

# Risk score for the prediction of arteriovenous fistula maturation

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## ABSTRACT

**Objective:** The poor maturation rate of arteriovenous fistulas (AVFs) remains a challenge. We aim to develop a parsimonious risk score equations that incorporate patients' demographics, comorbidities, and vessel characteristics to assist the access surgeons in predicting the likelihood of AVF maturation before surgery.

**Methods:** Data of AVFs created from 2015 to 2020 in National University Hospital Singapore was retrospectively obtained and used as the training dataset. Two prediction models were developed to predict: (1) the commencement of cannulation; and (2) functional maturation, by 3 months after creation. The models were internally validated using k-fold cross validation and externally validated on patients who had AVFs created in 2021 and 2022. The final models were converted to interpretable risk score equations for clinical usage.

**Results:** The training dataset included 474 AVF cases. Six and eight variables were selected for predicting: (1) the commencement of cannulation; and (2) functional maturation, respectively. The two models demonstrated satisfactory performance with C-statistics of 0.72 and 0.74, respectively. The C-statistics in internal validation were 0.7 and 0.69 for the two models, respectively. External validation was performed using the data of 220 different patients; the C-statistic was 0.7 in both models.

**Conclusions:** The two risk scores developed demonstrated reasonable preoperative predictive values for AVF maturation. They are potentially useful in aiding clinicians to make decisions about AVF creation sites. Further evaluation of these prediction scores in a large cohort is required to reveal their clinical value. (*J Vasc Surg* 2025;81:1485-94.)

**Keywords:** Arteriovenous fistula; Hemodialysis access; Maturation; Nomograms; Outcomes

The poor maturation rate of native vein arteriovenous fistulas (AVFs) remains a challenge for hemodialysis (HD) patients,<sup>1</sup> despite extensive efforts in multiple aspects.<sup>2-5</sup> A parsimonious risk score equation, incorporating patients' demographics, comorbidities, and vessel characteristics, is believed to be helpful in assisting the access surgeons to predict the likelihood of AVF maturation before operation, and make sensible clinical decisions. An effective prediction model could assist clinicians in selecting suitable AVF creation sites for specific patients. Speedy maturation of AVFs (repeated

successful two-needle cannulation of the fistula to support HD) is important for dialysis-dependent patients, as it avoids or minimizes patients' reliance on a central venous catheter (CVC), along with the associated complications. A high AVF maturation rate not only benefits the quality of life for HD patients but also optimizes the utilization of health care resources.<sup>6</sup>

Our group conducted a systematic review on the methods, model performance, and key factors in prediction models for AVF-related outcomes.<sup>7</sup> In the review, models that employed conventional statistics or machine learning methods were included. It revealed that risk scores derived from conventional statistical models are generally parsimonious, incorporating only a few key variables, and are easier to be adopted by the clinicians in the clinical setting. Models utilizing machine learning methods, on the other hand, demonstrated modestly superior predictive performance. Nonetheless, there were concerns about the limited interpretability of machine learning methods due to their 'black box' nature. Furthermore, several significant limitations were identified in the existing models. Some models focused only on one or two specific type(s) of AVFs,<sup>8-11</sup> making them less applicable to daily clinical practice. Also, certain variables used by the models might not be applicable in all clinical settings.<sup>10,12</sup> Additionally, most models lacked external validation and underreported calibration metrics, potentially leading to inaccurate risk estimates

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and misguided expectations.<sup>13</sup> All these limitations make the development of better calibrated models necessary.

Therefore, there is a need to develop a more robust predictive model to assist the access surgeons in predicting the success of the planned AVF, as well as to compare the potential success rates of different AVF sites when more than one option is available. This study aims to achieve the following objectives: (1) build a parsimonious and robust model for the prediction of AVF maturation; (2) evaluate model performance and perform external validation; and (3) convert the predictive model into a user-friendly risk score equation by creating a nomogram.

## METHODS

**Study cohort.** The study was a single-center retrospective study approved by the domain-specific review board (2023/00,298). Waiver of informed consent was approved by the domain-specific review board. The data of patients who underwent AVF creation between 2016 and 2022 in a tertiary hospital were collected from the hospital's electronic medical record. All AVF creations were performed by six vascular surgeons from the same specialty. Patients' identities (name, national registration identity card number) were removed after data collection, and a serial number was assigned to each case so that participants cannot be re-identified. All methods were performed in accordance with Declarations of Helsinki.

The following cases were excluded from the analysis: (1) Pre-emptive cases, as the maturation dates are less concrete to determine; (2) patients with no information on vessel sizes; (3) patients lost to follow-up and who refused cannulation after creation; and (4) those who died within 3 months after creation.

**Variable definitions.** There are two maturation outcomes of interest: (1) commencement of cannulation; and (2) functional maturation. Data for both outcomes were extracted up to 3 months post-creation.

The decision to initiate cannulation was based on the clinician's assessment, including clinical examination factors (visibility of fistula, thrill of fistula, clinical palpation of fistula with tourniquet on), and ultrasound evaluation (diameter and depth of fistula and brachial artery volume flow) during clinic reviews. Ultrasonographic criteria for commencement of cannulation were: fistula diameter  $\geq 5.5$  mm, depth  $< 6$  mm, and brachial artery volume flow  $\geq 500$  mL/min. Functional maturation was defined as HD sustained by the AVF only and removal of any CVC. The surgeons use the criteria of "successful two-needle cannulation during HD, sustaining a blood flow rate of  $> 200$  mL/min for at least six consecutive HD sessions" as an indication to arrange CVC removal. In our clinical setting, where fistulas are cannulated in the community dialysis centers, capturing the date of the six

## ARTICLE HIGHLIGHTS

- **Type of Research:** Single-center retrospective cohort study
- **Key Findings:** Two models were developed using 474 cases to predict the likelihood of arteriovenous fistula (AVF) cannulation and functional maturation 3 months after creation. When validated on a new cohort of 220 patients, the models demonstrated reasonable predictive value (C-statistic, 0.7). These could assist clinicians make informed decisions about AVF creation sites.
- **Take Home Message:** A parsimonious risk score equation converted from predictive model, incorporating patients' demographics, comorbidities, and vessel characteristics, is believed to be helpful in assisting the access surgeons to predict the likelihood of AVF maturation before operation, and make sensible clinical decisions.

consecutive successful cannulation is not reliable. As a more feasible and standardized alternative, the tunneled CVC removal date was recorded as the functional maturation date.

