Intraoperative Optimization of Radiocephalic Arteriovenous Fistula Surgery with Contemporary Techniques

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Background: This retrospective study assesses the impact of a standardized intraoperative procedure on radiocephalic arteriovenous fistula (RCAVF) outcomes, combining Transit Time Flow Measurement, papaverine administration, and an external support device.

Methods: Consecutive RCAVF patients were included at The Hague Medical Center between November 2021 and October 2024. Intraoperative flow rates, maturation rates, and (assisted) patency rates at 6 and 12 weeks, and 6 and 12 months were compared to a contemporary control group from the same center. Maturation was defined as a venous diameter $\geq$ 4 mm, a flow $\geq$ 500 mL/min, and a palpable thrill. The number of interventions and per-patient costs of interventions and procedures were also recorded and compared.

Results: The study compared 43 patients in the intervention group with 59 in a control group. The optimized procedure significantly improved intraoperative flow rates (210 ± 89 mL/min vs. 163 ± 85 mL/min, $P = 0.008$) and maturation rates at 6 weeks (77% vs. 43%, $P = 0.002$) and 12 weeks (91% vs. 59%, $P = 0.003$). Males showed higher overall maturation rates (66% vs. 38%, $P = 0.030$). However, no significant differences were found in primary patency at 12 months, nor in the average number of interventions per patient. There was a trend toward better assisted patency in the optimized procedure group at 12 months. The intervention group had significantly higher average costs per patient (€5858.77 vs. €4148.89, $P = 0.002$).

Conclusion: The optimized RCAVF procedure enhances intraoperative flow and early maturation rates, with the most notable effects in the initial postoperative months. Further research is needed to determine the long-term benefits and cost-effectiveness.

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Data availability: Data are available upon reasonable request by contacting the corresponding author.

The first two authors contributed to the preparation of this article in the same way.

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Study compares 43 optimized procedure patients to 59 control.

Optimized radiocephalic fistula procedure boosts 6-week maturation rates.

No significant unassisted patency differences found between groups.

Data shows limited long-term benefits of the optimization.

Contemporary techniques may enhance early maturation in arteriovenous fistulas.

INTRODUCTION

Radiocephalic arteriovenous fistulas (RCAVFs) remain the vascular access of choice for dialysis patients.[1,2] These RCAVFs provide durable autologous access with limited occurrence of excessively high flow,[1,2] hemodialysis access–induced ischemia,[3] or aneurysm formation.[4] However, compared to more proximal arteriovenous fistulas (AVFs), RCAVFs have lower maturation rates ranging from 56 to 77% in The Netherlands.[5–11] Globally, RCAVF maturation rates have also remained poor,[12] often necessitating interventions to achieve functionality.[2,13]

Several methods to improve maturation have been described in studies of variable size and quality. For example, the application of the vasodilator papaverine directly upon the anastomosis immediately after creation has been suggested to shorten maturation time by 1 week.[14] Second, monitoring intraoperative blood flow by Transit Time Flow Measurements (TTFMs) may aid in predicting maturation.[10] AVFs with insufficient flow can be widened through arterial dilation with an olive-shaped probe during index surgery[15] or surgically rectified, and followed more carefully. Recently, more evidence has suggested that an external support device around the anastomosis site may aid maturation and prevent stenosis formation by optimizing the anastomotic angle and local hemodynamic conditions.[16,17] Such a device is placed around the vein after ligation, and positioned in place (around the anastomosis and extending over the proximal outflow) after creating the AVF. It thereby creates a rigid support to maintain the anastomotic angle and flares the outflow to create a more uniform flow profile. Figure 1 shows the three optimization techniques used in this study. As such methods may individually provide merit, integrating multiple modalities in a standardized RCAVF procedure could yield superior results. Although this may increase procedural costs of RCAVF placement, the combination of such modalities may also hold promise for ultimately reducing the overall costs of AVF care by reducing the need for costly interventions.[2]

The presented study aims to retrospectively evaluate the effect of a standardized RCAVF procedure on AVF maturation and patency, including the intraoperative local application of papaverine and dilation of low-flow fistulas, and the utilization of an external support device. We assessed 12-month patency and 12-month estimated AVF maintenance costs versus a historic RCAVF control group[10] from the same center in The Netherlands.

