ELSEVIER

Clinical Research

Endovascular Creation of Arteriovenous Fistulae for Hemodialysis Access with a 4 Fr Device: Clinical Experience from the EASE Study

Todd L. Berland,[1] Jason Clement,[2] Joseph Griffin,[3] Gregory G. Westin,[1] and Adrian Ebner,[4] New York, New York, Vancouver, British Columbia, Canada, Baton Rouge, Louisiana, and Asuncion, Paraguay

Background: The use of arteriovenous fistula (AVF) is hampered by long surgical wait times, slow maturation, and upwards of 60% that do not mature. We describe our clinical experience in using a system with a 4F catheter profile for endovascular AVF creation in patients on hemodialysis.

Methods: This was a multioperator, single-center, single-arm, prospective study intended to evaluate safety and efficacy of a 4 Fr endovascular AVF (endoAVF) system for the creation of vascular access in hemodialysis patients. The study was performed after institutional review board approval at Italian Hospital (Asuncion, Paraguay). Patients were followed up at regular intervals through 6 months to determine procedural, maturation, and cannulation success as well as intervention rate and patency.

Results: From May to November 2016, 32 patients underwent the endoAVF procedure with no device-related adverse events. An endoAVF was successfully created in the proximal forearm for all 32 patients (20 between the radial artery and radial vein; 12 between the ulnar artery and ulnar vein). Wrist access was used for 72% (23/32) of the procedures for the arterial catheter and 59% (19/32) of the procedures for the venous catheter. The device successfully created an endoAVF in every patient for a technical success rate of 100% (32/32). The device- or procedure-related serious adverse event rate was 3% (1/32); one patient experienced a venous guidewire perforation successfully managed with a stent graft. Primary and cumulative patency rates through 6 months were 83% and 87%, respectively, with an intervention rate of 0.21 per patient-year. Physiological suitability, as defined by target flow rates $\geq$500 ml/min and cannulation vessel diameters $\geq$4 mm, was achieved in 91% (29/32) of patients by 90 days. Successful 2-needle cannulation was achieved in 78% (21/27) by 90 days, with mean time to cannulation of 43 $\pm$ 14 days. Functional cannulation, as defined by successful 2-needle cannulation for

Interim 3-month analysis was presented as the 10th International Congress of Vascular Access Society.

Conflict of interest: T.L.B. received stock options from TVA Medical, which he no longer holds. J.C. received consulting fees from the TVA Medical. J.G., G.G.W., and A.E. have no relevant interests to disclose.

Funding: This work was supported by TVA Medical (Austin, TX, USA). Data analysis and some composition of the clinical study report were performed by Syntactx Clinical Research Firm. The authors interpreted the data, reviewed all composition by the research firm, and made the decision to submit the final manuscript for publication.

[1]*Division of Vascular and Endovascular Surgery, NYU Langone Health, New York, NY.*

[2]*Department of Radiology, St. Paul's Hospital, Vancouver, BC, Canada.*

[3]*Division of Vascular Surgery, Baton Rouge Medical of Louisiana State University, Baton Rouge, LA.*

[4]*Cardiovascular Services, Italian Hospital, Asuncion, Paraguay.*

Correspondence to: Todd L. Berland, NYU Langone Health, 530 First Avenue, Suite 6F, New York, NY 10016, USA; E-mail: Todd.Berland@nyulangone.org

Ann Vasc Surg 2019; ■: 1–11
https://doi.org/10.1016/j.avsg.2019.02.023

Manuscript received: August 17, 2018; manuscript accepted: February 19, 2019; published online: ■ ■ ■

two-thirds of the dialysis sessions within 1 month, was achieved in 95% (20/21) of the patients who were successfully cannulated for an overall rate of 74% (20/27). All patients who achieved functional cannulation had their central venous catheters (CVCs) removed before the 90-day follow-up for a CVC removal rate of 74% (20/27).

Conclusions: The 4 Fr endoAVF system allowed for multiple access and fistula creation site options to tailor the procedure to individual patient anatomy. Furthermore, the outcomes are comparable to previous generation endoAVF technology, with a potentially improved safety profile because of the use of arteries at the wrist for access.

INTRODUCTION

Among the three primary hemodialysis access modalities—arteriovenous fistula (AVF), arteriovenous fistula graft (AVG), and indwelling central venous catheter (CVC)—AVF is associated with the lowest mortality, morbidity, and cost.[1–7] Despite initiatives to increase autogenous AVF use,[8] 83% of patients initiate hemodialysis with a CVC, whereas only 14% initiate with an AVF in the United States.[9] Furthermore, nearly 75% of those patients who initiate hemodialysis with a CVC remain reliant on CVC use three months later.[10] These patients remain exposed to higher mortality and infection rates unless converted to AVF or AVG.[1,5]

Numerous factors are responsible for the continued underutilization of AVF, such as surgical wait times, failure to mature, and patient refusal of surgery. The cumulative wait time for surgical review and eventual AVF creation varies greatly between different institutions but has been reported as long as 10 weeks in some locations.[11] After AVF creation, patients remain on catheters for 3–6 months, on average, waiting for the AVF to sufficiently mature to accommodate cannulation.[12] Between 20% and 60% of surgically created fistulae do not successfully mature and are rendered unusable for hemodialysis.[13–15] In addition, patients require an average of 1.5–3.3 interventions to facilitate AVF usability.[2,16–20] Ultimately, the combination of these factors increases patient reluctance to undergo surgical AVF, particularly those with previously failed fistulae.[21] There is a clear need for less-invasive, more immediate, and more durable hemodialysis access options.

Endovascular access for AVF creation (endoAVF) has been shown to reduce morbidity and improve patient acceptance. Several studies using a 6 Fr endoAVF system have reported high technical success rates with acceptable complication risks, high patency, and low intervention rates.[16,17,22–24] A lower profile 4 Fr endoAVF system was recently developed using similar magnetic catheters and the same mechanism of action (radiofrequency [RF] energy). Potential advantages of a lower profile endoAVF system include providing more procedural access sites (i.e., from the wrist), enabling additional endoAVF creation sites (ulnar artery/ulnar vein and radial artery/radial vein), and facilitating access site hemostasis. The objective of this study was to describe our experience with a lower profile, 4 Fr system for endoAVF creation.