Patients' demographics, comorbidities, characteristics of vessels constituting the AVF, and previous vascular access history were collected (variable names and abbreviations are listed in [Supplementary Table 1](#), online only). Characteristics of vessels constituting the AVF were extracted from preoperative ultrasound vessel mapping studies. These include the average diameter and presence of heavy calcification of the artery, as well as the average diameter of the superficial vein used for formation of the fistula (arteriovenous anastomosis). The history of vascular access (VA) in the ipsilateral arm was categorized into three categories: no prior VA, history of VA with primary failure, and history of functional VA. A history of primary failure was defined as a previous VA (either AVF or arteriovenous graft) that was abandoned before any successful cannulation. A history of functional VA referred to a previous VA that successfully supported HD.

Location of AVFs were classified as: (1) distal region; (2) proximal region single-stage; and (3) proximal region two-stage. 'Distal region' AVFs refer to those created below the elbow, including snuffbox and radio-cephalic AVF. 'Proximal region single-stage' AVFs refer to AVFs created over the cubital fossa or above, including Graz AVF, brachio-cephalic AVF, and single-stage brachio-basilic AVF (creation and transposition done in the same procedure). 'Proximal region two-stage' AVFs refer to brachio-basilic AVF with transposition of the fistula done weeks after the initial creation.

**Risk score development.** All statistical analyses were performed with R software (R-4.2.1). In the descriptive

analysis, patients' demographics, comorbidities, characteristics of vessels constituting the AVF, previous vascular access history, and intraoperative data were categorized into two groups: training data and test data. Categorical variables were presented as number with frequencies; the  $\chi^2$  test was used for comparison between two groups. Continuous variables were summarized as median (interquartile range) if the data distribution was skewed. They were presented as mean (standard deviation) if the data was normally distributed.

Those AVF cases created from the years 2016 to 2020 were used as the training dataset for the development of the model, whereas those created in 2021 and 2022 were used as the test dataset for external validation of the model. The flow of statistical analysis and methods used are illustrated in Fig 1.

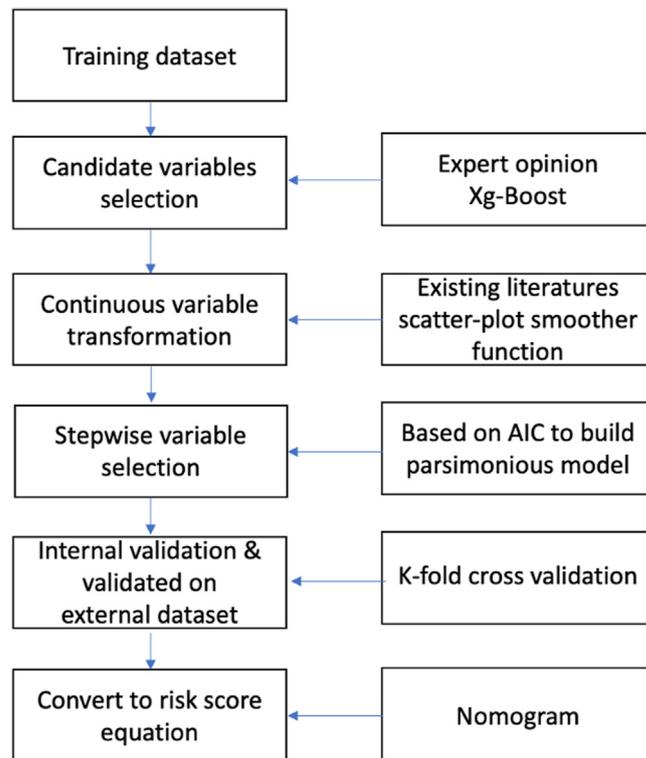
Two logistic regression models were built: Model 1, with 'commencement of cannulation at 3 months' as the outcome of interest, and Model 2, with 'functional maturation at 3 months' as the outcome. Candidate variables selection was based on both expert opinion and a machine learning method (Xg-boost). Xg-boost was used to identify the most important features (top 20 importance score) in the datasets to predict the outcome. A bar chart showing the importance of the variables is shown in Supplementary Figs 1 and 2 (online only).

All the continuous variables were transformed into categorical variables based on existing scatter-plot smoother function (Supplementary Fig 3, online only), and fine-tuned with domain knowledge to ensure the cutoffs are clinically meaningful.

Backwards stepwise regression using Akaike information criterion was used for the development of the final multivariable models from all the candidate variables. Variance inflation factor was used to assess the multicollinearity (variance inflation factor <5 for all the variables). The models' discrimination were assessed by the C-statistics (equivalent to area under the receiver operating characteristic) and its calibration by the Hosmer-Lemeshow goodness-of-fit test. Bootstrap (999 bootstrap replicates) was used to calculate the 95% confidence intervals (CIs) for C-statistics.

Internal validation was carried out in the original training dataset with K-fold cross validation. K-fold cross-validation is a method that randomly divides the training data into k groups ( $k = 5$ ); the model is fit on  $k-1$  folds, and then the remaining fold is used to evaluate model performance.

The performance of the two models were further evaluated in an external dataset (test dataset) from two dimensions: discrimination and calibration. R package 'predRupdate' was used for the external validation. The models' discrimination was assessed by the C-statistics and its calibration by the Hosmer-Lemeshow goodness-of-fit test.



**Fig 1.** Flow of statistical analysis. AIC, Akaike information criterion.

The two multivariable models were converted to interpretable nomograms and risk score equations for clinical usage. In the risk score equations, every selected variable was assigned a point in proportion to its coefficient in the original models. The total points accumulated by the selected variables correspond to the predicted probability for the clinical outcomes of interests (commencement of cannulation or functional maturation).

## RESULTS

**Study cohort.** In total, data of 694 newly created AVF cases were included in the analysis. Among the 694 cases, 474 cases and 220 cases were included in the training dataset and test dataset, respectively. The patients' demographics, comorbidities, dialysis-related histories, and characteristics constituting the index AVF for both datasets are presented in Table 1. There was no significant difference in terms of demographics, comorbidities, dialysis-related history, and vessel characteristics for AVF creation between training dataset and test dataset. Close to one-half of the patients were overweight or obese. More than 70% of the patients were independent in performing their activities of daily living (ADLs). In terms of patients' comorbidities, the majority of them (79.1% and 80.0%, respectively) had normal cardiac ejection fraction, in both datasets. A high percentage of patients had the "3 highs" diagnosed (diabetes, hypertension, hyperlipidemia), whereas only a small

**Table I.** Patients' demographics, comorbidities, dialysis-related histories, and vessel characteristics of index arteriovenous fistula (AVF) for both training dataset and test dataset

