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Original Article

Efficacy of Revision Using Distal Inflow in Patients with Symptomatic Dialysis Access-Associated Steal Syndrome

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Objectives: In this study, we aim to assess the efficacy of revision using distal inflow (RUDI) in patients with symptomatic dialysis access-associated steal syndrome (DASS).
Materials and Methods: All consecutive patients who were diagnosed with grade 3 or 4 DASS and have undergone RUDI in 4 years were included in this study.
Results: In total, 35 patients were included in this study; participants had a mean age of 47.5±7.52 years and 54% (n=19) were males. As per our findings, significant improvement was noted in terms of paresthesia (81.2%, p-value: 0.012), coolness (79.4%, p-value: 0.006), pain (78.1%, p-value: 0.006), discoloration (76.4%, p-value: 0.044), paresis (71.4%, p-value: 0.016), and ulcer healing (50%, p-value: 0.044). Gangrene did not further progress in all patients (n=35). Reduction in fistula flow rate after RUDI was 57.5% (682±121 ml/min, p-value: 0.001). Digital systolic pressure was noted to improve by 71.4% (60±9.2 mmHg, p-value: 0.002) after RUDI. Peak systolic velocity increased in both ulnar (66.1±8.2 cm/s, p-value: 0.04) and radial (64.2±7.6 cm/s, p-value: 0.024) arteries of the wrist. Cumulative patency of RUDI graft was 100%, 91.4%, and 85.7% at 3, 6, and 12 months, respectively.
Conclusion: RUDI has resulted in significant improvements in terms of DASS symptoms. Using a native vein as conduit, RUDI should be considered a procedure of choice for patients with high-flow DASS.

Keywords: steal syndrome, RUDI, AV fistula, dialysis access

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Introduction

Dialysis access-associated steal syndrome (DASS) has been identified to be a serious complication after hemodialysis access creation, which can result in significantly high morbidity in hemodialysis patients. Physiological steal is present in up to 90% of dialysis access cases, while clinically significant DASS that require surgical intervention is observed in 1%–8% of the patients, with prevalence of approximately 2% in radial and up to 20% in brachial access sites.[1)] Steal occurs when arterial inflow divides between two vascular beds with different resistances, which lead to the redirection of blood flow from the higher-resistance distal extremity to the lower-resistance arteriovenous access, and sometimes even causing a reversal of arterial flow.[2)] Various surgical options for the treatment of DASS have been advocated. Banding or plication,[3)] revision using distal inflow (RUDI),[4)] and short graft interposition[5)] are usually suggested for DASS associated with high-flow arteriovenous fistulas (AVFs); meanwhile, distal revascularization and interval ligation (DRIL)[6)] and proximalization of arterial inflow[7)] are suggested for DASS in normal- and low-flow AVFs.[8–10)] RUDI involves distalization of the original AVF to the proximal radial or ulnar artery in the forearm using a native vein or synthetic graft, so that a separate artery is preserved for blood flow to the hand, hence relieving the steal symptoms.[4,9)] Most of the studies have few cases. In this study, we have included a maximum number of patients from multiple centers to assess the efficacy of this procedure in terms of alleviating DASS while preserving the access for dialysis.

Materials and Methods

All consecutive patients who presented with steal syndrome after creation of an AVF for hemodialysis were included in this study. We performed this study at Combined Military Hospital (CMH) Lahore, CMH Multan, CMH Rawalpindi, and Midcity Hospital Lahore from January 2018 to January 2022. Severity of ischemia was diagnosed according to the classification by Tordoir et al.[11]: grade 1, mild symptoms like coolness without pain and are usually treated with observation only; Grade 2, pain in exertion and dialysis; grade 3, rest pain; and grade 4, tissue loss in the form of ulceration/gangrene. In this study, patients with grade 3 and 4 DASS were selected for RUDI. Patients who had any previous surgery for correction of steal syndrome such as banding, DRIL, or RUDI were excluded from this study. Furthermore, patients unfit to undergo surgery or patients who did not maintain a mandatory follow-up of at least 1 year were also excluded. The study was approved by the Institutional ethical review committee (Reference: 164/ERC/CMHLMC). All data were collected from the hospital records, and study protocols were followed according to the Declaration of Helsinki.

