Interventional Management of Vascular Complications after Renal Transplantation

Interventionelle Therapieoptionen vaskulärer Komplikationen nach Nierentransplantation

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ABSTRACT

Background Kidney transplantations are increasing due to demographic changes and are the treatment of choice for end-stage renal disease. Non-vascular and vascular complications may occur in the early phase after transplantation and at later stages. Overall postoperative complications after renal transplantations occur in approximately 12 % to 25 % of renal transplant patients. In these cases, minimally invasive therapeutic interventions are essential to ensure long-term graft function. This review article focuses on the most critical vascular complications after renal transplantation and highlights current recommendations for interventional treatment.

Method A literature search was performed in PubMed using the search terms “kidney transplantation”, “complications”, and “interventional treatment”. Furthermore, the 2022 annual report of the German Foundation for Organ Donation and the EAU guidelines for kidney transplantation (European Association of Urology) were considered.

Results and Conclusion Image-guided interventional techniques are favorable compared with surgical revision and should be used primarily for the treatment of vascular complications. The most common vascular complications after renal transplantation are arterial stenoses (3 %–12.5 %), followed by arterial and venous thromboses (0.1 %–8.2 %) and dissection (0.1 %). Less frequently, arteriovenous fistulas or pseudoaneurysms occur. In these cases, minimally invasive interventions show a low complication rate and good technical and clinical results. Diagnosis, treatment, and follow-up should be performed in an interdisciplinary approach at highly specialized centers to ensure the preservation of graft function. Surgical revision should be considered only after exhausting minimally invasive therapeutic strategies.

Key Points:

- Vascular complications after renal transplantation occur in 3 % to 15 % of patients.
- Image-guided interventional procedures should be performed primarily to treat vascular complications of renal transplantation.
- Minimally invasive interventions have a low complication rate with good technical and clinical outcomes.

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ZUSAMMENFASSUNG

Hintergrund Nierentransplantationen nehmen aufgrund des demografischen Wandels zu und sind die Behandlung der Wahl bei Nierenerkrankungen im Endstadium. Dabei kann es in der Frühphase nach Transplantation, aber auch im späteren Verlauf zu Komplikationen im Bereich der Transplantatgefäße sowie des Ureters kommen. Postoperative Komplikationen treten bei etwa 12 % bis 25 % der Patienten mit Nierentrans-

plantation auf. In diesen Fällen sind minimalinvasive therapeutische Maßnahmen entscheidend, um die Transplantatfunktion dauerhaft sicherzustellen. Ungeachtet der nicht vaskulären Komplikationen thematisiert dieser Übersichtsartikel die wichtigsten Komplikationen des Gefäßsystems nach erfolgter Nierentransplantation und erörtert aktuelle Empfehlungen zur interventionellen Behandlung.

Methode Es wurde eine selektive Literaturrecherche in PubMed mit den Suchbegriffen "kidney transplantation", "complications" und "interventional treatment" durchgeführt. Darüber hinaus wurden der Jahresbericht 2022 der Deutschen Stiftung Organspende sowie die aktuellen Leitlinien der Nierentransplantation der EAU (European Association of Urology) berücksichtigt.

Ergebnisse und Schlussfolgerung Interventionelle Therapietechniken sind im Vergleich zur operativen Revision minimalinvasiv und sollten für vaskuläre Komplikationen primär angewendet werden. Die häufigsten vaskulären Komplikationen nach Nierentransplantation sind arterielle Stenosen (3 %–12,5 %), gefolgt von arteriellen und venösen Thrombosen (0,1 %–8,2 %) und Dissektionen (0,1 %). Seltener treten arteriovenöse Fisteln oder Pseudoaneurysmen auf. In diesen Fällen weist die minimalinvasive Therapie neben guten technischen und klinischen Ergebnissen auch eine niedrige Komplikationsrate auf. Die Diagnostik, Behandlung und Nachsorge sollten interdisziplinär an hochspezialisierten Zentren erfolgen, um einen Erhalt der Transplantatfunktion zu gewährleisten. Nur bei ausbleibendem Erfolg der minimalinvasiven Therapieverfahren sollte eine chirurgische Revision erwogen werden.

Kernaussagen:

- Vaskuläre Komplikationen nach Nierentransplantation treten bei 3 % bis 15 % der Patienten auf.
- Interventionelle Verfahren sollten primär zur Behandlung von vaskulären Komplikationen bei Nierentransplantationen angewendet werden.
- Die minimalinvasive Therapie zeigt neben guten technischen und klinischen Ergebnissen eine niedrige Komplikationsrate.

Introduction

Kidney transplantation is the treatment of choice for end-stage renal disease [1]. The main indication for kidney transplantation in adults is chronic renal disease, while cystic renal disease is the most common indication in children [1]. In Germany, approximately 7,000 patients are currently waiting for a kidney transplant. The procedure is performed at 38 centers [1]. In 2021, 1929 kidneys were transplanted in Germany with 475 of the kidneys being from living donors. The number of organs from deceased donors in 2020 was 1,517 [1].

