024. The eligible patients were 20 years or older and had been diagnosed with ESKD and were scheduled for AVF creation. The exclusion criteria were patients with active infection, autoimmune diseases, malignancies, liver dysfunction, or unwilling to participate. The trial was approved by the Ethics Committee of the Institute Review Board at the Royal Thai Army (code: R087h/67)

Outcomes

The primary outcome was the area under the curve (AUC) of sVCAM level at baseline and the postoperative change of sVCAM at 4 weeks to predict AVF maturation 8 weeks after surgery. The secondary outcome was the identification of prognostic factors associated with AVF maturation. Hemodynamic maturation of AVF was defined as a blood flow rate ≥500 mL/min and a vessel diameter ≥5 mm at 8 weeks after the operation[7,11].

Data collection

All participants had a comprehensive medical history review to document baseline characteristics, including demographic parameters such as sex, age, BMI, hypertension, dyslipidemia, tobacco use, cardiovascular disease, cerebrovascular disease, and peripheral arterial disease. Also, preoperative ultrasound evaluation was performed, and the AVF site was marked.

Blood samples were collected from the contralateral forearm to the AVF site for sVCAM, complete blood count, fasting blood glucose, hemoglobin A1C, lipid profile, blood urea nitrogen, creatinine, and electrolytes.

Analysis of soluble vascular cell adhesion molecule levels

Soluble VCAM levels were analyzed at baseline and 4 weeks postoperatively. Unclotted blood samples were processed and maintained at 4°C, centrifuged at 3000 rpm, and the plasma supernatant was stored at -80°C until analysis. Plasma sVCAM levels were analyzed via quantitative sandwich enzyme-linked immunosorbent assay (ELISA) (Quantikine® ELISA Human VCAM-1/CD106 Immunoassay from Bio-Techne China Company Limited, Shanghai, China)

Sample size calculation

Using a maturation prevalence of 50% (20-60%)[7,8] and a sensitivity of 80% (76-85%)[13,16] with a two-tailed type 1 error (α) 0.05 and 80% power, the calculated sample size was 31.

Statistical analysis

Continuous variables were represented as means with standard deviations. Comparison of sVCAM levels between the two groups was analyzed using unpaired t-tests. Categorical variables were demonstrated as percentages and compared using Fisher's exact tests. The receiver operating characteristic curve (ROC) was used to determine the predictors of AVF maturation. Univariate and multivariate logistic regression analyses were employed to investigate the relationships between baseline factors and AVF maturation. Statistical analyses were performed using STATA version 17, and $p<0.05$ was considered statistically significant.

Results

Between July 2024 and December 2024, 26 patients underwent AVF creation surgery. Three patients were excluded from the study: one due to active infection, and the other two were unwilling to participate. At the end of the study, 19 of the 23 eligible patients remained in the study because three patients postponed surgery and one patient withdrew from the study. After 8 weeks of follow-up, AVF matured in 12 of 19 patients (63%).

