Comparative efficacy and safety of local and peripheral venous thrombolytic therapy with urokinase for thrombosed hemodialysis arteriovenous fistulas

ZIMING WAN[1*], RUI XIANG[2*], HUI WANG[1], QING ZHONG[1] and BO TU[3]

Departments of [1]Nephrology, [2]Cardiology and [3]Ultrasonography,
The First Affiliated Hospital of Chongqing Medical University, Chongqing 400042, P.R. China

Received September 15, 2018; Accepted March 6, 2019

DOI: 10.3892/etm.2019.7415

Abstract. Arteriovenous fistula (AVF) thrombosis is a common complication in patients undergoing hemodialysis, and early intervention is required. Urokinase has been used as a thrombolytic agent for declotting the thrombosed access. However, the optimal route for infusing urokinase remains to be determined. In the present retrospective observational study, 49 patients who underwent local venous infusion and 57 patients with peripheral venous infusion of urokinase were included. A urokinase dosage of 300,000 U was administered until successful thrombolysis, which was a maximum of three times. Age, sex, period of dialysis, time of AVF placement, systolic and diastolic blood pressure and thrombus age were similar between the two groups. The efficacy of urokinase infusion via the two routes in resolving thrombosed AVFs, defined as successful fibrinolysis, and the safety, defined as the number of bleeding events, was compared. The cumulative thrombolysis success rate following three sessions of thrombolytic therapy in the local venous thrombolysis group was higher compared with that in the peripheral venous thrombolysis group (85.7 vs. 68.4%; P=0.04). The local thrombolysis group exhibited less ecchymosis (4.1 vs. 14.0%; P=0.07), epistaxis (2.0 vs. 10.5%; P=0.08) and gingival bleeding (4.1 vs. 19.3%; P=0.02) events compared with the peripheral thrombolysis group. Further analyses demonstrated that systolic [odds ratio (OR)=1.10; 95% confidence interval (CI), 1.03-1.17; P<0.01] and diastolic (OR=1.08; 95% CI, 1.02-1.14; P<0.05) blood pressure were protective factors, whereas thrombus age (OR=0.91; 95% CI, 0.84-0.99; P<0.05) was a risk factor for thrombolysis success among patients who underwent local thrombolytic therapy. Overall, the results suggest that local venous infusion of urokinase is superior to peripheral venous infusion for the treatment of patients with thrombosed fistulas.

Correspondence to: Dr Bo Tu, Department of Ultrasonography, The First Affiliated Hospital of Chongqing Medical University, 1 Youyi Road, Chongqing 400042, P.R. China
E-mail: bo.tu@dr.com

*Contributed equally

Key words: arteriovenous fistula, thrombosis, stenosis, thrombolytic therapy, urokinase

Introduction

Thrombosis is a common complication of autologous arteriovenous fistulas (AVF) for hemodialysis access in patients with end-stage renal disease (1). AVF thrombosis accounts for 65-85% of permanent access loss (2). Following the creation of AVFs, early-onset thrombosis is due to inadequate blood inflow and late-onset thrombosis is associated with stenotic lesions (1,3,4). AVF thrombosis is also a major cause of permanent access loss (3), resulting in missed hemodialysis, hospitalization and increased medical costs (1). Taking into consideration that vascular injury, platelet abnormalities and hypercoagulability may contribute to fistula thrombosis, fish oil, anti-platelet agents and oral anti-coagulants have been tested in clinical trials for preventing thrombosed access. However, to the best of our knowledge, there is currently no pharmacological therapy with a proven ability to prevent AVF thrombosis (5).

Only a limited number of methods have been developed to treat access thrombosis, including pharmacological thrombolytic therapy, surgical thrombectomy and percutaneous declotting procedures (3). Urokinase has been successfully used as a thrombolytic agent for resolving thrombosed vascular access (6,7). Previously, urokinase was administered through a 22-gauge angiographic catheter introduced into the fistula prior to percutaneous interventions, also known as the 'lyse and wait' technique (2,8). Pulse-spray-aided pharmacomechanical thrombolysis employs the administration of tissue plasminogen activator and mechanical declotting techniques (9). According to the Clinical Practice Guidelines for Vascular Access published by the Vascular Access 2006 Work Group, thrombosed fistulas may be declotted purely by using a mechanical method or a thrombolytic agent (10). Intravenous (IV) infusion of urokinase is a feasible strategy that does not require introduction of a catheter. Urokinase has been used in thrombolytic treatment for venous thrombosis through the systemic and locoregional routes (11). In a thrombosed AVF,

urokinase infused via peripheral veins reaches the access thrombus from the radial artery end through the systemic blood flow, whereas urokinase infused into the fistulous vein may come in direct contact with the access thrombus. However, the optimal route for IV infusion of urokinase for the treatment of access thrombosis remains elusive.

