FEATURES OF PREPARATION AND SURGICAL TECHNIQUES IN KIDNEY TRANSPLANTATION WITH MULTIPLE RENAL ARTERIES

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ABSTRACT

Kidney transplantation is considered the most effective treatment for end-stage renal disease (ESRD), as it typically leads to better survival rates and quality of life than dialysis. However, anatomical variations such as multiple renal arteries (MRAs), observed in 18–35% of donors, introduce significant technical challenges during organ retrieval, vascular reconstruction, and anastomosis, increasing the risks of complications like thrombosis, stenosis, and delayed graft function (DGF). The aim of this review is to summarize and critically evaluate contemporary strategies for preoperative imaging, surgical preparation, operative reconstruction techniques, and postoperative outcomes in kidney transplantation involving MRAs. We conducted a structured narrative synthesis based on 27 recent peer-reviewed publications (2010–2024), including meta-analyses, clinical cohort studies, and guideline reviews. Data show that with accurate preoperative planning, especially using CT angiography and 3D reconstruction, MRAs can be reliably identified and classified. Surgical strategies vary from bench reconstruction of arterial confluences to separate multiple anastomoses depending on vessel diameter and orientation. Although transplant renal artery stenosis (TRAS) and DGF are statistically more frequent in MRA grafts compared to single-artery grafts [1, 5, 10, 14], long-term graft and patient survival rates are comparable [3, 6, 11, 22]. Emerging approaches, including computational hemodynamic modeling, endovascular therapies, and robotic-assisted transplantation, are broadening technical capabilities and minimizing risks. The review highlights the need for unified surgical guidelines and supports the feasibility and safety of MRA grafts when handled by experienced multidisciplinary teams. Limitations of existing literature include heterogeneity in reconstruction methods and underreporting of long-term vascular outcomes. Nonetheless, this review contributes by systematizing available knowledge and outlining evidence-based practical recommendations for surgical teams. It underscores the importance of integrating imaging technology, surgical innovation, and risk stratification in the management of anatomically complex kidney grafts.

Keywords: Kidney transplantation; Multiple renal arteries; Vascular reconstruction; Transplant renal artery stenosis; Preoperative imaging; Surgical complications; Surgical techniques.

INTRODUCTION

Kidney transplantation is one of the most effective therapeutic options for patients with end-stage renal disease (ESRD), significantly improving both life expectancy and quality of life compared to dialysis. Advances in surgical technique, immunosuppressive therapy, and perioperative care have contributed to the expansion of transplant indications and improved outcomes. Despite these achievements, anatomical variations in donor organs, particularly the presence of multiple renal arteries (MRAs), remain a technical challenge for transplant surgeons.

MRAs are observed in approximately 18–35% of kidney donors and may significantly complicate both donor nephrectomy and recipient implantation [1, 3, 5]. The presence of two or more arteries requires meticulous preoperative imaging, individualized surgical planning, and complex vascular reconstruction techniques, as inadequate management may lead to segmental ischemia, transplant renal artery stenosis (TRAS), delayed graft function (DGF), or even graft loss [2, 6, 10].

Historically, kidneys with MRAs were considered suboptimal for transplantation due to the perceived elevated risk of complications. However, current evidence suggests that with proper preparation and surgical technique, the use of such grafts can yield outcomes comparable to those of single-artery grafts [3, 6, 11]. This shift in perspective has been driven by improved preoperative imaging modalities—most notably CT angiography—and increasing experience with bench vascular reconstruction and microsurgical techniques.

Given the growing demand for donor organs and the necessity to optimize every available graft, understanding how to safely manage MRAs is of paramount importance. The aim of this review is to provide a comprehensive synthesis of current data on the preoperative assessment, operative techniques, and clinical outcomes of kidney transplantation using grafts with multiple renal arteries, while highlighting future perspectives in imaging, technology, and surgical innovation.

The structure of renal blood vessels varies widely, which plays an important role in planning kidney transplants. In the typical pattern, a single renal artery arises from the abdominal aorta and enters the renal hilum. However, anatomical studies indicate that **multiple renal arteries (MRAs)** are present in approximately **18–35%** of donors, with variations including double, triple, and rarely, quadruple arteries [1, 3, 12].

