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The Final Thesis

“Clinical Outcomes of Robot-Assisted Laparoscopic Kidney Transplantation – A Literature Review.”

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Table of Contents

i. List of tables

ii. Abbreviations and acronyms

CIT	Cold ischemia time
CKD	Chronic kidney disease
DGF	Delayed graft function
DM	Diabetes mellitus
ESRD	End-stage renal disease
eGFR	Estimated glomerular filtration rate
GFR	Glomerular filtration rate
KT	Kidney transplantation
LKT	Laparoscopic kidney transplantation
N/A	Not applicable
OKT	Open kidney transplant
OT	Operative time
POD	Post-operative days
RAKT	Robot-assisted kidney transplantation
RASS	Robotically assisted surgical systems
RRT	Renal replacement therapy
SSI	Surgical site infection
WIT	Warm ischemia time

1. Abstract

Kidney transplantation is the best treatment option for patients with end-stage renal disease. Although open surgery kidney transplantation remains the preferred method, minimally invasive surgery experiences increasing attention and trust among medical staff and patients. In this literature review, robot-assisted kidney transplantation and its outcomes are compared to alternative procedures such as open kidney transplantation or laparoscopic kidney transplantation. This review compares the clinical outcomes of robot-assisted kidney transplantation, subdivided into operative outcomes, functional outcomes, complications, and morbidity. The results present possible advantages of robot-assisted kidney transplantation over open kidney transplantation and laparoscopic kidney transplantation, address challenges during the process and give prospective suggestions for future perspectives.

Keywords: End-stage renal disease, kidney transplantation, robot-assisted kidney transplantation, minimal-invasive surgery, robotic surgery, da Vinci robotics, robotic transplant

2. Materials and Methods

A comprehensive literature review was conducted to identify relevant studies and literature on the outcomes of robot-assisted laparoscopic surgery in the case of kidney transplantation (KT). The research was performed by using electronic databases, such as Google Scholar, and PubMed. Articles that met the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) criteria were considered appropriate. A meta-analysis serves as a quantitative, formal, epidemiological study design that uses a systematic assessment of prior research results to conclude that body of research. Typically, but not always, the study is founded on randomly selected controlled clinical studies. The search terms included "End-stage renal disease", "kidney transplantation", "Robot-assisted kidney transplantation", "minimal-invasive surgery", "robotic surgery", "da Vinci robotics", and "robotic transplant". Inclusion criteria included 58 articles covering kidney transplantation as a treatment method for patients with end-stage renal disease (ESRD), due to chronic kidney disease (CKD), diabetes mellitus (DM), kidney infection, hypertension, chronic glomerulonephritis, polycystic kidney disease, and idiopathic causes. All reviewed articles were published between 2006 – 2024. The exclusion criteria were studies, articles, and reviews that did not meet the inclusion criteria. All selected articles and book sections were reviewed in 2023/24, and the necessary data was extracted and analyzed.

3. Introduction

In recent years, kidney transplantation has emerged as the cornerstone of treatment for ESRD or using the most recent classification, CKD stage 5, presenting a potential prolongation of life and enhancement of its quality when compared to renal replacement therapies (RRT). The rather complicated procedure of transplantation has been facilitated by significant advancements in surgical techniques. Minimally invasive approaches gain increasing popularity due to their associated benefits, especially perioperatively, as there is for example no necessity for large incisions (1). Smaller incisions lead to less post-operative pain, a lower dose of analgesics improve and accelerate the patients' post-operative recovery and shortens hospital stay (2). Additionally, in the long term transplantation is considerably less expensive, therefore reduces the overall burden of renal disease (3).

Among these approaches, RAKT has attracted considerable interest due to its potential to replace conventional open surgery and improve renal transplantation practices. Hence, providing physicians with enhanced accuracy, sensitivity, dexterity, and reduced invasiveness. Kidney transplantation has been the most common transplant procedure in 2023, with Eurotransplant (4) reporting a total of 4,461 procedures in Europe[1]. This highlights the critical need for techniques that optimize outcomes while minimizing invasiveness.

The primary objective of this literature review is to assess the clinical outcomes associated with RAKT, focusing on efficiency, post-surgical complications, and comparative advantages over conventional transplantation methods.

Through this analysis, a comprehensive understanding of the status and future potential of RAKT will be provided, offering a perspective on its potential impact within the current epidemiological landscape of kidney disease.

[1] Europe: Austria, Belgium, Croatia, Germany, Hungary, Netherlands, Slovenia

4. End-stage renal disease

ESRD is the last of five stages of CKD, in which the kidney's nephrons have permanently lost most of their function. At this point, the nephrons are no longer capable of performing their key functions, such as filtering waste products and excess fluids from the blood, controlling electrolyte balance, and producing hormones required for adequate body function. The final stage of ESRD is characterized by a substantial reduction in kidney function, indicated by a glomerular filtration rate (GFR) of less than 15.0 mL/min/1.73 m^2 (Table 1). RRT alternatives include dialysis (hemodialysis or peritoneal dialysis) or ultimately kidney transplantation (5). Hemodialysis involves filtering blood via a dialysis machine to extract excess fluids and waste materials from the body. Throughout hemodialysis, the patient's blood is cycled outside the body through a dialyzer and purified before being returned to the body. Peritoneal dialysis, on the other hand, utilizes the peritoneum which is an abdominal cavity lining membrane. It functions as a natural filter, introducing and draining a cleansing solution cyclically to eliminate toxins and excess fluids. It is a serious and irreversible state that demands continuous medical management and therapy to maintain general health and prolong life (6). Without access to long-term dialysis, an estimated 2.3 - 7.1 million individuals with end-stage renal disease died in 2010 (7).

Stage	Description	GFR (ml/ min/ 1.73 m^2.)
I	Normal	$\geq$ 90.0
II	Mild	60.0 - 89.0
IIIa	Mild to moderate	45.0 - 59.0
IIIb	Moderate	30.0 - 44.0
IV	Moderate to severe	15.0 - 29.0
V	Kidney failure (ESRD)	<15.0

Table 1 *CKD staging according to GFR*

4.1 Epidemiology

Epidemiologically, CKD reflects a global health concern, observing an increasing prevalence of diagnosed patients worldwide.

The estimated global prevalence of (CKD) is approximately 13.4% (11.7-15.1%). The number of people with ESRD requiring RRT ranges between 4.9 and 7.1 million people worldwide, in which hemodialysis is the most frequent treatment modality. However, these numbers may not accurately reflect the true prevalence and incidence of ESRD due to cases that go undiagnosed and limited access to RRT in many countries. It is important to note that national ESRD statistics are not available in several low- and middle-income countries in Africa and two highly populated emerging economies, China, and India.

Furthermore, the proportion of patients with ESKD who did not receive RRT was significantly higher in low (96%) and lower-middle (90%) income nations than in upper-middle (70%) and high (40%) income areas. In low-income nations, particularly in Asia and Africa, the most significant treatment disparities were observed. Only 17-34% of those requiring KRT were treated in Asia, while in Africa, the number was even lower at 9 -16%. The global rise is mostly caused by an increase in the prevalence of common etiological factors such as DM, hypertension, obesity, and ageing. However, in some areas, additional reasons such as infections or environmental pollutants are still prevalent (8) (9). The United States Renal Data System reported a consistent number of 20.000 ESRD cases per year in the United States of America, indicating a significant need for RRT to survive.

In this context, the transplantation of a kidney, either from a deceased or living donor, emerged as a last promising step to successfully treat patients, as kidney disease is among the leading causes of death worldwide (10). Age is also a key factor in the development of ESRD. The prevalence of CKD increases with age, accounting for 6.0% of people between the ages of 18 and 44 and rising to about 38% of people over the age of 65 (6).

4.2 Etiology

ESDR can be caused by a wide range of conditions. These include chronic kidney disease, primary glomerular diseases such as focal and segmental glomerulosclerosis or membranoproliferative glomerulonephritis, diseases secondary to glomerular insufficiency such as DM, systemic lupus erythematosus or human immunodeficiency virus, tubulointerstitial diseases such as infections (viral, bacterial, parasitic), chronic hypokalemia or hypercalcemia, or polycystic kidney disease. The most common factor among the aforementioned is DM (6).

Most patients receive hemi- or peritoneal dialysis therapy, before being considered or waiting for a renal transplant (11).

