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Combined Endovascular Treatment with Distal Radial Artery Coil Embolization and Angioplasty in Steal Syndrome Associated with Forearm Dialysis Fistula

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Abstract
Purpose The present study was performed to define the results of the endovascular treatment with angioplasty and distal radial artery embolization in ischemic steal syndrome associated with forearm arteriovenous accesses.
Method The cases referred to our interventional radiology unit with symptoms and physical examination findings suggestive of ischemic steal syndrome were retrospectively evaluated first by Doppler ultrasonography, and then by angiography. Cases with proximal artery stenosis were applied angioplasty, and those with steal syndrome underwent coil embolization to distal radial artery.
Results Of 589 patients who underwent endovascular intervention for dialysis arteriovenous fistulae (AVF)-associated problems, 6 (1.01 %) (5 female, 1 males; mean age 62 (range 41–78) with forearm fistula underwent combined endovascular treatment for steal syndrome. In addition to steal phenomenon, there were stenosis and/or occlusion in proximal radial and/or ulnar artery in 6 patients concurrently. Embolization of distal radial artery and angioplasty to proximal arterial stenoses were performed in all patients. Ischemic symptoms were eliminated in all patients and the AVF were in use at the time of study. In one patient, ischemic symptoms recurring 6 months later were alleviated by repeat angioplasty of ulnar artery.
Conclusion In palmar arch steal syndrome affecting forearm fistulae, combined distal radial embolization and angioplasty is also an effective treatment method in the presence of proximal radial and ulnar arterial stenoses and occlusions.

Keywords Percutaneous transluminal angioplasty · Hemodialysis · Steal syndrome · Embolization · Arteriovenous fistula

Introduction

Dialysis-associated steal syndrome (DASS) after the creation of arteriovenous (AV) fistula is a rare syndrome with potential serious clinical consequences. Pathophysiologically, it is characterized by a reduction of the amount of blood reaching distal vascular bed or reversal of distal arterial flow (steal phenomenon) due to a low-pressure medium created by AV fistula [1, 2]. Although steal phenomenon occurs in 73–91 % of patients with AV fistula, steal syndrome with typical signs and symptoms is observed at differing rates between 1 and 8 %, depending on the localization and type of fistula [3, 4]. DASS manifests with numbness, sensory loss, coldness, pain during dialysis and/or rest, and, in more severe cases, loss of function and tissue necrosis [5].

Dialysis-associated steal syndrome occurs more frequently in fistulae created from brachial artery as a result of a higher output. In forearm and wrist fistulae, on the other hand, DASS may occur at a rate of 1 %, where it is known as palmar arch steal syndrome (PASS) [2, 5]. PASS occurs by two separate pathophysiological mechanisms. The first

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one is particularly important in cases with risk factors such as long-standing diabetes, coronary artery disease, and peripheral artery disease, and characterized by reduced distal blood flow and signs of ischemia secondary to arterial stenoses and occlusions even in the presence of a normal-output fistula. In the second mechanism, on the other hand, retrograde blood flow toward fistula from normally functioning ulnar and interosseous arteries via palmar arch occurring due to a low-pressure medium created by high output in fistula causes hypoperfusion and ischemia in fingers [5, 6].

In DASS, surgical treatment options are preferred in upper arm fistulae whereas endovascular treatment options are more suitable for revascularization of forearm fistulae due to diminutiveness of target vessels [5]. To our best knowledge, solely angioplasty to relieve ischemia [7, 8] or solely coil embolization to prevent distal steal phenomenon [5, 9, 10] have been reported in some study and case reports on endovascular therapy of PASS. Unlike the literature, in this retrospective study, we examined the results of distal embolization technique combined with proximal inflow artery angioplasty in PASS.

Material and Method

Patients' records who underwent interventional process due to AVF problems between 2010 and 2015 were retrospectively analyzed from the hospital information system (HIS) and picture archiving and communication system (PACS). The patients suffering from DASS who underwent combined endovascular treatment with distal radial artery coil embolization and angioplasty, were included in the study. Futhermore the patients with DASS who underwent solely coil embolization or angioplasty were excluded from the study. Patients with fistulae of brachial artery origin or radial artery origin without DASS symptoms were also excluded. Symptoms, comorbidities, physical examination findings, Doppler ultrasonography (USG), and interventional procedures of patients referred to our interventional radiology clinic were recorded. Doppler USG examinations were carried out with a P5 (General Electric, Milwaukee, WI) ultrasonography device and an 11 L (3.4–10.8 MHz bandwidth) linear probe just before the interventional process. In the examination, brachial, ulnar, and radial arteries, fistula anastomosis, and efferent vein were evaluated for the presence of stenoses or occlusions. AV fistula output was measured and the presence of retrograde flow in radial artery distal to anastomosis was also sought for.

