JVA
ISSN 1129-7298

J Vasc Access 2017; 18 (Suppl 1): S5-S9
DOI: 10.5301/jva.5000672

REVIEW

Preoperative ultrasound still valuable for radio-cephalic arteriovenous fistula creation?

Jernej Pajek, Marko Malovrh

Department of Nephrology, University Medical Centre Ljubljana, Ljubljana - Slovenia

ABSTRACT

Radio-cephalic arteriovenous fistula is a prototype hemodialysis access with small incidences of infection and distal ischemia, it spares proximal veins for future access use and it helps in the maturation of veins that may be used for more proximal access creations. This access type is prone to higher early failure rates compared to more proximal fistulas and there are unsolved uncertainties regarding exact ultrasound parameters predictive of fistula outcome. Evolution of ultrasound use has yielded several functional parameters that can be measured in addition to anatomical lumen sizes, which remain core parameters on which the decision to construct fistula in radio-cephalic forearm position is based. We propose to use arterial hyperemic response and wall morphology to aid in this decision when radial artery diameter falls in the interval with predictive uncertainty of 1.6-1.9 mm and to use venous flow pattern, respiratory variation, radial artery status and possibly venous distensibility when cephalic vein augmented diameter lies in the borderline interval of 2-2.4 mm. Ultrasound preoperative mapping and planning should be followed by expert surgical technique and several technique modifications of the classical end-to-side approach are possible to enhance operation outcome and diminish the incidence of stenosis most often present at juxta-anastomotic location. In our experience radio-cephalic arteriovenous fistula remains the golden standard for hemodialysis access and preoperative ultrasound the single best imaging modality to plan the operation and predict its success.

Keywords: Arteries, Renal dialysis, Ultrasonography, Upper extremity, Veins

Introduction

Radio-cephalic arteriovenous fistula (RCAVF) creation proposed first by Brescia et al in 1966 was a ground-breaking technique that revolutionized vascular access creation and use (1). Today, many practicing nephrologists know that a well-matured and functioning RCAVF represents a precious access that may enable successful dialysis for more than 30 years (2). Unfortunately, RCAVFs suffer from high incidence of primary failure (pooled estimate of 15.3%) and a relatively poor long-term patency (i.e., pooled primary and secondary patencies at 1 year of 63% and 66%, respectively) (3). The success of RCAVF creation is hampered by the fact that the median age and comorbidity level of dialysis patients is on the rise. This is perhaps the main cause of observed tendency towards a higher primary failure rate of these fistulas constructed after 1991, since the average quality of vessels forming fistula circuit deteriorated (3). An additional factor may be a guideline supported drive to place arterio-venous (AV) access as distal as possible (4) and wrist RCAVF is the first option for access creation even in patients with diabetes and arteriosclerosis where risks of failure are larger. Therefore, techniques to improve the success rate of RCAVF are needed and ultrasound-guided preoperative mapping has emerged as a very useful technique for this purpose.

Evolution of ultrasound use in preoperative mapping

Identification of vessel anatomical location, patency, diameter and assessment of their ability to dilate and provide beneficial outward remodeling during access maturation may all be accomplished by the use of preoperative duplex ultrasound. In the 1990s, the problems with securing functional AVFs became increasingly apparent, a trend that paralleled the increase in incidence of end-stage renal disease, the prevalence of diabetes mellitus as the primary renal disease and increasing median age of dialysis patients (5, 6). At first, the most straightforward ability of ultrasound to identify and localize suitable veins was utilized. In our cohort of 116 access patients, suitable veins for AVF construction could only be found in 47% of patients by clinical examination; usage of duplex sonography helped to establish the presence of suitable veins in further 41% of patients thus leaving only 12%

Accepted: December 20, 2016
Published online: March 5, 2017

Corresponding author:
Jernej Pajek
Department of Nephrology
University Medical Centre Ljubljana
Zaloška 2
1525 Ljubljana, Slovenia
Jernej.pajek@mf.uni-lj.si

patients who required venography (7). Similarly, Wong et al have shown that the proportion of correct predictions for AVF postoperative function was improved by the ultrasound assessment of veins from 67% to 83% of cases (8). Investigator performing venous mapping should look beyond mere location, patency and diameter and also check venous distensibility (9), Doppler waveforms with respiratory variation and predicted suitability for cannulation (10). The ultimate goal of this effort is to find venous segment with predicted post-maturation length of optimally at least 10 cm, post-maturation width of at least 5-6 mm and less than 6 mm deep to accommodate repetitive needle placement (11).

