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Original Article

MSCTA imaging analysis of autologous arteriovenous fistula dysfunction in maintenance hemodialysis patients

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Abstract: Objective: To observe the multi-slice spiral CT angiography (MSCTA) imaging features of arteriovenous fistula dysfunction in patients undergoing maintenance hemodialysis and analyze the significance of the imaging examination. Methods: Altogether 90 patients with end-stage renal disease treated by maintenance hemodialysis in General Hospital of China Resources & Wisco from June 2020 to February 2023 were divided into a normal function group (n=68) and a dysfunction group (n=22) according to the function of autogenous arteriovenous fistula. The clinical data of the two groups were recorded. The MSCTA was performed in each patient, and the manifestations of arteriovenous fistula dysfunction were analyzed. Additionally, the vascular access stenosis, vascular access lumen stenosis, arteriovenous diameter, blood flow, and hemodynamic indices were tested, and the value of MSCTA in predicting arteriovenous fistula function was analyzed by Logistic regression. Results: The degree of vascular access stenosis and vascular access lumen stenosis in the normal group were less than those in the dysfunctional group ($P<0.05$). The arteriovenous diameter, blood flow, blood flow velocity at anastomotic vein end, dialysis adequacy (spKt/V), and von Willebrand factor (vWF) function in the normal group were larger than those in the dysfunction group, and the radial artery shear force was lower than in the dysfunction group, with statistical significance ($P<0.05$). Among the arteriovenous fistula dysfunction, there were 3 patients with anastomotic + outflow vein stenosis, 4 patients with outflow vein stenosis, 9 patients with inflow artery + anastomosis + outflow vein stenosis, and 6 patients with superior vena cava stenosis. Logistic regression analysis showed that slow blood flow velocity at the venous end of anastomosis and high shear force of radial artery were influencing factors of arteriovenous fistula dysfunction, and the area under ROC curve of blood flow velocity at the venous end of anastomosis plus shear force of radial artery was 0.93, with a sensitivity of 0.87 and a specificity of 0.85. Conclusion: MSCTA can be used to evaluate the dysfunction of autologous arteriovenous fistula in patients undergoing maintenance hemodialysis, and provide important reference information for the formulation of the next best clinical treatment plan.

Keywords: Maintenance hemodialysis, autologous arteriovenous fistula, poor function, multi-slice spiral CT angiography (MSCTA)

Introduction

Chronic kidney diseases can lead to the decline of renal function in affected patients. Hemodialysis is a process in which the blood is completely introduced into the dialyzer and filtered by special electrolytes [1]. Hemodialysis can filter heavy metals, improve patients' blood environment and reduce the metabolic load of liver and kidney functions [2]. Research has shown that vascular access with good hemodialysis function is very important to ensure dialysis treatment, and vascular access has attracted widespread attention in the clinic [3]. Arterio-Venous Fistula has the advantages of long service life and few complications, and it is the preferred vascular access for permanent hemodialysis at present, because it creates favorable conditions for hemodialysis treatment [4, 5]. Failure of hemodialysis access is the most common reason for hospitalization of patients with end-stage renal disease, and it is also the main reason for the long-term hospitalization in some hemodialysis centers. The development of stenosis is the main cause of vascular access dysfunction [6], so early diagnosis of autolo-

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gous arteriovenous fistula dysfunction and timely management are very important to prolong the survival of dialysis shunt.

Computed Tomography (CT) and Magnetic Resonance Imaging can detect small lesions in the body, clearly displaying the direction and pathological changes of blood vessels. However, they are both static images and cannot observe fluctuating blood vessels. Color Doppler ultrasound is a noninvasive method to evaluate the function of vascular access, but it is not accurate enough in detecting proximal vein stenosis, nor can it provide necessary angiograms for surgery or percutaneous treatment [7]. At present, digital subtraction angiography is considered as the first choice for evaluating suspicious vascular access, which usually requires hospitalization for the safety of patients [8]. Multi-slice spiral CT angiography (MSCTA) can reduce the scanning time and improve the spatial resolution. With the assistance of imaging software, MSCTA can reconstruct the three-dimensional structure of vascular pathways, thereby improving the sensitivity and specificity of this technology. In this study, 90 patients with end-stage renal disease undergoing maintenance hemodialysis were selected to observe the MSCTA imaging features of arteriovenous fistula dysfunction. The objective of this study was to analyze the significance of imaging examination, and clinically verify the role of contrast-enhanced MSCTA technology in detecting arteriovenous fistula dysfunction.

