Preoperative ultrasound improves patency and cost effectiveness in av fistula surgery

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ABSTRACT

Objective: We aimed to compare routine preoperative color-coded duplex ultrasound (DUS) to clinical examination (CE) alone in surgery for arteriovenous fistula (AVF) with special emphasis on long-term outcomes and cost effectiveness.

Methods: All patients undergoing an AVF formation or revision between January 1, 2011, and December 31, 2016, at our tertiary referral center were subject to analysis. Routine DUS was performed in 114 patients and CE alone in 217 patients. Primary and secondary patency, the need for revision or reintervention to obtain patency, and individual as well as overall costs were analyzed.

Results: Primary patency rate was higher in AVF after DUS compared with CE alone at 62% vs 26% ($P < .05$), respectively. Patients receiving DUS had significantly lower rates of revision and revisions per patient when compared with CE (25.4% vs 59.4% [$P < .0001$]; 0.36 ± 0.71 vs 1.06 ± 1.55 [$P < .0001$], respectively). Costs per patient were significantly lower in the DUS group compared with CE at 4074€ vs 6078€ ($P < .0001$).

Conclusions: We were able to show that patients receiving preoperative DUS showed higher patency rates and needed fewer revisions. Standard preoperative ultrasound examination is an easy tool to improve outcomes and cost effectiveness in AVF surgery. (J Vasc Surg 2018;■:1-6.)

Keywords: Arteriovenous fistula; Preoperative ultrasound; Outcome; Cost effectiveness

The prevalence of patients with end-stage renal disease in need of dialysis has been increasing steadily. The global incidence of hemodialysis has risen from 44 individuals per million population to 93 per million population in the past two decades.[1] Historically, clinical examination (CE) was the only tool to determine the anatomical suitability for primary arteriovenous fistula (AVF) surgery. It was not until 1998, when the use of duplex ultrasound (DUS) examination was first described for this indication.[2,3] As a consequence, DUS was postulated to increase primary patency rates in AVF formation.[3,4] However, there is considerate discrepancy in results reported on primary failure rates and their reduction through DUS.[5,6]

The aim of the present study was to assess the outcomes of AVF surgery in patients with CE alone compared with routine preoperative DUS and to analyze the cost effectiveness.

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METHODS

All patients with AVF surgery performed between January 1, 2011, and June 30, 2016, at our tertiary referral center were analyzed. CE alone was performed in 217 patients from 2011 to mid-2013. Routine preoperative DUS was performed in 114 patients beginning from mid-2013. The study was conducted according to the recommended standards for reports dealing with arteriovenous hemodialysis accesses and fistula nomenclature was used accordingly.[7]

Preoperative assessment

All examinations were performed in a standardized matter by a vascular and/or transplant surgery consultant.

CE group (2011-2013). CE included the Allen test, palpation of brachial artery pulse. Venous continuity and patency of the superficial forearm and antecubital veins were documented with a tourniquet applied. The quality of the vessels, approximate diameter and extensibility before and after congestion were assessed to rule out venous fibrosis.

DUS group (2013-2016). DUS was always performed in addition to CE. DUS patients underwent duplex vessel mapping with a 10-5 MHz linear transducer (SM175917Bx4 Vivid E, GE Healthcare, Little Chalfont, UK). In the transverse view, imaging of arteries and veins to their full extent was performed and the anteroposterior diameter measurement was performed. A minimum of 1.6 mm arterial inner edge to inner edge diameter, 2.5 mm venous diameter on the forearm, and 3.0 mm venous diameter on the upper arm were considered appropriate for AVF formation.[3,8-10] Peak systolic velocity determination was performed at the radial and brachial artery. Venous patency, thrombosis, and stenosis were assessed by color flow and compression. The most distal site on the nondominant arm was primarily considered for AVF formation. The dominant arm was examined only if the nondominant arm proved not suitable.

Surgery was generally performed with local anesthesia; however, general anesthesia was used at the surgeon's discretion in selected cases.

Standard demographic data, well-known risk factors for AVF surgery (arterial hypertension, diabetes mellitus, coronary artery disease, peripheral vascular disease, cerebrovascular disease, thrombotic and embolic events, medical and drug history), procedure-related data, previous vascular access history, and intervention/revision rates were prospectively recorded and analyzed in a retrospective manner. The presence of peripheral vascular disease was graded according to the Fontaine classification. Coronary artery disease was defined by a history of angina pectoris or a known event of myocardial infarction. All patients received surgical care, dialysis, and surgical follow-up at our center.