METHODS

Study Design

The everlinQ Endovascular Access System Enhancements (EASE) study was a multioperator, single-arm, prospective study intended to evaluate safety and efficacy through 6 months of follow-up of a 4 Fr endoAVF system (now WavelinQ™ endoAVF System, Becton Dickinson, Franklin Lakes, NJ) for the creation of vascular access in hemodialysis patients. Procedures were performed by four independent operators during four separate visits to the study site at the Italian Hospital (Asuncion, Paraguay). Each operator assessed patients for eligibility and consented them for further assessment and potential endoAVF creation within 30 days of their scheduled visit. Consented patients received final clinical evaluation and vessel mapping on the day of the index procedure to confirm eligibility. Patient follow-up visits occurred at 1 day, 30 days, 90 days, and 180 days. This study met Declaration of Helsinki guidelines related to the conduct of research in human subjects. The protocol was approved by the institutional review board at the Italian Hospital, registered with ClinicalTrials.gov (NCT03708770), and all patients provided written informed consent. Data were collected on case report forms and analyzed by an independent clinical research firm (Syntactx, New York, NY).

Patients

Eligible patients had established, nonreversible kidney failure requiring hemodialysis (including predialysis patients) and adequate target vein and artery diameters to accommodate the 4 Fr catheters. Patient screening included an Allen's test to assess

Table I. Patient eligibility criteria

Inclusion criteria
1. Established, nonreversible kidney failure requiring hemodialysis (including predialysis patients).
2. Adult (age >18 years old).
3. Superficial venous anatomy eligible to create a surgical native arteriovenous fistula in alignment with the KDOQI guidelines and that communicates with the target creation site.
4. Target vein diameter ≥2.0 mm or large enough to accommodate device diameter.
5. Target artery diameter ≥2.0 mm or large enough to accommodate device diameter.
6. Estimated life expectancy >1 year.
7. Free of clinically significant conditions or illness within 30 days before the AV fistula that may compromise the procedure.
Exclusion Criteria
1. Known central venous stenosis or central vein narrowing >50% based on imaging on the same side as the planned AVF creation.
2. Upper extremity venous occlusion(s) and/or vessel abnormality(ies) that precludes endoAVF creation.
3. Pregnant women.
4. New York Heart Association (NYHA) class III or IV heart failure.
5. Hypercoagulable state.
6. Known bleeding diathesis.
7. Immunosuppression, defined as use of immunosuppressive medications used to treat an active condition.
8. Planned major surgical procedure within 6 months of enrollment or previous major surgery within 30 days of enrollment.
9. Currently being treated with another investigational device or drug.
10. Known allergy to contrast dye which cannot be adequately premedicated.
11. Known adverse effects to sedation and/or anesthesia which cannot be adequately premedicated.
12. Distance between target artery and vein will not allow magnets to align vessels sufficiently to create the fistula.
13. Evidence of active infections on the day of the index procedure.
14. Written informed consent not obtained.

patency of the radial and ulnar arteries and vessel mapping via duplex ultrasound to determine vessel suitability for an AVF, according to published guidelines.[25,26] A complete list of inclusion and exclusion criteria for this study is provided in Table I.

EndoAVF System

The endoAVF system used in this study (Fig. 1) consisted of a 4 Fr venous catheter, a 4 Fr arterial catheter, and an electrosurgical generator (Becton Dickinson, Franklin Lakes, NJ). Rotational indicators provided visual confirmation under fluoroscopy of proper catheter orientation. Square magnets minimized the rotation of the catheters once coapted to one another. The venous catheter housed the RF electrode that, once activated, created a channel through vessel walls to the ceramic backstop on the arterial catheter.

Procedure

Operators were board-certified interventional radiologists or vascular surgeons trained with demonstration models on the procedure before their first case. The procedure followed a very similar protocol to that previously described in numerous publications.[22–24] Briefly, potential access sites were selected based on access vessel diameters. A target creation site was selected based on vessel diameters and available access sites. If a subject was eligible for fistula creation at both ulnar and radial locations, the study prioritized the radial site. Procedural access and creation site options are described in Figure 2. Both creation site options in the proximal forearm allow for multiple veins to mature for dialysis delivery, including the cephalic, median cubital, and basilic outflow veins (Fig. 3). The procedure began with vessel access gained under ultrasound guidance in the selected vein and then the selected artery. The arterial catheter was introduced into the creation site in the proximal forearm over a 0.014″ guidewire through a 5 Fr Glidesheath Slender® introducer sheath (Terumo Interventional Systems; Somerset New Jersey). Fluoroscopic imaging was set perpendicular to the plane of the target vein and artery to ensure the widest view was obtained to maximize accuracy of the rotational indicators. The venous device was then introduced over a 0.014′′ guidewire through a 5-French introducer sheath. Before reaching the creation site, both devices were rotationally aligned so the electrode and ceramic backstop were facing one