Patients with steal syndrome diagnosed by physical examination and Doppler USG were angiographically evaluated. In cases with no marked arterial pathology on Doppler USG, efferent vein was retrogradely used as the entry site. After the evaluation of venous outflow, the anastomosis was passed with a 0.035-inch hydrophilic glide guidewire (Radifocus^{TM} Terumo, Japan) and a 5-French Kumpe catheter (Cook, USA), proximal artery was reached, and the presence of any stenosis or occlusion in brachial artery, ulnar and radial arteries, and palmar arch was sought. Then, radial artery was reached distal to anastomosis and the presence of a retrograde flow was sought. Furthermore in patients with a suspected arterial stenosis or occlusion, brachial artery at the level of elbow was antegradely used as the first entry site under the USG guidance, and radial and ulnar arteries were selectively entered and angiograms were taken. Arterial stenoses and occlusions, and the presence of any shunt from palmar arch to radial artery at distal part were also evaluated.

After angiographic evaluation, angioplasty was carried out in patients with stenosis of proximal artery and ulnar artery. In patients with persistent steal after angioplasty, DRA (distal radial artery) was catheterized with a 5-F Kumpe catheter or a 2.7-F progreat microcatheter (Terumo, Japan) and embolized with 0.035 or 0.018 inch pushable Hilal coils (Cook, USA) of suitable diameter by protecting thenar arteries. The procedure was terminated when flow on arteriography was stopped or markedly slowed following embolization (Fig. 1). The patients were re-examined within 2 weeks when clinical symptoms were questioned and a repeat Doppler USG examination was performed at that time as well. By the relief of DASS symptoms, the patients are referred to the hemodialysis unit and routine follow-up of these patients are made by Nephrology clinic. The patients with any complain about the AVF in follow-up, referred to interventional radiology unit for further examination and intervention. By the time of this study all of the patients' AVF was in use without any complain.

Results

This study retrospectively analyzed from the HIS and PACS records of 589 patients who underwent intervention for AV fistula-associated problems between 2010 and 2015. Six (1.01 %) [5 females, 1 males; mean age 62 (range 41–78) years] patients underwent intervention for PASS created by a forearm AV fistula. Radiocephalic fistulae were located at wrist in 3 patients and at mid forearm in the other 3 (patient 1, 2, and 6). As comorbid conditions, 4 patients had diabetes mellitus, 3 had hypertension, 2 had coronary artery disease, and 1 had peripheral artery disease (Table 1). Two patients (patient 1 and 6) began to have symptoms within 1 month after the creation of AVF, while the symptoms of two (patient 2 and 3) patients started within 1 month after angioplasty for efferent AVF vein occlusion. The other 2 patients had no recent history of