All patients planned for operation had a Doppler scan done with 10 MHz linear vascular probe (LOGIQ Book, GE Medical Systems, Milwaukee, WI, USA). Complete mapping of the fistula was done to determine any stenosis or aneurysmal dilation. Peak systolic velocities (PSVs) in both arteries at the level of the wrist were recorded. This was done firstly to assess which artery is the dominant artery that supplies the hand and secondly to compare pre- and postoperative PSVs, which will be helpful in determining the efficacy of the RUDI. Postop PSVs were recorded at 3 months. Furthermore, flow rates (ml/min) in the fistula were recorded pre- and postoperatively for comparison. Patients suspected with arterial inflow disease underwent computed tomography angiography to further assess the arterial disease.

RUDI was performed under axillary block using standard technique. The venous end of the original AVF was taken down, leaving a 5 mm cuff of the vein at the anastomosis site to prevent any postoperative stenosis. A conduit of autologous vein or externally supported polytetrafluoroethylene (PTFE) graft of 7 mm in diameter was used to distalize the fistula with the proximal part of the non-dominant radial or ulnar artery at least 5 cm from the bifurcation of the brachial artery. Digital systolic pressures (DSP) were measured using wide beam 8 MHz Doppler probe using the digital cuff provided with the device (Huntleigh DMX Doppler, Argo, Inc., Addison, IL, USA). DSPs were taken immediately before and after the procedure.

The primary end point of this study was limb salvage and patency of the graft at 1 year. Limb salvage is defined as the resolution of ischemic rest pain and healing of ulcers (if present). Primary patency was defined as absence of any occlusion and stenosis in the graft segment. Assisted primary patency was defined as patency after an attempt was made to clear the occlusion/stenosis in the grafted segment. Primary and assisted primary patencies were assessed using Doppler at follow-up visits.

The data was analyzed using the Statistical Package for the Social Sciences (SPSS) version 21.0 software (SPSS Inc., Chicago, IL, USA). The numerical variables were expressed as means and standard deviations (SD), whereas categorical data were expressed as frequency and percentage. Comparison between pre- and postoperative symptom relief and flow rates was done using paired sample t-test with 95% confidence intervals. We also conducted Kaplan–Meier analysis using log rank test to assess the survival rates of RUDI. P-value (two-tailed) of ≤ 0.05 was considered to be statistically significant.

Results

During the study period, 400 patients presented with clinical features of DASS in vascular outpatient clinics. Among them, 81% (n = 324) had grade 1 or 2 symptoms. Of the remaining, 10% (n = 40) had grade 3 or 4 symptoms. Of these, a total of 35 patients underwent RUDI and fulfilled the inclusion criteria for this study. There were 54% (n = 19) males and 46% (n = 16) females, with a male : female ratio of 1.2 : 1. The mean age of the patients at the time of surgery was 47.5 ± 7.52 (range: 36–66) years. Diabetes mellitus was the most prevalent atherosclerotic risk factor in 77.1% (n = 27) of the patients (**Table 1**). Of the total 35 cases, 91.4% (n = 32) were brachiocephalic (BC) AVFs, whereas 8.6% (n = 3) were brachiobasilic (BB) AVFs. Majority of the patients did not have previously failed AVF [60% (n = 21)]. In the other 14 patients, 50% (n = 7) had 2, 42.8% (n = 6) had 1, and 7.1% (n = 1) had three previously failed AVFs.