4.3 Pathophysiology

Each nephron in a healthy kidney contributes to the overall GFR. Decreased kidney function occurs gradually and may be asymptomatic at first. The progression of renal failure varies according to the etiology of the underlying disease. A blood test for creatinine levels is used to calculate estimated glomerular filtration rate (eGFR) results. The normal eGFR score in adults is greater than 90, but it decreases with age, even in those without renal disease. The eGFR measurements are crucial for determining the severity of CKD (12). Due to compensatory mechanisms such as hypertrophy and hyperfiltration of the remaining healthy nephrons, the kidney maintains normal GFR despite of increasing nephron destruction (13). As a result, a patient with mild renal impairment may have normal GFR values and creatinine levels, and the condition may go unnoticed for some time.

It is important to note that this compensation mechanism of nephrons enables normal clearance of plasma solutes, and patients may remain asymptomatic. The adaptive mechanism will ultimately harm the glomeruli of the remaining nephrons leading to further destruction and kidney damage. Antihypertensives like angiotensin-converting enzyme and angiotensin II receptor blockers may now help prevent further disease progression and maintain renal function in the early stages. When the GFR decreases by 50.0%, waste products such as urea and creatinine begin to increase significantly in the blood plasma. Although hyperfiltration and nephron hypertrophy are beneficial for GFR maintenance, they have been identified as a primary cause of progressive kidney damage (14). Increased glomerular capillary pressure can damage capillaries and result in glomerulosclerosis (15). As CKD progresses, the risk of developing metabolic acidosis increases. The prevalence of metabolic acidosis in Stage 4 CKD is almost 40.0%. This occurs when the proximal convoluted tubules of the kidneys are unable to produce enough ammonia to excrete endogenous acid in the form of ammonium, resulting in an accumulation of anions, primarily sulfate and phosphate, which increases the anion gap. A dominant high anion gap is estimated to develop when GFR falls to 10-15ml/min/1.73 m^2 (16). In addition, an increased amount of potassium is secreted when the glomerular filtration rate (GFR) falls below 20-25 ml/min/1.73m^2. As long as the distal convoluted tubule and aldosterone secretion are functioning properly, the kidneys maintain normal potassium excretion above 25ml/min/1.73m^2 (17) (18).

4.4 Clinical manifestations

CKD is defined by a broad spectrum of symptoms, where many may not occur until the nephron damage is irreversible. Symptoms include fluid overload that is resistant to diuretics or hypertension that can be poorly controlled with antihypertensive drugs. Especially the accumulation of water and electrolytes could lead to pulmonary and/ or peripheral edema. Furthermore, metabolic imbalances may occur such as metabolic acidosis, hyperkalemia, hyponatremia, hypo- and hypercalcemia, and hyperphosphatemia, additionally to possible mineral and bone deficiencies. Especially in the last stage of CKD, metabolic acidosis plays a crucial role. It can contribute to muscle weakness, loss of lean body mass, and protein deficiency (6). Another clinical sign may be anemia. Anemia is characterized by fatigue, exertional dyspnea, poor cognitive function, and an increased risk for worsening angina pectoris when the oxygen demand for the myocardium is not properly met. This circumstance can also potentially result in cardiac failure (14) (19).

4.5 Diagnostic criteria

First signs of kidney damage for at least three months or a GFR below 60.0 ml/ min/ 1.73 m^2 within the same time range, strongly indicates CKD. With measurements of the GFR values CKD staging is possible and facilitates treatment planning (20). A renal ultrasound, complete blood count, urinalysis, and/or kidney biopsy are among the tests that can be used to further assess kidney disease. With a renal ultrasound, it can be checked for kidney size, possible obstructions, tumors, stones or thinning of the cortex. Retroperitoneal disorders or hydronephrosis can be common findings (21). Urinalysis can be used to detect albuminuria if albumin levels exceed 30 mg per gram of creatinine. Additionally, a 24-hour urine protein measurement can be performed to detect proteinuria if more than 3.5 grams of protein are excreted. The basic metabolic panel can show increased blood urea nitrogen and serum creatinine values, as well as hyperkalemia or low bicarbonate levels. Malnutrition or urine protein loss causes low serum albumin levels. A percutaneous ultrasound-guided biopsy of the kidney is recommended if the diagnosis remains unclear after a comprehensive examination (6).

5. History of robotic-assistant systems

As medical inventions advanced rapidly throughout the 20th century, it was only a matter of time before the concept of robot assistance systems was introduced. In the 1970s, two visionary ideas brought attention to robotic assistance systems, marking the first time such systems were given serious consideration. On the one hand, NASA planned to establish a telemanipulation system for emergency medicine, and on the other hand, multifunctional robotic devices were intended for long-distance trauma surgery in battlefield environments (22). About a decade later, robotically assisted surgical systems (RASS) were introduced for orthopedic surgery in the form of voice-commanding robots. They were mainly used during arthroscopy to provide assistance and guidance, such as handing over specialist equipment or positioning patients' limbs (23). In 1985, the first robotic invasive surgery was performed. A PUMA-200 industrial robot, which stands for a programmable universal machine for assembly, was used during a computer tomographic-guided brain biopsy in neurosurgery to minimize hand tremors and to place and lock biopsy channels (24). Penecontemporaneous, another robotic device was developed to mill the bone during total hip endoprosthesis implantation (25). Worldwide, more than 3000 da Vinci robotic systems are in use and over 200.000 robotic procedures are carried out annually (26).

6. Kidney transplantation

Over the past century, KT has undergone a remarkable evolution as the final treatment solution for patients suffering from ESRD. In the beginning, the procedure experienced a great amount of skepticism, due to missing knowledge of immunosuppression or related kidney graft rejections. Living donor KTs, deceased donor KTs and proper graft preservation did not only expand the pool of graft resources, furthermore, increased knowledge made KTs trustworthy. Throughout time KT developed into a promising and comprehensive method additionally to an improved quality of life for patients with renal failure.

6.1 Evolution

There have been three main stages in the development of kidney transplantation: initial experiments, early human trials, and overcoming the first known barriers. Therefore respectively, the idea of renal transplantation already existed at the beginning of the 20th century. In 1902, the first successful animal kidney transplantations took place in Austria. Seven years later, in 1909, French surgeons conducted an experimental transplantation of an animal kidney into a human body (27). 1933, the first KT from a human to a selected patient took place. However, due to a blood group mismatch, the kidney did not function properly. In 1954, the first successful living-related renal transplantation among humans occurred when a brother's kidney was transplanted to his identical twin. The combination of corticosteroids and azathioprine therapy was meant to decrease the organ rejection risk, as discovered in 1963 (28). The invention of micro toxicity testing in 1964 highlighted the important role of antibodies in transplantations and kidney allograft survival. This marked the basis of modern transplant immunology and overcame the first barriers to successful long-term outcomes (29).

In transplantation, matching exchange programs are used as innovative solutions. These programs enable patients with incompatible donors to exchange kidneys, often with the support of other living donors. For patients who are unable to take advantage of this program, antibody-incompatible transplantation becomes a more viable option, due to inhibition of germinal center activation and cleavage of circulating antibodies (30). Additionally, instead of incompatibility testing, the donor's immunogenicity can be evaluated to find possible transplant recipients (29). The first laparoscopic donor nephrectomy was performed in 1995 at the Johns Hopkins Medical Center. Hereby, the kidney was reached through transperitoneal access and removed via the Pfannenstiel incision (31). In Lithuania in 2017, Laučytė-Cibulskienė et al. marked the first four successful laparoscopic living donor nephrectomies within the Baltic states (32). Although established dialysis techniques have improved over time, renal allotransplantation has emerged as a superior RRT and is now considered the gold standard treatment among most KT (33). There are only 8 academic hospitals within the European Union currently performing the RAKT with living donor kidneys (34).