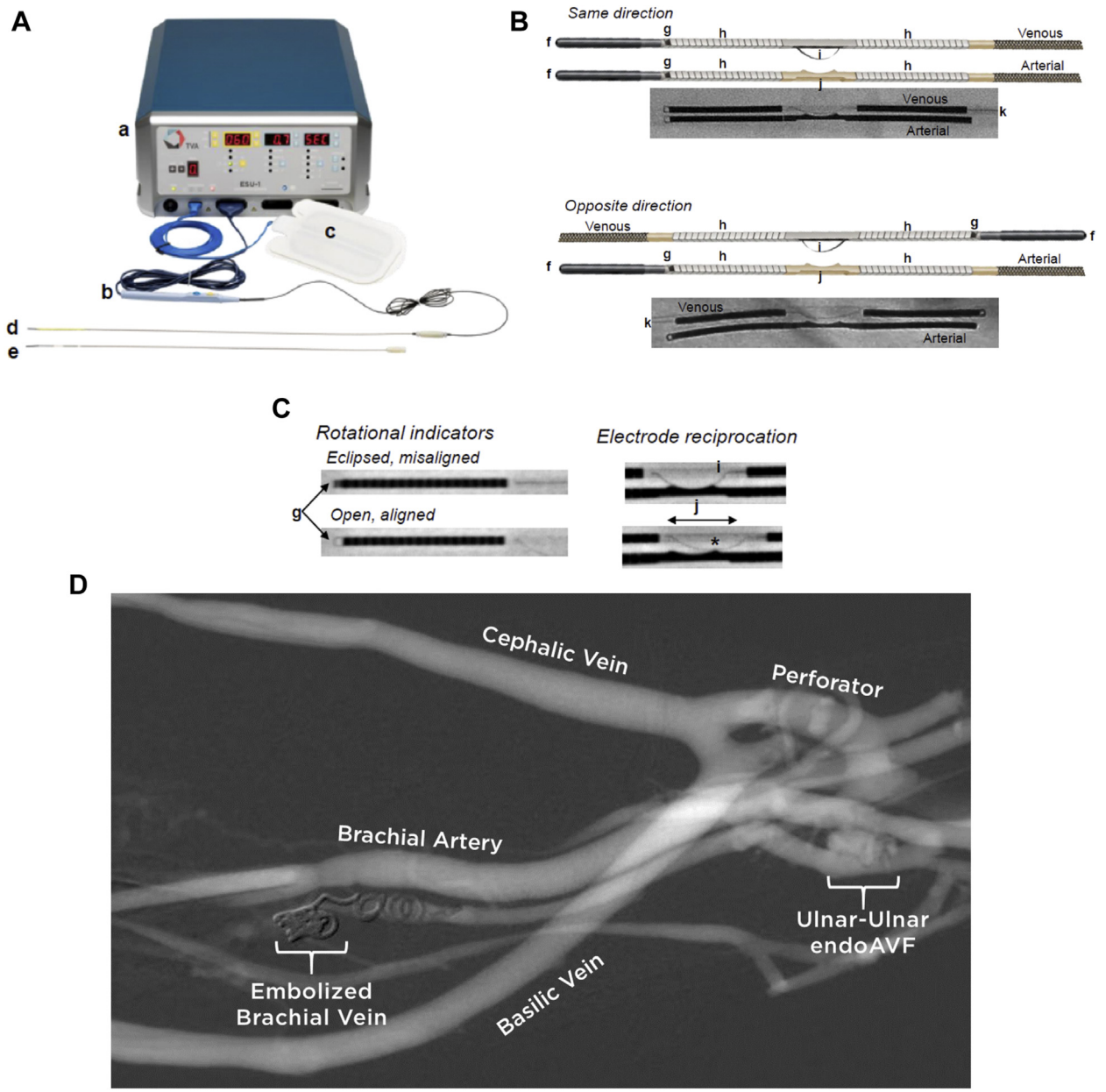


Fig. 1. The everlinQ 4 endoAVF System. **(A)** The system consists of an RF generator (a), electrosurgery pencil (b), ground pad (c), 4 Fr venous catheter (d), and 4 Fr arterial catheter (e). **(B)** Each catheter at their distal end has a rapid-exchange tip (f), rotational indicator (g), and square rare earth magnets (h). The venous catheter houses the electrode (i) to deliver the RF energy that creates the channel from the vein to the artery, connecting with the ceramic backstop (j) on the arterial catheter. Fluoroscopic images show the radiopaque elements of the catheters, such as the rotational indicators (g), magnets (h), electrode (i), ceramic backstop (j), and the wire that connects the electrode with the external power source (k). The devices can be oriented in either the same direction or in opposite directions depending on the access vessels selected to create the endoAVF. **(C)** Alignment indicators confirm the orientation of the catheters. Rotational indicators in the eclipsed position indicate misalignment, whereas the open position indicates alignment. Alignment is further confirmed by the communication (*) of the venous electrode with the arterial backstop when reciprocated. **(D)** At the completion of the procedure, one of the brachial veins is embolized to divert more flow from the endoAVF to the superficial cephalic, median cubital and basilic veins via a forearm perforating vein.

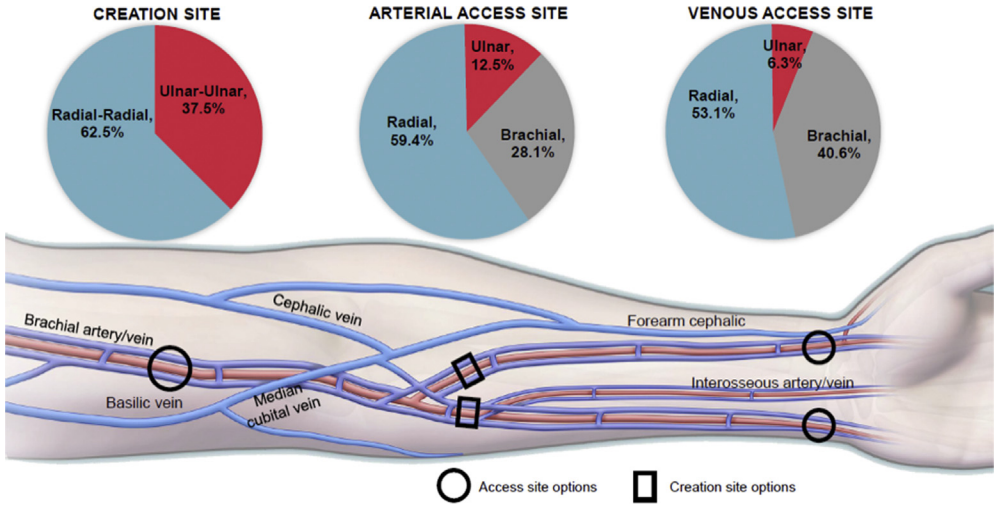


Fig. 2. Creation (rectangles) and access (circles) site options are identified on the image of the upper arm vascular anatomy. The deep venous system (dark purple) is connected by a proximal forearm perforator vein to the superficial system (light blue). The creation and access site distribution is represented as percentage of patients in the pie charts ($n = 32$).