In the present study, it was hypothesized that local venous infusion of urokinase is superior to peripheral administration for the treatment of patients with AVF thrombosis. Retrospective data analysis was performed, and comparisons of thrombolytic success rates and adverse events were performed between patients receiving local and peripheral venous infusion of urokinase for the treatment of access thrombosis. The factors affecting the success rate of local venous thrombolytic therapy were also examined.

Materials and methods

Study population. A total of 106 patients (56 males; median age, 47 years; age range, 27-66 years) who received hemodialysis at a single high-care hemodialysis unit at the First Affiliated Hospital of Chongqing Medical University (Chongqing, China) between January 2011 and December 2014 were included in the present study. All patients presented with acute thrombosis in their radio-cephalic AVFs. The thrombus age was determined as the time period from the moment the patients experienced disappearance of thrill, as reported by the patient, to the initiation of thrombolytic therapy. The diagnosis of a thrombosed fistula was based on the absence of thrill on physical examination and evidence of thrombosis on vascular ultrasound scanning. The exclusion criteria were as follows: i) Active bleeding or bleeding tendency; ii) active liver disease; iii) severe hypertension (systolic blood pressure >160 mmHg and/or diastolic blood pressure >90 mmHg). Informed consent to participate in the current study was obtained from all patients. The Institutional Review Board of the First Affiliated Hospital of Chongqing Medical University (Chongqing, China) reviewed and approved the study protocol.

Procedures and observations. Patients received urokinase infusion through either the fistulous vein (local venous thrombolysis) or the peripheral vein (peripheral venous thrombolysis). As illustrated in Fig. 1, for local thrombolysis, an IV needle was inserted into the fistulous vein with the needle tip directed towards the thrombus. For peripheral venous thrombolysis, the IV needle was inserted into the dorsal venous network of the hand. For each thrombolytic therapy, 300,000 U urokinase in 20 ml saline was infused within 1 h. The effect of the thrombolytic therapy was observed through physical examination every 20 min by detecting palpable thrill and bruit with auscultation. The urokinase thrombolytic therapy was performed three times in total with an interval period of 30 min until the thrombus was dissolved. The total amount of urokinase used in the thrombolytic therapy was recorded. Adverse effects, including ecchymosis, epistaxis, gingival bleeding, bleeding at punctures sites and systemic bleeding complications (i.e., gastrointestinal bleeding) were recorded as well. The criteria for considering a thrombolysis successful included the following: Recurrence of thrill and bruit on physical examination; dissolution of thrombi and restoration of blood flow in the AVF, verified by vascular ultrasound; and >1 completed hemodialysis session with a blood flow of >180 ml/min. This value was adapted from a previous study (12). In addition, a blood flow of <180 ml/min was considered to indicate access failure (13). Subsequent to thrombolysis therapy, the patients were administered the following for the next 7 days: Low-molecular-weight heparin (1 mg/kg, subcutaneously) twice daily and aspirin (100 mg/day, orally) daily.

Statistical analysis. Values are expressed as the mean ± standard deviation for continuous variables and as n (%) for categorical variables. Statistical analysis was performed using SSPS version 21.0 software (IBM Corp., Armonk, NY, USA). For comparison of continuous variables between two groups, the Student's t-test was performed. Categorical variables were analyzed using the χ^2 test. Factors that potentially affect the success of thrombolysis were analyzed by using binary logistic regression, and the odds ratio (OR) and confidence interval (CI) were calculated. $P<0.05$ was considered to indicate statistical significance.