In a more recent study, a simple measure of venous distensibility with absolute diameter increase above 0.4 mm after 2-minute tourniquet placement performed as the strongest predictive criterion for RCAVF success in a multivariate model adjusted for radial artery (RA) and cephalic vein (CV) diameter (12). This ultrasound-derived cut-off measure to predict RCAVF success was close to 0.35 mm threshold for venous diameter increase found with a venography study of forearm CVs (13). Probably, strong association of fistula creation success with venous distensibility in terms of absolute diameter increase was present due to dependence of this parameter not only on elastic properties of venous wall but also due to correlation with the absolute baseline diameter of CV. Our experience with relative venous diameter increase has shown a significant difference in increase of 48% and 11.8% in the groups with and without functioning RCAVF within 24 hours after construction (7). It must however be acknowledged that ultrasound measurement of non-augmented forearm venous diameters has been criticized as it suffers from low reproducibility (14). Supine patient position, stable ambient conditions (comfort warm temperature), application of warm gel and care to insonate veins without distorting them with the probe are crucial technical conditions to secure reliable diameter measurements and best reproducibility (15). So in our practice isolated non-augmented diameters are not used as a single venous criterion for decisions about access creation. A method to provoke venous congestion – a pressure cuff or tourniquet application showed no significant difference in augmented CV diameters and both methods may be used for proximal venous compression (16).

In the period of 1996 to 1998, studies evaluating radial arterial parameters began to emerge (8, 17, 18). At first the emphasis was put on artery diameter, later on other non-invasive parameters like reaction to reactive hyperemia (7, 19, 20), intima-media thickness (21), and the burden of calcifications (wall morphology) were increasingly taken into consideration. Blood flow estimates in a small caliber RA are often inaccurate using ultrasound techniques, so the suitability of RA should be judged predominantly by other aforementioned parameters (22). Narrow and calcified RA with thickened wall and no significant reactive hyperemia response cannot be expected to undergo proper dilatation during access maturation, neither provide adequate inflow for hemodialysis circuit.

A practical approach is to first define the radial arterial outline with color Doppler and further assess segments with abnormal color Doppler with B-mode and spectral Doppler; loss of signal either in color Doppler or B-mode helps to identify areas of calcification (Fig. 1) (22, 23). Hyperemic response of RA is provoked after release of a 2-3-minute long ischemia induced by clenching a fist. A normal response is a change in the Doppler spectral waveform from triphasic high-resistance to monophasic low-resistance shape, increase in the peak velocity and a fall in the resistance index (RI). RI change may be less prone to error than velocity increase assessment because it is less dependent on the Doppler angle. We have shown that a fall of RI below 0.7 at hyperemic response predicted greater success (95% vs. 35%) of RCAVF operation (7). Others have provided similar information by measuring hyperemic changes in peak velocity (19) or found usefulness of this hyperemic peak velocity change at least for females (20). Although functional parameters like this are valuable adjunct in arterial and venous evaluation, morphological information of vessel diameter may still be regarded as the key parameter in preoperative planning. Here, ongoing controversies about the optimal diameter cut-off values persist and yield some uncertainty in the preoperative decision-making process.

Decision-making controversies – vessel diameters, surgical techniques and beyond

In early studies, a minimal arterial diameter as low as 1.5-1.6 mm was found to be predictive of fistula success (8, 18). Others have reported increased success of autogenous fistula placement and reduced utilization of grafts and catheters through application of minimal ultrasound criteria for artery diameter of 2.0 mm (17). Later on, numerous additional studies on the subject emerged (24-27) and a recent systematic review suggested that the optimal RA diameter for construction of RCAVF should be at least 2 mm to predict successful maturation and primary patency (28). Attempts to construct RCAVF with RA diameters of 1.5 mm or below are not recommended. In the “grey zone” of RA diameters 1.6-1.9, mm we do not automatically discard the option to use RA but rely on functional parameters especially the reduction of RI and vessel dilatation in hyperemic response supplemented with B-mode impression about the vessel wall morphology. If there is no significant hyperemic RI decrement, a more proximal point for AVF is sought (values below 0.7 in hyperemic response are considered optimal, but RI below 0.8 still acceptable). When the decision concerning RA suitability is doubtful, we look at venous mapping results and often decide for the RCAVF formation attempt when there is a large, distensible CV present with normal Doppler venous waveform and well established phenomena of respiratory filling.