Patients who receive a kidney transplant have a significantly higher quality of life and longer life expectancy compared to patients undergoing dialysis treatment [2, 3]. An important part of the long-term survival of patients and transplant recipients after kidney transplantation is the early diagnosis, management, and especially prevention of complications. Not only for optimal care of new transplant patients but also for their long-term follow-up, interdisciplinary collaboration between radiologists, transplant surgeons, and nephrologists is important to detect, understand, and properly treat nephrological, immunological, and surgical complications. The increasing age of donors and recipients, the increasing number of comorbidities among recipients, the increasingly long dialysis times, and the growing number of transplant patients present new challenges for treating physicians [4].

Complications after kidney transplantation are categorized as vascular and non-vascular complications and occur in 12–20 % of patients [5]. Common non-vascular complications include ureter obstruction, ureter insufficiency, fluid collections at the transplant, hematoma, urinoma, abscesses, lymphocele, and transplant rejection.

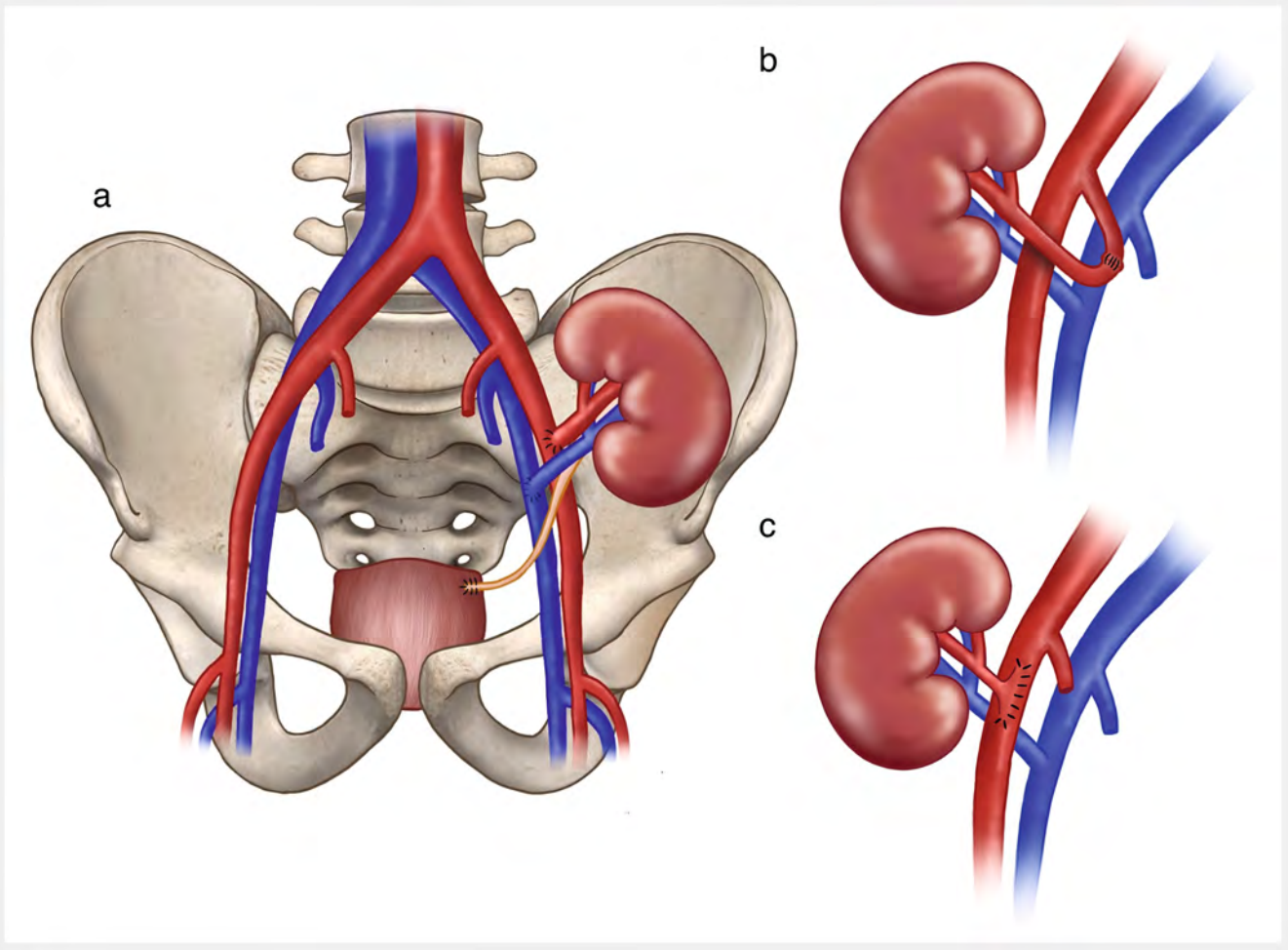
Ureter obstruction or stenosis is categorized depending on the time of occurrence after transplantation as early (< 3 months) or late (> 3 months) and is treated with splinting. Early ureter obstruction is usually due to mechanical causes like kinking, edema, clot, or restrictions in the submucosa and usually occurs at the ureterovesical junction [6]. Urethral ischemia is the most common cause of late ureteral obstruction and often occurs in the region of the distal ureter.

Urine leakage as an early complication after kidney transplantation can be attributed to ischemia, defects in the anastomosis, other surgical complications, or sometimes rupture of the urine collection system proximal to the ureteral obstruction [7, 8].