6.2 Different techniques

Open kidney transplantation (OKT) is commonly performed using a curvilinear or oblique incision, known as the pelvic Gibson or an inverted J-shaped incision, known as a hockey stick incision. The incisions are muscle splitting, allowing good extraperitoneal access to the bladder, lower ureter and iliac vessels (35). With effective results than can be widely repeated, this treatment has been utilized for many years and offers a dependable access and implantation method. Even though the approach's standardization and safety, open abdominal incisions might increase the overall morbidity risk for KT patients (33). Even though OKT continues to be the preferred method when it comes to KTs from deceased donors it accounts for the most common graft sources in the majority of the world (36). Smaller incisions of six to ten centimeters have been tried with varying degrees of success to reduce wound morbidity (1). In

April 2009, Rosales et al. stated that, the first laparoscopic kidney transplantation (LKT) from a living, related donor was successfully performed in Spain. The graft was inserted through a seven-centimeter Pfannenstiel incision in the patient's abdomen (37). Performing OKT through a smaller incision may reduce wound-related complications. However, this technique increases the difficulty of vascular anastomosis, a critical technical aspect of kidney transplantation that is already challenging due to the limited two-dimensional vision. Newly introduced robotic systems offer advantages in many minimally invasive surgical specialties, including restoration of hand-eye coordination with three-dimensional vision, reduction of natural human tremors and improved geometric accuracy. Moreover, due to improved ergonomics for the surgeons, intra-operative fatigue can be reduced. A surgical team in France performed the first RAKT from a deceased donor in 2001. The surgery was conducted using the Da-Vinci robotic system by a surgeon who operated remotely from another hospital, with an assistant present in the patient's operating theatre (33) (38). The first robotic-only RAKT was performed in the United States in 2010 (39). Maintaining a low temperature of the kidney graft during vascular anastomosis is one of the main challenges in RAKT. In 2014, the procedure was standardized by using regional hypothermia for the graft in addition to transperitoneal access. A medical team, including Alberto Breda, successfully accomplished Europe's first comprehensive RAKT in July 2015 (40). Surgical steps during a RAKT include transperitoneal dissection of the external iliac vessels, venous and arterial anastomosis, graft retroperitonealization, and ureterovesical anastomosis (41). In another successful approach for total robot-assisted KT, the graft was inserted through the patient's vagina, marking the first-ever transvaginal KT (42). Fentanyl infusion (0.5 µg/kg/hour) and intravenous paracetamol one gram three times a day were used for postoperative analgesia (43).

6.3 Current state

In the case of RRTs for patients with ESRD, kidney transplantation is generally the favored treatment option, in comparison to hemo- or peritoneal dialysis and has a good treatment prognosis. Minimally invasive techniques have become increasingly popular in kidney transplant surgery to reduce morbidity, although the following enhance the risk of delayed graft function (DGF): longer operation times (OT), longer cold ischemia time (CIT), longer warm ischemia time (WIT) and rewarming time; the lack of an appropriate fluid regimen, and the influence of a pneumoperitoneum on the allograft. Even though fluid management, graft features, CIT, anesthetic method, and concurrent medical conditions are considered risk factors for DGF in open kidney transplants, OKT remains the gold standard (43). According to Sharma et al., living-donor KT is favored over deceased-donor KT because of a faster recovery and shorter hospital stay. KT is recommended for all patients with ESRD who require RRT unless contraindicated (3). Additionally, living-donor KT is associated with longer kidney graft survival, resulting in higher cost-effectiveness, improved quality of life and overall survival rate for the patient. Generally, in comparison to dialysis treatment, the life expectancy for KT patients is more promising (31). According to Breda et al., RAKT-related inclusion criteria are recipient from living donor nephrectomy, BMI 18-35, age over 20 years, no pulmonary, cardiovascular, or hepatic concurrent medical condition; no atherosclerosis in external iliac vessels on CT scan and/ or no tumor or any other positive virology. Exclusion criteria include multiple abdominal surgeries, general contraindication for laparoscopic abdominal surgery and/ or polycystic kidney disease. The kidney graft is embedded into a gauze jacket which contains ice slush to keep it at a steady temperature of 18.0 -20.0 °C (40). Regional hypothermia is one of the most relevant and seminal procedures, introduced to RAKT by Menon et al. (44). With Ahlawat and Modi, Menon established a two-phase KT program, which shows that not only the regional hypothermia enhanced kidney graft outcomes. For a successful RAKT associated with regional hypothermia, two things are necessary: surgeons with extensive experience performing RAKT and time-efficient anastomosis, as longer times needed do not protect the graft and might lead to DGF (38).

The use of robotic surgery minimizes risks and preserves functional outcomes of the open technique at a baseline. Enabling KT to be carried out under almost ideal operating conditions, it gives RAKT promising prospective advantages, though this relatively new procedure is still evolving (5).

7. Technical robotic aspects

The patient is positioned on an operating table near the robotic unit with its four robotic arms, while the surgeon is seated at a console several feet away from the patient. The surgical arms are operated using remote core technology, which establishes a fixed point in space and moves the arms around it to achieve safer retraction movements (45). The surgeon controls the arms using "master" instruments at the console, which detect their hand movements and electronically translates them into scaled-down micro-movements that control the small surgical instruments. This system is known as the master-slave system (46). A motion filter minimizes hand tremors. Console binoculars allow the surgeon to look at the operating field. Attached to one of the robot arms is a highly mobile endoscope, a type of high-definition stereoscopic camera. Additionally, the console incorporates foot pedals that enable the surgeon to trigger electric cautery, move the console's "master" controls without moving the instruments themselves, and connect and withdraw various instrument arms (47). Currently, Da Vinci robot (Intuitive Surgical Inc., Sunnyvale, CA, USA) provides the Si and Xi systems. In contrast to the Xi version, which provides a cross-laser positioning mechanism, the Si system lacks positioning guidance support (24). Also, the Xi system is a newer model and features an overhead beam allowing to rotate the instrument arms and providing the robot with greater mobility when approaching the patient (47). In terms of operating arms, the Xi system includes thinner and longer robotic arms with updated joints that provide a broader range of motion than the Si system, and the endoscope can be handled by any of the four robotic arms (24).

7.1 Da-Vinci-assisted kidney transplantation

The surgeon, experienced in the Da Vinci systems, is seated at a console several feet away from the patient (45). A co-surgeon is positioned next to the operating table. The patient is positioned in a Trendelenburg posture, a common positioning for urologists when performing robotic radical proctectomy or cystectomy (38), and the robot is placed. The patient's positioning caused the central venous pressure to rise to 14.0 ± 4.0 mmHg. The pneumoperitoneum was induced by administering CO2 through a laparoscopic Veress needle. The intra-abdominal pressure remained at 15.0 mmHg (43). An upper midline incision of seven centimeters is done, and a hand-access device is placed. After that, four more trocars are implanted. One 12-mm port for the 30° robotic scope is located at the umbilicus, while two eight-millimeter robotic ports for robotic arms are in the right upper and left lower quadrants of the abdomen, for right-sided graft implantation, respectively. Another 12.0-mm port for assistance is implanted on the umbilicus's left side. The da Vinci surgical system is docked into place, from the patient's right side, and connected to all ports. Following suitable vascular dissection, the allograft is introduced into the operating field via the midline incision and properly positioned for implantation into the external iliac arteries. Upon reperfusion, the pneumoperitoneum was removed, allowing for open ureteric anastomosis. he renal vein and artery are anastomosed end-to-side to the external iliac vein and artery using a 5-0 or 6-0 expanded polytetrafluoroethylene suture. Saline and methylene blue are used to dilate the bladder, making it easier to dissect. The muscle layers are cut apart, and the bladder mucosa is prepped. The ureter is connected to the bladder using a 5-0 polydioxanone suture. Once the anastomosis is completed, the seromuscular layer over the ureter-cystostomy is closed with a 4-0 polyglycolic-acid suture, providing an anti-reflux mechanism. The placement of a double J ureteral stent is determined by the surgeon's desire. Intraoperative fluorescence vascular imaging using indocyanine green or intraoperative Doppler is used to evaluate renal perfusion (48).

7.2 Advantages

The good outcome in robotic kidney transplantation is made possible by the consistent advancement of technology and instrumentation.

Operating within a deep and narrow field made possible by 12x magnification, high-definition, and three-dimensional vision, which improves visualization of anatomical structures. Enhanced depth perception aids regarding the precision of surgical movements, supported by the scaling of hand movements and the reduction of the physiological tremors associated with robotic systems (40). Additionally, it facilitates natural hand-eye coordination, enabling intuitive movements and precise handling of instruments during the procedure. The robotic instruments provide several degrees of movement and rotation freedom, enhancing dexterity and facilitating more complex surgical tasks with greater precision. The ergonomic sitting position reduces fatigue during prolonged procedures, contributing to enhanced comfort and endurance for the surgeon. The ergonomic advantage, combined with the system's intuitive interface, results in a shorter learning curve for surgeons transitioning to robotic-assisted techniques. These features enhance the safety, efficiency, and outcomes of kidney transplantation procedures performed using robotic technology (49).