Criteria for venous size as a predictor of RCAVF outcome fluctuated even more than RA diameter cut-offs across published studies. Minimal CV internal diameters associated with RCAVF outcomes in the range of 1.6-2.6 mm were reported (7, 8, 17, 29, 30). As mentioned above, imaging of veins in either neutral or augmented state adds variability to reported threshold values and studies considered in systematic review did not report this aspect of methodology uniformly (28). CV diameter (non-augmented) of at least 2 mm was proposed as the optimal cut-off value for maturation and primary patency outcomes and similar to arterial data usage of veins below 1.5 mm was not advocated (28). In our current practice, we prefer to measure tourniquet augmented venous diameters

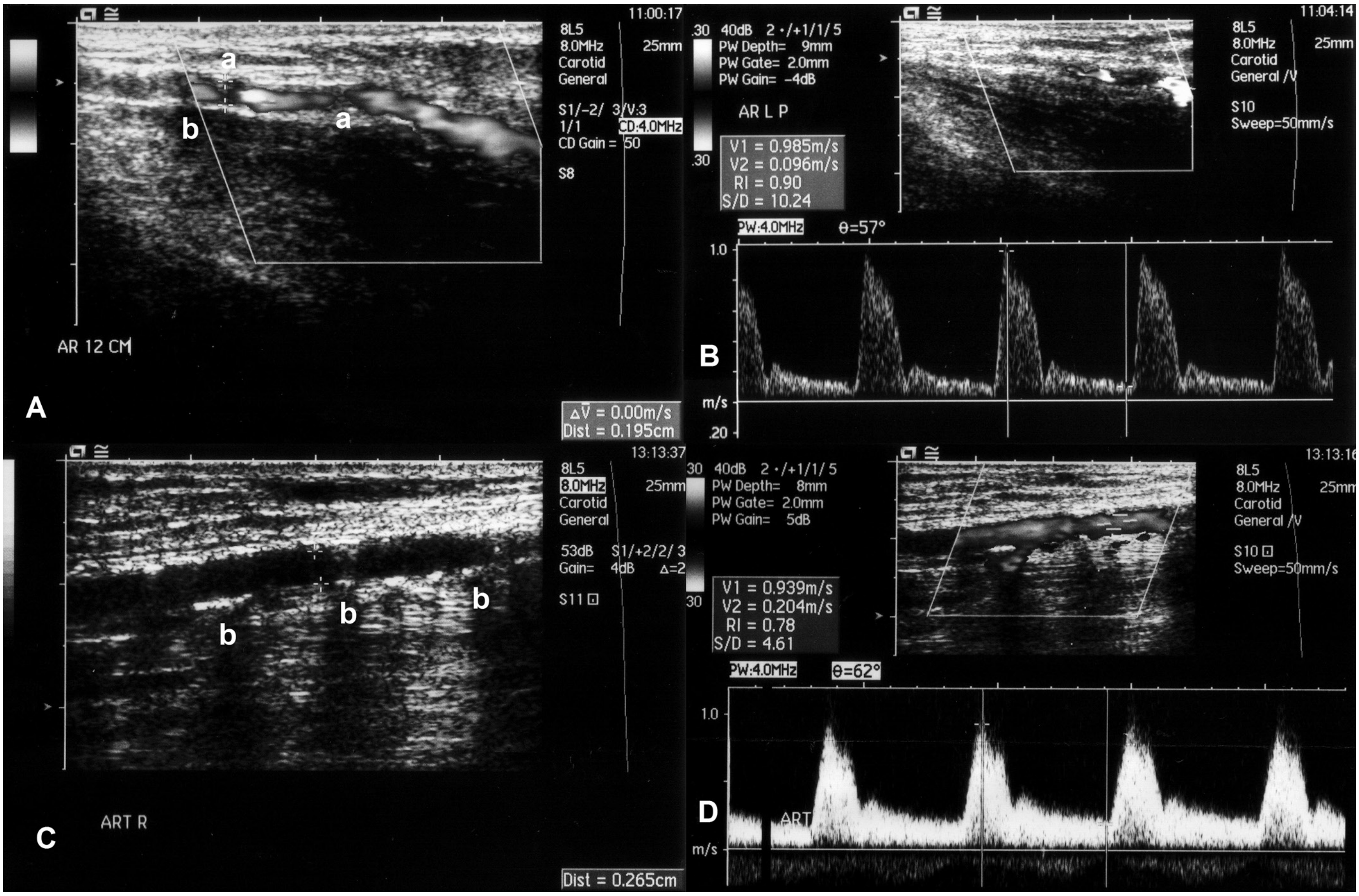

Fig. 1 - Calcified radial artery examples in two patients. **Panel A:** color Doppler radial artery (RA) image of patient 1; (a) note the loss of Doppler signal in areas of calcifications, the internal diameter of RA was 1.95 mm; (b) distal shadowing behind the areas of calcifications. **Panel B:** pulsed Doppler velocity of blood in patient 1 at hyperemic response, the resistance index (RI) of 0.9 was suboptimal but the decision to establish the fistula at this position was made due to excellent vein status (augmented cephalic vein diameter of 4.2 mm). **Panel C:** B-mode image of large (diameter 2.65 mm) calcified radial artery in patient 2; (b) note prominent distal shadowing behind areas of wall calcifications. **Panel D:** a significantly better hyperemic response with lower RI of 0.78 in patient 2.

and consider 2.5 mm or more as suitable for RCAVF creation (Fig. 2). We regard augmented diameters below 2.0 mm as insufficient except if RA is of very good quality and venous diameter is close to this threshold. In situations with augmented CV diameters of 2.0-2.4 mm, we meticulously inspect Doppler flow pattern, velocity, respiratory flow variation and the status of RA to reach the final decision.

Besides ultrasound-derived parameters, surgical expertise crucially impacts early failure rates. Many tips and tricks for technique improvement may be used (31, 32). A typical problem associated with surgical technique is the emergence of juxta-anastomotic stenosis in the mobilized “swing” segment of CV, a situation responsible for majority of cases of stenosis-associated AVF dysfunction (33). Computational simulations have shown that manipulation of venous stump to reach relatively small anastomosis angle of 30° would be the preferred surgical geometry to minimize areas of disturbed flow and consequently development of neointima in the classical end-to-side anastomosis configuration (34). Furthermore, avoiding the formation of swing by using the so called “piggyback” straight-line onlay technique (pSLOT) shows promise to improve RCAVF creation outcomes as it reduced the incidence of juxta-anastomotic stenosis and overall fistula failure (35). These approaches however are not widely adopted by surgeons and future prospective randomized studies are needed to confirm their benefit.

Finally, a notion on the possible alternative paradigm in upper-arm access construction should be made. Due to relatively low rates of achieving adequacy with forearm fistulas compared to upper-arm fistulas (i.e., 34% vs. 59%) a recommendation was made to construct AVF preferentially in the upper arm, at least for female, diabetic and older dialysis patients where achieving adequate fistula function was especially problematic (36). In situations without access to efficient ultrasound mapping service there is a clear commodity of predominantly reverting to upper-arm fistulas, since vessel diameters are larger and in the cubital region clinical examination is more easily positive for vein and artery localization. However, nowadays we have a substantial body of evidence showing that preoperative ultrasound mapping improves the proportion of patients with functional AVFs in early and late post-operative period (17, 37, 38). Provision of preoperative