Mean time from AVF to development of grade 3 or 4

Table 1 Demographics of the patients undergoing RUDI

Age [Years±SD]		47.51±7.52
Gender [% (n)]	Male	54 (19)
	Female	46 (16)
Atherosclerotic risk factors [% (n)]	Diabetes mellitus	77.1 (27)
	Hypertension	40 (14)
	Smoking	31.4 (11)
	Hyperlipidemia	20 (7)
Primary fistula [% (n)]	Brachiocephalic	91.4 (32)
	Brachiobasilic	8.6 (3)

RUDI: revision using distal inflow; SD: standard deviation

Table 2 Symptoms and their relief/recurrence after RUDI

Symptoms	Before RUDI [% (n)]	After RUDI [% (n)]	P-value	New symptoms after RUDI [% (n)]
Rest pain	91.4 (32)	20 (7)	0.006	14.3 (5)
Coolness	97.1 (34)	20 (7)	0.006	2.8 (1)
Discoloration	48.6 (17)	11.4 (4)	0.044	8.5 (3)
Paresthesia	91.4 (32)	17.1 (6)	0.012	2.8 (1)
Paresis	20 (7)	5.7 (2)	0.016	0 (0)
Ulceration	22.8 (8)	11.4 (4)	0.044	0 (0)

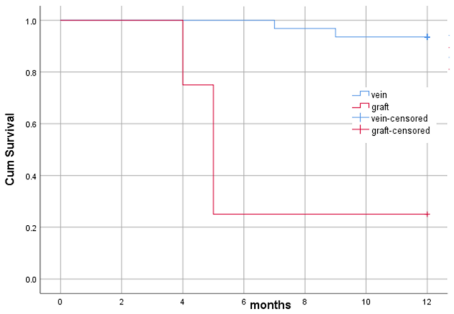
RUDI: revision using distal inflow

steal syndrome was 22.6 ± 6.2 (14–32) months. Preferably, autologous vein graft was used as a conduit in 88.6% (n = 31) of the patients, while PTFE graft was used in only 11.4% (n = 4) of the patients. Majority of the patients had anastomosis performed on their proximal radial artery (68.5%, n = 24), while 31.4% (n = 11) has it done on their proximal ulnar artery. Mean preoperative flow rate in the AVF was determined to be 1605 ± 210 ml/min; meanwhile, postoperatively, it was reduced to 682 ± 121 ml/min. This reduction in flow rate was deemed significant (57.5%, p-value: 0.001).

The most frequent symptom reported by the patients was coolness of the hand in 97.1% (n = 34) of the cases, followed by pain in 91.4% (n = 32) of the cases (**Table 2**). Statistically significant improvement was noted in terms of paresthesia (81.2%, p-value: 0.012), coolness (79.4%, p-value: 0.006), pain (78.1%, p-value: 0.006), discoloration (76.4%, p-value: 0.044), and paresis (71.4%, p-value: 0.016). Healing of ischemic ulcer was noted in 50% (n = 4) of the patients (p-value: 0.044). Digital gangrene was present in 14.2% (n = 5) of the patients before the procedure, but did not further progressed after the procedure. New onset of symptoms after RUDI was noted in 20% (n = 7) of the cases, with pain and discoloration being the most common symptoms in 14.3% (n = 5) and 8.5% (n = 3) of the patients, respectively. However, it is worth noting that no patient developed grade 4 symptoms like ulceration or gangrene after RUDI.

Pre- and postoperative DSPs were compared. DSP_{preop} was not detectable in 37.1% (n = 13) of the patients. Mean DSP_{preop} in the remaining 23 cases was 35 ± 3.4 mmHg. Mean DSP_{postop} rose by 71.4% to 60 ± 9.2 mmHg (p-value: 0.002). Pre- and postoperative PSVs in ulnar and radial arteries were also compared, wherein an increase in PSV was noted in the ulnar artery from 38.9 ± 3.8 cm/s to 66.1 ± 8.2 cm/s after RUDI. This increase in ulnar PSV was statistically significant (p-value: 0.04). Similarly, PSV in the radial artery also increased from 35.6 ± 4.2 cm/s to 64.2 ± 7.6 cm/s (p-value: 0.024) after the operation.