Study outcomes

Individual patient outcomes were assessed. Primary fistula patency, need for surgical or radiologic intervention, and time to AVF maturation were recorded. Fistula patency was verified on postoperative day 7 in the outpatient clinic and hemodialysis was initiated when the Kidney Disease Outcomes Quality Initiative Rule of Six criteria were met (6 mm AVF diameter and a minimum flow of 600 mL/min).[11] Functional patency was regularly assessed at dialysis. Fistulae not achieving patency or presenting with inadequate initiation of maturation were considered as primary failures as described in the classification of Al-Jaishi et al.[12]

Cost effectiveness of AVF formation

Individual cost calculation for standard AVF surgery, postoperative radiologic interventions, surgical revisions, and need for admission was performed according to the governments standardized performance-based hospital financing (LKF). AVF surgery and achievement of primary patency without further intervention were considered to be baseline costs. Individual and overall costs were calculated comparing the DUS and EC groups.

Statistical analysis

The sample size calculation was based on the condition to detect a 15% difference in a given parameter with a 1.5-fold standard deviation, a confidence level of 0.05 and power of 0.8, the study would require 100 patients in each group. A 10% dropout rate was taken in consideration.

Continuous variables were described as mean values and standard deviations. Comparison was performed using *t*-tests or Mann-Whitney *U* tests where applicable. Categorical variables were described as absolute and relative frequencies and compared by χ^2 tests with Yates' correction. Patency rates were described by Kaplan-Meier survival analysis. $P < .05$ was considered significant. Statistical analysis was performed using SPSS version 24 (IBM, New York, NY).

The study was approved by the local ethics review committee of the Medical University Vienna (EC 1410/2012) conducted according to the Declaration of Helsinki. All patients gave informed consent.

ARTICLE HIGHLIGHTS

- **Type of Research:** Single-center retrospective cohort analysis
- **Key Findings:** Creation of an arteriovenous fistula for hemodialysis resulted in improved primary patency (62% vs 26%; $P < .05$), a lower rate of revisions (25.4% vs 59.4%; $P < .001$), fewer revisions per patient (0.36 vs 1.061; $P < .0001$), and decreased costs when preoperative duplex ultrasound assessment was performed in 114 patients as opposed to clinical examination alone in 217 patients.
- **Take Home Message:** This study suggests that a preoperative duplex ultrasound examination improves arteriovenous fistula patency, durability, and cost effectiveness.

RESULTS

Between 2011 and 2016, 331 patients were included in this study. Routine preoperative ultrasound (DUS) was performed in 114 patients (34.4%) and CE alone (CE) in 217 patients (65.5%).

Demographic data and risk factors. Preoperative demographic data and risk factors of patients with DUS and CE are described in Table I. In the DUS group, male patients were predominant (70.2% male vs 58.1% female; $P = .031$) and coronary artery disease was found more frequently (36.8% males vs 24.0% females; $P = .015$). All other risk factors influencing outcome like peripheral arterial occlusive disease, diabetes, hyperlipidemia, congestive heart failure, and thromboembolic events were comparable between both groups. Median follow-up in the study population was 24.5 months (interquartile range, 10.8-49.9). No further differences were found between the two groups with regard to other demographic parameters.

In this cohort, 45.3% (n = 150) received autogenous radial-cephalic direct wrist accesses in end to side technique, 26.7% (n = 88) autogenous brachial-cephalic upper-arm direct accesses, and 28.1% (n = 93) other types of fistulas. In the DUS group, there were significantly more autogenous radial-cephalic direct wrist access compared with the CE group (56 [62%] vs 77 [40.5%]; $P = .001$). Autogenous brachial-cephalic upper arm direct accesses were evenly present in the DUS group vs the CE group (26%).