Variables	Training dataset (n = 474)	Test dataset (n = 220)
Demographics		
Age, years	63.4 (54.8-69.9)	63.8 (54.7-69.9)
Gender		
Male	293 (61.8)	127 (57.7)
Race		
Chinese	267 (56.3)	127 (57.7)
Malay	158 (33.3)	69 (31.4)
Indian	45 (9.5)	20 (9.1)
Others	4 (0.8)	4 (1.8)
BMI		
Underweight (BMI <18.5 kg/m <sup>2</sup> )	26 (5.5)	17 (7.7)
Normal (18.5 ≤ BMI <25 kg/m <sup>2</sup> )	224 (47.3)	102 (46.4)
Overweight or obese (BMI ≥25 kg/m <sup>2</sup> )	224 (47.3)	101 (45.9)
ADL		
Independent	346 (73.0)	159 (72.3)
Comorbidities		
CAD		
Requires PCI and/or CABG	132 (27.8)	46 (20.9)
Minor CAD	82 (17.3)	45 (20.5)
No	260 (54.9)	129 (58.6)
Ejection fraction		
≥50%	375 (79.1)	176 (80.0)
DM	330 (69.6)	161 (73.2)
Hypertension	433 (91.4)	209 (95.0)
Hyperlipidemia	332 (70.0)	176 (80.0)
Peripheral artery disease	60 (12.7)	18 (8.2)
Cerebral vascular accident	66 (13.9)	40 (18.2)
Ipsilateral weakness	7 (1.5)	1 (0.5)
Pacemaker	13 (2.7)	2 (1.0)
Antiplatelet and/or anticoagulant	398 (84.0)	150 (68.2)
Dialysis-related histories		
Etiology of end-stage renal failure		
DM/HTN	337 (71.1)	161 (73.2)
Glomerulonephritis	88 (18.6)	26 (11.8)
Others	49 (10.3)	33 (15.0)
History of other RRT modality		
Peritoneal dialysis	63 (13.3)	25 (11.4)
Transplant	17 (3.6)	6 (2.7)
Dialysis vintage, months	5.4 (1.8 to 17.9)	4.8 (1.8 to 11.0)

(Continued)

**Table I.** Continued.

Variables	Training dataset (n = 474)	Test dataset (n = 220)
Duration of central venous catheter before creation, months	2.6 (1.0 to 6.3)	3.4 (1.4 to 6.6)
Characteristics of index AVF		
History of VA on ipsilateral upper limb		
No	391 (82.5)	187 (85.0)
Primary failure	26 (5.5)	17 (7.7)
Functional VA	57 (12.0)	16 (7.3)
Location of AVF		
Distal region	170 (35.9)	100 (45.5)
Proximal region single-stage	212 (44.7)	89 (40.5)
Proximal region two-stage	92 (19.4)	31 (14.1)
Anastomotic vein size, mm	3.0 (1.0)	2.8 (1.0)
Anastomotic artery size, mm	3.8 (1.4)	3.6 (1.3)
Heavy calcification of anastomotic artery	64 (13.5)	26 (11.8)
<i>ADL</i> , Activity of daily living; <i>AVF</i> , arteriovenous fistula; <i>BMI</i> , body mass index; <i>CABG</i> , coronary artery bypass graft; <i>CAD</i> , coronary artery disease; <i>DM</i> , diabetes mellitus; <i>HTN</i> , hypertension; <i>PCI</i> , percutaneous coronary intervention; <i>RRT</i> , renal replacement therapy; <i>VA</i> , vascular access. Data are presented as number (%), median (interquartile range), or mean (standard deviation).		

percentage had ipsilateral upper limb weakness or pacemaker in situ.

In terms of histories related to kidney diseases and dialysis, most of the patients' kidney failure was due to either diabetes or hypertension. Median duration of tunneled CVC in situ before access creation were 2.6 months and 3.4 months for training and test datasets, respectively. For more than 80% of the patients, the studied AVF was the first vascular access created on the index upper extremity. A small percentage of patients (5.5% and 7.7%, respectively) had primary failure of past VA(s) on the ipsilateral limb, in both the training and test datasets.

The sizes of the anastomotic vessels were normally distributed across the study population. The average anastomotic vein size was 3.0 mm in the training dataset and 2.8 mm in the test dataset, whereas the average anastomotic artery size was 3.8 mm and 3.6 mm, respectively. Heavy calcification of the anastomotic artery was observed in approximately 10% of the patients.

**The prediction models and model performance in the original dataset.** The analysis outcomes of the two developed models are shown in [Table II](#). For Model 1,

**Table II.** Analysis outcome of the two developed models in the original dataset, internal validation, and external validation dataset

Prediction model	Performance in the training dataset (n = 474)		C-statistic results in internal validation (n = 474)	C-statistic results in external validation (n = 220)	
	C-statistics (bootstrap 95% CI)	Hosmer-lemeshow goodness-of-fit test	K-fold cross-validation (k = 5)	C-statistics (bootstrap 95% CI)	Hosmer-lemeshow goodness-of-fit test
Model 1: cannulation at 3 months	0.72 (0.70-0.79)	<i>P</i> = .66	0.70 (0.65-0.75)	0.70 (0.63-0.77)	<i>P</i> = .91
Model 2: functional maturation at 3 months	0.74 (0.71-0.81)	<i>P</i> = .10	0.69 (0.63-0.75)	0.70 (0.61-0.78)	<i>P</i> = .19

*C*-statistic, Concordance statistic; *CI*, confidence interval.  
C-statistics were used to evaluate models' discrimination ability; Hosmer-Lemeshow goodness-of-fit test was used to evaluate calibration ability.

**Table III.** Nomogram 1: points assigned for different values of the seven selected key variables to predict commencement of cannulation 3 months after creation

Variables	Points
Age, years	
<50	0
>60	15
50-60 (inclusive)	32
Gender	
Male	31
Female	0
Activity of daily living	
Independent	37
Assist or dependent	0
Presence of PAD	
No	26
Yes	0
Location of the AVF <sup>a</sup>	
Distal region	73
Proximal region single-stage	100
Proximal region two-stage	0
History of VA on ipsilateral arm	
No	0
Primary failure	9
Functional VA	47

AVF, Arteriovenous fistula; PAD, peripheral artery disease; VA, vascular access.  
<sup>a</sup>AVF created on distal region refers to snuff box and radiocephalic AVFs; AVF on proximal region single-stage refers to brachiocephalic AVFs, and brachio-basilic AVFs created and transposed at same time; AVF on proximal region two-stage refers to brachio-basilic AVFs transposed weeks after the creation.

predicting the commencement of cannulation by 3 months, six variables were selected in the final multivariable logistic regression. The C-statistic of Model 1 was 0.72 (95% CI, 0.70-0.79). The Hosmer and Lemeshow goodness-of-fit test (*P* = .66) indicated good calibration.