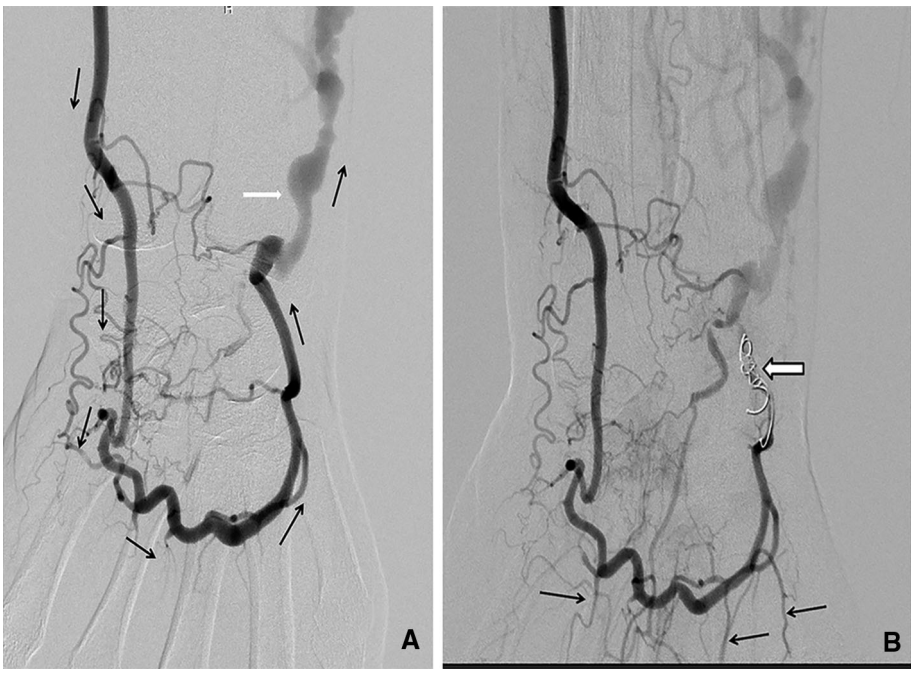

Fig. 1 **A** Contrast material flow to AV fistula vein (*white arrow*) (*black arrows* points the direction of flow) via a hypertrophic palmar arch in an arteriogram obtained by administering contrast agent via ulnar artery. No contrast uptake is present in digital arteries. **B** Filling of digital arteries (*black arrows*) following coil embolization of distal radial artery (*white arrow*)

Table 1 Patient characteristics and procedures

Patient	Age	Sex	Comorbid	Symptoms	Procedure	F/U duration	F/U
1	49	F	DM	Pain, cold	RA and UA PTA, DRA coil	8	No Sy, EV PTA
2	78	F	DM, CAD, HT	Pain, cold, cyanosis	UA and RA, and palmar arc PTA, DRA coil	3	No Sy
3	41	F	HT	Pain, cold, cyanosis	R A PTA, DRA coil	35	No Sy, EV Throm. and PTA
4	63	F	DM, PAD	Pain, cold, cyanosis, numbness	UA PTA, DRA coil	36	Recurring Sy of ischemia, UA re-angioplasty
5	71	M	HT	Pain, cold, cyanosis, numbness	RA PTA, DRA coil	41	No Sy
6	72	F	DM, CAD	Pain, cold, cyanosis, numbness	RA PTA, DRA coil	1.5	No Sy

F female, *M* male, *DM* diabetes mellitus, *CAD* coronary artery disease, *HT* hypertension, *PAD* peripheral artery disease, *RA* radial artery, *UA* ulnar artery, *DRA* distal radial artery, *PTA* percutaneous transluminal angioplasty, *EV* efferent vein, *F/U* follow-up (Months), *Sy* Symptom

creation of an AV fistula or an endovascular treatment. Doppler USG prior to the procedure detected retrograde flow in radial artery distal to anastomosis in all patients, severe stenoses and occlusions in radial and ulnar arteries in 2 patients (patient 1 and 2). After angiography all patients were detected to have steal phenomenon from ulnar artery via palmar arch. Three patients (patient 3, 5, and 6) had radial artery stenosis in addition to steal, 2 (patient 1 and 2) had ulnar artery stenosis, occlusion, and radial artery stenosis (Fig. 2.A–E), and 1 (patient 4) had ulnar artery stenosis. Patients with arterial stenoses and occlusions underwent angioplasty at the same session. In all patients but one, coil embolization to DRA was carried out at the same session for persistent steal phenomenon after angioplasty. In one patient (patient 1), stenoses of proximal radial artery and ulnar artery were dilated but no DRA embolization was performed. However, a distal radial artery embolization procedure was carried out for that patient for persistent symptoms at a second session 10 days later. No serious complication occurred in any patient. In one patient who underwent high insertion of vascular sheet into brachial artery (patient 6), a hematoma not requiring transfusion developed after the procedure. Symptomatic recovery was observed in all patients after embolization.

Efferent vein angioplasty was carried out for occlusion in 2 patients. One patient (patient 4) who underwent ulnar artery dilation, had recurrent ischemic symptoms and a small wound at the tip of the index finger 6 months after the first intervention. That patient was diagnosed with ulnar artery occlusion for which ulnar artery angioplasty was performed