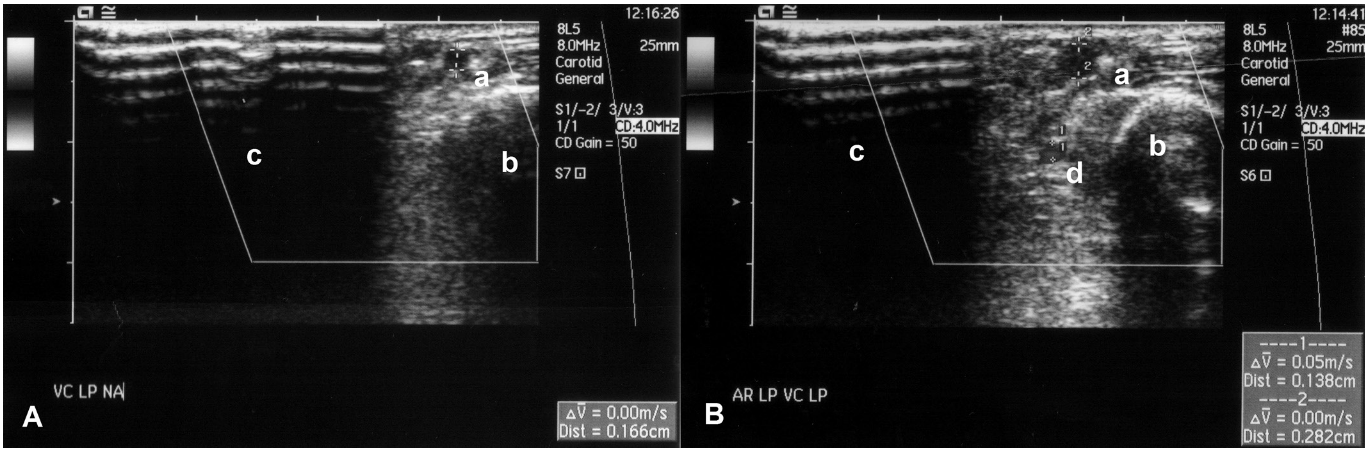

Fig. 2 - Cephalic vein (CV) distensibility assessment. **Panel A:** (a) non-augmented CV image of a female patient with diameter of 1.7 mm; (b) radial bone; (c) signal drop-out due to insonation of CV from the side and minimal contact of the probe with the skin to avoid compressing the vein. **Panel B:** (a) augmented CV diameter of 2.8 mm; (d) radial artery (RA) diameter was 1.4 mm; due to small RA diameter plan to perform fistula operation at this site was abandoned.

ultrasound mapping is therefore accepted as the standard of care (4) and vulnerable forearm RCAVF creations in terms of early failure and late patency rates may benefit most from the use of ultrasound for vessel mapping and assessment of their maturation potential. When the result of physical examination is favorable, the benefit of routine ultrasound usage is more difficult to prove (39). Recent meta-analysis evidence of moderate strength supported routine use of ultrasound for vessel mapping before the creation of any AVF (40). Our policy is to perform routine ultrasound mapping in all patients referred in need of vascular access and both the mapping and operation are performed by interventional nephrologists, often same person performs both procedures (41).

Conclusions

Successful RCAVF creation brings many benefits to dialysis patient. It is an access associated with low incidence of infection and distal ischemia, it spares proximal veins for future access use and it may help in the maturation of veins that may be used for more proximal access creations. In the radio-cephalic configuration, with higher risk of early failure and non-maturation than with fistulas in cubital position, the routine use of ultrasound is justified to avoid negative surgical explorations, procedures on inappropriate vessels with ultrasound features indicating incapacity to mature properly or lying too deep in the subcutaneous fat for reliable repetitive needling. Although there are controversies regarding the optimal methodology for ultrasound mapping (i.e., using augmented vs. neutral venous imaging) and regarding the optimal cut-offs of predictive parameters for fistula outcome, we propose that anatomical and functional parameters be judged together in the composite decision-making process about feasibility of RCAVF. When vessel diameters in the uncertain "grey-zone" interval are found, functional parameters (such as hyperemic RI, RA morphology, venous distensibility and Doppler flow pattern, respiratory flow variation) should be used to aid in a decision-making process. The interventional nephrologist is a professional with best insight in patient's projected time to the start of renal replacement therapy, cardiovascular comorbidities and transplantation capacity; this makes him/her also the optimal professional to coordinate vascular access establishing process and with proper motivation and devotion also to perform diagnostic and surgical procedures. In any hands, for the purpose of RCAVF creation, preoperative ultrasound should remain as the main and invaluable tool for preoperative planning and outcome prediction.

Disclosures

Financial support: No grants or funding have been received for this study.
Conflict of interest: None of the authors has financial interest related to this study to disclose.