Results

Patient characteristics. In total, 106 patients receiving hemodialysis were included. The patient characteristics in the two groups (local or peripheral venous thrombolysis) are presented in Table I. Age, sex, period of dialysis, time of AVF placement, systolic and diastolic blood pressure, and thrombus age were similar between patients who underwent local and peripheral venous thrombolytic therapy (Table I). All thrombi were located at juxta-anastomotic sites, as illustrated in Fig. 1. The total amount of urokinase used in the local and peripheral thrombolysis group was 31.4±16.6 and 34.2±14.8x10^4 U, respectively (Table I). Biochemical test results in the two groups prior to and after thrombolytic therapy are presented in Supplementary Table SI. Serum alanine aminotransferase levels were significantly increased (but the levels remained within the normal range) following thrombolytic therapy in the peripheral venous group ($P<0.05$), but the levels did not increase in the local venous group (Table SI). Serum creatinine levels were slightly and significantly increased (within the normal range) following thrombolysis in the peripheral and local venous groups (both $P<0.01$). Prothrombin time was significantly increased while fibrinogen levels were significantly decreased following thrombolytic therapy in the peripheral and local venous groups (all $P<0.01$).

Success rates of thrombolytic therapy. As presented in Table II, the cumulative success rates of thrombolytic therapy with urokinase were 44.9 vs. 29.8% ($P=0.11$) following one, 65.3 vs. 49.1% ($P=0.09$) following two and 85.7 vs. 68.4% ($P=0.04$) following three sessions. In the local thrombolysis group, the thrombolysis success rate was >85% following three sessions of thrombolytic therapy, which was significantly higher compared with that in the peripheral thrombolysis group ($P<0.05$; Table II).

Adverse effects of thrombolytic therapy. Mild superficial hemorrhages, including ecchymosis, epistaxis and gingival bleeding, occurring in patients of the local thrombolysis and peripheral venous thrombolysis groups were recorded

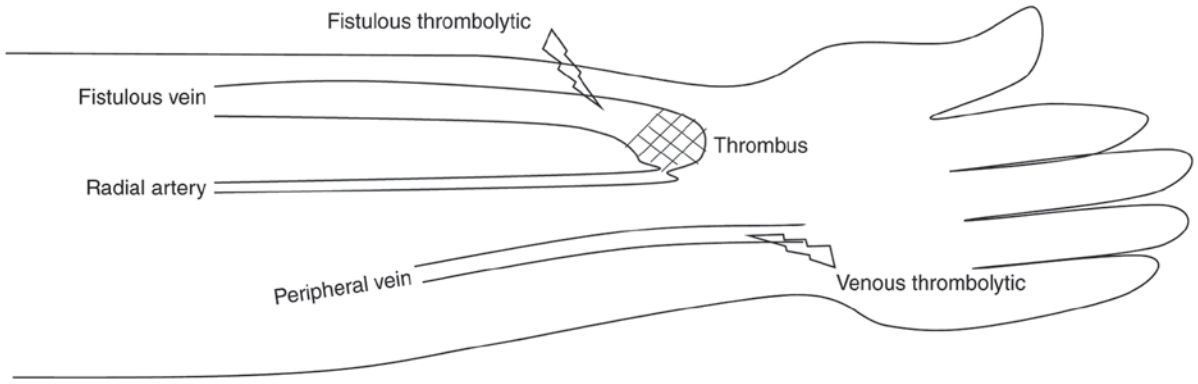

Figure 1. Schematic for local and peripheral venous infusion of urokinase for thrombolytic therapy of thrombosed arteriovenous fistulas.

(Table III). However, no massive hemorrhagic events were observed. Patients in the local thrombolysis group tended to have less ecchymosis (4.1 vs. 14.0%; P=0.07) and epistaxis (2.0 vs. 10.5%; P=0.08) events compared with those in the peripheral venous thrombolysis group. In particular, the rate of gingival bleeding was significantly lower in the local thrombolysis group compared with that in the peripheral venous thrombolysis group (4.1 vs. 19.3%; P=0.02; Table III). No infectious or thrombo-embolic complications were observed following the procedure.