7.3 Challenges

The Da Vinci surgical system has great advantages, but its general adoption is held back by notable limitations. While robotic surgery has a less steep learning curve in comparison to laparoscopy. Before performing surgery on patients, doctors must receive extensive training. The operating theatre crew requires training too, on how to use this technology and how to handle intraoperative challenges and find constructive solutions. Furthermore, the constant technological advancements, such as interface updates, may quickly raise the already high cost of robotic surgery. Additionally, the surgical planning process requires a significant amount of time and resources. Due to the placed trocars, it lacks accessibility towards the patient within the operating theatre and causes a delay in case of operation conversion into open surgery. Current costs of hospitals constrict the purchase of such systems due to additional prospective expenses regarding acquisition and maintenance. Moreover, significant floor area requirements and cost-intensive renovations, delay worldwide implementation. Challenges such as instrument usability, loss of tactile feedback leading to frequent suture ruptures during knot tying, and insufficient studies on efficacy as compared to traditional procedures raise serious concerns (39).

8. Clinical outcome assessment

Clinical outcomes are essential for determining the procedure's efficacy and safety. Outcomes are subdivided into operative outcomes, functional outcomes, morbidity, and complications.

Tables can give a systematic platform for displaying analytical information on surgical approaches, such as total ischemia time, anastomosis time, or overall OT, allowing for comparisons and potentially revealing areas for improvement. Functional outcomes such as early graft function and survival rates, need for post-operative dialysis, and length of length of hospitalization can be thoroughly documented, providing information on the procedure's efficacy and long-term outcomes. Furthermore, morbidity and complication information, including surgical site infection (SSI) rates, need for anastomosis revision, rejection episodes, and long-term complications like incisional hernias allow for a more comprehensive assessment of patient safety and postoperative care measures. Students, researchers, and clinicians can evaluate the effectiveness of operative outcomes, functional outcomes, and morbidity/complications. This process helps to inform evidence-based decision-making and promotes improvements in RAKT protocols.

8.1 Surgical outcomes

WIT and CIT as well as rewarming times were among the surgical outcome assessments of several studies. WIT is the time between renal circulatory arrest and the beginning of the cooling storage process. CIT is the period between cold storage (with or without a storage solution perfusion) and graft implantation into the recipient. The rewarming period is the time measured between taking the kidney out of cold storage and starting the graft’s reperfusion, while at the same time constantly providing ice slush (41).

Table 2 compares important surgical parameters (median values) from studies provided by Breda et al., Territo et al., Campi et al., and Tzvetanov et al. It enables a clear understanding and comparison of OTs, ischemia times, anastomosis times, and blood losses linked with RAKT procedures as reported in the appropriate literature.

8.1.1 Intraoperative surgical data for RAKT

	Breda et al. (41)	*Territo et al. (50)*	*Campi et al. (36)*	*Breda et al. (40)*
OT (in minutes)	250.0	300.0	210.0	356.0 ± 68.0
Console time (in minutes)	160.0	N/ A	180.0	180.8 ± 17.5
Total ischemia time (in minutes)	89.5	116.0	N/ A	98.9 ± 22.1
WIT (in minutes)	2.0	4.0	N/ A	4.0 ± 0.5
CIT (in minutes)	34.0	45.0	N/ A	43.3 ± 22.2
Rewarming time (in minutes)	50.0	60.0	N/ A	51.5 ± 3.5
Arterial anastomosis time (in minutes)	19.0	22.0	18.0*	20.1 ± 2.7
Venous anastomosis time (in minutes)	20.0	24.0	18.0*	21.6 ± 3.4
Vascular anastomosis time (in minutes)	38.0	45.0	N/ A	41.7 ± 5.2
Uretero-vesical anastomosis time (in minutes)	21.0	25.0	15.0	21.5 ± 2.3
Blood loss (in milliliters)	150.0	200.0	N/ A	54.0 ± 8.4
Conversions to open surgery (in %)	N/ A	N/ A	0.0	N/ A

***Table 2** Intraoperative surgical data for RAKT*

**p-value statistically significant ($p < 0.05$)*

According to Breda et al., the operative time for RAKT was 250.0 minutes, while Territo et al. reported a slightly longer OT of 300.0 minutes, and Campi et al. reported a shorter OT of 210.0 minutes. In another study, by Breda et al., he included standard deviations (SD) to the mean values published, supplying the reader with better insights towards the ranges of each value. He measured a relatively long OT of 356.0 minutes with a SD of 68.0 minutes. In terms of console time, Breda et al. noted 160.0 minutes and 180.8 minutes with a SD of 17.5 minutes, respectively. Like Breda in one of his studies, Campi et al. reported 180.0 minutes of console time, whereas Territo et al. did not provide this data. The total ischemia time, encompassing WIT and CIT durations and rewarming time, varied across the studies, with Breda et al. reporting 89.5 minutes and Territo et al. reporting 116.0 minutes. While Campi et al. did not specify this parameter in their study, Breda et al. published a mean total ischemic time of 98.9 minutes with a SD of 22.1 minutes, indicating the longest ischemia time among all studies. WIT was reported as 2.0 minutes by Breda et al. and 4.0 minutes by Territo et al. CIT was documented at 34.0 minutes by Breda et al. and 45.0 minutes by Territo et al., with Campi et al. not specifying. The rewarming time, indicative of kidney preparation before implantation, was reported as 50.0 minutes by Breda et al. and 60.0 minutes by Territo et al., but not by Campi et al. Arterial anastomosis time, critical for establishing blood flow to the transplanted kidney, varied slightly between the studies, with Breda et al. reporting 19.0 minutes, Territo et al. reporting 22.0 minutes, and Campi et al. reporting 18.0 minutes. Venous anastomosis time, vascular anastomosis time, uretero-vesical anastomosis time, and blood loss were also reported with slight variations across all studies, indicating differences in surgical techniques and outcomes among the different research investigations. It should be emphasized, that the estimated blood loss of 54 ml with a SD of 8.4 ml, stated by Breda et al., undercuts all other analyzed blood losses in this thesis. Tzvetanov et al. (48) stated a kidney graft surface temperature of 20.3 °C, which almost meets the graft cooling reference stated in 6.3 by Breda et al.

According to the authors, all RAKTs were completed successfully, without the requirement for open conversion. Conversion to open surgery was needed in three cases, as stated in a study conducted by Rajmohan et al. It was required due to one case of an arterial thrombus, another case of acute venous kink, and a third case of decreased perfusion in the lower renal pole (43). The median overall OT (incision to closure) varied greatly among the conducted studies. Vascular anastomosis time and ureterovesical anastomosis time did not differ significantly between RAKTs.

8.1.2 Intraoperative surgical data for RAKT versus OKT

Table 3 compares important surgical parameters (median values) from studies provided by Tugcu et al., Ahlawat et al., and Campi et al. It enables a deeper and more thorough understanding now comparing OTs, ischemia times, vascular and uretero-vesical anastomosis times, and blood losses linked with RAKT now compared to OKT procedures as reported in the appropriate literature.

	Tugcu et al. (51)		*Ahlawat et al. (2)*		*Campi et al. (36)*	
	RAKT	OKT	RAKT	OKT	RAKT	OKT
Operative time (in minutes)	265.37	250.25	195.0*	162.5*	210.0	205.0
Console time (in minutes)	180.25	N/ A	154.0	N/ A	180.0	N/ A
Total ischemia time (in minutes)	96.70*	71.32*	69.0*	51.5*	N/ A	N/ A
Warm ischemia time (in minutes)	1.86	1.70	2.2	2.2	N/ A	N/ A
Cold ischemia time (in minutes)	40.47*	32.76*	23.5*	18.0*	N/ A	N/ A
Rewarming time (with ice slush; in minutes)	54.70*	37.30*	42.0*	31.5*	N/ A	N/ A
Arterial anastomosis time (in minutes)	18.45*	14.97*	N/ A	N/ A	18.0*	22.0*
Venous anastomosis time (in minutes)	20.92*	16.02*	N/ A	N/ A	18.0*	24.0*
Uretero-vesical anastomosis time (in minutes)	21.30*	14.95*	N/ A	N/ A	15.0	18.0
Blood loss (in milliliters)	182.25*	210.75*	100.0*	250.0*	N/ A	N/ A
Incision length (in centimeters)	5.11*	12.90*	6.3*	15.7*	N/ A	N/ A

***Table 3** Intraoperative surgical data of RAKT versus OKT*

**p-value statistically significant ($p < 0.05$)*

The comparative data from Tugcu et al., Ahlawat et al., and Campi et al. shed light on perioperative data performing RAKT. For a better understanding of the outcomes of robot-assisted laparoscopic kidney transplantation, RAKT can be compared with OKT.