Fluid retention at the transplant is common after a kidney transplantation (up to 50 %). However, it is only clinically significant (lymphocele, hematoma, abscess, urinoma) in 15–20 % of cases [9]. While hematomas, abscesses, and urinomas typically occur early in the postoperative phase, it often takes much longer for lymphoceles to become visible [10]. In general, every perioperative fluid collection, particularly large hematomas, can become infected and result in a retroperitoneal abscess with typical clinical symptoms like fever, pain, and leukocytosis. Abscesses should be drained immediately (either minimally invasively via a drain or surgically depending on the location and size).

In addition to non-vascular complications, this article addresses vascular complications in particular since they are a relatively common but treatable cause of transplant failure in up to 25 % of cases [5]. Vascular complications include renal artery stenosis, vascular thrombosis of the arteries and veins, and arterial injuries like arteriovenous fistulas (AVF), pseudoaneurysms, and dissections.

Interventional radiology plays a key role in the minimally invasive treatment of postoperative vascular complications after kidney transplantation with regard to lowering morbidity and protecting transplant function [11].



▶ **Fig. 1** Possibilities of different NTX anastomoses. **a**. Kidney transplant in the left iliac fossa with end-to-end arterial and venous anastomosis between the graft vessels and the external iliac artery and vein. **b**. End-to-end anastomosis of the graft artery and internal iliac artery. **c**. Carrel patch to the external iliac artery in an end-to-side anastomosis.

The goal of this article is to provide the reader with an overview of the indication for and performance of interventional methods and techniques used in the case of vascular complications after a kidney transplantation.

Anatomy

With respect to the type and frequency of complications, understanding of the surgical details is essential. Prior to every intervention involving the vessels or structures of the urinary tract, it is therefore absolutely necessary to know the type of organ transplantation (deceased donor or living donor) and the type of arterial anastomosis, the type of venous anastomosis, and the type of urological anastomosis [12, 13].

Most kidney transplants are placed in the right or left iliac fossa (▶ **Fig. 1a**). The right iliac fossa is preferred because of the superficial position of the iliac vessels for anastomosis. In the case of vascular irregularities, like stenosis, calcification, or other anatomical variants of the bilateral pelvic vessels, the kidney transplant can be placed in an intraperitoneal position for the anastomosis [14]. The anastomosis of the transplant renal artery is usually an end-to-side anastomosis between the transplant artery and the external iliac artery of the recipient [15]. More rarely, an end-to-end anastomosis between the transplant artery and the internal iliac artery is used (▶ **Fig. 1b**) [15]. In the case of organs from deceased donors, the renal artery of the donor together with part of the aorta (Carrel patch) is typically connected to the external iliac artery of the recipient in an end-to-side anastomosis (▶ **Fig. 1c**) [15]. Of course, it is possible to deviate from the classic types of anastomosis (e. g., in the case of dominant pole arteries of the donor) and this must be taken into consideration during treatment planning.

Allogeneic transplants, vein conduits, or synthetic bypasses are used to reconnect short or damaged renal vessels. In the case of an intraperitoneal transplantation, arterial and venous anastomoses are made end-to-side to the aorta and the inferior vena cava, respectively.

The venous anastomosis is usually made end-to-side between the transplant renal vein and the external iliac vein of the recipient.

The ureteral anastomosis is typically made by implanting the transplant ureter in the bladder through a muscle tunnel in the

bladder wall (ureteroneocystostomy). Alternatively, anastomoses are made between the ureter of the donor kidney and the ipsilateral ureter of the recipient (ureteroureterostomy) or between the renal pelvis of the donor kidney and the ipsilateral ureter of the recipient (ureteropyelostomy). The latter is more common when the length of the transplant ureter is insufficient to reach the bladder or when the kidney transplant has a ureteral obstruction.

Diagnostic workup

Duplex sonography is the method of choice for the assessment of transplant vessels in the early postoperative phase. Regular duplex sonography examinations and laboratory tests of kidney function parameters are also performed in the long term [16]. The following values are determined to assess transplant vessels: Peak systolic velocity for determining the maximum flow rate in the transplant artery, intrarenal flow profiles, and resistance index (RI = peak systolic velocity – peak diastolic velocity/peak systolic velocity) of the intrarenal arteries. Vascular complications are normally detected with duplex sonography.

CT or MRI cross-sectional imaging is performed if the duplex sonography examination is abnormal in order to confirm the abnormal results and to plan treatment. Cross-sectional imaging, particularly MRI, can result in overestimation of the degree of stenosis. An angiography examination with the option of performing a pressure measurement can expand the diagnostic spectrum.

The risk of contrast-induced nephropathy is elevated in patients with poor renal function [17, 18]. According to the Contrast Medium Safety Committee of the European Society of Urogenital Radiology (ESUR), the risk of contrast-induced nephropathy is not higher in kidney transplant patients than in non-transplant patients. However, the society recommends caution among these patients in order to protect the transplant [19, 20]. However, in clinical practice, it is still assumed that the risk of renal damage increases with higher contrast agent doses and this must be taken into consideration particularly in kidney transplant patients [21, 22].

Based on newer retrospective studies [23–26], the risk of contrast-induced nephropathy after intravenous and intraarterial contrast administration with second-pass renal exposure seems to be similarly high. However, the ESUR considers high contrast agent doses administered intraarterially with first-pass renal exposure to be a risk factor for contrast-induced nephropathy [19, 20].