METHODS

Subjects and Study Design

Consecutive patients receiving an RCAVF with the optimization modalities between November 2021 and October 2024 were identified and included in the study. Patient demographics, medical history, antithrombotic therapy, type of anesthesia, and preoperative and postoperative vessel diameters were collected. Data on interventions and functional status at 6 and 12 weeks, and 6 and 12 months were also collected. A previously published, historic control cohort from the same center with patients included between January 2017 and December 2021[10] was used for statistical comparison. The research board of the Haaglanden Medical Center approved this study.

Surgical Procedure

Nondominant arm RCAVFs were the preferred type of vascular access. Through ultrasound and doppler imaging, feasibility of placing such fistulas was assessed by measuring vessel diameters with and without a tourniquet. Patients were considered eligible for RCAVF surgery when the internal diameters of the cephalic vein and radial artery were at least 2 mm. Surgery was performed preferentially under local brachial plexus block. TTFM was used as a predictive measure as described previously.[10] In the intraoperative optimization group, AVFs with an intraoperative flow of less than 160 mL/min received arterial dilation of the juxta-anastomotic site (max. 2 cm length in either direction) with an olive-shaped probe of up to 2.5 mm and blood pressure was medicinally increased for

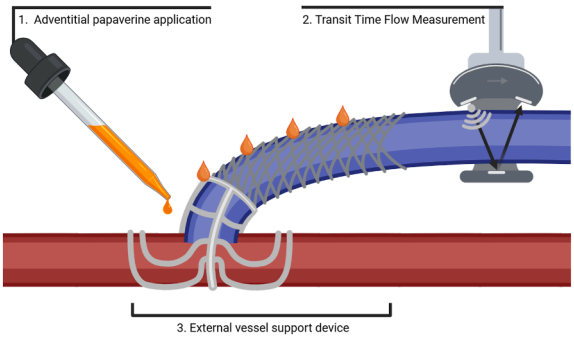

Fig. 1. Overview of the surgical modalities included in the arteriovenous fistula surgery of the intervention group. (1) Application of papaverine to the adventitia, (2) Transit Time Flow Measurement and arterial dilation of low-flow fistulas, and (3) an external vessel support device.

the first several postoperative hours in the recovery ward. If flow rates did not exceed 160 mL/min, patients were invited for an additional clinical assessment 1 week postsurgery for close monitoring. Although TTFM was also used in the control group, no such procedures were performed upon measuring the flow. A VasQ (Laminate Technologies, Tel Aviv, Israel) implant was used as external support device. It consists of a nitinol braid and brace that structurally reinforces the juxta-anastomotic segment and produces a more laminar flow transition. The placement of an external vessel support device was standard[18] with the addition of the administration of 1 mL papaverine to the adventitia of the vein and artery after AVF creation.[14] All surgeries were performed in the Haaglanden Medical Center in The Hague, The Netherlands.

Follow-Up

Patients were generally discharged on the day of surgery, after which patients were followed for a period of 12 months. Maturation of the AVFs was determined through ultrasound performed by technicians or a vascular surgeon in a vascular laboratory at 6 weeks. At 12 weeks and 6 months, functional status was assessed by the surgeon or a specialized dialysis nurse.

Definitions

AVF maturation 6 weeks postoperatively was considered as an adequate venous diameter ($\geq$4 mm over a length of at least 10 cm), a flow $\geq$500 mL/min, and a palpable thrill and superficial enough to be punctured with two cannulae for hemodialysis.[19]

Primary AVF patency was defined as intervention-free access survival. In assisted primary patency, an intervention such as a percutaneous transluminal angioplasty (PTA) was necessary to maintain patency, but no full occlusion had occurred. Nonmaturation, or maturation failure, is considered to be any AVF that is not mature at 6 weeks. Finally, acute failure was described as any vascular access failure that occurred within the first week after initial placement of the AVF.

Costs of Interventions

The following interventional procedures relating to maturation and patency were considered: PTA of matured AVFs, PTA and/or coiling of collaterals for assisted maturation, thrombectomy, and central line placement and revision surgery. Furthermore, a distinction was made in the costs of RCAVF placement between the studied groups, based on the additional costs of the study group procedure. The costs for each type of procedure were based on the costs of materials used, personnel costs, and costs of hospital admission in our center. On average, the intraoperative optimization requires 5 minutes of additional surgical time compared to the RCAVF procedures in the historical cohort. The breakdown of procedural costs is outlined in Supplemental Table I. The total cost of procedures relating to AVF maintenance at 12 months was determined by multiplying the total number of interventional procedures in each group by the costs of each procedure. This value was then divided by the number of patients in the groups to estimate the average per-patient costs. Only patients of which the full 6 months of data was available were included.