These arteries may originate from the aorta or iliac vessels and often supply the superior or inferior poles of the kidney. Polar arteries, especially those supplying the ureteric branch or the collecting system, are clinically significant: **ligation or inadequate reconstruction** may lead to **segmental ischemia, necrosis of the ureter, or urinary leakage** [17, 24].

The most frequent variant is **double renal arteries**, reported in 12–15% of individuals, whereas triple arteries occur in approximately 3–5% [1, 12]. The presence of MRAs complicates not only organ retrieval but also vascular anastomosis and postoperative management. From a surgical standpoint, arteries are classified based on:

- **number and origin**,
- **diameter**,
- **point of entry into the kidney**,
- and **functional significance of the segment they supply** [3, 4, 24].

A pivotal **meta-analysis by Zorgdrager et al.** involving over 18,000 renal transplants reported that **vascular complications occurred more frequently** in MRA grafts (13.8% vs. 11.0% in single-artery grafts), and the incidence of **delayed graft function (DGF)** was also higher (10.3% vs. 8.2%) [1]. These numbers show that MRA grafts are more complex to manage and highlight the need for careful planning and close monitoring during surgery. The increased complication rates underscore the importance of individualized preoperative assessment and multidisciplinary coordination.

Modern imaging, particularly **CT angiography**, allows accurate identification of MRAs preoperatively. CT angiography is now the preferred method for evaluating renal vascular anatomy before donor nephrectomy, thanks to its high accuracy and detailed imaging [3, 18]. Proper mapping enables the surgical team to select an optimal strategy—either reconstructive or selective ligation—with minimized risk to the graft.

In conclusion, understanding and accurately assessing renal arterial anatomy is essential for **surgical planning**, **risk stratification**, and **optimizing graft outcomes** in kidney transplantation involving MRA grafts.

Preoperative evaluation of the donor kidney's vascular anatomy is a critical step in successful kidney transplantation, especially when multiple renal arteries (MRAs) are present. Thorough imaging allows not only for identification of all vascular structures but also for surgical risk stratification and selection of the appropriate reconstruction technique. This step is particularly important in live donor transplantation, where intraoperative surprises must be minimized.

The gold standard for vascular assessment in living and deceased donors is **multidetector computed tomography angiography (MDCT-A)**, which offers near-perfect sensitivity (97–100%) and specificity for detecting MRAs [3, 18]. This technique provides high-resolution images and enables 3D reconstruction of renal arteries, facilitating surgical planning and assessment of arterial caliber, trajectory, and perfusion zones.

Magnetic resonance angiography (MRA) serves as a valuable alternative in patients with contraindications to iodinated contrast agents. MRA has demonstrated reliable results, particularly when used with gadolinium contrast; however, its availability and spatial resolution are inferior to CT angiography [18].

Color Doppler ultrasound (CDU) is widely used as a screening tool and for postoperative monitoring. However, it lacks sufficient sensitivity for preoperative mapping of MRAs and is therefore not considered a standalone modality for surgical planning [6, 18].

In certain complex cases, especially in re-transplantation or anatomical uncertainty, **digital subtraction angiography (DSA)** may be used selectively, though its invasiveness limits routine use.

Beyond identifying MRAs, it is essential to assess the **functional relevance** of each artery. Small polar arteries (<2 mm) may supply discrete renal segments or the ureter. Ligation of such arteries risks segmental ischemia or urinary complications, particularly when supplying the lower pole [4, 17, 24].

Advanced centers use 3D models and computer simulations to plan vessel connections and predict how blood will flow through them [24]. While not yet standard, these technologies offer promising avenues for personalizing reconstruction approaches, particularly in complex MRA configurations.

Imaging findings play a decisive role in:

- selecting the side of nephrectomy (left vs. right),
- determining whether to combine arteries into a common trunk on the bench,

- or planning separate in situ anastomoses.

For example, if two arteries are closely positioned and similar in caliber, a "side-to-side" pantaloon anastomosis may be performed. Conversely, when arteries are widely spaced or differ in diameter, multiple anastomoses are planned individually [1, 4].