References

1. Brescia MJ, Cimino JE, Appel K, Hurwich BJ. Chronic hemodialysis using venipuncture and a surgically created arteriovenous fistula. N Engl J Med. 1966;275(20):1089-1092.
2. Buturović-Ponikvar J, Persic V, Malovrh M, Ponikvar R. Vascular access in patients treated with chronic hemodialysis for 30 years or more. Ther Apher Dial. 2009;13(4):354-357.
3. Rooijens PPGM, Tordoir JHM, Stijnen T, Burgmans JPJ, Smet de AA, Yo TI. Radiocephalic wrist arteriovenous fistula for hemodialysis: meta-analysis indicates a high primary failure rate. Eur J Vasc Endovasc Surg. 2004;28(6):583-589.
4. Tordoir J, Canaud B, Haage P, et al. EBPG on Vascular Access. Nephrol Dial Transplant. 2007;22(Suppl 2):ii88-ii117.
5. Hsu CY, Vittinghoff E, Lin F, Shlipak MG. The incidence of end-stage renal disease is increasing faster than the prevalence of chronic renal insufficiency. Ann Intern Med. 2004;141(2):95-101.
6. Muntner P, Coresh J, Powe NR, Klag MJ. The contribution of increased diabetes prevalence and improved myocardial infarction and stroke survival to the increase in treated end-stage renal disease. J Am Soc Nephrol. 2003;14(6):1568-1577.
7. Malovrh M. Native arteriovenous fistula: preoperative evaluation. Am J Kidney Dis. 2002;39(6):1218-1225.
8. Wong V, Ward R, Taylor J, Selvakumar S, How TV, Bakran A. Factors associated with early failure of arteriovenous fistulae for