Primary patency of RUDI was 100% at 3 months. After 3 months, five patients (14.3%) (4 PTFE and one



	Mean				Median	
			95% Confidence Interval			
graftorvein	Estimate	Std. Error	Lower Bound	Upper Bound	Estimate	Std. Error
vein	11.742	.182	11.385	12.099	.	.
graft	6.500	1.601	3.362	9.638	5.000	.433
Overall	11.143	.373	10.412	11.874	.	.

	Chi-Square	df	Sig.
Log Rank (Mantel-Cox)	21.961	1	.000

Test of equality of survival distributions

Fig. 1 Kaplan–Meier analysis of revision using distal inflow patency over time.

autologous vein) presented with graft thrombosis; all of them then underwent thrombectomy, which was technically successful. However, at subsequent follow-ups, graft failure was noted in three of the four patients with PTFE, while the autologous vein graft remained patent. Henceforth, primary assisted patency rate was 91.4% (n = 32) by the end of 6 months (p-value: 0.023). Furthermore, two patients in the next 6 months with vein graft had graft failure despite attempts of salvage, thus resulting in final assisted primary patency of 85.7% (n = 30) by the end of 1 year (p-value: 0.006). Cumulative patency rates of PTFE and native vein graft are shown in **Fig. 1**. No mortality was recorded in the mandatory 1-year follow-up period. Alternatively, eight patients (22.8%) died in the second year of follow-up due to other comorbid condition. Mean follow-up after RUDI was 18.3 ± 3.1 (13–26) months.

Discussion

DASS is a known troublesome complication of dialysis access, and RUDI is one of the techniques employed for high-flow DASS. This technique finds its validation in principles of Hagen-Poiseuille's law, which describes fluid flow across a gradient. According to this law, the flow of a fluid is influenced by the fourth power of the lumen radius and is inversely proportional to the length of the conduit.[12] Therefore, in order to redirect the flow to the distal arteries and reduce flow in the stealing AVF, it is deemed logical to consider strategies that involve reducing the inflow radius and/or lengthening the conduit. RUDI technique capitalizes on both principles. It involves utilizing the radial and ulnar arteries instead of the brachial artery, hence extending the length of the conduit while preserving the fistula.[12] By employing these principles, RUDI aims to

optimize blood flow distribution and mitigate the stealing effect of the AVF.

However, there is paucity of literature on RUDI, and most of the studies done in the past had very few cases. A systemic review done by Shaikh et al. had average number of patients lesser than ten.[10] Kordzadeh et al. did a systemic review with maximum cases in a study not more than 21.[4] Considering the scarcity of the number of cases examined, we employed patients from multiple centers to maximize our sample size for better power and statistical analysis. To date, this can be considered the largest study in terms of sample size, hence giving us a better chance to assess the efficacy of RUDI.

Diagnosis of DASS is mostly based on clinical symptoms.[4,6,10] Although AVF compression test resulting in increase in digital pressures is employed in a few studies,[13] clinical features alone are 100% accurate in diagnosing patients with DASS, as suggested by Kordzadeh et al. in their systemic review.[4] We have also diagnosed patients with DASS based on clinical features and graded them according to the clinical classification by Tordoir et al.[11]

Apart from clinical alleviation of symptoms, various assessment methods have been employed to assess the improvement of blood flow to the hand. These include measurement of DSP, brachial digital pressure index (BDPI), digital saturation on pulse oximetry, and digital photoplethysmography.[14,15] We performed DSP in all our patients, and it showed significant improvement after the procedure (p-value: 0.002). Although Misskey et al. have intended to compare DSP and BDPI, only the BDPI results were determined, which rose from 0.25 to 0.58 (p-value <0.001) after RUDI; however, this comparison was only available in 68% of the cases.[14]