Table I. Demographic patient characteristics

Parameter	CE (n = 217)	DUS (n = 114)	*P* value
Age, years	58.74 (48.0-70.0)	60.68 (49.8-72.0)	.283[a]
Male sex	58.1	70.2	.031[b]
Diabetes mellitus	31.3	22.8	.124[c]
Hypertension	73.7	65.8	.161[c]
Hyperlipidemia	15.2	14.0	.871[c]
Peripheral arterial occlusive disease	16.5	14.9	.754[c]
Thrombotic and embolic events	20.3	12.3	.093[c]
Congestive heart failure	11.1	14.0	.479[c]
Coronary artery disease	24.0	36.8	.015[c]
Cerebrovascular disease	28.6	28.1	.999[c]
Statins	23.5	15.6	.438[c]
Antiaggregants/anticoagulants	64.7	56.3	.509[c]
Antihypertensive drugs	82.4	90.6	.375[c]
Autogenous radial-cephalic direct wrist access	40.5	62.0	.001[b]
Autogenous brachial-cephalic upper arm direct access	26.0	26.0	.967[b]
Revisions	59.0	25.0	<.0001[b]
Revisions per patient	1.06	0.368	<.0001[a]
Maturation time, days	82.0	92.6	.576[a]
Secondary AVF needed	21.7	13.0	.024[a]

AVF, Arteriovenous fistula; *CE,* clinical examination; *DUS,* duplex ultrasound.
Values are presented as median (quartile) or percentages.
[a] *t*-test.
[b] χ^2 test.
[c] Fisher exact test.

Table II. Vascular access characteristics

Parameter	CE (n = 217)	DUS (n = 114)	*P* value
Primary surgery			
Autogenous radial-cephalic direct wrist access	40.5	62.2	.001[a]
Autogenous brachial-cephalic upper-arm direct access	25.8	25.6	.999[a]
Others	33.7	12.2	.001
Autogenous brachial-basilic upper arm transposition	7.4	6.1	
Autogenous brachial-cubital upper arm direct access (Gracz)	6.9	5.2	
Prosthetic brachial-antecubital forearm loop access	12.9	0.9	
Autogenous radial-brachial indirect saphenous vein translocation	2.3		
Prosthetic femoral-femoral looped inguinal access	4.2		
Revisions			
Autogenous radial-cephalic direct wrist access revisions	68.8	32.1	<.0001[b]
Autogenous brachial-cephalic upper-arm direct access revisions	57.1	30.4	.045[b]

CE, Clinical examination; *DUS,* duplex ultrasound.
Values are presented as percentages.
[a] *t*-test.
[b] χ^2 test.

Diabetic patients were found to receive a higher rate of primary autogenous brachial-cephalic upper arm direct accesses than radial-cephalic direct wrist accesses (37.3% vs 30.7%, respectively; $P = .039$). Vascular access characteristics are shown in Table II.

Patency. The time until maturation after AVF was 82.0 ± 104.8 days in the CE group compared with 92.6 ± 100.3 days in the DUS group ($P = .576$). The primary failure rate within 72 hours according to the North American Vascular Access Consortium and Society for Vascular