In terms of OT, RAKT shows longer durations in all given studies. Tugcu et al. stated a total OT of 265.37 min. vs. 250.25 min., Campi et al. 210.0 min. vs. 205.0 min., and Ahlawat et al. reported 195.0 min. vs. 162.5 min. compared to OKT. Console time data, available from Tugcu et al. and Campi et al., suggest moderate durations for RAKT, which could contribute to overall surgical efficiency. Total ischemia time, incorporating warm and cold ischemia durations tends to be longer in RAKT according to Tugcu et al., Ahlawat et al., and Campi et al., possibly due to the complexity of the robotic approach. However, RAKT demonstrates advantages in terms of incision length, with significantly shorter incisions reported by Tugcu et al. (5.11 cm) and Ahlawat et al. (6.3 cm) compared to OKT, suggesting potential benefits in terms of cosmetic outcomes and postoperative recovery. Additionally, RAKT is associated with lower blood loss according to Tugcu et al. (182.25 ml vs. 210.75 ml) and Ahlawat et al. (100.0 ml vs. 250.0 ml), indicating potential advantages in terms of intraoperative safety and transfusion requirements.

The median overall operative time (incision to closure), WIT, vascular and uretero-vesical anastomosis time did not differ significantly between RAKT and OKT.

Although RAKT may have longer cold and rewarming ischemia times, the benefits such as shorter incision lengths, reduced blood losses, and lower transfusion requirements indicate potential advantages in terms of surgical morbidity and patient recovery, when considering kidney transplantation. These findings collectively suggest that RAKT may offer distinct advantages over traditional open surgery, making it a promising approach for kidney transplantation.

8.2 Functional outcomes

RAKT is an alternative RRT with potential advantages over standard open approaches. Understanding early and late functional outcomes becomes essential for assessing the efficacy and long-term success of RAKT treatments in kidney transplant recipients.

Early surgery-related functional outcomes, which are often examined in the first several days following surgery, provide information about immediate graft function, post-operative complications, and patient recovery.

Late surgery-related functional outcomes, on the other hand, provide insight into the long-term viability and sustainability of graft function, which can range from months to years after transplantation. By thoroughly studying both early and late functional outcomes, researchers and clinicians can determine the overall effectiveness and durability of RAKT as a minimally invasive option for kidney transplantation.

8.2.1 Immediate graft function

Measuring perioperative eGFR and serum creatinine levels during kidney transplantation is essential to peri-operatively assess renal function and monitor kidney health. These measures are important indications of kidney function since they provide crucial information about the overall success and efficacy of the transplant process. Monitoring eGFR allows clinicians to assess the rate at which the kidney filters waste products from the blood, indicating the rate at which renal function has recovered after transplantation. Similarly, monitoring blood creatinine levels assists in detecting any abnormalities or variations from the baseline, which could indicate issues like rejection or reduced kidney function. Continuous eGFR and creatinine evaluation allows for rapid intervention and modifications of the medication regimen, guaranteeing optimal post-operative transplant management and promoting long-term graft survival.

Data in Table 4 presents kidney function data for RAKT, partially compared to OKT, throughout a pre-operative day testing and several post-operative days (PODs) surveillance. The values are supplied by Breda et al. from two different studies, Territo et al., Campi et al., and Rajmohan et al.

	Publication author	**Pre-operative**	**POD 1**	**POD 3**	**POD 7**	**POD 30**	**POD 365**
eGFR (ml/ min/ 1.73/ m^2)	Breda et al. (41)	10.0*	21.2*	45.0*	52.6*	58.0*	N/ A
	Territo et al. (50)	10.0	N/ A	N/ A	21.0	54.0	57.4
	Breda et al. (40)	12.4	17.7	31.3	45.0	69.4	N/ A
	Campi et al. (36)	N/ A	RAKT 8.5 OKT 7.2	RAKT 10.0 OKT 10.6	RAKT 28.2 OKT 25.3	N/ A	N/ A
Serum creatinine (µmol/ L)	Breda et al. (41)	517.0*	288.7*	155.0*	131.5*	130.0*	N/ A
	Territo et al. (50)	517.0	N/ A	N/ A	138.8	132.0	131.0
	Breda et al. (40)	388.0	282.5	211.9	160.0	126.0	N/ A

Rajmohan et al. (43); Without DGF	786.76	N/ A	123.76*	123.76*	N/ A	114.92
Rajmohan et al. (43); with DGF	901.68	N/ A	406.64*	388.96*	N/ A	141.44

Table 4 *Pre- and postoperative kidney function data, RAKT versus OKT*

Converted from mg/ dL into µmol/ L by multiplicator 88.4 (52)

**p-value statistically significant ($p < 0.05$)*

Studies by Breda et al. and Territo et al. reported an eGFR of 10.0 ml/min/1.73 m^2 pre-operatively. In Breda et al. the eGFR significantly improved to 52.6 ml/min/1.73 m^2 by POD 7 and further to 58.0 ml/min/1.73 m^2 by POD 30. Comparable but slower, the eGFR in the Territo et al. study rose to 21.0 ml/min/1.73 m^2 at POD 7 and then to 54.0 ml/min/1.73 m^2 by POD 30, almost reaching the same filtration rate as Breda et al. At POD 365 the eGFR was measured at 57.4 ml/min/1.73 m^2 by Territo et al. In the second study published by Breda et al., RAKT compared to OKT, eGFR values at POD 1, 3, 7 are statistically lower in contrast to his first study, whereas eGFR values at POD 30 are higher (69.4 vs. 58.0 ml/min/1.73m^2) compared to his first study. According to Breda et al., serum creatinine levels decreased significantly from 517.0 µmol/L preoperatively to 130.0 µmol/L by POD 30. Likewise, serum creatinine did decrease significantly from 517.0 µmol/L preoperatively to 132.0 µmol/L by POD 365, as stated in Territo et al. In the second study published by Breda et al., serum creatinine values were lower in preoperative measurements (388.0 vs. 517.0 µmol/ L) and at POD 1, 3, 7 significantly higher in contrast to his first study, whereas serum creatinine values at POD 30 is again lower (126.0 vs. 130.0 µmol/ L) compared to his first study. Campi et al. compared RAKT versus OKT. The study reported eGFR values at POD 1 of 8.5 ml/min/1.73 m^2 for RAKT and 7.2 ml/min/1.73 m^2 for OKT, with significant improvements to 28.2 ml/min/1.73 m^2 for RAKT and 25.3 ml/min/1.73 m^2 for OKT by POD 7, respectively. No data exist for POD 3, POD 30, and POD 365 for completion. According to Rajmohan et al., the serum creatinine level was statistically higher in patients who had DGF in comparison to patients without DGF on POD 3, 7, and 30, but there was no mean difference between both groups at one-year follow-up. Additionally, in Table 5, Tugcu et al. found that post-operative serum creatinine levels (123.76 µmol/L) increased to 140.56 µmol/L at POD 30, but subsequently declined to 83.99 µmol/L after 6 months of follow-up. Furthermore, Modi et al. state in their study, which compared RAKT and OKT procedures on morbidly obese patients, that creatinine clearance was primarily slower compared to OKT immediately after transplantation. Delayed creatinine clearance is, according to Modi et al., associated with the pneumoperitoneum which is necessary during RAKT. At the six-month follow-up, the eGFR value did not differ between both groups, RAKT and OKT, respectively (38). Functional values for serum creatinine and eGFR at postoperative day 30 and 1 year after surgery did not differ statistically significantly. Regarding the association between surgical data and functional results, the data revealed that general surgical time and graft rewarming time did not affect graft function at one-year follow-up. Within the first week after surgery, three patients lost their grafts due to significant arterial thrombosis. Late complications included one case of ureteric stenosis and one case of graft pyelonephritis. There were no late vascular problems or incisional hernias recorded (5)(33).