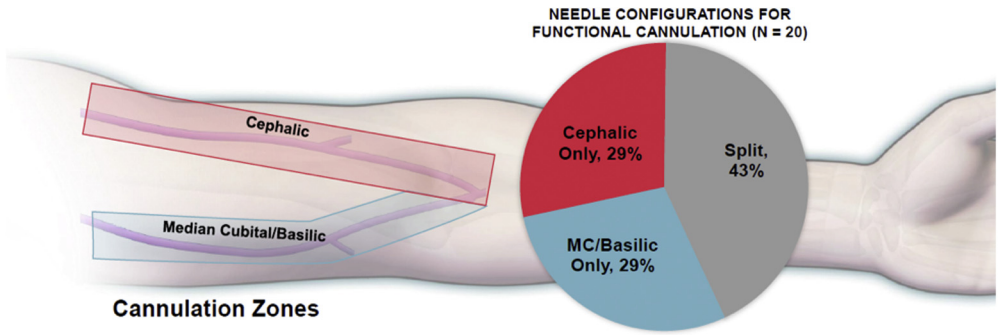


Fig. 3. Illustration of the arm to highlight the potential cannulation zones for dialysis with the proportion of patients who used the various needle configurations.

another. The advancement of the venous catheter continued until the devices were coapted via the magnets and the electrode was centered on the backstop. The device was activated to deliver 60W of RF energy for 0.7 seconds through the venous electrode to cut a channel to the arterial backstop, similar to the previously described 6 Fr endoAVF system.[22–24] The devices were then removed, a fistulogram was performed to confirm successful endoAVF creation, and a deep brachial vein was embolized to divert more arterialized flow to the more superficial cephalic, median cubital, and basilic veins.

Outcome Measures

Technical success was only achieved if the endoAVF was patent at the 1-day follow-up visit. Physiological suitability was achieved once the endoAVF recorded brachial artery flow of at least 500 ml/min and at least 4 mm vein diameter (as measured by duplex ultrasound and reported by the study site) or successful 2-needle cannulation for dialysis occurred. Cannulation success of the endoAVF was achieved at the first dialysis session delivered via 2-needle cannulation. Functional cannulation success was achieved after successive 2-needle cannulation for at least two-thirds of the dialysis sessions within 1 month;

Table II. Baseline patient characteristics ($n = 32$)[a]

Characteristic	Value
Demographics	
Age, years	51 ± 13
Male sex	31 (97)
Hispanic ethnicity	32 (100)
Body mass index, kg/m^2	26 ± 3
Comorbidities	
Hypertension	27 (90)[b]
Diabetes	17 (53)
Congestive heart failure (NYHA I or II)	2 (7)[c]
Hemodialysis access status	
Central venous catheter	31 (97)
Predialysis	1 (3)
AV fistula or AV graft	0

AV, arteriovenous; NYHA, New York Heart Association.
[a]Values are mean ± standard deviation, or *n* (%).
[b]Data available on 30 patients.
[c]Data available on 28 patients.

time to cannulation was defined as the duration between endoAVF creation and the first occurrence of 2-needle cannulation. Primary and cumulative patencies were defined per Society of Vascular Surgery guidelines.[25] Device or procedure-related serious adverse events were defined as events associated with the application of the device or performance of the procedure that resulted in death, serious deterioration in health resulting in death, permanent impairment, and/or a need for an intervention or hospitalization. All adverse events were adjudicated by an independent panel of physicians that comprised the studies Clinical Evaluation Committee.

Statistical Analysis

Continuous variables were reported as mean and standard deviation. Categorical variables were reported as counts and percentages. Time-to-event data were analyzed with Kaplan-Meier methods and life tables. Statistical analyses were performed using SAS version 9.4 (SAS Institute, Cary, NC). Patient deaths unrelated to the device or procedure before the 90-day follow-up were censored from the analysis of successful cannulation and functional cannulation.

RESULTS

Patient Recruitment and Follow-up

From May to November 2016, during four separate visits to the study center, four independent operators performed the endoAVF procedure on 32 patients. The baseline characteristics of the patients are described in Table II. Only one patient was not yet on dialysis at the time of the procedure; 97% (31/32) were receiving dialysis via a CVC. No patient reported a history of previous surgical AVF or arteriovenous graft (AVG). During the study, five patient deaths occurred for reasons unrelated to the device or procedure. One patient death was associated with Dengue fever and pneumonia/influenza type B, one with sepsis related to a CVC, one with suspected myocardial infarction, and two with unknown causes. Patient disposition through the 180-day follow-up period is shown in Figure 4.

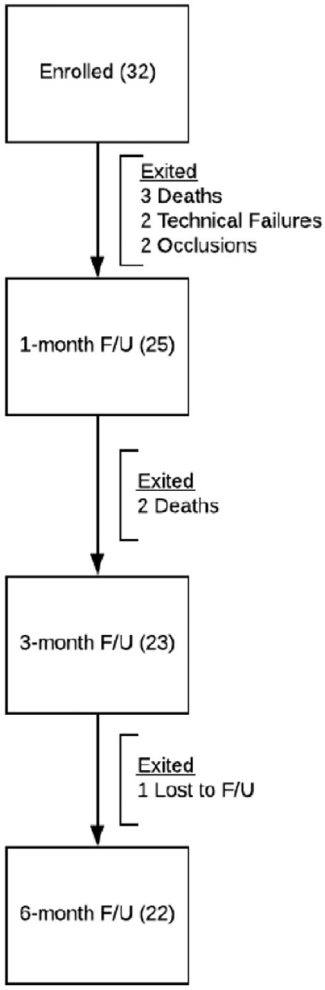


Fig. 4. Patient disposition through 6 months of follow-up.

Procedural Outcomes

An endoAVF was successfully created in all 32 patients, with 20 fistulas created between the radial artery and radial vein and 12 created between the ulnar artery and ulnar vein. Wrist access was used

for 72% (23/32) of the procedures for the arterial catheter and 59% (19/32) of the procedures for the venous catheter. Access artery diameters averaged 3.2 ± 1.1 mm and access vein diameters averaged 2.9 ± 0.8 mm. Average AVF creation site diameters were 3.1 ± 0.7 mm and 2.7 ± 0.7 mm for the target artery and vein, respectively. No device-related serious adverse events were reported. One patient experienced a procedure-related serious adverse event because of a venous guidewire perforation that resulted in extravasation for an overall procedure-related serious adverse event rate of 3% (1/32). The perforation was successfully managed with a stent graft that covered the endoAVF. Another patient experienced a thrombosis within 24 hours of treatment and the subsequent intervention failed to restore patency for an overall technical success of 94% (30/32).