Factors affecting the success of thrombolysis. A comparison of the demographic and clinical characteristics between patients who had a successful and an unsuccessful thrombolysis in the local thrombolysis group was performed. The results indicated that age, sex, period of dialysis, time of AVF placement and the total amount of infused urokinase were similar between patients with successful and unsuccessful thrombolysis (Table IV). In the local venous thrombolysis group, systolic and diastolic blood pressure levels were higher (P<0.01), but the age of the thrombi (P<0.05) was lower in patients with successful thrombolysis compared with that in patients with unsuccessful thrombolysis (Table IV). Univariate logistic regression analysis demonstrated that systolic (OR=1.10; 95% CI, 1.03-1.17; P<0.01) and diastolic (OR=1.08; 95% CI, 1.02-1.14; P<0.05) blood pressure were protective factors, whereas thrombus age (OR=0.91; 95% CI, 0.84-0.99; P<0.05) was a risk factor for thrombolysis success among patients who underwent local thrombolytic therapy (Table V). However, a multivariate logistic regression analysis only identified systolic blood pressure as a protective factor for thrombolysis success in local thrombolytic therapy (OR=1.11; 95% CI, 1.02-1.21; P<0.05; Table V). In the peripheral venous thrombolysis group, only the thrombus age was higher in patients with failed thrombolysis compared with patients with successful thrombolysis (P<0.01; Table IV). Univariate logistic regression analysis demonstrated that the thrombus age was a risk factor for thrombolysis success in patients who underwent peripheral thrombolytic therapy (OR=0.94; 95% CI, 0.90-0.99; P<0.05).

Discussion

The major result of the present study was that thrombolytic therapy with urokinase infusion into the local fistulous vein was superior to peripheral venous infusion in terms of thrombolytic and adverse effects. In addition, a relatively higher blood pressure was associated with higher thrombolysis success, while thrombus age was associated with thrombolysis failure with local infusion of urokinase.

Thrombosis is a common complication of AVF and arteriovenous grafts. Compared with thrombosed grafts, AVF thrombosis has a higher risk and requires treatment within 48 h; otherwise, thrombi may adhere to the vessel wall, making it difficult to remove then (3,14). In the present study, only thrombosed AVFs were included. Surgical thrombectomy and endovascular interventions have been developed to salvage thrombosed AVF accesses (3). It was reported that the initial success rate of surgical thrombectomy was 84% for thrombosed AVFs (15). Surgical thrombectomy was reported to produce an immediate success rate of 93.8% in thrombosed AVF and a success rate of 78% in thrombosed arteriovenous grafts (16,17). Endovascular interventions involve pharmacological thrombolysis and mechanical thromboaspiration. Previous studies have reported that endovascular intervention has a success rate of >78% in thrombosed fistulas (15,18,19). An advantage of endovascular intervention is that underlying stenosis may be treated at the same time as the declotting treatment. In the present study, pharmacological thrombolysis with urokinase monotherapy achieved a success rate of >85% in acutely thrombosed fistulas, which was comparable to the success rates of surgical and percutaneous approaches. Of note, the cost of urokinase monotherapy is lower compared with that of surgical and percutaneous procedures. Therefore, urokinase infusion-based thrombolytic therapy should be considered as an alternative option for the salvage of acutely thrombosed fistulas. A head-to-head study comparing the thrombolytic effects of urokinase monotherapy and mechanical declotting procedures should be performed in the future to provide further evidence.

In terms of adverse events, only superficial hemorrhages were observed in the present study during and following urokinase infusion, which were minor and acceptable. It remains elusive whether the increased epistaxis was associated with higher blood pressure. It was reported that 4% (4/107) of patients who underwent surgical thrombectomy suffered a post-operative infection and required a repeated procedure and antibiotic therapy (20). Endovascular interventions are associated with embolization (21-23), in particular arterial emboli, which occur in >6% of patients

Table I. Demographic and clinical characteristics of the patients.

Parameter	Local venous thrombolysis (n=49)	Peripheral venous thrombolysis (n=57)	P-value
Age (years)	46.4±7.3	47.0±9.1	0.74
Males	26 (53.1)	30 (52.6)	0.96
Dialysis period (months)	54.0±15.2	58.1±17.9	0.22
Fistula age (months)	45.1±23.5	46.5±16.5	0.71
SBP (mmHg)	142.7±18.8	143.0±20.3	0.94
DBP (mmHg)	84.1±17.3	81.7±16.1	0.46
Thrombus age (h)	25.6±12.6	27.3±13.6	0.52
Urokinase dose (x10^4 U)	31.4±16.6	34.2±14.8	0.36

Values are expressed as the mean ± standard deviation or n (%). SBP, systolic blood pressure; DBP, diastolic blood pressure.

Table II. Rates of successful thrombolysis.