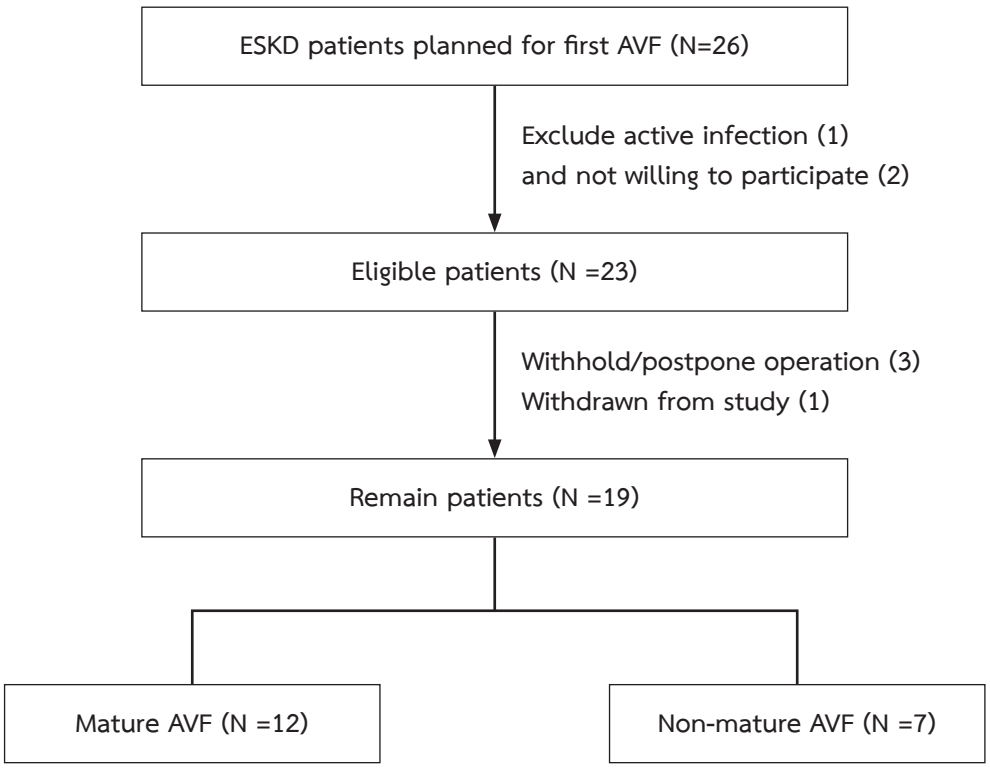

Figure 1 Study Flow Diagram
ESKD, end-stage kidney disease; AVF, arteriovenous filstua

The baseline characteristics of all patients are presented in **Table 2**. Patients with mature AVFs tended to be older and had a lower BMI than those with non-mature AVFs; however, these differences did not reach statistical significance. Both groups had similar demographic data and comorbidities. The dialysis vintage, history of central venous catheter use, and CAVeA2T2 scores were comparable between groups. The mean arterial and venous diameters were largely similar between mature and non-mature groups. No significant differences were observed in the laboratory data.

Table 2 Baseline demographic and laboratory data of all patients

Characteristics	Mature group (n=12)	Non-mature group (n=7)	All patients (n=19)	p-value
Age	62.25±14.57	49.29±16.02	57.47±16.02	0.089
Sex				
Male	11 (91.7%)	4 (57.1%)	15 (78.9%)	0.117
Female	1 (8.3%)	3 (42.9%)	4 (21.1%)	0.117
BMI (kg/m^2)	25.03±4.9	29.47±5.68	26.67±5.5	0.090
Types of arteriovenous fistula				
Radiocephalic	5 (41.7%)	5 (71.4%)		
Brachiocephalic	7 (59.3%)	2 (28.6%)		
Underlying diseases				
Diabetes mellitus	5 (41.7%)	4 (57.1%)	9 (47.4%)	0.650
Hypertension	12 (100%)	7 (100%)	19 (100%)	NA
Dyslipidemia	9 (75%)	6 (85.7%)	15 (78.9%)	1
Smoking	1 (8.3%)	2 (28.6%)	3 (15.8%)	0.523
Cardiovascular disease	3 (25%)	0 (0%)	3 (15.8%)	0.263
Stroke	1 (8.3%)	2 (28.6%)	3 (15.8%)	0.523
Dialysis Vintage (months)	8.67±9.86	12.14±21.48	9.95±14.7	0.633
History of CVC placement	7 (58.3%)	4 (57.1%)	11 (57.9%)	1
History of vascular repair	0 (0%)	0 (0%)	0 (0%)	NA
CAVeA2T2 score				
0	2 (16.7%)	2 (28.6%)	4 (21.1%)	0.603
1	6 (50%)	3 (42.9%)	9 (47.4%)	1
2	4 (33.3%)	2 (28.6%)	6 (31.6%)	1
Arterial diameter (mm)	3.6±1.22	4.07±1.1	3.77±1.17	0.412
Venous diameter (mm)	2.6±0.66	2.89±0.7	2.71±0.67	0.386
Labs				
Hemoglobin (g/dl)	10.87±1.5	10.19±1.88	10.62±1.63	0.396
Platelets (x 10^{3}cells/mm^3)	245.8±50.1	268±55.8	254±51.9	0.383
Calcium (mg/dL)	9.18±0.74	8.95±1.04	9.1±0.84	0.566
Phosphate (mg/dL)	5.18±1.61	4.86±1.73	5.06±1.61	0.692
Magnesium (mg/dL)	2.1±0.29	1.96±0.28	2.05±0.29	0.309
Intact-PTH (pg/mL)	312.1±243.9	535.7±467.6	394.5±348.6	0.185
25-OH-D (ng/mL)	39.37±20.39	37.71±20.56	38.76±19.89	0.866
FPG (mg/dL)	133.9±74.4	90.24±13	117.8±62.5	0.147
Hemoglobin A1c (%)	6.67±2.21	5.93±1.21	6.39±1.9	0.429
LDL (mg/dL)	105.8±53.1	92.8±36.1	101±46.9	0.575
Triglycerides (mg/dL)	138.1±41.9	110.1±39.5	127.8±42.2	0.170
HDL (mg/dL)	45.22±9.66	47.63±11.48	46.11±10.11	0.631
Ferritin (ng/mL)	519.5±564.7	451.2±468.2	494.3±518.7	0.791
Transferrin saturation (%)	29.75±11.6	32.43±23.56	30.74±16.4	0.786