Patency and Interventions

Primary and cumulative patencies through 6 months were 83% and 87%, respectively (Fig. 5). Aside from the two procedural failures, one patient underwent angioplasty because of low flow, and two patients experienced thrombosis within 30 days of the procedure. One patient with thrombosis was converted to surgical AVF and the other patient received no intervention because a kidney transplant was scheduled. No other thrombotic events were observed throughout the course of the study. The overall intervention rate was 0.21 per patient-year.

Physiological Suitability, Cannulation, and CVC Removal

Target flow rates ≥500 ml/min and cannulation vessel diameters ≥4 mm for physiological suitability were achieved in 91% (29/32) of patients by the 90-day follow-up. The mean arterial flow rates were 751 ± 374 ml/min, 886.6 ± 498.2 ml/min, and 845.2 ± 428.6 ml/min at the 1-day, 30-day, and 180-day follow-up visits, respectively.

Successful cannulation was achieved in 78% (21/27) of patients by 90 days, with mean time to cannulation of 43 ± 14 days, excluding five prior patient deaths unrelated to the device or procedure. Four patients had their endoAVFs abandoned (two procedural failures and two thrombotic occlusions) and two patients had endoAVFs that remained patent but were not successfully cannulated by the end of the study period. The veins used to deliver dialysis were the cephalic (15/21), median cubital (14/21), and basilic (10/21). For 2-needle cannulation, patients either used only the cephalic vein (6/21), only the median cubital and basilic veins (6/21), or split-needle configuration with one needle in the cephalic and the second in the median cubital/basilic vein (9/21). All median cubital and basilica vein cannulations were performed in the superficial vein segment (proximal forearm to the distal upper arm) without the need for elevation or transposition procedures.

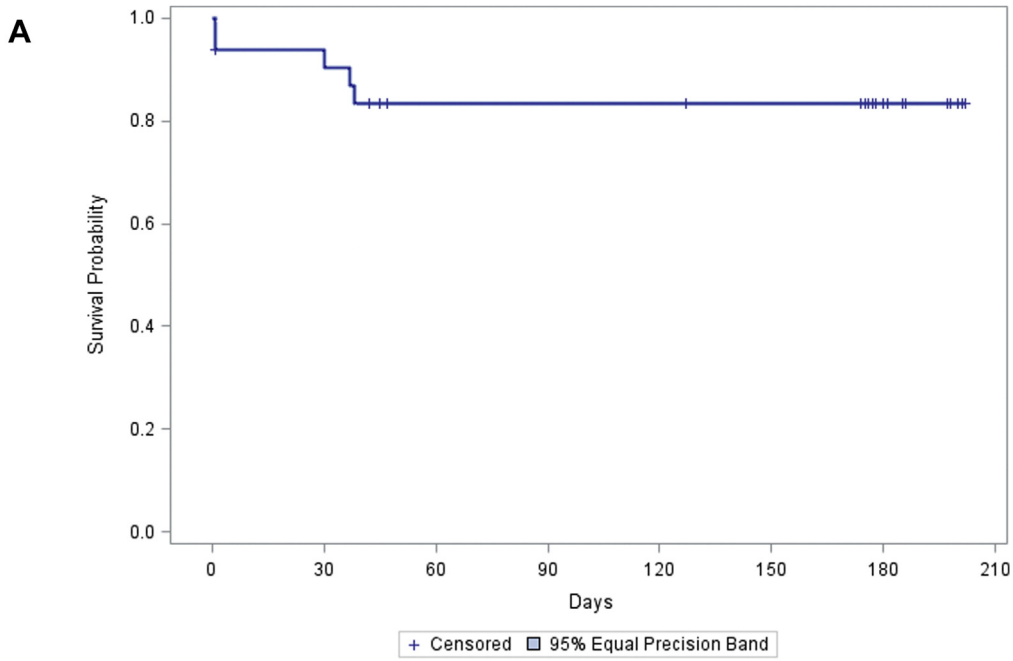
Functional cannulation was achieved in 95% (20/21) of the patients that were successfully cannulated for an overall rate of 74% (20/27). One patient experienced intermittent 2-needle cannulation in combination with using 1-needle cannulation inflow plus CVC outflow. This patient was cleared to begin successive 2-needle cannulation at the 180-day follow-up but did not achieve functional cannulation during the study period. All patients who achieved functional cannulation had their CVCs removed before the 180-day follow-up for a CVC removal rate of 74% (20/27).

DISCUSSION

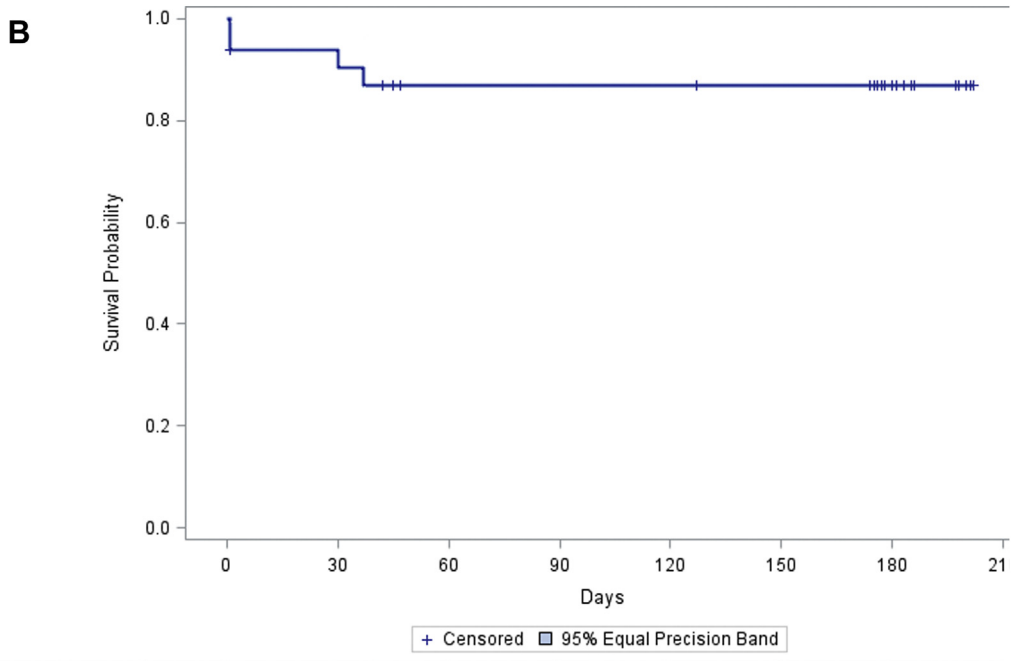
This study presents evidence that suggests an endoAVF can be safely and effectively created with a minimally invasive procedure using the WavelinQ 4F endoAVF system. An endoAVF was successfully created in the proximal forearm for all 32 patients, with only one patient (3%; 1/32) experiencing a device- or procedure-related serious adverse event. Successful 2-needle cannulation was achieved in 78% (21/27) by 90 days, with mean time to cannulation of 43 ± 14 days. CVCs were removed in 69% (9/16) of patients at 90 days and 74% (20/27) of patients at 180 days. The primary and cumulative patencies through 6 months were 83% and 87%, respectively, with an intervention rate of 0.21 per patient-year.