Data and methods

General information

In this retrospective study, 90 patients with end-stage renal disease undergoing maintenance hemodialysis in the General Hospital of China Resources & Wisco from June 2020 to February 2023 were selected, including 57 males and 33 females, with an average age of (55.98±4.45) years.

Inclusion criteria: patients who were diagnosed and treated in accordance with the *Clinical Practice Guide for Evaluation and Management of Chronic Kidney Disease* [9]; patients who were 20-65 years old; patients who received treatment for autologous arteriovenous fistula; patients with complete clinical information, clear consciousness, and normal language ability; patients who received routine maintenance hemodialysis for longer than 6 months, with 2-3 dialysis sessions per week, 3-4 hours each time; patients with an expected survival period of at least 6 months.

Exclusion criteria: those with malignant tumors; individuals with severe abnormalities in heart, liver, or lung function; individuals with other diseases that may cause disorders in mineral metabolism in the body, such as hypothyroidism; individuals with neurological or psychiatric disorders who were unable to communicate normally; individuals with a history of thromboembolism, coagulation and immune dysfunction, or previous mental illness.

This study was approved by the Medical Ethics Committee of General Hospital of China Resources & Wisco, and the subjects and their families were informed of the research and signed written informed consent.

Methods

According to the *Clinical Practice Guide for Evaluation and Management of Chronic Kidney Disease* [9], the 90 selected patients were divided into a normal function group (n=68) and a dysfunction group (n=22) according to the function of autogenous arteriovenous internal fistula. Patients with blood flow <200 m/min or venous pressure >200 mmHg during hemodialysis were assessed as having poor arteriovenous fistula function.

During MSCTA [10, 11], all patients were scanned with a 16-slice scanner. Firstly, non-enhanced MSCTA was performed, and then contrast-enhanced MSCTA was performed. The acquisition parameters of MSCTA were as follows: the thickness was 1.0 mm, the interval was 0.8 mm, and the pitch was 3. It was set to a high-quality mode, with a voltage of 120-135 kVp and a current of 200-300 mA. The scanning sequence extended from the arteriovenous fistula level to the right atrium. Thereafter, 90 mL of iohexol, a low-permeability iodinated contrast agent, was placed in the No. 18 or No. 20 catheter of the peripheral vein of the other upper limb and injected intravenously with a power injector at a rate of 3 ml/s. After a delay of 25-30 s, MSCTA started. The horizontal source images were reformatted into MIP, VR and MPR or CPR images, and the whole process was completed within 20-30 minutes. The angiographic results were analyzed by Vitrea 2 workstation, using MIP, VR and MPR images. The window width of MSCTA image was 650 HU and the window height was 160 HU. The patient received additional hemodialysis on the day after MSCTA to accelerate the clearance of contrast media. The angiographic results were analyzed and interpreted by two radiologists.

Observation indices

Clinical data analysis of the two groups of patients: The clinical data of the two groups were statistically analyzed, including age, sex, diabetes, anastomotic diameter, and the duration of arteriovenous fistula.

Degree of vascular access stenosis and vascular access lumen stenosis: Vascular access stenosis and vascular access lumen stenosis were measured and evaluated by two independent vascular surgeons by reading the MSCTA imaging features. Vascular access stenosis includes localized stenosis (single stenosis, two stenosis, three stenosis, and four stenosis) and segmental stenosis (stenosis length 1-2 cm, stenosis length 2-3 cm, stenosis length >3 cm). The stenosis grades were divided into grade 1 (0-25%), grade 2 (25-49%) and grade 3 (50-74%).

Detection of dialysis adequacy (spKt/V) and von Willebrand factor (vWF): The level of plasma vWF activity was detected by sandwich ELISA with anti-vWF double antibody established in the thrombus room of Suzhou University. Plasma spKt/V activity was measured according to spKt/V formula.

MSCTA manifestations and dynamic parameters analysis of arteriovenous fistula dysfunction: According to the position of vascular access stenosis, the arteriovenous fistula of the forearm section was divided into four segments: outflow artery, outflow vein, superior vena cava, and anastomosis. Dysfunctional fistula caused by stenosis/occlusion of upper arm or central vein was excluded in this study. Besides, the internal diameter of artery and vein, blood flow, blood flow velocity at the end of anastomotic vein, and radial artery shear force were measured [12].