Item	Local venous thrombolysis (n=49)	Peripheral venous thrombolysis (n=57)	P-value
First thrombolytic therapy	22 (44.9)	17 (29.8)	0.11
Second thrombolytic therapy	10 (37.0)	11 (27.5)	0.43
Third thrombolytic therapy	10 (58.8)	11 (37.9)	0.23
Cumulative success after second thrombolytic therapy	32 (65.3)	28 (49.1)	0.09
Cumulative success after third thrombolytic therapy	42 (85.7)	39 (68.4)	0.04

Values are expressed as n (%).

Table III. Adverse effects in patients who underwent thrombolytic therapy.

Adverse event	Local venous thrombolysis (n=49)	Peripheral venous thrombolysis (n=57)	P-value
Ecchymosis	2 (4.1)	8 (14.0)	0.07
Epistaxis	1 (2.0)	6 (10.5)	0.08
Gingival bleeding	2 (4.1)	11 (19.3)	0.02
Total events	5 (10.2)	25 (43.9)	<0.01

Values are expressed as n (%).

receiving percutaneous declotting (24,25). To avoid severe adverse effects, a methodical approach to patient selection is important and patients with contraindications for each procedure should be excluded (2,24). Taking the efficacy and safety into account, the optimal available declotting procedure should be selected for each given patient with a thrombosed fistula.

The present study demonstrated that local infusion of urokinase was superior to venous administration. The advantage of the local infusion is that urokinase is able to concentrate in the fistula vein and is in direct contact with the thrombus, which may decrease systemic adverse effects and improve the success rate of thrombolysis. A previous study used a tourniquet to restrict urokinase within the fistula (26). The disadvantage of the local infusion is that urokinase is infused in a retrograde direction, in addition to being downstream from the thrombus. Once the fistula blood flow is partially restored, the urokinase infused into the local vein is flushed away along the blood stream without coming into immediate contact with the thrombus, therefore leading to a decreased thrombolytic effect and an increased risk of hemorrhage. Urokinase infused into the peripheral vein reaches the thrombus via the systemic circulation, while the advantage of this is that urokinase will be transported to the thrombus by the arterial blood flow in an antegrade direction. In general, intra-fistula infusion of thrombolytic agents provides a pharmacological thrombolytic therapy that avoids the use of a catheter. An early

Table IV. Characteristics of patients with successful or failed thrombolytic therapy.

	Local venous thrombolysis		Peripheral venous thrombolysis	
Parameter	Successful (n=42)	Failed (n=7)	Successful (n=39)	Failed (n=18)
Age (years)	45.5±8.7	46.7±9.2	47.6±9.5	45.7±8.4
Males	22 (52.4)	4 (57.1)	20 (51.3)	10 (55.6)
Dialysis age (months)	55.2±17.4	57.7±18.2	60.5±18.6	52.7±15.4
Fistula age, months	44.6±25.2	45.7±16.4	47.2±17.3	45.1±15.0
SBP (mmHg)	146.8±16.2	118.3±14.9[a]	142.5±20.4	143.9±20.6
DBP (mmHg)	87.0±16.9	66.9±6.8[a]	80.8±16.1	83.6±16.3
Thrombus age (h)	23.9±11.6	35.9±14.3[b]	24.3±11.8	33.7±15.4[b]

Values are expressed as the mean ± standard deviation or n (%). [a]P<0.05, [b]P<0.01 vs. the successful group. SBP, systolic blood pressure; DBP, diastolic blood pressure.

Table V. Factors contributing to successful local venous thrombolytic therapy.

A, Univariate logistic regression analysis

Parameter	β	SE	P-value	OR	95%CI
SBP (mmHg)	0.10	0.03	<0.01	1.10	1.03-1.17
DBP (mmHg)	0.08	0.03	<0.05	1.08	1.02-1.14
Thrombus age (h)	-0.09	0.04	<0.05	0.91	0.84-0.99

B, Multivariate logistic regression analysis

SBP (mmHg)	0.10	0.04	<0.05	1.11	1.02-1.21
DBP (mmHg)	0.09	0.05	0.06	1.10	1.00-1.21
Thrombus age (h)	-0.05	0.05	0.39	0.95	0.86-1.06

SE, standard error; SBP, systolic blood pressure; DBP, diastolic blood pressure; OR, odds ratio; CI, confidence interval.

study attempted thrombolysis using a bolus of urokinase; however, a subsequent angioplasty was performed to restore the blood flow of thrombosed fistula (27). Furthermore, the half-life of urokinase is 10-20 min in the plasma; therefore, continuous IV administration is essential to warrant thrombolytic efficacy of urokinase. A previous study reported a 94% technical success rate of thrombolysis by using a small dose of urokinase in combination with balloon angioplasty in 15 patients (7).