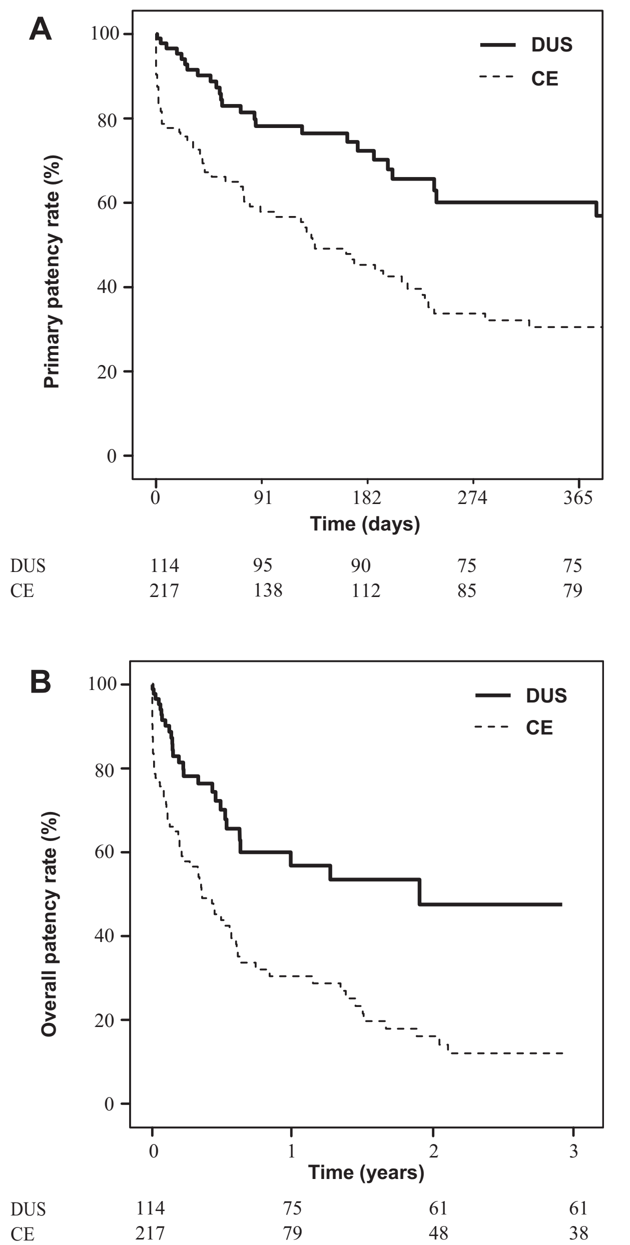

Fig. A, One-year primary patency rate: Duplex ultrasound (*DUS*) vs clinical examination (*CE*). **B,** Overall patency rate: DUS vs CE.

Surgery definition[12] was evenly matched in both groups (12 [5.5%] vs 7 [6.1%]; $P = .583$). Autogenous brachial-cephalic upper arm direct accesses showed a significantly higher rate of maturation compared with autogenous radiocephalic direct wrist accesses (93.5% vs 75%; $P = .013$). The 1-year primary patency rates were described by Kaplan-Meier survival as DUS 61.6% vs CE 26% ($P = .045$; Fig, *A*). Overall patency rates for DUS vs CE were found to be 53.6% vs 8%, respectively ($P = .012$; Fig, *B*).

Revisions. In total, 158 patients (50.8%) required at least one revision after AVF formation. Patients receiving DUS had significantly fewer revisions compared with CE group (29 of 114 [25%] vs 129 of 217 [59%], respectively; $P < .0001$). Revisions per patient in DUS and CE were found to be 0.36 ± 0.71 vs 1.06 ± 1.55, respectively ($P < .0001$). Revisions were generally performed in a functioning access, in selected cases before initiation of first dialysis (DUS, 2 [1.8%]; CE, 9 [4.1%]; $P = .248$).

The most common interventions after AVF creation were thrombectomies (31% of all surgical interventions), followed by revision surgery (21%), percutaneous transluminal angioplasty (21%), and other surgical interventions (27%). All patients were admitted to the hospital in case of revision surgery.

Cost effectiveness. Based on our hospital and health financing, the estimated overall costs were 464,419.04€ in the DUS group compared with 1,318,830.98€ in the CE group. These results are equivalent to a significantly lower mean per patient cost of 4074€ in the DUS group compared with 6078€ in the CE group ($P < .0001$). Hospital admittance costs are included in this analysis. Table III shows the detailed cost analysis for DUS and CE patients.

DISCUSSION

Establishing a long-term functioning vascular access is essential for patients with end-stage renal disease in need of dialysis. The use of DUS was investigated in the past years aiming to improve primary and long-term patency rates. The reported results, however, were controversial and derived mainly from small retrospective analyses.[3,4,13] To the best of our knowledge, detailed data on cost effectiveness of long-term follow-up investigations are lacking so far.

This thorough investigation adds several key findings to the current literature. Most important, we found a significantly higher 1-year primary patency in the DUS group compared with the CE group. This is an effect that especially seems to pay off in the long-term follow-up, where 53% of patients in the DUS group show a patent AVF compared with only 8% in the CE group. These findings are in contrast with previously performed investigations, which failed to show significant differences in primary failure or complication rates.[14,15] In addition, these previous studies have to be interpreted with caution, because DUS was selectively used and results included only short-term follow-up data.