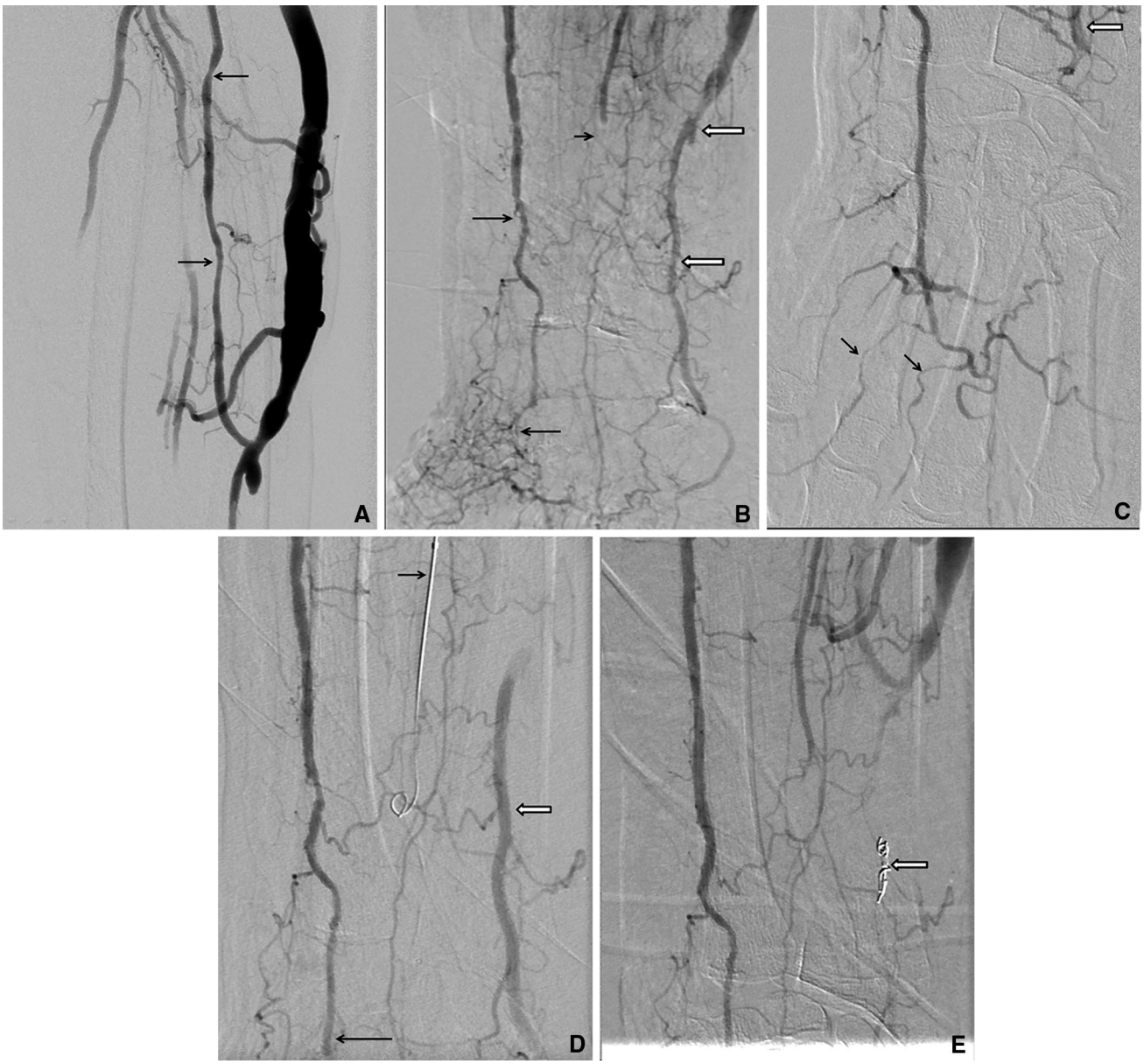

Fig. 2 **A** A 78-year-old female patient. Radial artery stenoses in brachial arteriogram (*arrows*). **B** Ulnar artery stenoses and occlusion in distal ulnar artery, palmar arch (*long black arrows*) occlusion in the distal part of interosseous artery (*short black arrow*), and retrograde flow from collateral vessels in distal radial artery (*white arrows*). **C**, **D** Severe stenoses in digital arteries filled (*black arrows* in Fig. 2C) after successful angioplasty for stenoses and occlusions of ulnar artery and continued radial artery filling from collaterals (*white arrows* in Fig. 2C and D). Guidewire in the interosseous artery (*black arrow* in Fig. 2C). **E** Retrograde flow is not observed after coil embolization to distal radial artery (*white arrow*)

and recanalization was achieved. The wound disappeared and ischemic symptoms abated later at follow-up.

Discussion

Patients with chronic renal failure dependent on hemodialysis need adequate vascular access for survival. Although both reduced blood flow to hand and steal phenomenon is observed in the majority of patients following the creation of AV fistula, associated ischemic symptoms are very rare. Despite being more common in upper arm AV accesses where fistula output is higher, DASS is also observed in 1–2 % of forearm fistulae, as in our study [2, 3, 5, 11]. In forearm fistulae, ischemia occurs as a result of inadequate blood supply to hand due to proximal arterial stenoses or, alternatively, passage of nearly all blood coming from normal arterial structures to venous side through fistula shunt via palmar arch due to high output and resultant low resistance in a fistula [5]. Although steal

phenomenon characterized by retrograde flow distal to fistula exists in the majority of forearm fistulae, not every patient develops signs of ischemia [3]. The main risk factors for ischemia include comorbid conditions such as diabetes, coronary artery disease, and peripheral arterial disease, and high fistula flow [1, 4, 6]. In our case series, the majority of patients had comorbidities as risk factors; hence 75 % stenoses or occlusions limiting the flow radial or ulnar arterial stenosis were present proximal to anastomosis.