**Table IV.** Total points in nomogram 1 and their corresponding probability of cannulation 3 months after creation

Total points	Probability of cannulation at 3 months
<162	<40% (Low)
162-201	40%-60% (Moderate)
>201	>60% (High)

In Model 2, with 'functional maturation at 3-months' as the outcome, eight variables were selected in the final model. The C-statistic of Model 2 was 0.74 (95% CI, 0.71-0.81). The Hosmer and Lemeshow goodness-of-fit test (*P* = .10) indicated a good calibration.

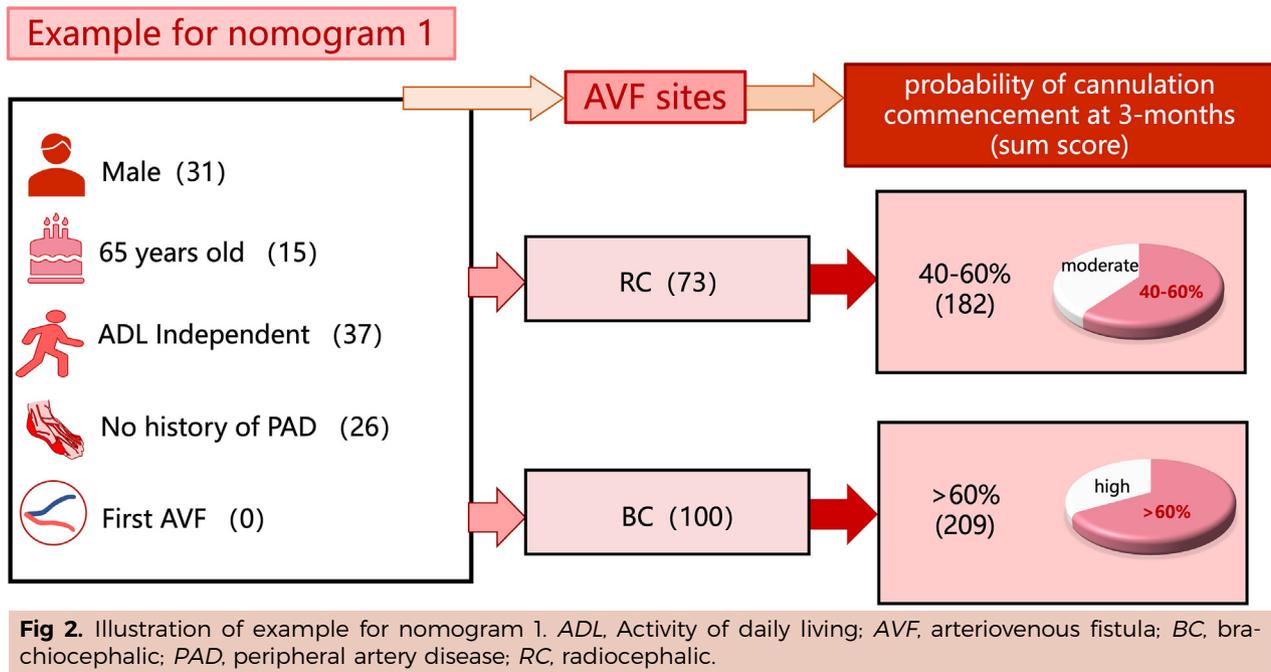
The two derived logistic regression models are presented in [Supplementary Table II](#) (online only).

**Internal validation (K-fold cross validation).** The performance of the models from the internal validation process is presented in [Table II](#). In the K-fold cross validation, the C-statistics for Model 1 and Model 2 were 0.70 (95% CI, 0.65-0.75) and 0.69 (95% CI, 0.63-0.75), respectively.

**External validation.** The two prediction models were applied to the external validation dataset consisting 220 new cases. The C-statistics for the predicting cannulation at 3 months (Model 1) was 0.70 (95% CI, 0.63-0.77), and for predicting functional maturation at 3 months was 0.70 (95% CI, 0.61-0.78) (Model 2).

The Hosmer-Lemeshow goodness-of-fit test (*P* = .91 and *P* = .19, respectively) indicated good calibration of both Model 1 and Model 2 in the test dataset.

**Nomogram/risk score equation.** Nomograms were developed to translate the multivariable logistic regression models into clinically user-friendly scoring systems for predicting AVF maturation. For the outcome 1, commencement of cannulation at 3 months, a



nomogram was developed based on six factors identified, and the risk score equation was derived from the weighting of the different variables. The points assigned for individual variables are presented in Table III, and the predicted probability of cannulation commencement corresponding to the total score is presented in Table IV.

For example, a male patient (31) aged 65 (15) required AVF creation. He is ADL-independent (37) and no history of PAD (26). This is his first vascular access creation to support HD without any history of prior primary failure (0). The total score for this patient will be 182 if a radiocephalic AVF (73) is planned for him. The corresponding probability of cannulation after 3 months of creation will be moderate (40%-60%). However, if a single-stage proximal region AVF (100) is created (eg, brachiocephalic AVF), the probability of cannulation being initiated will be >60%, based on the total score of 209 (Fig 2).

Similarly, Table V presents the points assigned for individual variables used for the prediction of functional maturation and the probability corresponding to their score (Table VI).

For example, a male patient (39) is 48 years old (25) and ADL-independent (26). The patient's body mass index is 28 kg/m<sup>2</sup> (10). An ipsilateral snuff box AVF was created 3 months ago with primary failure (21). On the latest venous mapping, there is no calcification noted on the radio artery and brachial artery (71). The average forearm cephalic vein size was 2.4 mm (0), and average arm cephalic vein size was 2.8 mm (16). If a radiocephalic AVF (73) is planned for the patient, the total score will be 265 and the probability of successful functional maturation will be <40% (low). If a new brachiocephalic AVF

creation (100) is possible, this will increase the probability of success to 40% to 60% (sum of score: 308) (Fig 3).

## DISCUSSION

There are a multitude of factors exerting impact on AVF maturation and also multiple options of site for AVF creation in each patient. A critical challenge vascular access surgeons are facing is how to integrate various factors to arrive at a best surgical decision of access creation. This study is potentially valuable in assisting clinicians to make decisions regarding the AVF creation site.