Arterial stenosis after kidney transplantation

Transplant renal artery stenosis (TRAS)

Renal artery stenosis after renal artery transplantation is a common complication with an incidence of 3–12.5 % (up to 25 %) and a multifactorial etiology [27–32]. Patients with stenosis of the transplant artery can be asymptomatic or have treatment-resistant hypertension with or without transplant dysfunction. The most common cause of renal artery stenosis is surgical complications of the vascular anastomoses as well as vascular injury or intimal dissection caused by vascular clamps [33, 34]. A higher incidence is seen in end-to-end anastomoses and in organs from deceased donors. Intimal hyperplasia, extrinsic compression due to an increase in fibrotic in tissue, or a mechanical kink in the renal artery can also reduce the arterial perfusion of the transplant kidney. Vascular injuries or clamp-related damage as well as arterial kinks/torsion are often diagnosed early after transplantation and are then usually associated with the surgical technique [11]. Atherosclerotic or immune-mediated vascular changes and intimal hyperplasia occur over time after kidney transplantation. The cutoff values for stenoses requiring treatment are defined by the Society of Interventional Radiology and are listed in ▶ **Table 1** [11, 35].

The primary treatment for transplant artery stenosis is percutaneous transluminal angioplasty (PTA) [33, 34]. The reported technical success rates for PTA of renal artery stenoses is 60–94 % with a complication rate of 0–8.3 % [36]. The restenosis rate in an observation period of 36 months is estimated to be 10–12 % of patients [37, 38]. The long-term survival rate of patients after endovascular treatment of renal artery stenosis is similar to that of patients without stenosis [38]. The study by Patel et al. [38] was able to show in a mean follow-up period of 10.6 years that balloon or stent angioplasty of a TRAS resulted in a long-term decrease in both blood pressure and kidney function parameters and in comparable transplant function and patient survival to that of patients without TRAS.

According to the current literature, primary stent PTA (▶ **Fig. 2**) results in lower restenosis rates compared to balloon PTA [39–44]. There is no difference between the two methods with respect to the complication rate. In a retrospective meta-analysis regarding arteriosclerotic renal artery stenosis, stent PTA yielded better results than PTA with respect to lowering blood pressure. However, less improvement in renal function was seen, but this may be due to the inclusion of more patients with renal insufficiency in the stent PTA studies included in this meta-analysis [41].

The use of drug-eluting stents (DESs) in coronary arteries drastically lowered the restenosis rates, particularly in small vessels where it was observed for the first time that a small lumen diameter is a strong predictor of in-stent restenosis [45]. Initial studies have shown that primary stent implantation with a DES is a safe and effective treatment for TRAS [46]. However, further randomized studies and long-term follow-up are needed to determine whether the placement of drug-eluting stents has advantages compared to the treatment strategies used to date.

Kinking

Kinking of a transplant artery can be difficult to differentiate from stenosis and can be the result of vascular displacement or displacement of the transplant over time. Surgery is still the treatment of choice for kinking of vessels. PTA represents an alternative in patients not suitable for surgical intervention. However, it has a lower success rate and a risk of arterial spasms and dissections. Moreover, the use of both a self-expandable and a balloon-expandable stent in a combined technique can be needed to properly treat kinking. The balloon-expandable stent with its in-

▶ **Table 1** Diagnostic criteria for renal artery stenosis relevant to therapy (modified from: Kolli and LaBerge [6]: Imaging Criteria for the Diagnosis of Transplant Renal Artery Stenosis, in Interventional Management of Vascular Renal Transplant Complications, based on Nikolic, Rose, Ortiz, et al. [41].

Modality	Cutoff value
Duplex sonography	**Transplant artery:** ▪ Peak systolic velocity measured at a scan angle < 60°: > 2.5 m/s ▪ Broadening of the frequency band with complete filling of the systolic window in spectral Doppler ▪ Peak systolic velocity in the iliac artery divided by the peak systolic velocity in the transplant artery > 3.5 **Intraparenchymal arteries:** ▪ Delayed acceleration time = time in seconds until peak velocity is reached (> 0.1 s) ▪ Intrarenal flow profile: "Parvus et tardus" waveform ▪ Resistance index RI < 0.55
CT/MR angiography DSA	▪ > 50 % diameter reduction (measured as the ratio of the diameter of the constriction to the diameter proximal to the stenosis or distal to the poststenotic dilation segment)
▪ Invasive pressure measurements	▪ Systolic pressure gradient > 10 % ▪ Pressure difference at the stenosis Peak value ≥ 20 mmHg or mean difference ≥ 10 mmHg (measured with a 5F diagnostic catheter or a measurement probe ▪ Hyperemic systolic gradient > 21 mmHg after selective injection of a vasodilator. ▪ Pressure ratio < 0.9 between the main renal artery distal to the stenosis and the aorta

creased transverse force is used to correct the kink and the longer self-expandable stent is then inserted to reduce the risk of displacing the kink.

Pseudo-transplant renal artery stenosis (pseudo-TRAS)

Further risks of reduced flow of the transplant artery include atherosclerotic changes in the arteries of the pelvis proximal to the anastomosis [47]. Reduced flow of the transplant renal artery due to aortoiliac stenosis is usually associated with progression of atherosclerotic occlusive disease and usually occurs later after transplantation.

Dissection

Dissection of the renal artery is another rare complication (0.1 %) [48]. In this situation, stent PTA can be used to stabilize the intima.