Statistical methods

SPSS-20 software (SPSS Inc., Chicago, Illinois) was used for statistical analysis. Continuous measurements were expressed by mean and standard deviation (SD), and comparisons between groups were rendered by using Student t test or Mann-Witney U test as required. Qualitative variables are expressed as proportion (%). For statistical analysis, χ^2 test or Fisher exact test was used. At first, the influence of hemodynamics on the function of arteriovenous fistula was studied by variable analysis, then the variables with a significant level <0.05 were included in the multivariate Logistic regression model, and linear and logistic regression analysis was carried out to estimate the adjustment results for confounding factors. The adjusted odds (OR) and 95% CI were calculated for the outcome. A significance level of P<0.05 was considered indicative of statistical significance.

Results

Comparison of clinical data between the two groups

There were no statistical differences between the two groups in terms of sex and whether they had diabetes (P>0.05), but there were statistical differences in terms of age, anastomotic diameter, and duration of arteriovenous fistula (P<0.05, **Table 1**).

Analysis of vascular access stenosis in two groups

The percentage of patients with single stenosis, double stenosis, three stenosis, and four stenosis were 77.94%, 5.88%, 1.47%, and 0, respectively, in the normal group, while those were 9.09%, 22.73%, 36.36%, and 9, respectively, in the dysfunctional group. In the normal group, the percentage of patients with stenosis length of 1-2 cm, 2-3 cm and >3 cm were 13.25%, 1.46%, and 0, respectively, while those in the dysfunctional group were 4.55%, 13.65%, and 4.55%, respectively. There was a significant difference in vascular stenosis between the two groups (P<0.05, **Table 2**).

Analysis of the stenosis degree of vascular access lumen in two groups

The proportion of patients with vascular access lumen stenosis of grade 1, grade 2, grade 3,

Table 1. Comparison of clinical data between the two groups

Group	Normal function group (n=68)	Dysfunctional group (n=22)	T/χ^2 value	*P* value
Sex			0.452	0.119
Male	42 (61.76)	15 (68.18)		
Female	26 (38.24)	7 (31.82)		
Age (years)			12.093	0.001
<55	53 (77.94)	4 (18.18)		
≥55	15 (22.06)	18 (81.82)		
Diabetes			0.673	0.298
Have	39 (57.35)	13 (59.09)		
Without	29 (42.65)	9 (40.91)		
Anastomosis diameter (mm)			10.972	0.001
<4	47 (69.12)	5 (22.73)		
≥4	21 (30.88)	17 (77.27)		
Duration of arteriovenous fistula (months)			15.440	0.001
<33	40 (58.82)	6 (27.27)		
≥33	28 (41.18)	16 (72.73)		
Glomerular filtration rate				
<110 ml/min	2 (2.94)	20 (90.91)		
≥110 ml/min	66 (97.06)	2 (9.09)	11.269	0.001
Anemia				
Have	8 (11.76)	14 (63.64)		
Without	60 (88.24)	8 (36.36)	9.865	0.001
Osteoporosis				
Have	10 (14.71)	16 (72.73)		
Without	58 (85.29)	6 (27.27)	12.397	0.001
Treatment History				
Have	1 (1.47)	21 (95.45)		
Without	67 (98.53)	1 (4.55)	16.328	0.001

grade 4 and grade 5 in the normal group were 92.65%, 5.88%, 1.47%, 0, and 0, respectively, while those in the dysfunctional group were 9.09%, 27.27%, 36.36%, 22.73%, and 4.55, respectively. There was a significant difference in the degree of lumen stenosis between the two groups (P<0.05, **Table 3**).

MSCTA manifestations of arteriovenous fistula dysfunction

Among the patients with arteriovenous fistula dysfunction, there were 3 patients with anastomotic + outflow vein stenosis, 4 patients with outflow vein stenosis, 9 patients with inflow artery + anastomosis + outflow vein stenosis, and 6 patients with superior vena cava stenosis (**Table 4**).

Comparison of arteriovenous diameter and blood flow between the two groups

The arteriovenous diameter and blood flow in the normal function group were significantly higher than those in the dysfunction group (P<0.05, **Table 5**; **Figures 1** and **2**).

Comparison of hemodynamic parameters between the two groups

The blood flow velocity at the venous end of anastomotic stoma in the normal function group was significantly higher than that in the dysfunction group, and the shear force of radial artery in the normal function group was significantly lower than that in the dysfunction group, with statistical significance (P<0.05, **Table 6**).