BMI, body mass index; CVC, central venous catheter, PTH, parathyroid hormone; 25-OH-D, 25-hydroxyvitamin D; FPG, fasting plasma glucose; LDL, low-density lipoprotein; HDL, high-density lipoprotein

As shown in **Table 3**, the group of patients with AVF demonstrated significantly higher baseline sVCAM levels compared to the group with non-mature AVFs (1505.9±383.1 ng/mL vs. 1029.9±378.3 ng/mL, p = 0.018). Interestingly, no significant difference was observed in sVCAM levels at 4 weeks after the operation between the two groups (1300.5±353.7 ng/mL vs. 1200.7±326.1 ng/mL, p = 0.550). There was a divergent pattern in the percentage change of sVCAM between the two groups. The group with mature AVF exhibited a mean decrease of 6.6±35.8% in sVCAM levels, whereas the non-mature group showed a significant increase of 19.4±10.8% (p = 0.035). The absolute change in sVCAM showed a mean decrease of -205.5±629.5 ng/mL in the mature group compared to an increase of +170.7±93.0 ng/mL in the non-mature group, although the difference did not reach statistical significance (p = 0.065).

Table 3 Soluble vascular cell adhesion molecule levels in the mature and non-mature groups

Soluble VCAM	Mature group (N=12)	Non-mature group (N=7)	p-value
Baseline sVCAM levels (ng/mL)	1505.9±383.1	1029.9±378.3	0.018
sVCAM levels at 4 weeks (ng/mL)	1300.5±353.7	1200.7±326.1	0.550
Change of sVCAM levels at 4 weeks from baseline (ng/mL)	-205.5±629.5	170.7±93.0	0.065
% Change of sVCAM levels 4 weeks from baseline	-6.6±35.8	19.4±10.8	0.035

sVCAM, soluble vascular cell adhesion molecule

The performance of sVCAM level at baseline for predicting AVF maturation at 8 weeks is illustrated in **Table 4** and **Figure 2**. The threshold value of ≥985.9 ng/mL demonstrated excellent 100% sensitivity and 71.4% specificity, yielding a favorable likelihood ratio (LR+) of 3.5 for predicting AVF maturation. The area under the receiver operating characteristic curve (AUC) was 0.845 (95% CI: 0.632-1.000), indicating good discriminative ability. The predictive performance further improved when combining sVCAM at baseline with demographic and clinical parameters. The combination of sVCAM with age <73 years yielded an AUC of 0.893, and the combination with BMI <30 kg/m² resulted in an AUC of 0.905. The highest predictive accuracy was achieved when incorporating BMI <30 kg/m² and age <73 years, yielding the highest AUC of 0.935.

Table 4 Baseline soluble vascular cell adhesion molecule levels in predicting arteriovenous fistula maturation

Parameters	Sensitivity (%)	Specificity (%)	LR+	AUC	95% CI
sVCAM ≥985.9 ng/mL	100	71.4	3.5	0.845	0.632-1.000
sVCAM with Age <73 years	100	71.4	3.5	0.893	0.726-1.000
sVCAM with BMI <30 kg/m^2	100	71.4	3.5	0.905	0.732-1.000
sVCAM with BMI <30 kg/m^2 and age <73 years	100	71.4	3.5	0.935	0.804-1.000

sVCAM, soluble vascular cell adhesion molecules; BMI, body mass index; AUC, area under the curve; LR+, positive likelihood ratio; CI, confidence interval

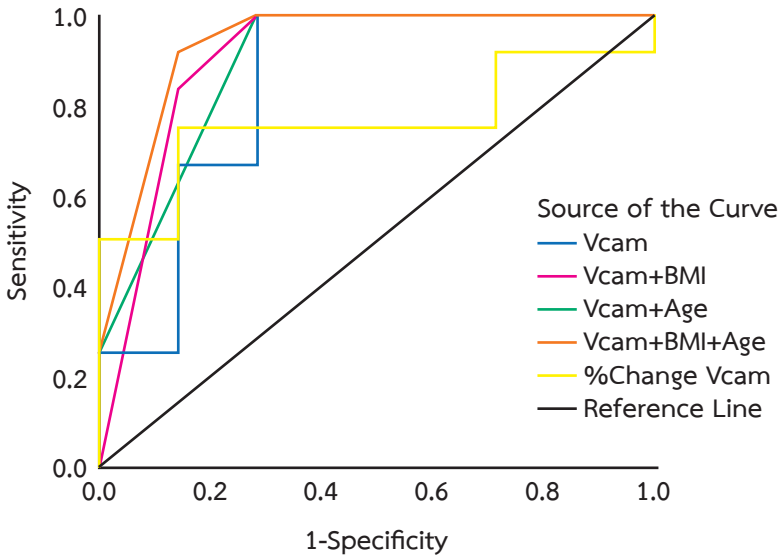

Figure 2 Receiver operating characteristic curve of baseline soluble vascular cell adhesion molecule levels in predicting arteriovenous fistula maturation
VCAM, vascular cell adhesion molecule; BMI, body mass index