Vascular injuries after biopsy

Complications after routine percutaneous biopsy occur in up to 18 % of cases [30, 49]. The most frequent complications include arterial pseudoaneurysms and arteriovenous fistulas (AVFs). If they do not heal spontaneously, the primary treatment of AVFs is superselective coil embolization (▶ **Fig. 3** and ▶ **Fig. 4**, ▶ **Video 1**). The etiology of AV fistulas is related to the simultaneous injury of neighboring arterial and venous branches. A pseudoaneurysm occurs when only the arterial branch is damaged. AVF treatment is indicated in the case of symptomatic vascular changes (worsening kidney function) and increasing vascular changes (70 % of smaller AVFs can resolve spontaneously within 2 years). The treatment of pseudoaneurysms is indicated regardless of their size. The technical success rate of the endovascular treatment of AVFs and pseudoaneurysms is 71 % to 100 % [50]. Superselective placement of coils helps to minimize the loss of the parenchyma of the transplant.

Thromboses

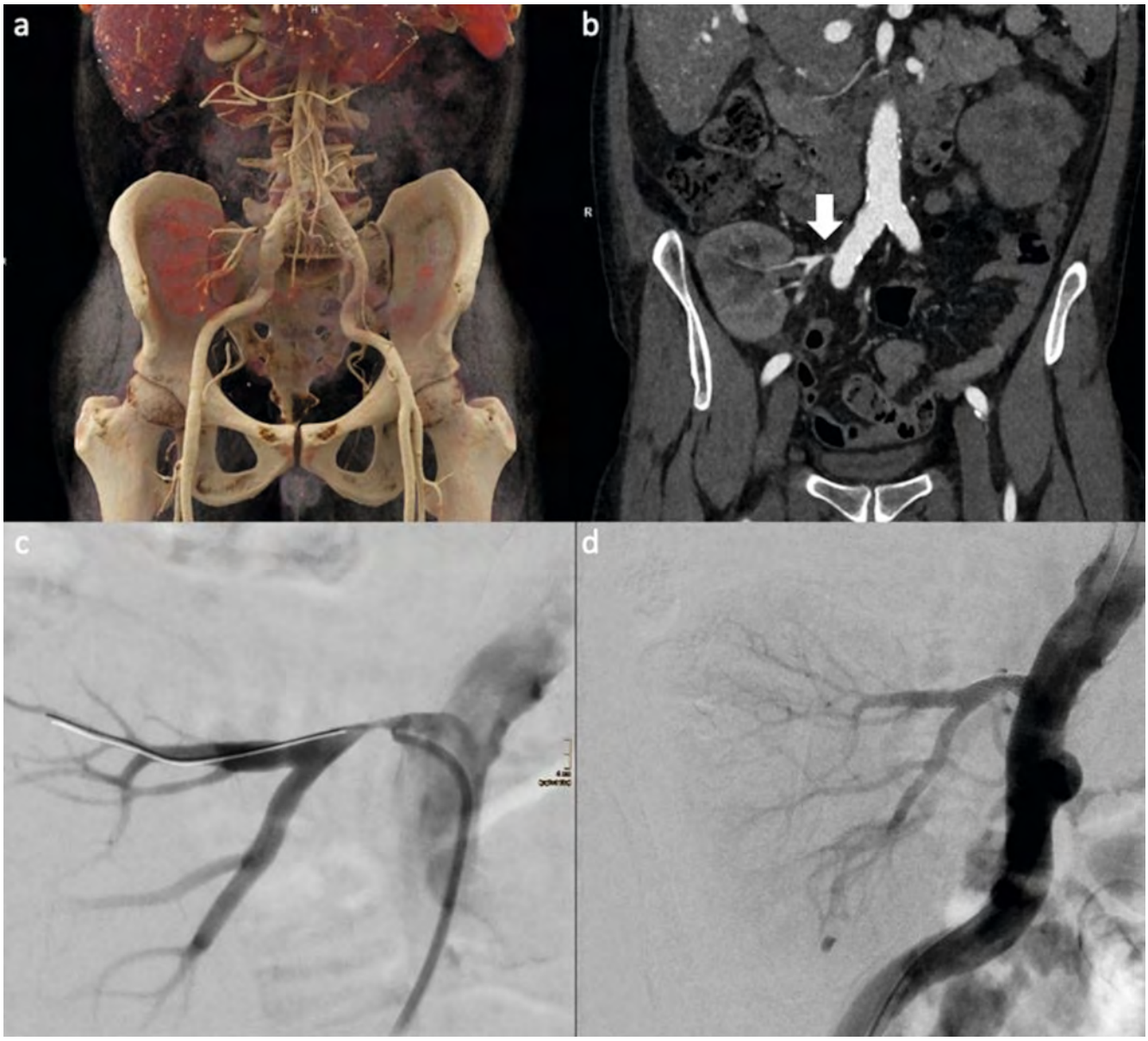
Thromboses in the arterial and venous renal vessels of the transplant are the main cause of early transplant failure [51]. They are typically the result of a technical error in the anastomosis. However, other causes are possible depending on the condition of the donor artery and the recipient artery. Injury to the intima during removal of the kidney, an acute rejection episode, external compression, hypercoagulation, and toxicity from immunosuppressants (cyclosporine or sirolimus) are associated with thromboses [51–54].