Table 2. Analysis of vascular stenosis in two groups [n (%)]

Group	Normal function group (n=68)	Dysfunctional group (n=22)	t/χ^2 value	*P* value
Localized stenosis			19.803	0.001
Single stenosis	53 (77.94)	2 (9.09)		
Double stenosis	4 (5.88)	5 (22.73)		
Three strictures	1 (1.47)	8 (36.36)		
Narrow everywhere	0 (0.00)	2 (9.09)		
Segmental stenosis			15.559	0.001
Stenosis length is 1-2 cm	9 (13.25)	1 (4.55)		
Stenosis length is 2-3 cm	1 (1.46)	3 (13.64)		
Stenosis length >3 cm	0 (0.00)	1 (4.55)		

Table 3. Analysis of lumen stenosis degree of vascular access in two groups [n (%)]

Group	Normal function group (n=68)	Dysfunctional group (n=22)	t/χ^2 value	*P* value
Level 1 (0-25%)	63 (92.65)	2 (9.09)	25.787	0.001
Grade 2 (25-49%)	4 (5.88)	6 (27.27)		
Grade 3 (50-74%)	1 (1.47)	8 (36.36)		
Grade 4 (75-99%)	0 (0.00)	5 (22.73)		
Level 5 (complete occlusion)	0 (0.00)	1 (4.55)		

Table 4. MSCTA manifestations of arteriovenous fistula dysfunction (n=22)

Stenosis	Outflow artery	Outflow vein	Superior vena cava	Anastomosis	Total
Anastomosis + outflow vein	-	2	-	One	Three
Simple outflow vein	-	Three	-	One	Four
Inflow artery + anastomosis + outflow vein	Three	2	-	Four	Nine
Superior vena cava	-	-	Five	One	Six
Anastomosis	-	-	-	-	-
Total	Three	Seven	Five	Seven	22

Note: MSCTA: multi-slice spiral CT angiography.

Table 5. Comparison of arteriovenous diameter and blood flow between the two groups ($\bar{x} \pm sd$)

Group	Internal diameter of artery and vein (mm)	Blood flow (cm/s)
Normal function group (n=68)	4.48±1.01	61.33±5.07
Dysfunctional group (n=22)	2.42±0.90	33.87±4.79
t value	15.778	11.930
P value	0.001	0.001

Hemodynamic effects on the function of arteriovenous fistula

Taking the blood flow velocity at the anastomotic vein end and the shear force of radial artery as independent variables, and the function of arteriovenous fistula as an dependent variable, the Logistic regression analysis showed that slow blood flow velocity at the anastomotic vein end (OR=1.187, P=0.001) and high shear force of the torsion artery (OR=1.039, P=0.001) were the influencing elements for the dysfunction of arteriovenous fistula (**Table 7**).

The predictive value of hemodynamics for arteriovenous fistula function

Using SPSS software combined with ROC theory model, Logistic comprehensive regression was conducted to predict the function of arteriovenous fistula by hemodynamics. Based on the obtained regression coefficient B, the normalized weighted calculation was carried out, then the sample data were processed, and the ROC analysis of combined application was carried out accordingly. The area under ROC curve for predicting the function of arteriovenous fistula was 0.93, with a

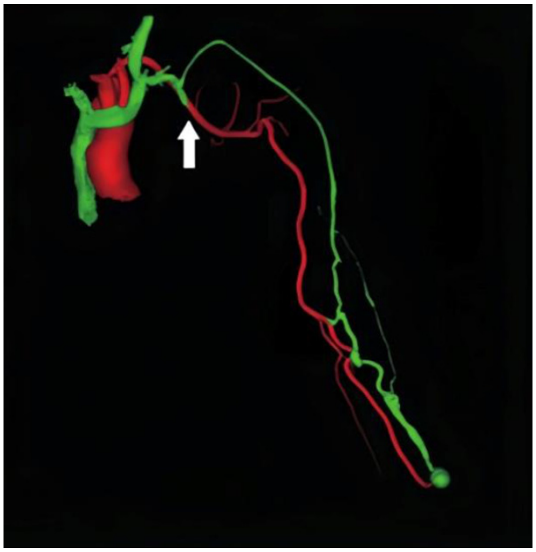

Figure 1. MSCTA image of a patient with dysfunction (end-to-end anastomosis of radial artery and cephalic vein). The arrow shows the vascular anastomosis. MSCTA: multi-slice spiral CT angiography.