The 4 Fr endoAVF system demonstrated technical and procedural success rates consistent with previous generation device outcomes and similar to technical success rates reported in other prospective studies with the 6 Fr WavelinQ system (97–98%).[16,18] When considering surgical AVF creation, procedural failures are rare but not unexpected, with rates ranging from 1% to 12%.[27–30] Similarly, two procedural failures were reported using the 4 Fr endoAVF system. Therefore, the data suggest that technical and procedural success for the 4 Fr endoAVF device was comparable to both the previous generation endoAVF device and to surgical AVF creation.

No device-related serious adverse events were observed in the study, and only one procedure-



Interval (days)	0	1-30	31-60	61-90	91-120	121-150	151-180	181-210
At Risk	32	32	26	21	21	21	20	10
Censored	0	3	3	0	0	1	10	10
Failures	0	3	2	0	0	0	0	0
Success Rate	100.0%	90.3%	83.3%	83.3%	83.3%	83.3%	83.3%	83.3%
Greenwood SE	0.0%	5.3%	6.8%	6.8%	6.8%	6.8%	6.8%	6.8%



Interval (days)	0	1-30	31-60	61-90	91-120	121-150	151-180	181-210
At Risk	32	32	26	22	22	22	21	11
Censored	0	3	3	0	0	1	10	11
Failures	0	3	1	0	0	0	0	0
Success Rate	100.0%	90.3%	86.8%	86.8%	86.8%	86.8%	86.8%	86.8%
Greenwood SE	0.0%	5.3%	6.2%	6.2%	6.2%	6.2%	6.2%	6.2%

Fig. 5. Primary **(A)** and cumulative **(B)** patency rates with endoAVF through 6 months of follow-up.

related serious adverse event was observed, which compares favorably to previously reported rates.[22–24] The previous 6 Fr device required access from the brachial artery, which was associated with nearly half of the serious adverse related events.[22] The available option to access the arteries from the wrist in this study may have improved the safety relative to the required brachial artery access from the previous generation device. The safety profile is accentuated by the fact that this was the first use of the 4 Fr endoAVF system for all four operators and two of the operators had no prior experience with creating an endoAVF using the 6 Fr version. The endoAVF procedure with the new generation device appears intuitive for new operators to learn, with very little learning curve. In general, decreasing device profile has been correlated with an improved safety profile for arterial arm access in a variety of procedures.[31,32]

A key benefit of the 4 Fr device profile was the successful use of additional vessel access options from the wrist and the addition of another endoAVF location between the radial artery and radial vein. In this study, arterial access was primarily gained from the wrist and hemostasis was achieved through manual compression for all patients. In patients with brachial artery access, manual compression was used to achieve hemostasis of the brachial artery. The additional access sites at the wrist enable more options for the physician to plan the best procedural access point and endoAVF creation site for each individual patient. The expanded options may allow physicians the ability to create an endoAVF in patients who would otherwise be anatomically ineligible for the procedure, thereby expanding the eligible patient population.

The eventual clinical success of the endoAVFs was demonstrated by the high rate of functional cannulation success. Functional cannulation is a key metric for determining clinical success of an AVF as it demonstrates the utility of the newly created vascular access to facilitate adequate hemodialysis. The functional cannulation rate of 74% (20/27) in this study was comparable to prior reports for both endoAVF and surgical AVF rates.[22,33,34] The evidence from this study supports the ability of the endoAVF to create functional vascular access for hemodialysis patients at comparable rates to surgical AVFs.

The ability to achieve functional cannulation led to a high rate of CVC removal in the study population. All endoAVF patients who achieved functional cannulation had their CVC removed for an overall rate of 74% (20/27) at the 180-day follow-up, leaving 26% of patients with a CVC at 6 months. CVC removal is critical to minimize the risk of serious complications to dialysis patients and is one of the focal points of the national Fistula First Catheter Last Workgroup Coalition.[35] In the United States, most hemodialysis patients initiate dialysis on a CVC and roughly 30% refuse surgical AVF,[36] some due to factors such as fear of arm disfigurement or surgical fatigue. Permanent CVCs are widely accepted as the last option for vascular access because of high rates of infection and risk of mortality relative to surgical AVF.[4,6,7] Removal of CVCs also has broader health care cost implications. A recent study of Medicare patients reported that the cost of remaining on a CVC was 3 to 4 times greater than receiving dialysis through a patent AVF.[2] The potential impact of the endoAVF system in helping to facilitate timely CVC removal on the dialysis population cannot be understated.