Thromboses are typically detected based on sudden oliguria or anuria with limited function of the transplant [51]. The incidence fluctuates between 0.2–7.5 % and 0.1–8.2 %, respectively [55–57].

The traditional treatment for arterial and venous thrombosis is surgical thrombectomy. Catheter-directed thrombolysis can be performed in the case of a low thrombotic burden or segmental arterial thrombosis or if surgery is not possible. In the first 10 to 14 days after transplantation, catheter-directed thrombolytic therapy should be avoided because the anastomoses are still vulnerable [56]. In individual cases and after interdisciplinary consultation, thrombolysis can be implemented early as an individualized approach.

Technical features

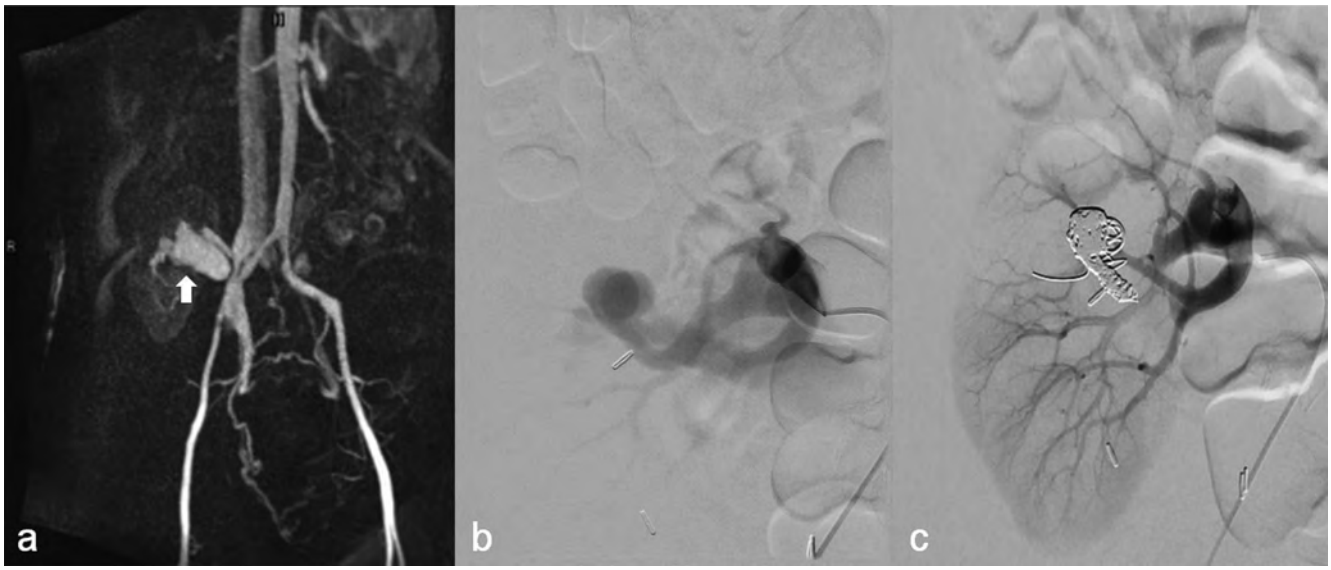
Transfemoral, ipsilateral, or contralateral access in relation to the transplant can be selected for interventional access to the arterial system. In the case of special anatomical features or individual



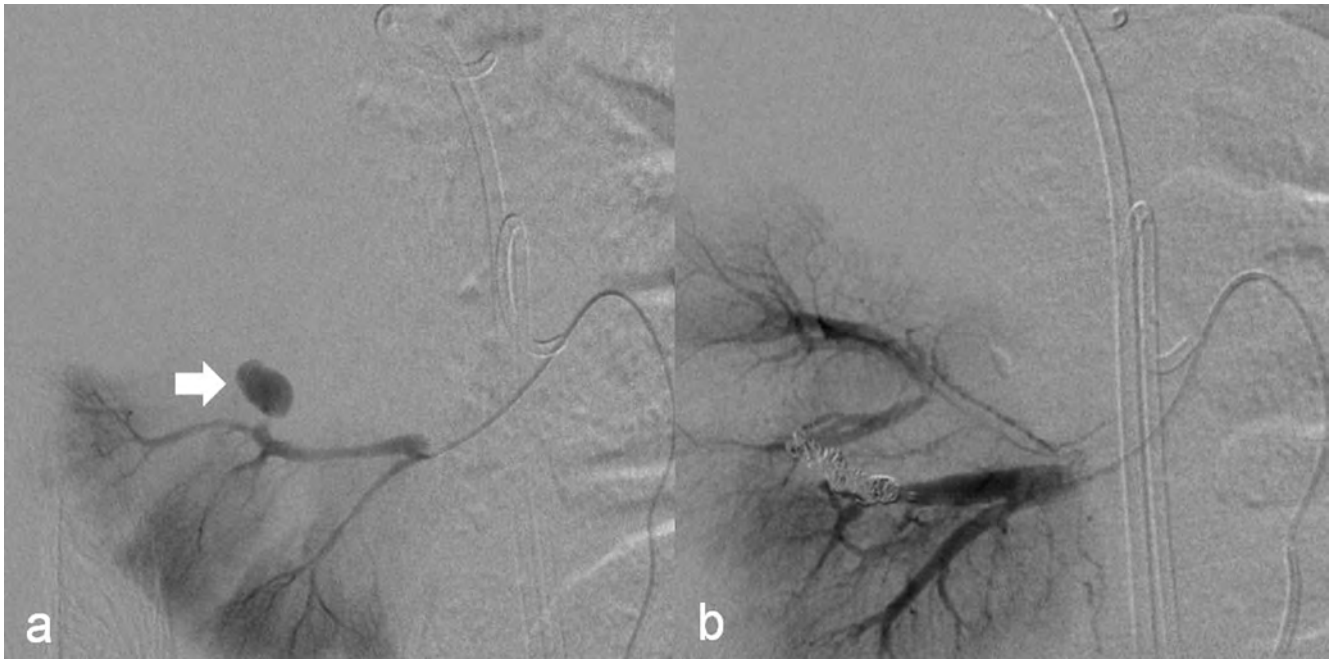
▶ **Fig. 2** (**a–d**): Relevant stenosis of the transplanted renal artery in a 44-year-old patient after living kidney donation for autosomal recessive polycystic kidney disease. The patient's serum creatinine was elevated. Duplex ultrasound performed on the same day detected delayed perfusion of the transplanted kidney. **a**. Cinematic rendering VRT showing the transplanted kidney in the right iliac fossa **b**. Coronary reformation of CT angiography showing subtotal stenosis of the transplanted renal artery (arrow). **c**. Selective angiogram of the transplanted renal artery shows subtotal stenosis. **d**. Outcome after percutaneous transluminal angioplasty and insertion of a balloon-expandable stent without evidence of relevant residual stenosis.