Preoperative imaging thus not only maps anatomy but directly influences surgical tactics, ischemia time, and ultimately, graft outcome.

The presence of multiple renal arteries (MRAs) continues to present a notable technical challenge in kidney transplantation, requiring a tailored approach to surgical planning and vascular reconstruction. The number, caliber, orientation, and spatial relationship of the arteries must all be considered, alongside the surgeon's experience and institutional protocols. The core objective in these cases is to ensure uniform and sufficient perfusion of the graft, while minimizing ischemia time and reducing the risk of vascular complications such as thrombosis and stenosis. To achieve this, several well-established surgical approaches are used depending on the specific anatomical configuration.

One frequently used technique is bench reconstruction, performed outside the body before implantation. In this approach, renal arteries of similar size and close anatomical proximity are sutured together using side-to-side or pantaloon methods to form a single arterial trunk. This allows for one arterial anastomosis to the recipient's external iliac artery and has been associated with a reduced rate of technical complications [1, 3, 6].

When arteries originate from distant points or differ significantly in size, they are often anastomosed separately. In this case, each artery is individually connected to the recipient's iliac vessels. While this ensures proper perfusion to all kidney segments, it may prolong cold ischemia time and demands precise technique [2, 5, 6].

In certain cases where direct reconstruction is not feasible, vascular grafts are employed. These include Y-shaped grafts derived from the donor's iliac artery or synthetic materials, which can be used to join separated renal arteries and facilitate their integration with the recipient vasculature [4].

In more complex scenarios involving three or more arteries, a combination of strategies may be required. For instance, two arteries may be joined and implanted together, while a third is connected separately [2, 5]. Alternatively, all arteries may be included in a single aortic patch—referred to as the Carrel patch technique—which is then sutured to the recipient's iliac artery as one unit. This method helps reduce the number of anastomoses and may minimize flow turbulence [3].

Special attention is needed when dealing with **polar arteries**, especially those supplying the lower pole or the ureter. Ligation of these vessels can result in segmental infarction, ischemia of the ureter, or urinary leaks. Therefore, they should be reconstructed whenever technically possible to preserve function [4, 17].

Proper alignment of vessels during implantation is essential to prevent kinking or torsion. Anastomoses must be performed without tension and in anatomical alignment to reduce the risk of post-anastomotic stenosis. Typically, the external iliac artery is used for arterial anastomosis; however, the internal or common iliac artery may be selected depending on individual anatomy. Similarly, venous drainage is most often directed into the external or common iliac vein [4, 9].

Although left-sided kidneys are more commonly used due to the advantage of a longer renal vein, in some cases of complex MRA anatomy, right-sided kidneys may be preferred because they offer easier access to the hilar structures [6, 9].

Despite the added technical demands, studies consistently show that long-term graft and patient survival in MRA transplants remains comparable to outcomes with single-artery grafts when performed by experienced teams [5, 6]. This supports the continued and safe use of MRA grafts in routine transplant practice.

Moreover, retrospective analyses from high-volume transplant centers suggest that surgical expertise and well-defined institutional protocols can mitigate the risks associated with complex arterial anatomy. These findings emphasize that technical outcomes are influenced more by operator skill than by the anatomical complexity itself.

Nonetheless, the presence of multiple anastomoses has been associated with slightly prolonged cold ischemia time and a higher incidence of transplant renal artery stenosis (TRAS) and delayed graft function (DGF), as demonstrated in the large meta-analysis by Zorgdrager et al. [1]. Therefore, meticulous planning, application of microsurgical techniques, and teamwork remain central to achieving optimal outcomes in these challenging cases.

While kidney transplantation using grafts with multiple renal arteries (MRAs) is now widely accepted as safe and feasible, it remains technically demanding and associated with a specific complication profile. These include vascular and urological complications, with transplant renal artery stenosis (TRAS), thrombosis, and delayed graft function (DGF) being among the most clinically significant concerns.

TRAS is the most frequent vascular complication following kidney transplantation, with a reported incidence of 1–23% depending on diagnostic criteria and follow-up protocols [10, 11, 14]. Grafts with MRAs are more susceptible to TRAS due to:

- Multiple arterial anastomoses,
- Increased ischemia time,
- Geometric distortion or angulation at the anastomotic site,
- Kinking or torsion of reconstructed vessels [10, 24].