Another potential benefit of the endoAVF over surgical AVF is the reduced need for interventions to mature access and maintain function. Surgical AVFs often require additional procedures to prepare the vascular access circuit for dialysis. Mechanistically, trauma to vessels during surgical creation has been associated with negative remodeling that leads to flow-limiting early stenosis and necessitates intervention.[34,37,38] A high proportion of patients with surgical AVF require an intervention outside of planned vein superficializations. For example, the Hemodialysis Fistula Maturation study reported that 39% of patients with surgical AVF who achieved functional cannulation required at least one intervention.[34] Lee et al. reported that 51% of patients were unable to use AVF in 6 months and 42% of the successful AVFs required at least one intervention to make them useable.[39] Furthermore, Thamer et al. reported that 83% of patients with AVF had at least one intervention in the first year.[2] By contrast, the endoAVF procedure minimizes vessel trauma, potentially lessening the stimulus for negative remodeling that leads to frequent reinteventions.[22] Of the patients who achieved functional cannulation in this study, none required an intervention. The potential benefit of a lower intervention rate for the endoAVF has been previously explored via a comparison with both propensity score matched Medicare and United States Renal Data System cohorts of patients with surgical AVF.[16,17] That comparison reported a significantly lower rate of interventions and cost of care within the first year of creation with endoAVF relative to surgical AVF. In addition, the risk of loss of cumulative patency increases once a patient's AVF has experienced an intervention.[40,41] Minimizing the need for interventions may help maintain the high cumulative patency reported here and in previous

studies.[22,24] Finally, a lower intervention rate has the potential to minimize the impact of surgical fatigue cited by some patients as the primary reason to choose a permanent CVC over a new surgical AVF.[21] Of note, no elevation or transposition procedures were required in this study, but other dialysis populations may require such procedures to superficialize veins sufficiently for cannulation. For example, Lok et al. reported 8% (5/60) of endoAVF patients required a transposition in a population comprising citizens of Canada, Australia, and New Zealand.[22] If a patient would require an elevation or transposition procedure for a surgical AVF creation using the cephalic or basilic vein, they would still likely require one for an endoAVF creation, as well.

The potential benefits of endoAVF warrant its consideration as a primary option to create functional access in patients who are not ideal candidates for radiocephalic fistulae. The location of an endoAVF, central to the radiocephalic creation site but peripheral to the Gracz creation site, is a new anatomic location for AVF creation that has not been readily used surgically. When considering access options for a patient, those who are ideally suited for radiocephalic fistula placement (patients with a $\geq$2 mm diameter radial artery with no significant atherosclerosis or calcification at the wrist and a $\geq$2.5 mm diameter cephalic vein at the wrist with at least a 10 cm straight length) will still be well served with a surgical radiocephalic AVF. However, patients who do not meet the ideal radiocephalic standards have been shown to have a higher likelihood of success with a more central option.[42] The introduction of the endoAVF procedure provides nonideal as well as failed radiocephalic AVF patients with an option to receive a functional AVF while preserving more central options for future access, such as a proximal forearm Gracz or upper arm brachiocephalic or brachiobasilic surgical AVF. The endoAVF is not expected to replace or compete with surgical AVF creation but instead to provide a new anatomic location for AVF placement in addition to current surgical AVF options.

There were a few limitations associated with this study that warrant further discussion. First, single-center study designs tend to be limited in their scope to adequately compare the outcomes to multicenter studies because of regional differences in patient population, operator skill set, cannulation practices, and access to health care. However, the patient population treated represented common comorbidities of the U.S. patient population, such as a high proportion of diabetes and hypertension. In addition, four different operators participated independently to minimize the potential operator bias and support the validity of multicenter study comparisons. Second, the follow-up time was limited to 6 months. Although longer term data would be helpful to verify the durability, in particular, for key clinical metrics such as functional patency, the follow-up time of 6 months may be sufficient to draw conclusions on clinical metrics such as safety, physiological suitability, functional cannulation, and patency as the outcomes reported here are consistent with previously reported endoAVF studies.[22–24] Finally, screen failures were not captured within the study protocol to assess the percentage of patients who were anatomically suitable for the procedure using the WavelinQ™ 4F EndoAVF System. As a reference for estimating patient anatomic eligibility, Lok et al. reported in the multicenter NEAT study assessing the 6Fr version of the device that 25% (46/183) of patients screened for enrollment did not meet the anatomical eligibility for the procedure.

CONCLUSIONS

Initial experience with a 4 Fr endoAVF system allowed for multiple access and fistula creation site options to tailor the procedure to individual patient anatomy. Furthermore, excellent procedural success was observed with a low rate of complications, resulting in high rates of functional cannulation success and patency without the need for additional postcreation interventions. Overall, the outcomes are comparable to the previous generation endoAVF technology with a potentially improved safety profile because of the utilization of arteries at the wrist for access.

The authors thank Larry Miller, PhD, for editorial assistance.

REFERENCES

1. Malas MB, Canner JK, Hicks CW, et al. Trends in incident hemodialysis access and mortality. JAMA Surg 2015;150:441–8.
2. Thamer M, Lee TC, Wasse H, et al. Medicare costs associated with arteriovenous fistulas among US hemodialysis patients. Am J Kidney Dis 2018;72:10–8.
3. Lok CE, Sontrop JM, Tomlinson G, et al. Cumulative patency of contemporary fistulas versus grafts (2000–2010). Clin J Am Soc Nephrol 2013 2013;8:810–8.
4. Woo K, Yao J, Selevan D, et al. Influence of vascular access type on sex and ethnicity-related mortality in hemodialysis-dependent patients. Perm J 2012;16:4–9.
5. Ng YY, Hung YN, Wu SC, et al. Characteristics and 3-year mortality and infection rates among incident hemodialysis patients with a permanent catheter undergoing a first