haemodialysis access. Eur J Vasc Endovasc Surg. 1996;12(2): 207-213.
9. van der Linden J, Lameris TW, van den Meiracker AH, de Smet AAEA, Blankestijn PJ, van den Dorpel MA. Forearm venous distensibility predicts successful arteriovenous fistula. Am J Kidney Dis. 2006;47(6):1013-1019.
10. Malovrh M. Approach to patients with end-stage renal disease who need an arteriovenous fistula. Nephrol Dial Transplant. 2003;18(90005)(Suppl 5):v50-v52.
11. Malovrh M. Emerging role of vascular ultrasound in arteriovenous dialysis access. In: Asif A, Agarwal AK, Yevzlin AS, Wu S, Beathard GA, eds. Interventional nephrology. New York: McGraw Hill; 2012:525-532.
12. Jemcov TK. Morphologic and functional vessels characteristics assessed by ultrasonography for prediction of radiocephalic fistula maturation. J Vasc Access. 2013;14(4):356-363.
13. Kim JT, Chang WH, Oh TY, Jeong YK. Venous distensibility as a key factor in the success of arteriovenous fistulas at the wrist. Ann Vasc Surg. 2011;25(8):1094-1098.
14. Planken RN, Leiner T, Tordoir JHM. Forearm venous distensibility measurements with ultrasound techniques are poorly reproducible. Am J Kidney Dis. 2007;49(2):347.
15. Planken RN, Keuter XH, Kessels AG, Hoeks AP, Leiner T, Tordoir JH. Forearm cephalic vein cross-sectional area changes at incremental congestion pressures: towards a standardized and reproducible vein mapping protocol. J Vasc Surg. 2006;44(2): 353-358.
16. Planken RN, Keuter XHA, Hoeks APG, et al. Diameter measurements of the forearm cephalic vein prior to vascular access creation in end-stage renal disease patients: graduated pressure cuff versus tourniquet vessel dilatation. Nephrol Dial Transplant. 2006;21(3):802-806.
17. Silva MB Jr, Hobson RWII, Pappas PJ, et al. A strategy for increasing use of autogenous hemodialysis access procedures: impact of preoperative noninvasive evaluation. J Vasc Surg. 1998;27(2):302-307, discussion 307-308.
18. Malovrh M. Non-invasive evaluation of vessels by duplex sonography prior to construction of arteriovenous fistulas for haemodialysis. Nephrol Dial Transplant. 1998;13(1):125-129.
19. Wall LP, Gasparis A, Callahan S, van Bemmelen P, Criado E, Ricotta J. Impaired hyperemic response is predictive of early access failure. Ann Vasc Surg. 2004;18(2):167-171.
20. Lockhart ME, Robbin ML, Allon M. Preoperative sonographic radial artery evaluation and correlation with subsequent radiocephalic fistula outcome. J Ultrasound Med. 2004;23(2): 161-168, quiz 169-171.
21. Ku YM, Kim YO, Kim JI, et al. Ultrasonographic measurement of intima-media thickness of radial artery in pre-dialysis uraemic patients: comparison with histological examination. Nephrol Dial Transplant. 2006;21(3):715-720.
22. Ferring M, Henderson J, Wilmink A, Smith S. Vascular ultrasound for the pre-operative evaluation prior to arteriovenous fistula formation for haemodialysis: review of the evidence. Nephrol Dial Transplant. 2008;23(6):1809-1815.
23. Malovrh M. The role of sonography in the planning of arteriovenous fistulas for hemodialysis. Semin Dial. 2003;16(4): 299-303.
24. Korten E, Toonder IM, Schrama YC, Hop WCJ, van der Ham AC, Wittens CHA. Dialysis fistulae patency and preoperative diameter ultrasound measurements. Eur J Vasc Endovasc Surg. 2007;33(4):467-471.