anastomoses, a transbrachial/radial access can be evaluated as an alternative access. To select the optimum access, exact knowledge of the anatomy of the transplant vessels is needed in advance. CT or MRI cross-sectional imaging can greatly simplify the selection process, decreases the intervention time, and reduces the intra-arterial contrast dose during the intervention. Ipsilateral transfemoral access usually offers optimal lines of force for endovascular interventions when the transplant renal artery is anastomosed to the external iliac artery. Contralateral access should be selected when treating the less common anastomosis between the internal iliac artery and the transplant renal artery. In the case of an anastomosis to the abdominal aorta, both an ipsilateral and a contralateral access can be selected [11].

For a better overview of the vascular anastomoses, nonselective imaging of the aortoiliac blood flow via carbon dioxide angiography can be performed to minimize the risk of iodinated contrast-induced nephropathy. Diagnosis is usually performed using a 5-F pigtail catheter to ensure contrast administration with sufficient flow [11]. Angiography examinations should be performed in both frontal and contralateral projection to rule out lesions obstructing the aortoiliac blood flow [11]. If no pathology is identified, the pigtail catheter can be partly retracted into the external



▶ **Fig. 3** AV fistula at the upper pole in a kidney transplanted to the right iliac axis in a 54-year-old patient with chronic glomerulonephritis. **a**. Visualization of the AV fistula in high-resolution MRI twist angiography. The transplanted renal upper pole artery can be identified as an antegrade feeder (arrow) **b**. Visualization of the large AV fistula in digital subtraction angiography **c**. Successful elimination of the AV fistula by superselective coil embolization.

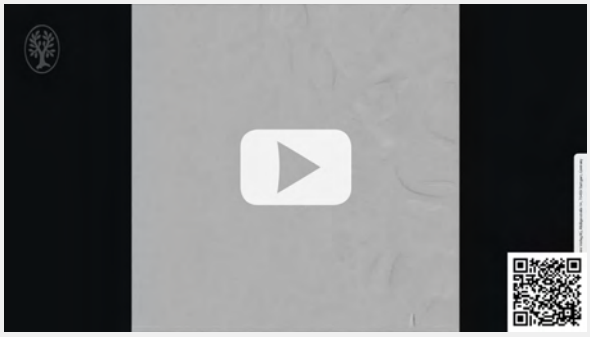


▶ **Fig. 4** (a, b) Pseudoaneurysm at the right lower pole of a transplanted kidney in a 43-year-old patient with previous terminal renal insufficiency of unclear etiology. 20 days after kidney transplantation, the serum creatinine remained elevated; for further diagnostic workup an ultrasound-guided renal biopsy was performed. Duplex ultrasound the following day revealed a large pseudoaneurysm at the renal lower pole. **a**. Pseudoaneurysm originating from the caudal segmental artery (arrow) **b**. Elimination of the pseudoaneurysm by superselective coil embolization.

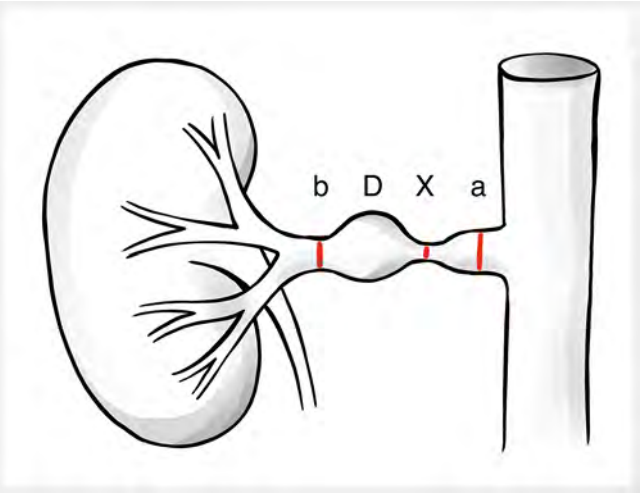
iliac artery proximal to the anastomosis of the transplant renal artery (ipsilateral femoral access) or a 5-French angiography catheter can be advanced into the contralateral common iliac artery (contralateral femoral access) to acquire a selective contrast-enhanced (or carbon dioxide-enhanced) digital subtraction angiogram for a better overview of the internal or external iliac artery or, if necessary, the transplant artery in multiple projections.