Statistical Analysis

SPSS version 27.0.1.0 (IBM, Armonk, New York) was used for statistical analysis of the collected data. Unpaired sample *t*-tests were performed on the intraoperative blood flow, vein diameter, and blood flow in the outflow vein. This was also done separately for males and females. *Chi*-squared tests were used to compare acute failures, interventions and AVF maturation rates between the two groups. A Kaplan–Meier and Cox regression survival analysis was implemented to determine the hazard ratio for loss of (assisted) patency of the RCAVFs between the control and intervention groups. A Mann–Whitney *U* test was performed to determine differences in per patient number of interventions, costs per type of intervention, and total costs.

Table I. Baseline characteristics historic control versus current cohort including comorbidities and diameters

Patient characteristics	Control ($n = 59$)	Intraoperative optimization ($n = 43$)	P value
Age (mean, (SD))	63.5 (12.6)	58.9 (16.7)	0.07
BMI (mean, (SD))	28.7 (6.4)	28.3 (6.1)	0.38
Sex (% male)	66.1	85.4	
Smoking (%)	23.7	29.3	
Hypertension (%)	83.1	92.7	
Diabetes (%)	50.8	53.7	
Preexisting heart failure (%)	13.6	24.4	
Dialysis before surgery (%)	25.4	26.8	
Antithrombotic therapy before surgery (%)	54.2	53.7	
Anesthesia by brachial plexus (%)	83.1	95.1	
Preoperative venous diameters			
All patients (mm; mean, (SD))	2.45 (0.81)	2.44 (0.59)	0.47
Females (mm; mean, (SD))	2.11 (0.61)	2.64 (0.45)	**0.02**
Males (mm; mean, (SD))	2.63 (0.85)	2.41 (0.61)	0.10

Bold values indicate statistically significant P-Values. BMI, body mass index.

RESULTS

Study Population

Fifty-nine patients were included in the historical control group, and 43 underwent the optimized RCAVF surgery in the intervention group during the study period. This included every patient eligible for an RCAVF surgery, except for 2 who did not receive the optimized surgery due to nickel allergy ($n = 1$), and patient preference ($n = 1$). Table I shows the baseline characteristics of the patient populations. At 6 months postsurgery, 10 patients had incomplete follow-up data in the control group, and 3 in the intervention group. This was due to patients receiving a kidney transplant, transfers to a different center, and loss to follow-up. One patient developed distal emboli due to a proximal arterial stenosis not seen in preoperative duplex ultrasound. As this was most likely a preexisting condition, this patient was excluded from the postoperative analysis. One patient died from causes not related to the procedure.

Procedure Outcomes

All surgical procedures were technically successful, with the external support device (VasQ™, Laminate Medical, Tel Aviv, Israel) implanted, and papaverine and dilation of low-flow AVFs applied in the intervention group. Figure 2 displays the intraoperative venous flow, as measured by TTFM, in both groups, and split into male and female populations. One intervention group patient received arterial dilation during the index surgery after measuring a fistula flow <160 mL/min, in addition to standard blood pressure augmentation. Mean fistula flow was significantly higher in the intervention group than the control when including all patients (210 mL/min vs. 163 mL/min, $P = 0.008$). When examining by sex, only men had a significantly higher intraoperative flow rate in the intervention group ($P = 0.019$ for males, $P = 0.556$ for females).

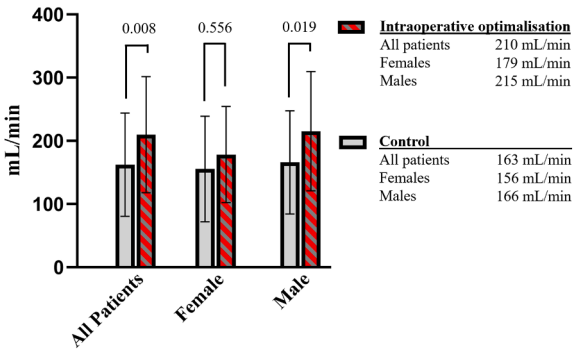

Fig. 2. Intraoperative venous blood flow rates. Measured by Transit Time Flow Measurement.