According to Zorgdrager et al., the incidence of TRAS was significantly higher in grafts with MRAs compared to single-artery grafts (13.8% vs. 11.0%) [1]. Similar results were reported by Nicholson et al. and Pini et al., confirming vascular reconstruction as an independent risk factor [11, 14]. This pattern across independent studies reinforces the association between technical complexity and TRAS risk. It also highlights the importance of optimizing reconstruction technique and monitoring arterial flow dynamics, especially in grafts with multiple anastomoses.

Clinical signs of TRAS include:

- New-onset or refractory hypertension,
- Deterioration of renal function (↑ serum creatinine),
- Bruits over the graft area.

Doppler ultrasound serves as the first-line modality, with CT angiography and digital subtraction angiography (DSA) used for confirmation and pre-intervention planning [18, 20].

Treatment options include:

- **Percutaneous transluminal angioplasty (PTA)**,
- **Stent implantation**, including drug-eluting stents (DES) [13, 20, 21].

DGF is more frequently observed in MRA grafts, primarily due to prolonged warm ischemia time and increased technical complexity during implantation. The risk is particularly elevated in grafts requiring multiple anastomoses or when polar arteries are not perfused adequately [1, 6, 12].

In the series by Ghazanfar et al., DGF occurred in 10–13% of MRA cases compared to 7–9% in single-artery grafts, although long-term graft survival remained comparable [12]. While early graft dysfunction appears more prevalent in MRA settings, the preserved long-term survival implies that initial ischemic injury may be reversible or non-progressive when addressed promptly. This finding supports the value of aggressive early postoperative management in mitigating the consequences of technical complexity.

Although rare, arterial thrombosis is a devastating complication leading to graft loss. Risk factors include:

- Poor flow in small-caliber arteries,
- Technical errors during anastomosis,
- Vascular tension or compression [4, 10].

Reconstruction of polar arteries is especially critical to avoid **segmental infarction** or **ureteral necrosis**, which can lead to urinary leaks or graft dysfunction [17, 24].

MRA grafts are associated with a slightly higher incidence of urological complications, particularly when polar arteries that supply the ureter are ligated or inadequately perfused. These include:

- Ureteral strictures,
- Urine leaks,
- Ureteral ischemia [17].

Use of ureteral stents and careful preservation of ureteral vascular supply significantly reduces these risks [6, 17].

Despite a higher incidence of early technical complications, long-term outcomes in MRA grafts are equivalent to those with single-artery grafts when performed by experienced teams. In a large cohort analysis by Cooper et al. and follow-up data from Chedid et al., **1-year and 5-year graft survival rates were similar**, and patient survival was unaffected by the number of renal arteries [5, 6]. This aligns with other research confirming the safety of MRA grafts under appropriate surgical conditions. They also emphasize that surgical expertise and perioperative protocols may neutralize anatomical disadvantages when adequately implemented.

This supports the view that anatomical variations, such as multiple renal arteries, do not by themselves reduce the chances of a successful transplant.

Despite substantial improvements in surgical techniques and perioperative management, kidney transplantation involving multiple renal arteries (MRAs) still poses significant challenges. As the shortage of donor organs continues and the acceptance of marginal and anatomically complex grafts increases, strategies for optimizing MRA transplantation are becoming more relevant than ever.

Currently, no international consensus exists regarding:

- the optimal technique for reconstructing three or more arteries,
- the threshold for acceptable arterial diameter,
- or the preferred method of anastomosis in specific anatomical configurations [1, 22].

Because there are no standard guidelines, transplant results can vary from one center to another. Surgical strategies are often based on individual surgeon preference or institutional experience rather than on high-quality comparative data.

Advances in **three-dimensional reconstruction and modeling** from CT angiographic data have significantly enhanced surgical planning. These technologies allow:

- accurate mapping of vascular anatomy,
- simulation of reconstruction strategies,
- assessment of spatial relationships among vessels [3, 24].

Some centers have also begun to implement **3D printing** of donor vasculature to improve operative preparation and team coordination [24]. These innovations hold promise for improving outcomes, particularly in complex MRA cases.