There exist some treatment options for DASS including flow-limiting surgical operations such as fistula closure, plication, or narrowing of efferent vein with banding; revascularization operations such as proximalization of arterial inflow (PAI), revision using distal inflow (RUDI), and distal revascularization–interval ligation (DRIL); and endovascular treatment options such as elimination of arterial stenosis by angioplasty; and DRA embolization especially in forearm fistulae [2, 5, 6, 9, 12–14]. Closure of fistula provides a definitive solution for eliminating steal syndrome and improving distal perfusion although it results in the loss of dialysis access, which is vital for a patient, creating a great disadvantage for patients who are dependent on a functioning dialysis access on the long term. It is highly likely that the options for creation of a new AV fistula will be limited, and steal syndrome will recur by creating a new fistula in upper arm. As similar symptoms emerge upon the creation of a new fistula on the contralateral extremity in many cases, fistula closure should be only used when other surgical or endovascular treatment options fail [2, 15].

Among these surgical treatment options, DRIL is the most accepted technique that is most successful at correcting signs of steal phenomenon by preserving access patency. It is based on the principle of ligating brachial artery just distal to anastomosis and bypass grafting the distal part of the artery connected to a site more proximal than anastomosis [2]. However, DRIL operation is technically difficult and has a low chance of success in wrist fistulae due to a considerably smaller diameter of the involved arteries that contain severe calcifications in at-risk persons [5]. Hence, in case of the forearm AVF, surgical ligation or endovascular embolization of radial artery distal to anastomosis is mostly preferred treatment option. Miller et al. [5] performed endovascular coil embolization in 10 patients and surgical ligation in 5 patients, and detected symptomatic improvement in all patients in the endovascular group and in 3 patients in the ligation group. The advantages of endovascular therapy include a minimally invasive nature, suitability for being performed simultaneously with diagnostic angiography, and the ability of not only occluding distal radial artery, but also other branches creating leaks to fistula [9]. In addition, dilatation of concurrent stenoses with angioplasty also increases blood flow to fistula and hand. Endovascular dilation is feasible in distal forearm and palmar arch arteries where surgical revascularization is not feasible. Therefore, when a stenosis is identified in proximal artery by diagnostic angiograms, the initial treatment attempt should be made with percutaneous transluminal angioplasty [6, 8].

Distal radial artery embolization and, if present, recanalization and angioplasty of ulnar artery stenoses and occlusions provide essentially the same results with DRIL operation, which is considered as the most efficient treatment modality in DASS in terms of hemodynamics so far. While coil occlusion of DRA prevents steal phenomenon in a similar manner to that of interval ligation, a normal or angioplastically corrected ulnar artery provides distal blood flow with the same hemodynamic effect as bypass graft. In our patient group, stenoses and occlusions of inflow arteries were detected in addition to steal phenomenon. Therefore, endovascular therapy was considered as the first option. DRA embolization was also carried out at the same session with angioplasty in all but 1 patient. In a patient in whom embolization was not performed at the same session, distal radial artery embolization was performed 10 days after the first procedure because of persistent symptoms. DRA embolization may create a serious risk for increased hand ischemia in patients with severe arterial stenoses and occlusions [7]. In contrast, we did not observe any ischemic symptoms at follow-up except for a patient who underwent ulnar artery dilatation at the initial session. In that patient, a repeat balloon angioplasty to ulnar artery established luminal dilatation and alleviated ischemic signs and symptoms. In such patients, when endovascular techniques fail, surgical closure of fistula can be considered.

This retrospective study has several major limitations. Our study population is relatively small and the surgically treated control group has not been constituted due to the low frequency of DASS in forearm according to brachial AV fistula. Furthermore, to the best of our knowledge, there is no study which compares the endovascular treatment with surgery in the literature. Prospective studies are needed to evaluate the efficacy of endovascular treatment vs surgery in DASS.

In conclusion, our study suggests that by preserving vascular access in PASS, a rare subtype of DASS, the combined technique employing DRA embolization with proximal artery angioplasty can be used as an efficient treatment method for alleviating symptoms, even in patients with severe ulnar and radial artery lesions.

Compliance with Ethical Standards

Conflict of interest All authors declare that they have no conflict of interest.

Informed Consent Informed consent was obtained from all individual participants included in the study.

Human and Animal Rights Statement All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. For this type of study formal consent is not required.

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