Follow-Up

The intervention group demonstrated significantly higher maturation rates than the control group at both 6 weeks (77.1% vs. 43.2%, $P = 0.002$), and 12 weeks (90.6% vs. 58.8%, $P = 0.003$) (Table II). Additionally, overall males showed a significantly higher 6-week maturation rate (65.5% vs. 38.1%, $P = 0.029$), though no significant sex differences

Table II. Venous diameters and postoperative maturation data at 6 and 12 weeks in the control and intraoperative optimization groups

	Preoperative duplex		6 Weeks postoperative duplex			12 Weeks postoperative control		
	Control	Intraoperative optimization	Control	Intraoperative optimalization	*P* value	Control	Intraoperative optimalization	*P* value
Acute failure (%)			5.4	0.0	0.137			
Interventions (%)			7.1	2.8	0.367	7.3	9.7	0.695
Venous diameter								
All patients (mm (SD))	2.45 (0.81)	2.44 (0.59)	4.1 (1.5)	4.4 (0.7)	0.306			
Female patients (mm (SD))	2.11 (0.61)	2.64 (0.45)	4.2 (1.8)	3.7 (1.4)	0.676			
Male patients (mm (SD))	2.63 (0.85)	2.41 (0.61)	4.1 (1.3)	4.5 (0.6)	0.162			
Blood flow								
All patients (mL/min (SD))			699 (309)	764 (303)	0.387			
Female patients (mL/min (SD))			590 (205)	723 (171)	0.318			
Male patients (mL/min (SD))			754 (340)	769 (316)	0.871			
AVF maturation								
All patients (%)			43.2	77.1	**0.002**	58.8	90.6	**0.003**
Female patients (%)			29.4	75.0	0.091	50.0	75.0	0.383
Male patients (%)			51.9	77.4	**0.041**	63.6	92.9	**0.010**

Bold values indicate statistically significant *P*-Values.
AVF, arteriovenous fistula.

Table III. Sex differences in arteriovenous fistula maturation in the total cohort, and control and intraoperative optimization groups

	6 Weeks postoperatively			12 Weeks postoperatively		
	Females	Males	*P* value	Females	Males	*P* value
AVF maturation						
All surgical approaches (%)	38.1	65.5	**0.029**	56.3	80.0	0.059
Control (%)	29.4	51.9	0.143	50.0	63.6	0.440
Intraoperative optimization (%)	75.0	77.4	0.914	75.0	92.9	0.252

Bold values indicate statistically significant P-Values.

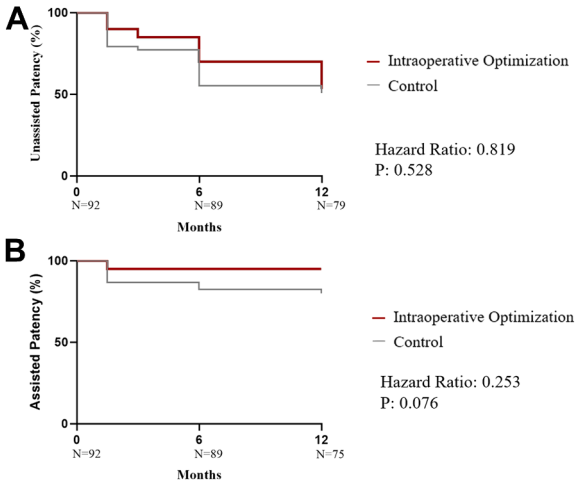

Fig. 3. Kaplan–Meier curves. **(A)** Unassisted patency and **(B)** assisted patency rates in the intraoperative optimization group versus the Control group.

were observed within the specific study groups or at 12 weeks (Table III). The improved unassisted maturation in the optimization group resulted in a somewhat higher patency within the first 3 months. At this time point, 53.1% of the AVFs in the intervention group were successfully used for dialysis compared to 47.1% in the control group ($P = 0.289$). Over a 12-month period, there were no higher patency rates observed in the intervention group and a trend toward higher assisted patency (Fig. 3). Full details on preoperative and postoperative measurements, as well as intervention and failure rates, are outlined in Tables II and III.