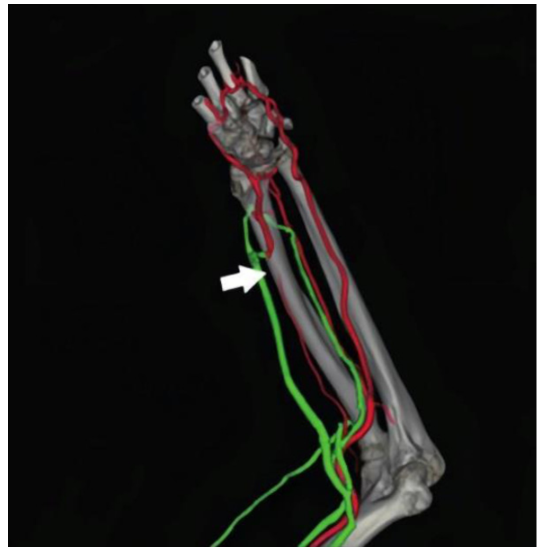

Figure 2. Arterial stenosis near anastomosis in a patient with dysfunction. The arrow shows the vascular anastomosis.

sensitivity of 0.87 and a specificity of 0.85 (**Table 8**).

Comparison of spKt/V and vWF between the two groups

SpKt/V and vWF in the normal function group were significantly higher than those in the dysfunction group (P<0.05, **Table 9**).

Discussion

Maintaining the long-term function of vascular access is a challenge in the management of patients undergoing hemodialysis. Early detection of vascular access dysfunction as well as timely and effective intervention are the key points to deal with renal system diseases [13]. Clinical studies have found that the parameters of arteriovenous fistula dysfunction include the increase of venous pressure during hemodialysis and the difficulty of obtaining enough blood flow from the channel. Image analysis data often plays a vital role in the diagnosis of arteriovenous fistula dysfunction, which can supply useful communication for further treatment [14].

MSCTA is a non-invasive technology, which can supply high spatial resolution. With the help of imaging software, MSCTA can reconstruct the three-dimensional structure of vascular access, further improving the sensitivity of this technology [15]. In this study, the value of MSCTA on accessing arteriovenous fistula dysfunction in patients undergoing maintenance hemodialysis was analyzed. It was found that there were 3 patients with anastomotic + outflow vein stenosis, 4 patients with outflow vein stenosis, 9 patients with inflow artery + anastomosis + outflow vein stenosis, and 6 patients with superior vena cava stenosis. There were 36.36% patients with three stenosis, and 13.64% patients with stenosis length of 2-3 cm. In previous reports, Bian et al. used single-slice CT angiography and MSCTA to estimate the vascular access of 9 hemodialysis patients, and it was found that both single-slice CT angiography and MSCTA yielded confident indications of arteriovenous fistula dysfunction [16]. However, compared with MSCTA, the image quality of single-slice CT angiography was much worse and the examination time was longer. This is because MSCTA can display blood vessels through three-dimensional images, and the whole dialysis blood vessel pathway can be displayed by choosing appropriate display threshold and transparency, so that it is easy to find the position of internal fistula and the dysfunctional part, thus giving effective evaluation. Similarly, Romeih et al. used MSCTA to evaluate 22 hemodialysis patients with suspected arteriovenous fistula dysfunction [17]. All patients obtained high-resolution images, which clearly

Table 6. Comparison of hemodynamic parameters between the two groups ($\bar{x}$ ± sd)

Group	Blood flow velocity at venous end of anastomosis (cm/s)	Shear force of radial artery (dyne/cm^2)
Normal function group (n=68)	121.53±10.33	31.75±4.32
Dysfunctional group (n=22)	74.64±5.82	45.72±6.98
t value	9.098	14.535
P value	0.001	0.001

Table 7. Effect of hemodynamics on the function of arteriovenous fistula

Influencing factor	S.E.	Wald/χ^2	OR	95% CI	*P* value
Blood flow velocity at venous end of anastomosis	0.035	23.682	1.187	1.036-5.167	0.001
Radial artery shear force	0.083	14.174	1.039	1.694-3.824	0.001

Note: S.E.: standard error; OR: odds ratio; CI: confidence interval.

Table 8. The value of hemodynamics in predicting the function of arteriovenous fistula

Variable	AUC	95% CI	*P* value	Sensitivity	Specificity
Blood flow velocity at venous end of anastomosis	0.81	0.85-0.97	0.52	0.73	0.95
Radial artery shear force	0.87	0.67-0.87	0.36	0.70	0.75
Blood flow velocity at venous end of anastomosis + radial artery shear force	0.93	0.87-0.98	0.35	0.87	0.85

Note: AUC: area under curve; CI: confidence interval.