In the present study, it was indicated that higher blood pressure levels were associated with increased thrombolysis success rates in the local venous thrombolytic therapy. This phenomenon, to the best of our knowledge, has not been reported in previous studies. The underlying mechanism remains elusive; however, it is clear that hypotension and reduced blood flow increase the risk for thrombosis (3,28,29). It was also indicated that thrombus age was associated with a reduced thrombolysis success rate. In other words, it was more difficult to resolve older thrombi by thrombolytic therapy. Although thrombectomy of a fistula that has been thrombosed for several days may still be successful (10), the prognosis is better if treatment is performed early (9).

Of note, the present study has certain limitations. The size of the thrombi was not measured and the study did not focus on underlying stenosis, while these two parameters may constitute as confounding factors (20). Another limitation of the study was the lack of long-term follow-up. The long-term efficacy and safety of thrombolytic therapy with urokinase require further evaluation.

Acknowledgements

Not applicable.

Funding

No funding received.

Availability of data and materials

All data generated or analyzed during this study are included in this published article.

Authors' contributions

ZW and BT designed the study. ZW, RX, HW, QZ and BT analyzed and interpreted the data. ZW and BT drafted and revised the manuscript. All authors read and approved the final manuscript.

Ethical approval and consent to participate

Informed consent was obtained from all patients. The Institutional Review Board of the First Affiliated Hospital of Chongqing Medical University (Chongqing, China) reviewed and approved the study protocol.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