Interventions and Cost of Care

There was no significant difference in the average number of interventions per patient in the intervention group versus the control in the study period (0.38 vs. 0.61, $P = 0.23$). The average per patient cost of interventions performed during the 12 months follow-up period and the total cost of care per-patient as previously defined are found in Figure 4 (detailed cost breakdown in Supplemental Table II). The average per patient costs in the intervention group was significantly higher than in the control group due to the higher costs of the index procedure as a consequence of external support placement (€5858.77 vs. €4148.89, $P = 0.002$). Revision surgery consisted of proximalization of the AVF ($n = 10$ in the control group and 2 in the intervention group).

DISCUSSION

The current study shows optimizing RCAVFs using simple and readily available measures has a positive effect on maturation outcomes. The application of the procedural standardization with papaverine, prediction with TTFM, and the external support device resulted in higher intraoperative blood flows and higher maturation rates than the conventional surgical RCAVF technique. However, no significant effect on unassisted patency was found, nor a decrease in the number of interventions. Average cost of care was higher in the group receiving the optimized RCAVF procedure.

Although preoperative venous and arterial diameters did not differ, there was a substantial increase in maturation rates in the intraoperative optimization group. This was profound at both the early postoperative time points. This suggests that the intraoperative optimization results in better and faster maturation, which may be specifically beneficial for patients already on dialysis or patients who need to start hemodialysis soon after creation. Consequently, this could result in less central venous catheter (CVC) indwelling time and prevent new CVC placements. This needs to be confirmed in larger studies.

The difference in maturation rate between the groups is mainly provoked by a small and nonsignificant difference in venous diameters around the cut-

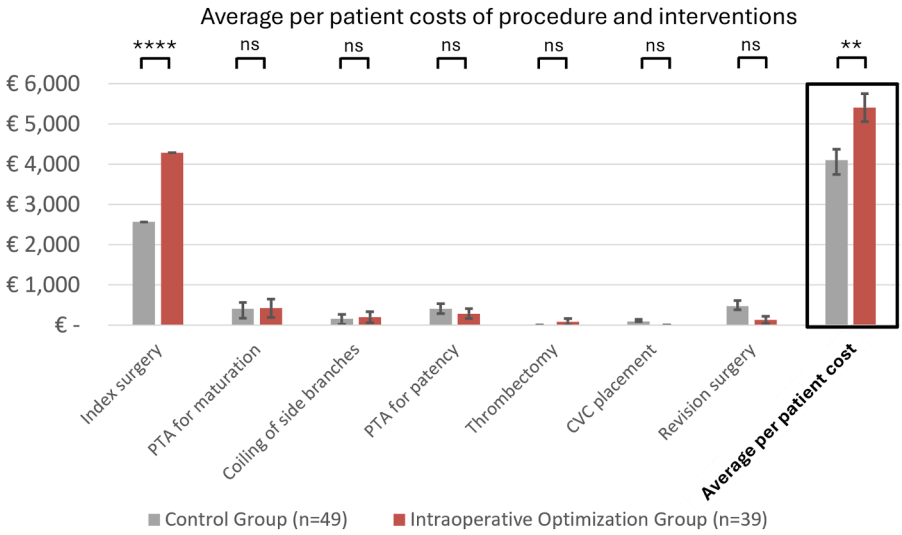

Fig. 4. Intervention costs. Standard errors of the means of different radiocephalic arteriovenous fistula (RCAVF) strategies at 12 months from placement are included. ns, not significant; PTA, percutaneous transluminal angioplasty; CVC, central venous catheter.