When treating a TRAS, the sheath or guide catheter is first inserted into the common iliac artery via a contralateral or ipsilateral access as described above. After selective administration of unfractionated heparin, the renal artery to be treated is probed

OP-VIDEO



▶ **Video 1** AV fistula at the upper pole in a kidney transplanted to the right iliac axis in a 54-year-old patient with chronic glomerulonephritis. Visualization of the large AV fistula in digital subtraction angiography (2 pictures per second).



▶ **Fig. 5** Sketch of a transplant stenosis measurement (S): The diameter of the stenosis (X) is measured and the quotient to the vessel diameter of the transplant artery immediately proximal to the stenosis (**a**), or in case of poststenotic dilatation (D), immediately distal to it (**b**) is determined. S = X/a or S = X/b. If S < 0.5, hemodynamic relevance is assumed and there is an indication for intervention.

with a diagnostic or guide catheter and an angiogram is acquired. The degree of stenosis is calculated as the ratio between the diameter of the renal artery at the stenosis and the diameter of the renal artery proximal to the stenosis or distal to the poststenotic dilation segment [35] (▶ **Fig. 5**). A TRAS ≥ 50 % is considered significant and an endovascular intervention is typically subsequently performed. In the case of constrictions of unclear etiology, an invasive pressure measurement can be performed before treatment. The diagnostic criteria for the pressure measurement are summarized in ▶ **Table 1** [11, 35]. The lesion is carefully traversed with a hydrophilic guide wire and then with an angiography catheter. Subsequently, the balloon catheter or the stent is placed over the constriction. The diameter of the angioplasty balloon and the stent should be selected to be the same size as or 1 mm greater than the diameter of the normal part of the renal artery adjacent to the stenosis. In the case of primary stenting, balloon-expandable stents are to be given preference over self-expandable stents since they have a greater radial force and a more precise opening mechanism. However, in the case of high-grade stenoses, pretreatment with balloon PTA should be performed to avoid the risk of stent dislocation by the balloon while treating the constriction [11]. In the case of lesions of unclear etiology, a pressure measurement can additionally be performed via the angiography catheter prior to treatment. Nitroglycerin (10 µg/ml) can be administered to prevent vasospasms of the renal artery and its branches during instrumentation or to treat any vasospasms that occur [11]. A selective angiogram with the guide wire distal to the constriction shows the postinterventional result. In the case of residual stenosis following balloon PTA, a stent-based procedure can be performed during the same intervention. In the case of kinking of the stent, post-dilation via balloon PTA can also be performed.

When treating AVFs or pseudoaneurysms, the transplant renal artery is also probed, and a selective angiogram is acquired. A super-selective approach with a microcatheter being advanced until immediately before the aneurysm or the point of the fistula is then performed. Embolization should be performed using the *front-door/back-door* technique for the neck of the aneurysm. Alternatively, direct embolization of the point of the fistula can be performed. Primary coil embolization is used during treatment. Therapeutic embolization is considered a technical success when no flow can be detected in the region of the vascular injury on the subsequent angiography scan (▶ **Fig. 4**).

Follow-up

Most vascular interventions require monitoring for at least one night. Duplex sonography is the most suitable imaging method for visualizing the status after endovascular treatment and should be performed one day after the intervention or prior to discharge in the case of a short hospital stay. Kidney function parameters, particularly serum creatinine, are regularly monitored as part of outpatient follow-up. The patient's blood pressure is also routinely checked. If there is clinical suspicion of restenosis (worsening of transplant function or blood pressure), duplex sonography should be repeated. After balloon PTA, lifelong treatment with ASS is recommended. After stent PTA, platelet aggregation inhibition therapy, e. g. with clopidogrel, for 6 months in combination with lifelong treatment with ASS is indicated [11].

Conclusion

The diagnosis, treatment, and follow-up of kidney transplant patients should be performed on an interdisciplinary basis at highly specialized centers. For the most frequent vascular complications after kidney transplantation (transplant renal artery stenosis, dissections, arteriovenous fistulas, and pseudoaneurysms), minimally invasive treatment has good technical and clinical re-

▶ **Table 2** Summary of treatment recommendations considering current guidelines and literature.

Pathology	Primary treatment option	Alternative
Renal artery stenosis	Stent PTA	Balloon PTA
Refractory renal artery stenosis after PTA	Stent PTA	Operation
Arteriovenous fistula	Superselective embolization	
Pseudoaneurysm (intraparenchymal)	Superselective embolization	Stent graft PTA (with corresponding diameter of the carrier vessel)
Vessel kinking	Operation	Stent PTA
Renal vein thrombosis	Operation	Catheter-based thrombolysis
Vessel dissection	Stent PTA	Operation

sults as well as a low complication rate and is therefore the treatment of first choice (▶ **Table 2**).

Conflict of Interest

The authors declare that they have no conflict of interest.

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