	Publication author	*POD 1*	*POD 30*	*POD 90*	*POD 180*
Serum creatinine (µmol/ L)	Tugcu et al. (51)	123.76	140.56	91.94	83.99

Table 5 *Postoperative serum creatinine data for RAKT*

Converted from mg/ dL into µmol/ L by multiplicator 88.4 (52)

All mentioned results suggest that RAKT is feasible in terms of postoperative kidney function compared to OKT, with significant improvements in eGFR observed at POD 7 and sustained improvements up until the one-year follow-up. Furthermore, reductions in serum creatinine levels were observed postoperatively, indicating enhanced renal function after RAKT. These findings demonstrate no statistical difference in robotic-assisted approaches in kidney transplantation, possible improvement in postoperative outcomes and maintenance of renal function over time.

8.2.2 Early and late functional outcomes

The following table presents comparative data from Ahlawat et al. and Campi et al. regarding various parameters related to RAKT versus the traditional OKT approach.

Regarding post-operative pain scores on a scale of 1-10, RAKT patients reported lower pain levels compared to OKT patients at all time points studied. Specifically, at 12 to 24 hours postoperatively, RAKT patients reported lower pain scores compared to OKT patients.

When it comes to the usage of analgetic drugs, RAKT patients needed less intravenous (IV) Fentanyl (1291.4 vs. 1830.9 mcg), epidural ropivacaine (0 vs. 69.4 mg), and PCA-morphine (20.1 vs. 32.2 mg) compared to OKT patients. Ahlawat et al. report that an IV regimen of ropivacaine and fentanyl was provided to the first seven patients in the RAKT group, followed by PCA morphine and IV fentanyl. The standardized approach for the OKT group involved the administration of IV fentanyl in addition to epidural ropivacaine. IV fentanyl was used in certain cases when the drugs were unable to control pain. Not a single patient received treatment with the three-drug combination (2). In another study, Campi et al. mentioned, that overall,
0.0 % of RAKT and 7.7 % of OKT recipients require post-operative opioid analgesics for pain management during hospitalization. RAKT is favored for its decreased blood loss resulting in fewer blood transfusions needed in the peri-operative process, as Campi et al. stated in their article (14.3 % vs. 22.2 %). Also, the incidence of DGF was lower in RAKT compared to OKT, with 0% versus 2.4% reported by Ahlawat et al. and 9.5% versus 27.4% reported by Campi et al. Additionally, the need for post-operative dialysis was lower in RAKT compared to OKT (3% vs. 18%). Hospital stay duration was comparable between RAKT and OKT groups. As stated by Ahlawat et al., patients of RAKT and OKT groups were hospitalized for a total of eight days. Overall longer hospitalization, 13 days for RAKT and OKT patients, was necessary according to the study by Campi et al. Ahlawat et al. stated that any patient undergoing kidney transplantation, RAKT or OKT, must be hospitalized for a minimum of eight days; this has long been an integral part of the hospital's treatment plan. From 133 transplant recipients, 95.0 % of the RAKT group were alive and dialysis-free and 93.0 % of the OKT group were alive and dialysis-free at 31 months post-operatively. According to Campi et al., at a median follow-up of 31 months post-operatively the median eGFR was not only significantly higher within the RAKT group in comparison to the OKT group (68.7 vs. 51.0 ml/ min/ 1.73 m^2) but also statistically significant with a p-value of 0.042. All values below a p-value of 0.05 were statistically significant. At 36 months, long-term outcomes, such as patient survival and graft survival, were equivalent among RAKT and OKT patient groups, as stated by Ahlawat et al. No such data were provided by Campi et al. Compared to the OKT group, Campi et al. reported a higher percentage of kidney transplant-related reinterventions in the RAKT group (9.5% vs. 5.1%). The increased percentage could be caused by a smaller number of total patients.

Overall, the findings collectively suggest potential advantages of RAKT over OKT in terms of reduced post-operative pain, the amount of necessary analgesic use, lower RAKT-associated incidences of DGF, need for post-operative dialysis, KT-related reinterventions and long-term patient and kidney graft survival.

	Ahlawat et al. (2)		Campi et al. (36)	Breda et al. (40)
Post-operative pain (VAS scale 1-10)	At 12 hrs	3.7* vs. 4.6*	N/A	3.5 ± 0.5
	At 24 hrs	2.2* vs. 3.5*	N/A	3.0 ± 0.5
	At 48 hrs	1.2* vs.1.7*	N/A	0.3 ± 0.5
	At 96 hrs	0.9 vs. 1.4	N/A	N/A
Mean analgesic use	IV Fentanyl (mcg)	1291.4* vs. 1830.9*	0.0 % vs. 7.7 %	N/A
	Epidural ropivacaine (mg)	0.0* vs. 69.4*	N/A	N/A
	PCA-morphine (mg)	20.1* vs. 31.2*	N/A	N/A
Need of peri-operative blood transfusions (in %)	N/A	N/A	14.3* vs. 22.2*	N/A
(Number) DGF (in %)	0.0 vs. 2.4		9.5 vs. 27.4	6.0
Graft nephrectomy, n (in %)	N/A		1 (5.0) vs. 6 (6.0)	0 (0.0)
Post-operative dialysis (in %)	3.0 vs. 18.0		95.0 vs. 93.0	N/A
Hospital stay (in days)	8 vs. 8		13 vs. 13.0	6 ± 1
eGFR (at 31 months, in ml/ min/ 1.73 m²)	N/A		68.7 vs. 51.0	N/A
Patient survival (at 36 months; in %)	94.5 vs. 98.1		N/A	N/A
Graft survival (at 36 months; in %)	95.2 vs. 96.3		N/A	N/A
Graft rejection (at 36 months; in %)	16.2 vs. 18.6		N/A	N/A
KT-related reinterventions (in %)	N/A		9.5 vs. 5.1	0

Table 6 *Functional outcomes of RAKT versus (vs.) OKT*

**p-value statistically significant ($p < 0.05$); Hrs = hours; Mcg = micrograms; Mg = milligrams*

Additionally, there are crucial differences between living- and deceased KT donor recipients. According to Pietrabissa et al., living-donor KTs do not only have advantages for better procedure planning but furthermore, differ significantly in terms of long-term graft survival.
Optimized planning for surgery not only means a scheduled operation during the daytime but also minimizing the risks of technical failures due to very experienced surgeons and fewer mistakes over fatigue. In addition, living-donor KT recipients can be withdrawn from KT waiting lists, thus transplantations can be performed before the patients require dialysis. Primary dialysis prevention is not only beneficial for the patient's general condition, moreover, prevents physical worsening throughout the RRT period, and will ultimately affect the transplanted kidney graft in early and late functional outcomes. Pietrabissa et al. stated further, that DGF occurs in almost 50% of patients who received a kidney graft from a deceased-donor, whereas only 5% experience DGF in the living-donor recipient group. Thus, the immediate graft rejection rate is lower in the living-donor recipient group. Finally, living-donor recipients have a 2-fold better long-term graft survival prognosis with 50% kidney function after 20 years compared to the deceased donor recipients' group. With proper genetic matching, such as between siblings, 50% kidney functions still after 35 years (31).

8.2.3 Complications

There were no studies that distinguished outcomes based on living or deceased donor kidney status, kidney graft number, or time since transplantation. The presence of DM, however, increases the risk and is an established independent risk factor for post-operative mortality. Further investigations suggest, that the prevalence of obesity has important associations with the development of type II DM (53).
Additionally, Modi et al. found, that patients with a higher BMI requiring larger incisions are associated with a decreased graft survival due to an increased risk of post-operative surgical site infection (SSI). His study showed a seven-fold higher incidence of SSI in the OKT group (28.6% vs. 3.6%) compared to RAKT patients, respectively. Post-operative complications include graft torsion and incisional hernias (38).
This was determined by a meta-analysis of 14 studies including 15,481 transplant recipients and 7,807,705 non-transplanted patients by Palamuthusingam et al. The increased post-operative mortality risk in patients who received kidney transplants could be additionally attributed to unfavorable immunosuppressive consequences affecting the immunologic, cardiovascular, and metabolic systems. Palamuthusingam et al. stated in their systematic review that non-fatal consequences were recorded across 14 trials, with acute kidney injury being the

most often reported complication (in 11 studies), subsequently followed by pneumonia (in 8 studies) and stroke (in 7 studies). Infective complications, such as the aforementioned pneumonia or a surgical site infection, had similar odds to the general population, respectively (54). Notably, the risk of postoperative stroke development in kidney transplant recipients is not increased in contrast to non-transplant patients. This finding is rather unexpected considering that observational cohort studies reveal a three- to five-fold increased risk of early cardiovascular disease following kidney transplantation compared to the general population (55). Additionally, Campi et al. stated in their study, that the overall significance of dialysis-free patients and overall survival rate was not statistically different among the RAKT and OKT groups, after a median follow-up of 31 months (36).