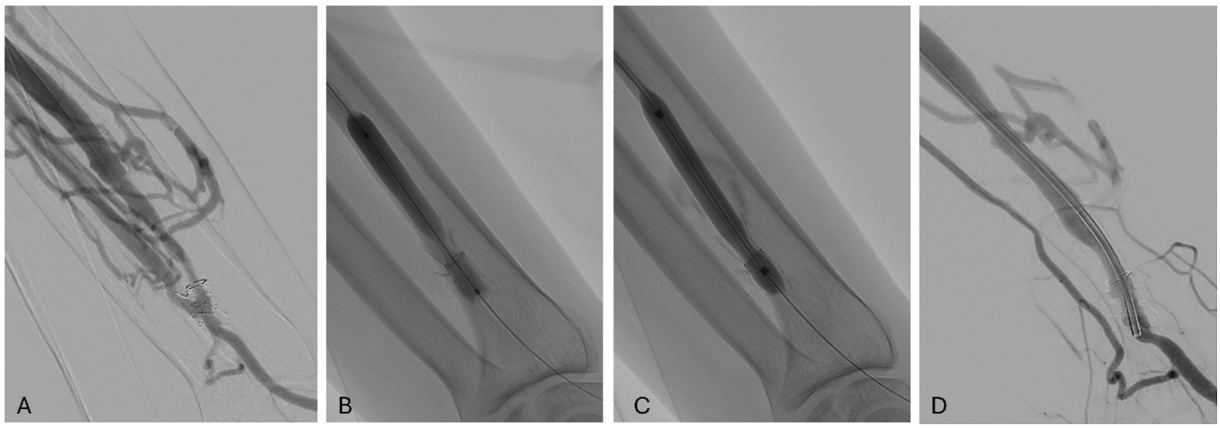

Fig. 5. Angiography images of a fistula with external support device. **(A)** Six-month old radiocephalic fistula with a juxta-anastomotic stenosis originating within the outflow part of the external support device. **(B)** Angioplasty with a 5-mm high-pressure balloon showing resistant stenoses, **(C)** that was treated with a cutting balloon and repeated 5 mm high-pressure balloon, **(D)** resulting in a clinically sufficient result.

off point of 4 mm. It may be possible that higher flow rates in the intervention group at the time of creation led to more shear stress-mediated venous distension. Additionally, the reduced early juxta-anastomotic stenosis as has been observed in other studies with the external support device may have contributed to the improved maturation rates in our intervention group.[16,17,20] However, the device may not preclude stenoses that can also occur within the device outflow part, whereas the support mesh and any fibrotic tissue that forms around the implant likely stiffens the vessel, possibly complicating the angioplasty (Fig. 5). Moreover, this device does not prevent stenosis further down the outflow other than a presumed limitation of turbulent and high-flow in the longer run, possibly resulting in less shear stress and intimal hyperplasia.[20]

Furthermore, it must be noted that this study was not randomized, which could have introduced bias in the study cohort. The intervention group included more male patients, a factor known to positively influence maturation[21–23] and supported

by the presented data. However, although numbers were too low to reach statistical significance, the data suggest very similar trends in maturation in both men and women between groups, and the upper arm fistula and graft placement rate remained fairly constant in the study period as compared to previous periods. If patients had been selected for RCAVF based on larger cephalic vein diameters, these rates would have likely increased. In fact, these diameters were similar in the study cohort versus the historical controls and compared to other studies in the Netherlands.[24] Moreover, the rate of diabetic patients, which has been found to have a negative impact on maturation rates,[25,26] remained equally high over time (50−55%) in our center, and notably higher than the 40% in other Dutch cohorts reported in the past decade.[7,8,24] Additionally, the mean age in the control group was higher, which could affect vein quality. However, age has previously not been found to predict nonmaturation in our region.[11] Together, this may suggest that the effect of bias is limited.

The results in both groups were comparable with a general assessment of RCAVF maturation in the Netherlands.[11] Supplemental Table III shows an overview of published RCAVF rates in the Netherlands since 2002. RCAVF maturation rates in the Netherlands seem to have decreased from 73% in 2002[5] to 50−61% in more recent years.[7−10,24] This may be an effect of aging population and the rise in diabetic patients from an average of 16% in 2002[5] to 51−59% in most recent cohorts in our region.[9,10] However, the current study shows that even in a population with a high rate of diabetes it is possible to achieve high maturation rates. Moreover, Dutch vascular access surgery is fragmented over many centers and therefore this study differs considerably with other studies with the external support device that report excellent RCAVF maturation of 89−100%.[16,17,20] These series are often nonrandomized and originate from high volume centers with experienced and specialized vascular access surgeons. Although the prospective, pivotal trial of the external support device in the United States demonstrated superior patency as compared to a historical control group, the study only included 15 RCAVFs (10% of the study population).[27] Only 1 randomized pivotal study is available that was aimed to show safety and that was not powered to prove superiority.[18]

The overall cost of care was higher in the intraoperative optimization group. Although there is a nonsignificant reduction in interventions, and therefore related costs, this is negated by the increased costs of a more expensive index procedure in the intervention group when including the intraoperative optimization modalities. It is important to note that RCAVFs are generally the most cost-effective option initially.[28] However, costs rise significantly when complications such as stenoses develop or when more proximal fistulas are required as alternatives. This further emphasizes the importance of optimizing RCAVF procedures to avoid these costly complications.