Table 9. Comparison of spKt/V and vWF between the two groups ($\bar{x}$ ± sd)

Group	spKt/V	vWF (%)
Normal function group (n=68)	1.59±0.05	249.62±33.98
Dysfunctional group (n=22)	1.07±0.02	201.48±25.48
T value	8.483	10.275
P value	0.001	0.001

Note: spKt/V: dialysis adequacy; vWF: von Willebrand factor.

showed the lesion site and degree of arteriovenous fistula. According to the vascular access map obtained by MSCTA, the 22 subjects were further treated, and the findings of MSCTA were later affirmed by surgery or digital angiography.

In this study, we found that the degree of stenosis of vascular access and lumen of vascular access in patients with a normal arteriovenous fistula function were lower than those in patients with a poor function. In addition, patients with a normal function exhibited longer arteriovenous diameter, more blood flow, higher blood flow velocity of anastomotic vein, and lower shear force of radial artery than patients with a poor function. Logistic regression analysis showed that slow blood flow velocity at the venous end of anastomosis and high shear force of radial artery were the influencing factors of arteriovenous fistula dysfunction, and the area under ROC curve of blood flow velocity at the venous end of anastomosis plus shear force of radial artery for predicting arteriovenous fistula dysfunction was 0.93, with a sensitivity of 0.87 and a specificity of 0.85. Recent research has shown that [18], MSCTA is the first choice for non-invasive vascular access imaging in some hemodialysis centers. MSCTA can realize the visualization of channels without using ionizing radiation or intravenous contrast agent, and it is also better than digital angiography in evaluating hemodialysis access. This is because the blood flow velocity at the radial artery end of the anastomosis is gradually increasing, which leads to the gradual increase of the shear force of the radial artery, while the blood flow velocity at the venous end of the anastomosis is gradually decreasing, which leads to the gradual decrease of the shear force. This in turn leads to a series of unstable shear forces, the functional disorder of vascular endothelium, the destruction of vascular endothelial cell function, and finally the dysfunction of arteriovenous fistula [19]. In addition, MSCTA can effectively observe the combination of the graft and the radial blood vessels of the superior vena cava. Although most of the stenosis occurs at or near the venous anastomosis, more than one third of the stenosis is located in the venous outflow tract of the graft. By using intravenous contrast agent, MSCTA can shorten the examination time and be promising in judging vascular stenosis. Therefore, patients with certain types of aneurysm clips, incompatible stimulators, anastomotic clips, and severe claustrophobia are also candidates suitable for MSCTA examination [20]. Finally, in the current medical environment in China, the examination cost of MSCTA is low. Of course, at present, MSCTA is a limited diagnostic technique, and patients who receive MSCTA must be exposed to radiation, which may cause allergic reactions. We are confident that the wide application of MSCTA in arterial disease diagnosis will gradually address this issue.

SpKt/V is an important clinical index to evaluate dialysis adequacy. At present, its diagnostic value has been recognized clinically. It is calculated according to the principle of single-chamber urea kinetic model. However, some studies suggest that when the single-chamber model has high blood flow and short dialysis time, the uneven distribution of urea is easy to cause Kt/V deviation. Kt/V detection requires multiple blood draws and is easily affected by dialyzers, dialyzers and other factors. vWF is one of the main glycoproteins in hemostasis and thrombosis in human body. Plasma vWF is mainly synthesized by vascular endothelial cells and stored in the Weibel-pallade small body of endothelial cells. vWF is used as a specific biochemical marker to determine vascular endothelial function. Plasma vWF level can reflect the damage degree and hypercoagulability of vascular endothelial cells and be used as one of the evaluation indexes for treatment and prognosis. This study found that the spKt/V and vWF in patients with a normal arteriovenous fistula function were significantly higher than those in patients with a poor function. Therefore, spKt/V and vWF can be applied as laboratory indexes to identify vulnerable plaque and predict thrombosis.

The limitations of this study are that the relatively small sample size and its single-center design, leading to limited regional representation. Subsequently, we will organize multicenter larger sample studies to enhance the credibility of research results.

To sum up, MSCTA can be a detection method to evaluate the dysfunction of autologous arteriovenous fistula in patients undergoing maintenance hemodialysis, and provide important reference information for the formulation of next clinical treatment plan, thereby is worthy of clinical promotion.

Disclosure of conflict of interest

None.

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