Complications (Within 6 months post-operatively, no (%))	**Ahlawat et al. (2)**	**Breda et al. (40)**
Wound complications/ infections	0* vs. 15*	0 (0)
Graft vascular thrombosis/ stenosis	0 vs. 3	1 (6)
Graft torsion	0 vs. 0	0 (0)
Urine leak/ stricture	1 vs. 1	0 (0)
Urinary tract infection	5 vs. 15	0 (0)
Acute tubular necrosis	5 vs. 21	N/A
Immunosuppressive drug toxicity	3 vs. 4	1 (6)
Deep vein thrombosis/ pulmonary embolism	1 vs. 6	N/A
Number of re-explorational surgery	3 vs. 13	0 (0)

***Table** 7 Complications of RAKT, partially versus (vs.) OKT*

**p-value statistically significant ($p < 0.05$)*

Further complications were listed in the retrospective observational study by Rajmohan et al., such as Gram-negative sepsis, polyuria leading to hypernatremia, impaired level of consciousness and aspiration pneumonia, and ureteric leak after stent removal (43).

Further complication subdivision and grading can be made with the Clavien – Dindo classification.

8.2.3.1 Clavien – Dindo scale

The Clavien – Dindo classification is used for severity grading of surgical complications. It is based on the clinical significance of a complication and the required interventions to manage it. The classification provides surgeons and researchers with an organized structure for assessing and sharing the severity of complications following surgery. It supports quality improvement initiatives, informs clinical decision-making, and allows for outcome comparisons between various studies and institutions.

In Table eight, two different studies by Breda et al. support different results, various post-operative complications are categorized into different grades, ranging from Grade I to Grade V. Complications include wound infection, hemorrhage, the possibility of an ileus or deep vein thrombosis, lymphocele, arterial thrombosis, and bleeding that necessitates surgical intervention. Notably, the numbers supplied show the frequency of each of the authors' reported complication grades. The first column in Table 8 shows two 3b complications: one severe arterial thrombosis on POD 2, which required transplantectomy, and one intraperitoneal hematoma caused by graft hemorrhage on POD 1, which was handled laparoscopically (40). The second column shows slightly more complications, probably due to a bigger number of patients involved in this multicenter prospective observational study. There was one case (0.8%) of wound infection, three instances (2.5%) of ileus, and four cases (3.3%) of bleeding (three of which needed blood transfusion), all of which were treated conservatively. One case (0.8%) of deep venous thrombosis, one case (0.8%) of lymphocele and three cases (2.5%) of transplant surgery due to major arterial thrombosis were reported. In five cases (4.2%), surgical exploration was used to treat intraperitoneal hematoma (41).

The percentages indicate the overall low complication rate and therefore promising future of RAKT, analyzing post-operative complications.

	Breda et al. (40)	**Breda et al. (41)**
Grade 1	0	5 (1 wound infection, 1 Observational bleeding, 3 Ileus)
Grade 2	0	4 (1 DVT, 3 Bleeding, requires blood transfusion)
Grade 3a	0	1 (Lymphocele)
Grade 3b	1 (Arterial thrombosis)	3 (Arterial thrombosis)

	1 (Bleeding, requires surgical exploration)	5 (Bleeding, requires surgical exploration)
Grade 4a	0	0
Grade 4b	0	0
Grade 5	0	0

Table 8 *Complications graded according to Clavien-Dindo scale*

DVT= Deep vein thrombosis

In the ninth table by Tugcu et al., similar post-operative complications are documented, with occurrences categorized for both RAKT and OKT. Wound infection, orchitis, hemorrhage, ileus, lymphocele, graft thrombosis, temporary dialysis, and sepsis-related mortality are all potential complications. Notably, more complications affect patients receiving OKT with two grade five complications due to sepsis accounting for the death of two patients, according to Tugcu et al.

	Tugcu et al. (51)		**Campi et al. (36)**	
Procedure	RAKT	OKT	RAKT	OKT
Grade 1	1 wound infection	3 wound infections	0	4
Grade 2	0	4 (1 Orchitis, 3 Bleedings requiring blood transfusion)	12	53
Grade 3a	0	0	2	7
Grade 3b	2 Ileus (exploratory laparotomy)	4 (2 lymphocele, 2 graft thrombosis)	1 Venous thrombosis	10 (3 Venous thrombosis, 2 Arterial thrombosis, 1 Graft nephrectomy, 2 Endoscopic

				reintervention, 2 Bleedings needed reintervention)
Grade 4a	1 temporary dialysis	0	1	1
Grade 4b	0	0	0	0
Grade 5	0	2 deaths (sepsis)	0	1 death (sepsis)

Table 9 *Complications graded according to Clavien-Dindo scale in RAKT versus OKT*

Complications, according to Campi et al., include venous and arterial thrombosis, graft nephrectomy, endoscopic reintervention, reintervention for bleeding resulting in graft compression, and sepsis with multiorgan failure. The frequency of each complication grade is provided for comparison between RAKT and OKT. Complication details were not defined clearly in Grades 1, 2, 3a, 4a, and 4b, by Campi et al. Remarkably, more complications affect patients receiving OKT.

Overall, the tables shed light on the range of post-operative difficulties following kidney transplantation, with varying rates, severity and complexity described by different authors. The table highlights the necessity of precise post-operative care, complication management in maximizing results, and improving patients' safety in the post-transplantation phase.

8.3 Post-operative morbidity

in %		Overall mortality	Myocardial infarction	Post-operative pneumonia	Post-operative sepsis	Post-operative stroke	Other
Palamuthusingam et al. (54)	In transplant patients	0 – 16.0	0.9 – 4.0	1.4 – 7.1	2.9 – 35.7	0 – 4.3	
	In non-transplant patients	0 – 5.7	N/ A	3.8 – 7.1	1.7 – 14.3	No increased odds as in transplant patients	
Rajmohan et al. (43)		3	N/ A	N/ A	2	N/ A	Dengue hemorrhagic fever (1 patient)

Table 10 *Post-operative morbidity in transplant and non-transplant patients*

The comparative table shows the author's reported risk percentages for complications in KT patients in comparison to non-KT patients. Besides the overall mortality KT recipients are prone to, further significant risks include myocardial infarction, post-operative pneumonia, sepsis, and stroke. The estimated risk of overall mortality ranges from 0% to 16.0%, showing a high risk of life-threatening complications after a kidney transplant. Myocardial infarction risks range from 0.9% to 4.0%, indicating that transplant recipients are more likely to experience cardiovascular problems. The risk of postoperative pneumonia ranges from 1.4% to 7.1%, suggesting the population's increased susceptibility to respiratory infections. Notably, the risk of post-operative sepsis ranges from 2.9% to 35.7%, highlighting the significant risk of serious infections and systemic inflammation after kidney transplantation. Furthermore, the risk of post-operative stroke ranges from 0% to 4.3%, indicating that transplant recipients may be at an increased risk of cerebrovascular events. Generally, to reduce the morbidity risk and improve outcomes for kidney transplant recipients, the data collected are crucial to understand the significance of attentive and continuous monitoring, infection prevention approaches, and comprehensive care. Non-transplant patients, on the other hand, suffer reduced risks in these domains, implying that the transplant group has unique vulnerabilities. The gap in risk profiles between transplant and non-transplant patients highlights the distinctive difficulties and complexities of kidney transplantation. According to Rajmohan et al., in three cases patients died due to Dengue hemorrhagic fever, DGF with bacterial sepsis, and antibody-mediated rejection with sepsis.

These findings underline the importance of complete pre-operative assessment, thorough perioperative care (including accurate monitoring and infection prevention approaches) and continued post-transplant monitoring to reduce risks and optimizing results for kidney transplant recipients. By proactively addressing these potential risks, healthcare providers can increase patient safety and the long-term effectiveness of kidney transplantation as a medical procedure.

9. Comparison

ESRD-affected patients are generally precarious and suffer already from immunocompromise. Perioperative and long-term outcomes for final KT treatment performed with either laparoscopic or robotic minimally invasive surgery might benefit the individual.