Clinicians' decision-making involves a holistic approach that considers various factors, including the timing of dialysis initiation, the use of temporary dialysis catheters, the patient's comfort and preferences, and specific anatomical conditions. In the first scenario given in the results section, if an AVF creation is planned preemptively before dialysis initiation, a radiocephalic AVF can be considered as a favorable option, as there is ample time for the AVF to mature for needling. On the other hand, with the same demographic and VA history, if the patient was already using a tunneled CVC for HD, a single-stage proximal region AVF should be a more favorable option. Similarly, in the second scenario, if the patient experiences frequent CVC complications and requires rapid AVF maturation, a brachiocephalic AVF offers a higher likelihood of successful maturation within 3 months compared with a radiocephalic AVF, thereby reducing the risk of line infections. Importantly, these decisions should be made together with the patients to ensure selecting the most appropriate option for their individual circumstances. A predictive score will help the

**Table V.** Nomogram 2: points assigned for different values of the eight selected key variables to predict functional maturation 3 months after creation

Variables	Points
<b>Age, years</b>	
<50	25
>60	0
50-60 (inclusive)	29
<b>Gender</b>	
Male	39
Female	0
<b>Activity of daily living</b>	
Independent	26
Assist or dependent	0
<b>BMI</b>	
Normal ( $18.5 \leq \text{BMI} < 25 \text{ kg/m}^2$ )	29
Overweight or obese ( $\text{BMI} \geq 25 \text{ kg/m}^2$ )	10
Underweight ( $\text{BMI} < 18.5 \text{ kg/m}^2$ )	0
<b>Location of the AVF<sup>a</sup></b>	
Distal region	73
Proximal region single-stage	100
Proximal region two-stage	0
<b>History of VA on ipsilateral arm</b>	
No	0
Primary failure	21
Functional VA	49
<b>Calcification on anastomotic artery</b>	
No	71
Yes	0
<b>Average diameter of vein for AV anastomosis</b>	
<2.5 mm	0
$\geq 2.5 \text{ mm}$	16

AV, Arteriovenous; AVF, arteriovenous fistula; BMI, body mass index; VA, vascular access.  
<sup>a</sup>AVF created on distal region refers to snuff box and radiocephalic AVFs; AVF on proximal region single-stage refers to brachio-cephalic AVFs, and brachio-basilic AVFs created and transposed at same time; AVF on proximal region two-stage refers to brachio-basilic AVFs transposed weeks after the creation.

clinician to counsel patients and their caregivers to understand the differences between various options of vascular access creation easier.

Lok et al<sup>8</sup> developed a failure to maturation scoring system using four predictors—age, peripheral artery disease, coronary artery disease, and race. However, several studies<sup>12,14,15</sup> found its discriminative power to be weak (C-statistics, 0.52-0.53) in new patient cohorts. Tng et al<sup>12</sup> later identified gender, race, immediate postoperative good thrill, and the need for preoperative vein mapping as predictors. In their study population,<sup>12</sup> vein mapping was not required for patients with visible veins, but this practice might not be standardizable. Clinicians' subjective judgement of good 'visible veins' can vary

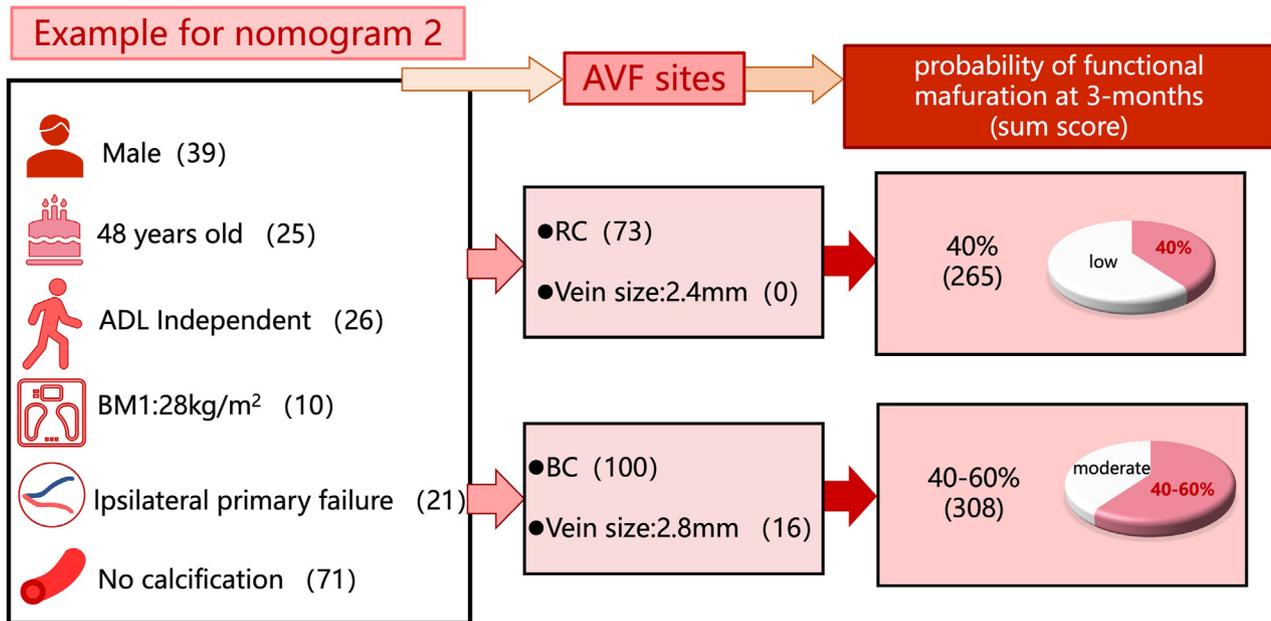
**Table VI.** Total points in nomogram 2 and their corresponding probability of functional maturation 3 months after creation

Total points	Probability of functional maturation at 3 months
<291	<40% (Low)
291-333	40%-60% (Moderate)
>333	>60% (High)

substantially. Our study used more objective ultrasound data, including average diameter of artery and vein, and presence of heavy calcification over artery used for creating anastomosis. Two other studies<sup>9,10</sup> developed an failure to maturation scoring system, but each focused on specific patient subgroups, limiting their broader application. Kumar et al<sup>10</sup> used the maximum diameter of the radial artery observed in the study population (2.5 mm) minus the radial artery diameter as a predictor. However, this value is not available at the time the model is applied and may not apply to all populations. Although these scoring systems helped to predict the probability of AVF maturation, they offer limited help in deciding AVF creation sites.

Both of our models have important clinical implications. Model 1, which predicts the commencement of cannulation using fewer variables, is useful in situations where the influence of nurses' cannulation skills is not considered. Model 2, predicting functional maturation—the ultimate outcome—has a greater impact on patient care. In clinical settings where dialysis nurses possess similar cannulation skills, Model 2 becomes more valuable.