vascular access conversion. Clin Exp Nephrol 2014;18:329–38.
6. Ravani P, Quinn R, Oliver M, et al. Examining the association between hemodialysis access type and mortality: the role of access complications. Clin J Am Soc Nephrol 2017;12:955–64.
7. Lukowsky LR, Kheifets L, Arah OA, et al. Patterns and Predictors of early mortality in incident hemodialysis patients: new insights. Am J Nephrol 2012;35:548–58.
8. Peters VJ, Clemons G, Augustine B. ''Fistula First'' as a CMS breakthrough initiative: improving vascular access through collaboration. Nephrol Nurs J 2005;32:686–7.
9. USRDS. U.S. Renal Data System. USRDS 2016 Annual Data Report: Atlas of Chronic Kidney Disease and End-Stage Renal Disease in the United States, National Institutes of Health. Chapter 1: Incidence, Prevalence, Patient Characteristics, and Treatment Modalities. Bethesda, MD: National Institute of Diabetes and Digestive and Kidney Diseases, 2016.
10. Kinney R. 2005 annual report: ESRD clinical performance measures project. Am J Kidney Dis 2006;48:S1–106.
11. Lopez-Vargas PA, Craig JC, Gallagher MP, et al. Barriers to timely arteriovenous fistula creation: a study of providers and patients. Am J Kidney Dis 2011;57:873–82.
12. Saran R, Li Y, Robinson B, et al. US renal data system 2014 annual data report: epidemiology of kidney disease in the United States. Am J Kidney Dis 2015;65:A7.
13. Asif A, Roy-Chaudhury P, Beathard GA. Early arteriovenous fistula failure: a logical proposal for when and how to intervene. Clin J Am Soc Nephrol 2006;1:332–9.
14. Dember LM, Beck GJ, Allon M, et al. Effect of clopidogrel on early failure of arteriovenous fistulas for hemodialysis: a randomized controlled trial. JAMA 2008;299:2164–71.
15. Al-Jaishi AA, Oliver MJ, Thomas SM, et al. Patency rates of the arteriovenous fistula for hemodialysis: a systematic review and meta-analysis. Am J Kidney Dis 2014;63:464–78.
16. Yang S, Lok C, Arnold R, et al. Comparison of post-creation procedures and costs between surgical and an endovascular approach to arteriovenous fistula creation. J Vasc Access 2017;18:8–14.
17. Arnold R, Han Y, Balakrishnan R, et al. Evaluation of hemodialysis arteriovenous fistula interventions and associated costs: comparison between surgical and endovascular AV fistula. J Vasc Interv Radiol 2018;29:1558–1566.e2.
18. Biuckians A, Scott EC, Meier GH, et al. The natural history of autologous fistulas as first-time dialysis access in the KDOQI era. J Vasc Surg 2008;47:415–21. discussion: 20-21.
19. Falk A. Maintenance and salvage of arteriovenous fistulas. J Vasc Interv Radiol 2006;17:807–13.
20. Rooijens PP, Burgmans JP, Yo TI, et al. Autogenous radial-cephalic or prosthetic brachial-antecubital forearm loop AVF in patients with compromised vessels? A randomized, multicenter study of the patency of primary hemodialysis access. J Vasc Surg 2005;42:481–6. discussions: 7.
21. Chaudhry M, Bhola C, Joarder M, et al. Seeing eye to eye: the key to reducing catheter use. J Vasc Access 2011;12:120–6.
22. Lok CE, Rajan DK, Clement J, et al. Endovascular proximal forearm arteriovenous fistula for hemodialysis access: results of the prospective, multicenter Novel Endovascular Access Trial (NEAT). Am J Kidney Dis 2017;70:486–97.
23. Radosa CG, Radosa JC, Weiss N, et al. Endovascular creation of an arteriovenous fistula (endoAVF) for hemodialysis access: first results. Cardiovasc Intervent Radiol 2017;40:1545–51.
24. Rajan DK, Ebner A, Desai SB, et al. Percutaneous creation of an arteriovenous fistula for hemodialysis access. J Vasc Interv Radiol 2015;26:484–90.
25. Sidawy AN, Spergel LM, Besarab A, et al. The Society for Vascular Surgery: clinical practice guidelines for the surgical placement and maintenance of arteriovenous hemodialysis access. J Vasc Surg 2008;48:2S–25S.
26. The National Kidney Foundation. NKF-DOQI clinical practice guidelines for vascular access. National Kidney Foundation-Dialysis Outcomes Quality Initiative. Am J Kidney Dis 1997;30:S150–91.
27. Ayez N, van Houten VA, de Smet AA, et al. The basilic vein and the cephalic vein perform equally in upper arm arteriovenous fistulae. Eur J Vasc Endovasc Surg 2012;44:227–31.
28. Harper SJ, Goncalves I, Doughman T, et al. Arteriovenous fistula formation using transposed basilic vein: extensive single centre experience. Eur J Vasc Endovasc Surg 2008;36:237–41.
29. Ferring M, Claridge M, Smith SA, et al. Routine preoperative vascular ultrasound improves patency and use of arteriovenous fistulas for hemodialysis: a randomized trial. Clin J Am Soc Nephrol 2010;5:2236–44.
30. Kats M, Hawxby AM, Barker J, et al. Impact of obesity on arteriovenous fistula outcomes in dialysis patients. Kidney Int 2007;71:39–43.
31. Mirza AK, Steerman SN, Ahanchi SS, et al. Analysis of vascular closure devices after transbrachial artery access. Vasc Endovascular Surg 2014;48:466–9.
32. Parviz Y, Rowe R, Vijayan S, et al. Percutaneous brachial artery access for coronary artery procedures: feasible and safe in the current era. Cardiovasc Revasc Med 2015;16:447–9.
33. Irish AB, Viecelli AK, Hawley CM, 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 2017;177:184–93.
34. Cheung AK, Imrey PB, Alpers CE, et al. Intimal hyperplasia, stenosis, and arteriovenous fistula maturation failure in the hemodialysis fistula maturation study. J Am Soc Nephrol 2017;28:3005–13.
35. Lacson E Jr, Lazarus JM, Himmelfarb J, et al. Balancing fistula first with catheters last. Am J Kidney Dis 2007;50:379–95.
36. Casey JR, Hanson CS, Winkelmayer WC, et al. Patients' perspectives on hemodialysis vascular access: a systematic review of qualitative studies. Am J Kidney Dis 2014;64:937–53.
37. Roy-Chaudhury P, Sukhatme VP, Cheung AK. Hemodialysis vascular access dysfunction: a cellular and molecular viewpoint. J Am Soc Nephrol 2006;17:1112–27.
38. Lee T, Roy-Chaudhury P. Advances and new frontiers in the pathophysiology of venous neointimal hyperplasia and dialysis access stenosis. Adv Chronic Kidney Dis 2009;16:329–38.
39. Lee T, Qian J, Thamer M, et al. Tradeoffs in vascular access selection in Elderly patients initiating hemodialysis with a catheter. Am J Kidney Dis 2018;72:509–18.
40. Lee T, Ullah A, Allon M, et al. Decreased cumulative access survival in arteriovenous fistulas requiring interventions to promote maturation. Clin J Am Soc Nephrol 2011;6:575–81.
41. Harms JC, Rangarajan S, Young CJ, et al. Outcomes of arteriovenous fistulas and grafts with or without intervention before successful use. J Vasc Surg 2016;64:155–62.
42. Kim JJ, Gifford E, Nguyen V, et al. Increased use of brachiocephalic arteriovenous fistulas improves functional primary patency. J Vasc Surg 2015;62:442–7.