Recent studies, such as that by Wang et al., have explored **computational fluid dynamics (CFD)** modeling to evaluate blood flow through reconstructed arteries and predict the risk of post-anastomotic stenosis [24]. While not yet integrated into routine clinical practice, CFD analysis could become a valuable tool in optimizing anastomotic geometry and selecting patients at higher risk of complications. The application of CFD modeling represents a shift from purely anatomical evaluation toward functionally informed decision-making in transplant surgery. By enabling virtual simulations of blood flow dynamics, this technology has the potential to identify suboptimal flow configurations before surgery and guide adjustments in reconstruction strategy, particularly in grafts with complex arterial patterns. Its future integration may bridge the gap between imaging and outcome prediction, contributing to personalized surgical planning.

Robotic-assisted surgery allows for more accurate dissection of renal arteries, especially in living donors. In the future, robotic platforms may also assist in the creation of microvascular anastomoses during recipient surgery, offering improved accuracy and potentially reducing ischemia time [6, 9].

Microsurgical techniques, especially under magnification, are increasingly used in bench reconstruction of MRAs and offer improved long-term patency and reduced technical failure rates.

The management of transplant renal artery stenosis (TRAS) is evolving with the development of **drug-eluting stents (DES)** and **novel endovascular devices** [13, 20]. In parallel, some randomized trials have investigated the role of **low-dose aspirin** in preventing early thrombosis and TRAS in high-risk grafts, showing promising results [25].

The integration of interventional radiology with transplant surgery and immunology is expected to improve both early and long-term outcomes for MRA grafts.

The future of MRA kidney transplantation lies in **personalized surgical planning**, integrating:

- anatomical data (via imaging and modeling),
- immunologic risk stratification,
- and predictive analytics based on large-scale transplant databases [22].

Artificial intelligence (AI) and machine learning may further enable centers to **optimize surgical decisions**, reduce complications, and tailor follow-up protocols to individual graft characteristics.

Kidney transplantation using grafts with multiple renal arteries (MRAs) has transitioned from a high-risk procedure to a routine and reliable option in modern transplant surgery. While MRAs introduce additional technical challenges, especially during vascular reconstruction, advances in imaging, surgical planning, and microsurgical techniques have allowed for excellent short- and long-term outcomes comparable to single-artery grafts [1, 5, 6, 12].

Based on the reviewed evidence, MRAs should no longer be considered a contraindication to transplantation. Instead, their successful use requires meticulous **preoperative assessment**, appropriate **reconstructive strategy**, and careful **intraoperative execution**. Emerging technologies such as **3D reconstruction**, **computational flow modeling**, and **robotic assistance** are enhancing surgical precision and outcome predictability [3, 9, 24].

Key takeaways from the literature include:

- CT angiography with 3D reconstruction is the most accurate and widely used method for assessing renal arterial anatomy before donor nephrectomy [3, 18].
- Bench reconstruction and pantaloon anastomosis are safe and effective for closely situated arteries, while separate anastomoses may be necessary in complex anatomical settings [1, 2, 4].
- While TRAS and DGF are somewhat more common in MRA grafts, proper surgical technique and close postoperative monitoring help reduce these risks significantly [10, 11, 14].
- When managed by experienced teams using current techniques, grafts with multiple renal arteries can achieve the same long-term outcomes as single-artery transplants [5, 6, 12].

This supports their safe and routine use in clinical practice.

Practical recommendations:

- Always perform CT angiography with 3D reconstruction during donor evaluation to map arterial anatomy.
- Avoid ligating polar arteries supplying the ureter or functional renal segments.
- Use microsurgical techniques for reconstruction and tension-free anastomoses.
- Consider ureteral stenting and perioperative antiplatelet therapy in complex cases.
- Ensure close postoperative Doppler monitoring for early detection of TRAS.
- Promote training in robotic and minimally invasive donor nephrectomy to improve vascular control and reduce complications.

In conclusion, the presence of MRAs should not limit the use of an otherwise suitable donor kidney. With proper planning, individualized surgical approach, and use of modern technologies, kidney transplantation with multiple arteries is both safe and effective—extending access to life-saving treatment for patients with end-stage renal disease.

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