In the equations developed in our study, both age and gender were selected for the prediction of the outcomes of 'commencement of needling' and 'functional maturation.' These are factors selected in previous equations as well.<sup>8,12</sup> A previous meta-analysis<sup>16</sup> that synthesised 13 cohort studies revealed that there was a significant higher rate of radiocephalic AVF failure among elderly patients compared with their non-elderly counterparts. In our study, patients under 50 years old had poorer maturation outcomes compared with those between 50 and 60 years old. It is likely that patients under 50 years old had different etiologies of end-stage kidney disease (ESKD) compared with older patients, with hypertension and diabetes being less common causes. In our study cohort, 71.4% of patients with ESKD and an underlying cause of systemic lupus erythematosus were under 50 years old. Studies by Chen et al<sup>17</sup> and Cuen-Ojeda et al<sup>18</sup> reported lower AVF patency rates among patients with ESKD and an underlying cause of systemic lupus erythematosus. Additionally, 7.3% of patients under 50 years old experienced a failed transplant, compared with 1.6% in those over 60 years and 4.7% in those



**Fig 3.** Illustration of example for nomogram 2. ADL, Activity of daily living; AVF, arteriovenous fistula; BC, brachiocephalic; BMI, body mass index; RC, radiocephalic.

aged 50 to 60 years. These patients often required more intravenous infusions, leading to increased vessel damage. In contrast, hypertension, which is more common in older patients, has been associated with higher AVF maturation rates.<sup>19</sup> Accumulating studies have provided a strong evidence that female gender is associated with a worse outcome of fistulas.<sup>20-22</sup> Peripheral artery disease, included as a predictor in the risk score equation, aligns with Lok et al's equation<sup>8</sup> and other studies.<sup>23-25</sup>

This study utilized two additional demographic predictors: body mass index and ADL status. A recent systematic review found that obesity to be significantly associated with poor AVF maturation outcomes,<sup>26</sup> possibly due to factors such as soft tissue compression of venous outflow,<sup>27</sup> hypercoagulable state, or more aggressive myointimal hyperplasia<sup>28</sup> in obese patients. ADL status has also been linked to readmission rate<sup>29</sup> and maturation rate.<sup>5</sup> In an Asian study, frailty, including low physical activity, was identified as a prognostic factor for vascular access thrombosis.<sup>30</sup> The ability to perform upper extremity exercise could mediate this association. Patients requiring assistance with ADL might have limited strength to perform upper extremity exercise, resulting in poorer maturation outcomes.

A history of vascular access in the ipsilateral arm was also a key predictor in model development. Favorable outcomes were observed in cases where the index AVF was not the first vascular access on that arm, particularly when there was a history of successfully matured AVFs or arteriovenous grafts. This likely occurs because previous vascular access creation may lead to dilation of both the

inflow artery and the connecting veins, improving the probability of maturation for subsequent AVF creation.

There is consensus that vein diameter is one of the independent prognostic factors for fistula maturation,<sup>31,32</sup> and a vein diameter of <2.5 mm is considered inadequate for formation of an AVF.<sup>32,33</sup> There has been evidence suggesting a role of arterial calcification in AVF failure.<sup>34-36</sup> Although the pathophysiology is not entirely clear, it has been hypothesized that vascular calcification decreases arterial distensibility and increased stiffness.<sup>37,38</sup>

The location of the AVF was a key factor in both equations. Surgeons can assign different scores based on the chosen site to illustrate to the patients the probabilities of success during preoperative counseling. This facilitates both parties to have realistic expectations and be able to make more informed decisions.

Model 1, which predicts the 'commencement of needling,' relies solely on patient demographics, comorbidities, vascular access history, and AVF location, without accounting for vessel conditions critical to arteriovenous anastomosis. In contrast, Model 2, which predicts 'functional maturation,' includes vessel conditions relevant to the arteriovenous anastomosis (calcification of artery and average vein size), factors that clinicians typically expect to significantly influence AVF maturation. However, the importance of vessel conditions influencing AVF maturation might be under-represented in these models. The datasets used for these models only include cases where the upper limb artery and superficial vein were not that poor such that clinicians proceeded for AVF creation. There is an assumption of acceptable artery and superficial vein conditions when

applying these models to perform the prediction. This assumption explains why vessel quality did not impact the probability cannulation within 3 months post-creation in Model 1. Nonetheless, these factors remain important, affecting the probability of ultimate functional maturation of the AVF. In real-world clinical situations, specific superficial veins may become fibrotic and scarred due to previous intravenous infusion or be initially too small—scenarios where these models may not apply. Clinicians should exercise basic clinical judgment to avoid creating an AVF with poor quality vessels.

The study has the strengths of: (1) capturing a broader patient population, including those with AVFs created at different sites, and with or without a history of prior vascular access creation; (2) the developed model was externally validated in a separate group of patients; (3) both the discriminative and calibration power of the model was evaluated; and (4) the variables selected are clinically relevant and can be easily generalized in other clinical settings.

Nonetheless, this study also has its limitations: (1) as a retrospective study, anastomotic vessel sizes were extracted from vessel mapping studies average sizes and not exactly the site taken for anastomosis creation. Future prospective studies with accurate recording of anastomotic vessel characteristics would be beneficial; (2) a small dataset limits the fine tuning of the model; (3) not all predictors can be included in the model. For instance, factors like patients' pre- and postoperative upper limb exercises to dilate the anastomotic vein, postoperative care coordination for monitoring AVF maturation, and the confidence levels of dialysis nurses and patients in cannulation and CVC removal are challenging to quantify. Surgeons' experience and preferences are believed to play a crucial role in outcomes. However, this factor cannot be easily generalized in other institutions, where surgeons have varying levels of expertise and differing approaches in AVF maturation and follow-up. Due to the complexity and variability of these factors, developing a model or risk score equation with very high performance (C-statistics  $\geq 0.75$ ) is not feasible.

Despite the limitations, the results would still have clinical implication to assist access surgeons in making decisions of site of AVF creation, especially for beginners. Furthermore, similar to all other predictive tools, whether this predictive score could be utilized by clinicians to generate clinical benefits has to be further evaluated in a large prospective cohort with a diverse population. Additionally, Model 1, which predicts the commencement of cannulation, can also be evaluated for predicting the physiologic maturation of pre-emptively created AVFs in future research.

### AUTHOR CONTRIBUTIONS

Conception and design: LM, PH  
Analysis and interpretation: LM, PH

Data collection: WG  
Writing the article: LM  
Critical revision of the article: PH, WG  
Final approval of the article: LM, PH, WG  
Statistical analysis: LM  
Obtained funding: Not applicable  
Overall responsibility: PH

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### DISCLOSURES

None.

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Additional material for this article may be found online at [www.jvascsurg.org](http://www.jvascsurg.org).