In the present study, significantly more radial-cephalic direct wrist accesses were prevalent in the DUS group. This finding is in concordance with previously published recommendations to select the most distal position feasible for surgery preserve the more proximal situated vessels for future AVF.[14,15]

The higher prevalence of distal fistulae was not associated with a higher primary failure rate in the DUS group (5.5% vs 6.1%; $P =$ NS); furthermore, it did not result in a higher rate of secondary AVF. These findings are in

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Table III. Arteriovenous fistula (*AVF*) surgery and revision cost analysis according to groups

	Costs
DUS	
AVF-formation - 1 patient	3000 × 1.17 × 0.848161 = 2977.05€
AVF-formation - DUS-Group (n = 114)	2977.04511 × 114 = 339,383.14€
1. Revision (n = 29)	2977.04511 × 29 = 86,334.31€
2. Revision (n = 11)	2977.04511 × 11 = 32,747.50€
3. Revision (n = 2)	2977.04511 × 2 = 5,954.09€
Overall (n = 114)	464,419.04€
Overall (n = 1)	464,419.038 / 114 = 4,073.85€ per patient
CE	
AVF formation, 1 patient	3000 × 1.17 × 0.848161 = 2977.05€
AVF formation, non-DUS group (n = 217)	2977.04511 × 217 = 646,018.79€
1. Revision (n = 128)	2977.04511 × 128 = 381,061.77€
2. Revision (n = 50)	2977.04511 × 50 = 148,852.26€
3. Revision (n = 19)	2977.04511 × 19 = 56,563.86€
4. Revision (n = 10)	2977.04511 × 10 = 29,770.45€
5. Revision (n = 6)	2977.04511 × 6 = 17,862.27€
6. and 7. Revision (n = 4)	2977.04511 × 4 = 11,908.18€
8. and 9. and 10. Revision (n = 6)	2977.04511 × 6 = 17,862.27€
11. and 12. and 13. Revision (n = 3)	2977.04511 × 3 = 8931.14€
Overall (n = 217)	1,318,830.98€
Overall (n = 1)	1,318,830.98 / 217 = 6077.56€ per patient

CE, Clinical examination; *DUS,* duplex ultrasound.

contrast with previous studies reporting significantly higher failure rates and need for more secondary fistulae.[4,14-16]

In our study, patients in the DUS group did not wait longer until functional dialysis when compared with clinically examined patients. In the current literature, AVF maturation times vary between 25 and 285 days, which is comparable with our data.[17-19] Premature first dialysis is known to have a 1.8 times higher relative risk for failure. Consequently, the need for early dialysis must be balanced against adequate maturation time. A minimum time span of 14 days has been postulated until the initiation of hemodialysis.[17] Our study cohort showed a mean maturation time of 92.6 days in patients in the DUS group. More than 80% of these patients underwent dialysis compared with 65.6% in other studies.[18] Thus, DUS had no longer maturation time and improved overall clinical success.

Patients in the DUS group had significantly fewer revisions to achieve patency when compared with CE group. This finding is of interest because our overall revision rate of 51% in the CE group was already low compared with current literature, where 1.3 revisions per patient are reported.[20] These results could be further improved by another reduction of about 30% in the DUS group.[3,21]

As a consequence, the overall costs in this cohort were decreased by more than 2000€ per patient. Based on an expected volume of 200 cases per year this translates to closely 400,000€ savings every year, providing a substantial economic impact.

Several limitations of the present study have to be addressed. Despite the prospective recruitment of patients, the analysis was performed in retrospective manner. Further, despite adequate sample calculation, we were not able to confirm the benefit of distal fistulae in the long run. Last, a cost analysis is specific for the respective health system and its comparability between different institutions might be subject to bias.

CONCLUSIONS

This large series evaluated standard DUS for AVF creation. We were able to show that DUS improved long-term outcomes and significantly decreased the need for revisions after AVF surgery. Both factors contributed to a marked improvement in cost effectiveness. Therefore, standard preoperative DUS can be recommended as a useful tool for planning AVF surgery in addition to CE.

AUTHOR CONTRIBUTIONS

Conception and design: GG, SR
Analysis and interpretation: GG, WE, CN, SR, GB
Data collection: GG, WE, LD, SR
Writing the article: GG, WE, LD
Critical revision of the article: GG, WE, CN, SR, GB

Final approval of the article: GG, WE, LD, CN, SR, GB
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GG and WE contributed equally and share co-first authorship.

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