25. Ilhan G, Esi E, Bozok S, et al. The clinical utility of vascular mapping with Doppler ultrasound prior to arteriovenous fistula construction for hemodialysis access. J Vasc Access. 2013;14(1):83-88.
26. Bojakowski K, Gorczyca-Wiśniewska E, Szatkowski M, Walecki J, Andziak P. Preoperative ultrasonographic examination of the radial artery and the cephalic vein and risks of dialysis arteriovenous fistula dysfunction. Pol J Radiol. 2010;75(1):7-12.
27. Parmar J, Aslam M, Standfield N. Pre-operative radial arterial diameter predicts early failure of arteriovenous fistula (AVF) for haemodialysis. Eur J Vasc Endovasc Surg. 2007;33(1): 113-115.
28. Kordzadeh A, Chung J, Panayiotopoulos YP. Cephalic vein and radial artery diameter in formation of radiocephalic arteriovenous fistula: a systematic review. J Vasc Access. 2015;16(6): 506-511.
29. Brimble KS, Rabbat ChG, Treleaven DJ, Ingram AJ. Utility of ultrasonographic venous assessment prior to forearm arteriovenous fistula creation. Clin Nephrol. 2002;58(2):122-127.
30. Mendes RR, Farber MA, Marston WA, Dinwiddie LC, Keagy BA, Burnham SJ. Prediction of wrist arteriovenous fistula maturation with preoperative vein mapping with ultrasonography. J Vasc Surg. 2002;36(3):460-463.
31. Konner K. The anastomosis of the arteriovenous fistulacommon errors and their avoidance. Nephrol Dial Transplant. 2002;17(3):376-379.
32. Bourquelot P, Pirozzi N. Tips and tricks in creation of forearm arteriovenous fistulae. J Vasc Access. 2014;15(Suppl 7): S45-S49.
33. Badero OJ, Salifu MO, Wasse H, Work J. Frequency of swing-segment stenosis in referred dialysis patients with angiographically documented lesions. Am J Kidney Dis. 2008;51(1):93-98.
34. Ene-Iordache B, Cattaneo L, Dubini G, Remuzzi A. Effect of anastomosis angle on the localization of disturbed flow in side-to-end fistulae for haemodialysis access. Nephrol Dial Transplant. 2013;28(4):997-1005.
35. Bharat A, Jaenicke M, Shenoy S. A novel technique of vascular anastomosis to prevent juxta-anastomotic stenosis following arteriovenous fistula creation. J Vasc Surg. 2012;55(1): 274-280.
36. Miller PE, Tolwani A, Luscy CP, et al. Predictors of adequacy of arteriovenous fistulas in hemodialysis patients. Kidney Int. 1999;56(1):275-280.
37. Allon M, Lockhart ME, Lilly RZ, et al. Effect of preoperative sonographic mapping on vascular access outcomes in hemodialysis patients. Kidney Int. 2001;60(5):2013-2020.
38. Ferring M, Claridge M, Smith SA, Wilmink T. Routine preoperative vascular ultrasound improves patency and use of arteriovenous fistulas for hemodialysis: a randomized trial. Clin J Am Soc Nephrol. 2010;5(12):2236-2244.
39. Nursal TZ, Oguzkurt L, Tercan F, et al. Is routine preoperative ultrasonographic mapping for arteriovenous fistula creation necessary in patients with favorable physical examination findings? Results of a randomized controlled trial. World J Surg. 2006;30(6):1100-1107.
40. Georgiadis GS, Charalampidis DG, Argyriou C, Georgakarakos EI, Lazarides MK. The necessity for routine pre-operative ultrasound mapping before arteriovenous fistula creation: A meta-analysis. Eur J Vasc Endovasc Surg. 2015;49(5):600-605.
41. Malovrh M. Vascular access creation and care should be provided by nephrologists. J Vasc Access. 2015;16(Suppl 9):S20-S23.