References

1. Smits JH, van der Linden J, Blankestijn PJ and Rabelink TJ: Coagulation and haemodialysis access thrombosis. Nephrol Dial Transplant 15: 1755-1760, 2000.
2. Quencer KB and Friedman T: Declotting the thrombosed access. Tech Vasc Interv Radiol 20: 38-47, 2017.
3. MacRae JM, Dipchand C, Oliver M, Moist L, Lok C, Clark E, Hiremath S, Kappel J, Kiaii M, Luscombe R, *et al*: Arteriovenous access failure, stenosis, and thrombosis. Can J Kidney Health Dis 3: 2054358116669126, 2016.
4. May RE, Himmelfarb J, Yenicesu M, Knights S, Ikizler TA, Schulman G, Hernanz-Schulman M, Shyr Y and Hakim RM: Predictive measures of vascular access thrombosis: A prospective study. Kidney Int 52: 1656-1662, 1997.
5. Irish AB, Viecelli AK, Hawley CM, Hooi LS, Pascoe EM, Paul-Brent PA, Badve SV, Mori TA, Cass A, Kerr PG, *et al*: Effect of Fish Oil Supplementation and Aspirin Use on arteriovenous fistula failure in patients requiring hemodialysis: A randomized clinical trial. JAMA Intern Med 177: 184-193, 2017.
6. Mangiarotti G, Canavese C, Thea A, Segoloni GP, Stratta P, Salomone M and Vercellone A: Urokinase treatment for arteriovenous fistulae declotting in dialyzed patients. Nephron 36: 60-64, 1984.
7. Schon D and Mishler R: Salvage of occluded autologous arteriovenous fistulae. Am J Kidney Dis 36: 804-810, 2000.
8. Vogel PM, Bansal V and Marshall MW: Thrombosed hemodialysis grafts: Lyse and wait with tissue plasminogen activator or urokinase compared to mechanical thrombolysis with the arrow-trerotola percutaneous thrombolytic device. J Vasc Interv Radiol 12: 1157-1165, 2001.
9. Quencer KB and Oklu R: Hemodialysis access thrombosis. Cardiovasc Diagn Ther 7 (Suppl 3): S299-S308, 2017.
10. Vascular Access Work Group: Clinical practice guidelines for vascular access. Am J Kidney Dis 48 (Suppl 1): S176-S247, 2006.
11. Schweizer J, Kirch W, Koch R, Elix H, Hellner G, Forkmann L and Graf A: Short- and long-term results after thrombolytic treatment of deep venous thrombosis. J Am Coll Cardiol 36: 1336-1343, 2000.
12. Wang X, Su F, Ding J, Zhu H, Zhu X and Xing C: Salvage of an occluded radiocephalic fistula using urokinase and a tourniquet for patients undergoing hemodialysis. Int J Clin Exp Med 11: 812-817, 2018.
13. Gamal WM and Wagdy WM: Short-term follow-up of the effect of preoperative radial arterial diameter on early failure of arteriovenous fistula for hemodialysis. Ital J Vasc Endovasc 23: 144-147, 2016.
14. Sadaghianloo N, Jean-Baptiste E, Gaid H, Islam MS, Robino C, Declemy S, Dardik A and Hassen-Khodja R: Early surgical thrombectomy improves salvage of thrombosed vascular accesses. J Vasc Surg 59: 1377-1384 e1-2, 2014.
15. Lipari G, Tessitore N, Poli A, Bedogna V, Impedovo A, Lupo A and Baggio E: Outcomes of surgical revision of stenosed and thrombosed forearm arteriovenous fistulae for haemodialysis. Nephrol Dial Transplant 22: 2605-2612, 2007.
16. Ponikvar R: Surgical salvage of thrombosed native arteriovenous fistulas for hemodialysis by interventional nephrologists. Ther Apher Dial 13: 340-344, 2009.
17. Ponikvar R, Premru V and Kersnic B: Surgical thrombectomy of thrombosed arteriovenous grafts by interventional nephrologists. Ther Apher Dial 15: 306-310, 2011.
18. Turmel-Rodrigues L, Pengloan J, Baudin S, Testou D, Abaza M, Dahdah G, Mouton A and Blanchard D: Treatment of stenosis and thrombosis in haemodialysis fistulas and grafts by interventional radiology. Nephrol Dial Transplant 15: 2029-2036, 2000.
19. Schon D and Mishler R: Pharmacomechanical thrombolysis of natural vein fistulas: Reduced dose of TPA and long-term follow-up. Semin Dial 16: 272-275, 2003.
20. Koraen-Smith L, Krasun M, Bottai M, Hedin U, Wahlgren CM and Gillgren P: Haemodialysis access thrombosis: Outcomes after surgical thrombectomy versus catheter-directed thrombolytic infusion. J Vasc Access 19: 535-541, 2018.
21. Sadjadi SA and Sharif-Hassanabadi M: Fatal pulmonary embolism after hemodialysis vascular access declotting. Am J Case Rep 15: 172-175, 2014.
22. Wu S, Ahmad I, Qayyum S, Wicky S and Kalva SP: Paradoxical embolism after declotting of hemodialysis fistulae/grafts in patients with patent foramen ovale. Clin J Am Soc Nephrol 6: 1333-1336, 2011.
23. Pinard EA, Fazal S and Schussler JM: Catastrophic paradoxical embolus after hemodialysis access thrombectomy in a patient with a patent foramen ovale. Int Urol Nephrol 45: 1215-1217, 2013.
24. Weng FL and Berns JS: Complications of percutaneous treatment of thrombosed hemodialysis access grafts. Semin Dial 16: 257-262, 2003.
25. Kim DH, Goo DE, Yang SB, Moon C and Choi DL: Endovascular management of immediate procedure-related complications of failed hemodialysis access recanalization. Korean J Radiol 6: 185-195, 2005.
26. Kim HK, Kwon TW, Cho YP and Moon KM: Outcomes of salvage procedures for occluded autogenous radiocephalic arteriovenous fistula. Ther Apher Dial 15: 448-453, 2011.
27. Zaleski GX, Funaki B, Kenney S, Lorenz JM and Garofalo R: Angioplasty and bolus urokinase infusion for the restoration of function in thrombosed Brescia-Cimino dialysis fistulas. J Vasc Interv Radiol 10: 129-136, 1999.
28. Chang TI, Paik J, Greene T, Desai M, Bech F, Cheung AK and Chertow GM: Intradialytic hypotension and vascular access thrombosis. J Am Soc Nephrol 22: 1526-1533, 2011.
29. Neyra NR, Ikizler TA, May RE, Himmelfarb J, Schulman G, Shyr Y and Hakim RM: Change in access blood flow over time predicts vascular access thrombosis. Kidney Int 54: 1714-1719, 1998.