The literature review by Kordzadeh et al. noted that radial artery was used for proximal anastomosis in 61.5% of the cases.[4] We also used the non-dominant (radial, 68.5%) artery of the hand for proximal anastomosis. This kept the dominant artery as a separate inline flow channel for the hand. The postop PSVs rose to almost double the preoperative values. Furthermore, there was also increase in post-op PSV in the anastomotic artery despite the AVF flow diversion in it. We hypothesize that it may be due to the retrograde flow after RUDI. Whether this retrograde flow is clinically important in terms of relieving hand ischemia symptoms or not remains to be elucidated. Since we did not measure the flow direction, we can only hypothesize. However, Gerrickens et al. concluded that radial arterial flow in antegrade or retrograde direction was clinically irrelevant with respect to hand ischemia symptoms in RUDI patients.[15]

We compared PSVs of distal radial and ulnar arteries of the wrist before and after RUDI. There was significant improvement in PSVs in both radial (p-value 0.024) and ulnar (p-value 0.04) arteries. Gerrickens et al. have also measured the PSVs in radial and ulnar arteries at two points in the forearm and compared the pre- and postoperative velocities,[15] wherein they concluded a significant increase in both radial (p-value: 0.002) and ulnar (p-value: <0.02) artery PSVs and end-diastolic velocities after the procedure. Similarly, Usman et al. have also compared pre- and postoperative PSVs as a measure to validate the efficacy of DRIL in patients with DASS.[6] Consequently, they found statistically significant increase in the postoperative ulnar velocities (p-value: 0.01), while the radial artery was deemed insignificant (p-value: 0.07). However, they took the mean of the PSVs done at three sites in the forearm. This may create bias since the PSV of the proximal forearm may reflect the blood supply mainly to the muscle tissue and the PSV of distal forearm may reflect blood flow to the peripheral tissue such as the fingers. We advocate that the process of averaging PSVs at three different points might weaken the specificity of PSV for peripheral circulation. Hence, we took PSVs at the level of the wrist only, which we presume is a better reflection of blood supply to the hand. Nonetheless, the use of flow velocities to assess the efficacy of such procedures for DASS is still new; thus, further studies are needed to validate their use.

Our study showed a cumulative patency of 80% at 1 year, which is deemed comparable to previous studies.[14–16] We used PTFE graft in four patients, wherein failure was noted in three (75%) cases despite attempts of salvage. This led us to advocate that autologous vein should be used for RUDI, and every possible effort should be made to avoid synthetic graft. Contrary to our findings, Misskey et al. used PTFE graft in 15 of its patients (75%) and reported failure in only two of them (13.3%).[14] The reason of having high graft failure is unclear in our study. We can postulate it may be due to patient factors such as non-compliance with anticoagulation. Gerrickens et al., in his multicenter study of 21 patients, had shown a cumulative patency of 84% at 3 years.[17] It is worth noting that they only used native autologous vein as a conduit; moreover, only seven out of the 21 patients had clinical symptoms of DASS in their study. This leads us to postulate that studies with larger number of patients and longer follow-ups are needed in the future to precisely assess the efficacy of RUDI.

This study has certain limitations that should be acknowledged. Although we incorporated cases from multiple centers, the sample size was still small, which may limit the statistical power and generalizability of our findings to a larger population. Additionally, the follow-up duration of only 12 months may not capture the long-term outcomes and complications associated with RUDI. We did not include the patients with asymptomatic high-flow access. Furthermore, this study did not include a comparison

group receiving alternative treatment modalities, making it difficult to determine the relative effectiveness of RUDI as compared to other available options. We thus recommend that future studies include a control arm as well as comparison to other modalities such as banding and a longer follow-up period, to assess the efficacy of such procedures for high-flow access steal.

Conclusion

RUDI has been determined to be a very effective tool in surgical armamentarium in terms alleviating hand ischemia of high-flow access-related steal. However, larger comparative studies with other modalities and longer follow-ups are advised to assess the long-term outcomes of this procedure.

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Author Contributions

Study conception: RU
Data collection: RU, SM, AS
Analysis: RU, MJ, RF, MM
Investigation: SM, AS
Writing: RU, RF, MM
Critical review and revision: all authors
Final approval of the article: all authors
Accountability for all aspects of the work: all authors

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