**Supplementary Table I (online only).** List of variables collected related to patients' demographics, comorbidities, characteristics of vessels constituting the arteriovenous fistula (AVF), and previous vascular access histories

Variable	Variable name	Codes/units
Gender	Gender	1: Male; 2: Female
Race	Race	1: Chinese; 2: Malay; 3: Indian; 4: Others
Age	Age	Years
Height	Height	Meters
Weight	Weight	Kilograms
BMI	Bmi2	[weight]/([height]*[height])
ADL	Adl	1: Independent; 2: Assisted; 3: Dependent
Ejection fraction	Ef	%
Diabetes	Dm	1: Yes; 0: No
Hypertension	Htn	1: Yes; 0: No
Hyperlipidemia	Hld	1: Yes; 0: No
Significant PAD requires intervention	Pad	1: Yes; 0: No
CAD	Cad	1: Yes; 0: No
History of coronary intervention: none	coronary_intervention_0	1: Yes; 0: No
History of coronary intervention: PCI	coronary_intervention_1	1: Yes; 0: No
History of coronary intervention: CABG surgery	coronary_intervention_2	1: Yes; 0: No
History of coronary intervention: patient declined CABG	coronary_intervention_3	1: Yes; 0: No
Ipsilateral upper limb weakness	Ipsilateral_weakness	1: Yes; 0: No
Pacemaker	pace_maker	1: Yes; 0: No
Cerebral vascular accident	Cva	1: Yes; 0: No
Etiology of ESKD: diabetes	etiology_eskd_1	1: Yes; 0: No
Etiology of ESKD: hypertension	etiology_eskd_2	1: Yes; 0: No
Etiology of ESKD: systemic lupus erythematosus	etiology_eskd_3	1: Yes; 0: No
Etiology of ESKD: glomerulonephritis	etiology_eskd_4	1: Yes; 0: No
Etiology of ESKD: structural related	etiology_eskd_5	1: Yes; 0: No
Etiology of ESKD: others	etiology_eskd_6	1: Yes; 0: No
History of other renal replacement therapy: No	Hx_other_modality___0	1: Yes; 0: No
History of other renal replacement therapy: peritoneal dialysis	Hx_other_modality___1	1: Yes; 0: No
History of other renal replacement therapy: transplant	Hx_other_modality___2	1: Yes; 0: No
Location of CVC: left IJ	Location_cvc___1	1: Yes; 0: No
Location of CVC: right IJ	Location_cvc___2	1: Yes; 0: No
Location of CVC: left subclavian	Location_cvc___3	1: Yes; 0: No
Location of CVC: right subclavian	Location_cvc___4	1: Yes; 0: No
Location of CVC: left femoral	Location_cvc___5	1: Yes; 0: No
Location of CVC: right femoral	Location_cvc___6	1: Yes; 0: No
Duration of CVC before AVF creation, months	Cvcdays	Imputed by: (operation date – date of CVC insertion)/30
Vintage of HD before AVF creation, months	Vintage	Imputed by: (operation date – date of HD commencement)/30

(Continued on next page)

**Supplementary Table I (online only).** Continued.

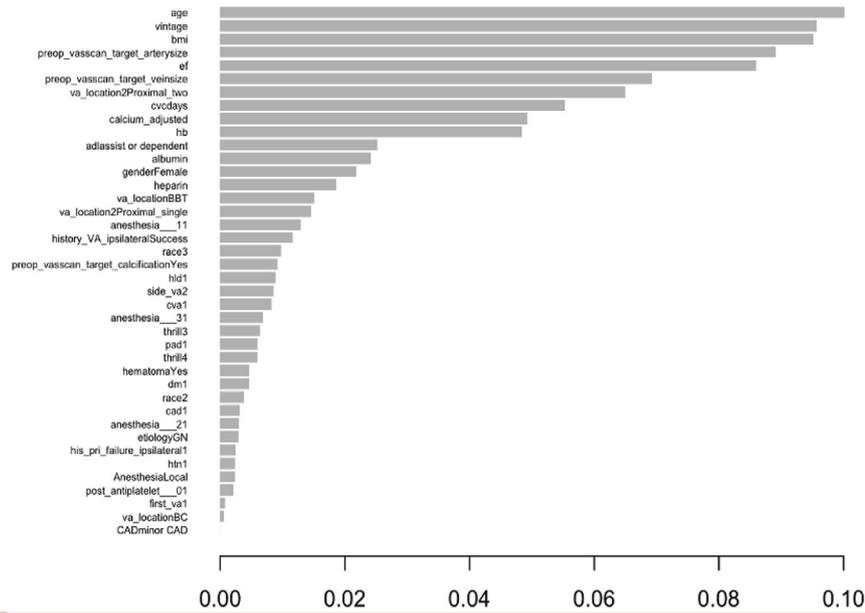
Variable	Variable name	Codes/units
VA location	va_location	1: Snuffbox; 2: Radiocephalic; 3: Proximal radiocephalic; 4: Brachial-cephalic; 5: Brachial-basilic transposition; 6: Others
Side of VA	side_va	1: Left upper extremity; 2: Right upper extremity; 3: Others
First surgically created VA on index upper extremity	first_va_index_arm	Yes/No
History of primary failure of ipsilateral VA	His_pri_failure_ipsilateral	1: Yes; 0: No
History of VA on ipsilateral arm	history_VA_ipsilateral	First/PF/Success
Preoperative serum albumin	Albumin	g/dL
Antiplatelet	post_antiplatelet__0	Yes/No
Blood thinner (antiplatelet and/or anticoagulant)	Bloodthiner	Yes/No
Type of anesthesia: local	anesthesia__1	1: Yes; 0: No
Type of anesthesia: monitored anesthesia care	anesthesia__2	1: Yes; 0: No
Type of anesthesia: regional anesthesia	anesthesia__3	1: Yes; 0: No
Type of anesthesia: general anesthesia	anesthesia__4	1: Yes; 0: No
Preoperative vascular scan anastomotic vein size	preop_vasscan_target_veinsize	mm
Preoperative vascular scan anastomotic artery size	preop_vasscan_target_arterysize	mm
Preoperative vascular scan anastomotic artery calcification	preop_vasscan_target_calcification	Yes/No

ADL, Activity of daily living; AVF, arteriovenous fistula; BMI, body mass index; CABG, coronary artery bypass graft; CAD, coronary artery disease; CVC, central venous catheter; ESKD, end-stage kidney disease; HD, hemodialysis; IJ, internal jugular; PAD, peripheral artery disease; PCI, percutaneous coronary intervention; VA, vascular access.