Univariate and Multivariate Logistic Regression Analysis

Table 5 shows the results of univariate and multivariate logistic regression analysis examining predictors of AVF maturation. In the univariate analysis, baseline sVCAM levels demonstrated a statistically significant association with AVF maturation. While other factors, including percentage change in sVCAM from baseline, age, BMI, venous diameter, and history of central venous catheter (CVC) insertion, were not significantly associated with AVF maturation. In multivariate analysis, the significance of baseline sVCAM levels was lost after adjusting for potential confounders.

Table 5 Logistic regression analyses of factors predicting arteriovenous fistula maturation

Variables	Univariate Analysis			Multivariate Analysis		
	OR	95% CI	P-value	Adjusted OR	95% CI	P-value
Baseline sVCAM levels	1.004	1.000 - 1.008	0.049	1.01	1.00 - 1.01	0.297
% Change in sVCAM levels at 4 weeks from baseline	0.958	0.91-1.01	0.126	1.01	0.92 - 1.09	0.973
Age	1.06	0.99 - 1.14	0.097	1.09	0.97 - 1.22	0.131
Body mass index	0.85	0.69 – 1.03	0.101	0.85	0.64 - 1.14	0.288
Venous diameter < 2.2 mm	1.25	0.16 – 9.54	0.830	1.11	0.05 - 25.15	0.946
History of CVC insertion	1.05	0.16 – 6.92	0.960	2.42	0.09 - 68.25	0.605

sVCAM, soluble vascular cell adhesion molecules; CVC, central venous catheter; OR, odds ratio; CI, confidence interval

Discussion

The present study demonstrated that preoperative sVCAM levels provided good predictive value for maturation of AVF 8 weeks after the creation. The group of patients with mature AVF showed significantly higher preoperative sVCAM levels. Soluble VCAM levels ≥985.9 ng/mL demonstrated 100% sensitivity and 71.4% specificity in predicting maturation of the AVF. Combining baseline sVCAM levels with clinical parameters, including BMI <30 kg/m² and age <73 years, yielded the highest AUC in predicting AVF maturation.

In the early phase after surgery, substantial blood flow through the new AVF generates shear stress. The endothelial cells exposed to shear stress secrete cytokines, creating a pro-inflammatory environment. This process is called the inflammation infiltration process, which is beneficial to AVF in the early maturation phase because it promotes vascular outward remodeling to accommodate high blood flow[14]. In depth, sVCAM-1 regulates JunB-mediated IL-8/CXCL1 expression, resulting in neovascularization[15]. This explains the association between higher baseline sVCAM levels and AVF maturation after surgery. The preoperative sVCAM level was a good predictor of AVF maturation at 8 weeks, with an AUC of 0.85. Moreover, combining baseline sVCAM with other clinical parameters, such as BMI and age, increased the AUC to 0.94. This level of accuracy is similar to the previous study that used direct postoperative flow measurement of AVF to predict AVF maturation[16]. Therefore, preoperative sVCAM level can be a promising predictive marker for AVF maturation. In addition, preoperative sVCAM level can also be helpful in early risk stratification, which may aid physicians in optimizing the management of AV access in ESKD patients, in conjunction with the standard of care.

The present study demonstrated reduced sVCAM levels in patients with mature AVF, whereas the levels increased in the non-mature AVF group. It is possible that, later after surgery, the initial inflammatory process subsides. Still, if endothelial cells are exposed to a prolonged toxic environment or persistent inflammation, the endothelial-mesenchymal transition can occur. Released cytokines, such as platelet-derived growth factor (PDGF) and tumor growth factor β (TGF-β), activate the phenotypic switching of vascular smooth muscle cells, leading to neointimal hyperplasia[14]. Additionally, they induce inward vascular remodeling, which can lead to AVF stenosis. Therefore, a substantial increase in sVCAM level at 4 weeks post-operation is an early dynamic indicator to guide early vascular intervention.

The major limitation of this study is the small population. Additionally, confounders to sVCAM level, such as subclinical inflammation and thrombosis, were not investigated or accounted for in this study.

Conclusion

Preoperative sVCAM level can be a promising predictive marker for AVF maturation at 8 weeks post-creation. Incorporating clinical parameters alongside sVCAM further enhances predictive performance. Postoperative change in sVCAM level may serve as a dynamic indicator to predict AVF maturation and help guide early vascular intervention strategies.

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