Compared to the average first-year AVF costs of care of ~15 k USD found in an extensive US cohort,[28] expenses found in the present study are considerably lower. It is important to notice that angioplasties in our center take place in an outpatient setting, coupled to the dialysis session, thus limiting admission costs. Although differences in prices and demographics between countries are not accounted for, this data does underscore that the cost analysis in this study likely underestimates the true financial burden, as it primarily focuses on interventions to promote maturation. An additional hurdle for cost-effectiveness of the external support device is the different sizes, requiring a larger amount of products to be taken in stock and at risk of expiration. This holds especially true for smaller volume centers that are common in the Netherlands. Lastly, hidden costs, such as failed punctures, missed dialysis sessions due to difficult-to-cannulate fistulas, and the need for further interventions, may not have been fully accounted for in the present cohort, emphasizing the need for improved further study into costs of care.

Every intervention-free day is valuable for a dialysis patient. However, in The Netherlands, a 6-week reimbursement limit for the specific diagnosis is placed by health insurers. For vascular access surgery, this limit is typically insufficient to include costly intraoperative measures such as endovascular devices or external support systems, which may hamper their introduction. Our data show a significant increase in intraoperative flow and 6-week maturation rates. It should thus be clear that including a more expensive modality, such as the external support device, can add value for patients, but could also reduce overall costs for the payers if maturation rates improve. Future randomized studies with longer-term results and robust cost-effectiveness analysis should steer decisions on the feasibility in our current healthcare system.

Finally, the presented study cannot differentiate between the effects of papaverine, intraoperative flow measurements, or the external support device. Currently, it cannot be concluded that each modality individually provides benefit, nor that they do not adversely affect each other. All measures taken

together provide a clinical, but no financial benefit, considering the price of the external support device and the increased time of the procedure. Moreover, the same surgeon performed or oversaw surgeries in the intervention group, but only created roughly half of the RCAVFs in the control cohort. There has been a debate on AVF surgical expertise and volume, suggesting a high prior-volume of AVFs positively correlates with maturation rates.[29,30] Additionally, functional status assessment of the AVFs was not always done by the same individual. Both these factors may thus have introduced bias, which is not accounted for in this study. To investigate the effect of the external support device, a randomized clinical trial is currently being designed at our and other institutions to fill the gap of level-1 evidence in which the same standardization of RCAVF procedure is anticipated, with the support device as only variable.

CONCLUSION

This study examined an optimized intraoperative RCAVF procedure that included the administration of papaverine, TTFM, and the placement of an external vessel support device. The effect of this procedure was studied on intraoperative flows, 6- and 12-week maturation rates, and 12-month primary and assisted patency. Compared to a historical control group from the same center, superior intraoperative flow rates and 6- and 12-week maturation rates were found. No significant improvement in 12-month unassisted patency was observed and a trend toward improved assisted patency was seen. Due to the increased cost of the optimized procedure, costs of care increased. The optimized procedure may assist in achieving higher maturation rates, but long-term benefits so far seem limited based on this preliminary data. More randomized controlled trials are necessary to gain more insight into specific effects of each modality.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Nicholas A. White: Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. **Eduard P. de Winter:** Writing – review & editing, Writing – original draft, Project administration, Investigation, Formal analysis, Data curation, Conceptualization. **Ruth MA. Bulder:** Writing – review & editing, Data curation. **Thijs AJ. Urlings:** Writing – review & editing, Data curation. **Timothy J. van der Steenhoven:** Writing – review & editing, Data curation. **Daniel Eefting:** Writing – review & editing, Data curation. **Willem Jan de Jong:** Writing – review & editing, Data curation. **Janna C. Specken-Welleweerd:** Writing – review & editing, Data curation. **Laima Siddiqi Nadery:** Writing – review & editing, Data curation. **Suzanne Oliveira-Martens:** Writing – review & editing, Data curation. **Joris I. Rotmans:** Writing – review & editing, Writing – original draft, Supervision, Formal analysis. **Koen EA. van der Bogt:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

SUPPLEMENTARY DATA

Supplementary data related to this article can be found at https://doi.org/10.1016/j.avsg.2026.05.083.

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