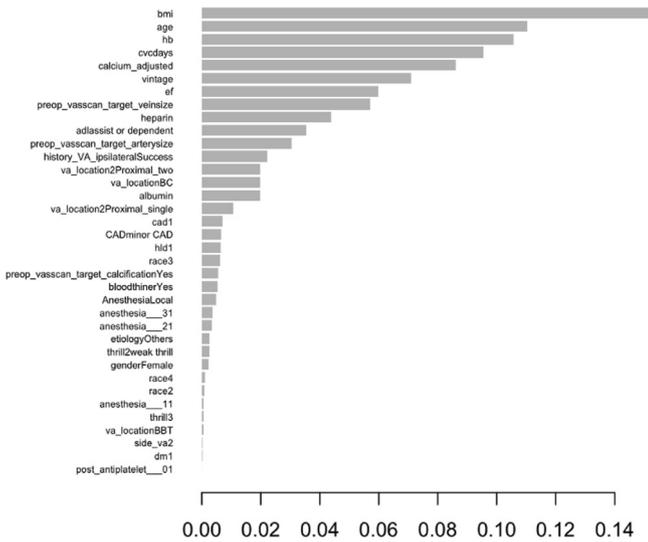
**Supplementary Table II (online only).** Logistic regression output for the two models

Outcomes		Logistic regressions output
Model 1	Commencement of needling by 3 months	$\log(p/(1-p)) = -3.78 + 0.32 \times (\text{Age} > 60) + 0.67 \times (50 \leq \text{Age} \leq 60) + 0.66 (\text{Male gender}) + 0.76 (\text{ADL independent}) + 0.55 \times (\text{no peripheral artery disease}) + 1.53 (\text{distal region}) + 2.09 \times (\text{proximal region single stage}) + 0.18 \times (\text{history of primary failure of VA on the ipsilateral upper extremity}) + 0.98 \times (\text{history of functional VA on ipsilateral upper limb}).$
Model 2	Functional maturation by 3 months	$\log(p/(1-p)) = -6.04 + 0.49 \times (\text{Age} < 50) + 0.56 \times (50 \leq \text{Age} \leq 60) + 0.75 (\text{male gender}) + 0.50 (\text{ADL independent}) + 0.57 (\text{normal BMI}) + 0.19 \times (\text{Overweight or obese}) + 1.41 \times (\text{distal region}) + 1.94 \times (\text{proximal region single-stage}) + 1.38 \times (\text{no preoperative anastomotic artery calcification}) + 0.31 (\text{preoperative anastomotic vein size} \geq 2.5 \text{ mm}) + 0.41 (\text{history of primary failure of VA on ipsilateral upper limb}) + 0.96 (\text{history of functional VA on ipsilateral upper limb}).$

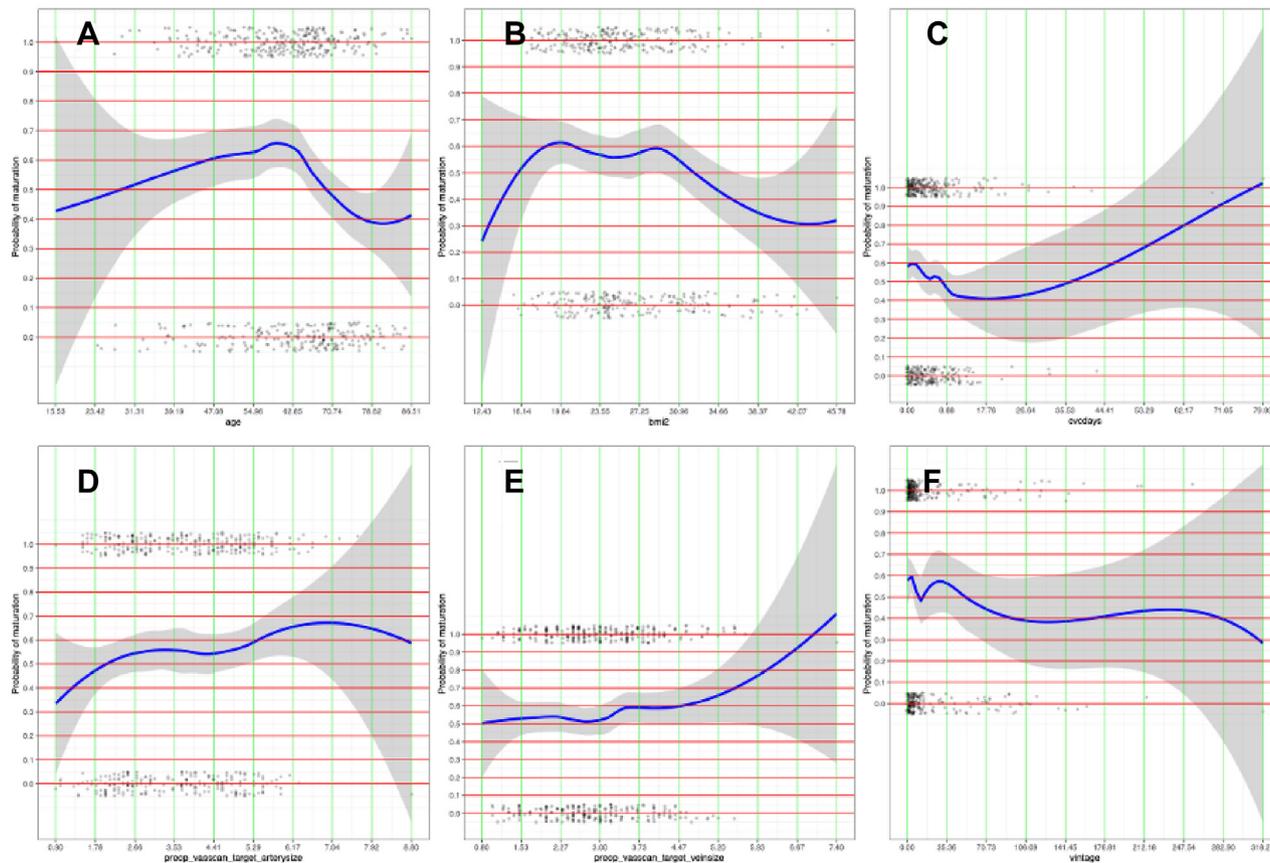
*ADL*, Activity of daily living; *BMI*, body mass index; *VA*, vascular access.



**Supplementary Fig 1 (online only).** Importance of variables predicting commencement of cannulation using Xg-boost. The variable names and codes (eg, 0: No; 1: left upper extremity) used in the study were shown in [Supplementary Table 1](#).



**Supplementary Fig 2 (online only).** Importance of variables predicting functional maturation using Xg-boost. The variable names and codes shown in the figure were listed in [Supplementary Table 1](#).



**Supplementary Fig 3 (online only).** Locally estimated scatterplot smoothing (LOESS) for continuous variables. **A**, Age; **B**, Body mass index (BMI); **C**, duration of central venous catheter (CVC) in months; **D**, anastomotic artery size in mm; **E**, anastomotic vein size in mm; **F**, dialysis vintage before AVF creation in months).