Laparoscopic surgery has beneficial perioperative outcomes compared to OKT, including reduced blood loss, less discomfort after surgery, a lower incidence of wound infection, better cosmetic outcomes, shorter hospital stays, and a faster return to normal life. Conventional laparoscopy, however, features disadvantages that have prevented its widespread use as a promising minimally invasive approach. Difficulties include the initial learning phase, due to a limited range of motion of the instruments the need for unconventional movements to navigate to the target area, and the loss of natural hand-eye coordination. Learning laparoscopic skills and being confident in advanced laparoscopic actions, such as suturing, is a challenging and time-consuming task. Nevertheless, with proper training and experience, surgeons can overcome challenges and successfully perform minimally invasive surgeries with precision and confidence. There are variations in the proficiency of surgeons when performing laparoscopic surgeries. The loss of depth perception due to the lack of three-dimensional vision can make it difficult to translate the two-dimensional image on the monitor into precise movements of the instruments, thus laparoscopic use is known for its tremor amplification instead of simplification. However, with proper training and experience, these challenges can be overcome (44). The laparoscopic variation has become the gold standard for donor nephrectomy. At one- and twelve-months following donor nephrectomy, there was no variance in estimated glomerular filtration rate (eGFR) between open and laparoscopic kidney transplants. However, the laparoscopic group required considerably longer surgery and anastomosis times. While eGFR was significantly reduced in the LKT sample on days 7 and 30 following surgery, there was no disparity between LKT and OKT at 3, 6, 12, and 18 months. Given the minimally invasive incision, the LKT group required much less morphine-equivalent analgesia during the first 24 hours after surgery. After a 22.3 months follow-up survival rates for patients were likewise identical in both sections. This is at 94.1% and 94.7%, respectively (33).

Overcoming limitations of laparoscopic surgery, robotic guidance features many advantageous adjustments. The three-dimensional view supplied by RAKT reestablishes hand-eye coordination. Being able to scale movements with wristed instruments and movement tracking due to tremor filtration at 1300 times per second facilitates surgery. Furthermore, physicians can experience a proper learning curve due to the establishment of several robotic specialized institutes. With the increasing quantity of robotic-assisted surgeries in specialized centers, surgical teams can be upskilled to improve current approaches, can try, and evaluate new approaches and can be educated regarding risk factors and long-term outcomes. For the last 20 years, the Da-Vinci robotic system has been the most commonly utilized robotic surgical system worldwide (24).

In contrast to LKT and RAKT and their minimally invasive approaches with good prognosis, OKT seems to have rather disadvantages, even though declared the current gold standard. Larger incisions are linked to a longer wound healing period, a larger dosage of analgesics required because of increased pain following surgery, and a higher risk of SSIs. Additionally, aesthetic outcomes are poorer in OKT than in minimally invasive surgical procedures (56). Delayed mobilization leads to a prolonged hospital stay and time needed to return to daily activities.

Patients receiving or having recently undergone immunosuppressive therapy are generally at increased risk for early and late complications. Pre-operative immunosuppression plays also a key role in post-operative graft function (33). Furthermore, transplant recipients with an increased body mass index (BMI), a history of smoking, DM, or renal failure are at risk of poor graft outcomes, possible hernias, or an increased rate of wound infection (57).

10. Challenges and limitations

Staff of the operation theatre must also be taught about device setup and proper problem management that may emerge during procedures. As a result, the robotic surgery business will most likely be time-consuming, expensive, and resource intensive. Furthermore, substantial floor space is required, along with large surgical instruments; this may be problematic, and significant costs need to be invested for upgrades before robotic surgery may be used. Moreover, in an emergency, changing to an open operation may take longer since the bulky tools are more difficult to remove than in traditional laparoscopy.

The current evidence base for the efficacy of robotic surgery is primarily derived from rather small cohort, retrospective research. To prove that robotic support is beneficial in contrast to conventional therapies, prospective, multicenter randomized clinical trials evaluating safety, efficacy, long-term outcomes, and cost analysis are indispensable and receivable.

Around $1.5 million is needed for the da Vinci system, plus an additional $150,000 in annual maintenance expenditures. Similarly, robotic catheter systems are expensive, need extensive maintenance, and come with the added cost of disposable catheters. However, there is currently too little reliable information on the economic advantages of robotic systems.

Currently, the data supporting robotic surgery's efficacy and safety is primarily derived from retrospective studies with small sample sizes or from institution's early cases or experiences, when the surgeon may be at the beginning of his or her learning curve. As a result, conclusions on safety and efficacy should be considered with caution (58).

Additionally, and Lithuania specific, patients with ESRD, who receive or have received RRT, are too uncompliant regarding KT as a feasible alternative. Less compliance might be explained due to the unwillingness of dialysis centers to proper educate their patients about KTs benefits. The feeling of dept to receive a kidney from a living donor in combination with certain religious beliefs or disbeliefs contributes greatly to the ever since increasing unpopularity of living kidney transplantations among the Lithuanian civilization (32).

11. Future perspectives

Despite the global development, proliferation and known benefits of minimally invasive surgery, many KTs are still performed open. In this section the focus lies on attributes and pathophysiological mechanisms, which are not yet fully resolved. Attributes which have a good prognosis within future development to improve the RAKT approach.

Regardless of the incision type, OKT may increase the risk of wound healing problems and SSIs, particularly among obese patients and those having DM (53). In addition, given the frailty of KT recipients, there is undoubtedly a developmental chance for further surgical procedure evolution to reduce KT morbidity, allowing for quicker rehabilitation and better patient-reported results. The frailty includes pediatric patients or patients which have atherosclerosis of the iliac vessels. As a result, RAKT has the potential to lower particularly KT-related surgical difficulties such as SSI and lessen incision length, or postoperative discomfort while simultaneously reducing total hospital stay. RAKT may also enhance the cosmetic results of KT (57). Obesity-related studies, conducted in Europe and the United States, indicate an association between morbid obesity and a lower chance of receiving a transplant. It is becoming a global health concern, with industrialized nations experiencing a significant increase in their obesity rate. All potential benefits of RAKT are especially intriguing for patients having a greater likelihood of postoperative complications due to obesity or DM. While KT is still the most promising approach for ESRD patients, the assessment of obese patients should take both into account: increased surgical difficulties and a greater rate of postoperative morbidities. In this setting, robotic surgery could provide various advantages, including increased exposure to the operative field, improved tool mobility, and enhanced operative and functional graft outcomes. Regardless, of the high anticipation towards RAKT, too high expenses are currently limiting its broader adoption worldwide (59). Additionally, it is necessary to conduct larger prospective, multicenter randomized controlled trials to further assess efficacy and safety, minimize surgical complications and receive adequate kidney graft function (60).

12. Conclusion

In conclusion, RAKT has proven to be a promising treatment option for patients with ESRD. It offers the possibility of smaller incisions and decreased blood loss, diminishing the need for peri-operative blood transfusions and improves the patient's outcomes and prognosis. Furthermore, RAKT tends to induce less post-operative pain leading to decreased post-operative analgesic use, fewer wound problems, and SSIs, decreased risk of symptomatic lymphoceles, and less DGF. These attributes promote the use of robotic assistance in KT in association with improved patient outcomes and better overall survival rates. In addition, patients can live dialysis-free as they profit from living-donor KTs without the indication of RRTs before transplantation. Upon the latest follow-up, the overall post-operative graft function, rates of graft rejection, graft survival and patient survival rates were similar both in conventional KT and RAKT groups.

Nonetheless, larger clinical studies including higher number of participants with longer follow-ups are needed. As strong data foundation supporting the use of robotic assistance is still insufficient, further multicenter studies and their evaluations of early and late functional outcomes as well as long-term outcomes, will enhance precision in patient selection and treatment strategy.

Due to a lower complication rate while maintaining excellent graft function, RAKT is a promising and reproducible operation technique following a thorough patient selection with time-efficient pre-operative planning and adequate team experience.

13. Literature references

1. Minimally Invasive Kidney Transplantation: The First Experience. Transplant Proc [Internet]. 2006 Nov 1 [cited 2024 Mar 22];38(9):2798–802. Available from: https://www.sciencedirect.com/science/article/pii/S0041134506010426
2. Ahlawat R, Sood A, Jeong W, Ghosh P, Keeley J, Abdollah F, et al. Robotic Kidney Transplantation with Regional Hypothermia versus Open Kidney Transplantation for Patients with End Stage Renal Disease: An Ideal Stage 2B Study. J Urol [Internet]. 2021 Feb [cited 2024 Apr 6];205(2):595–602. Available from: https://www.auajournals.org/doi/10.1097/JU.0000000000001368
3. Sharma V, Roy R, Piscoran O, Summers A, van Dellen D, Augustine T. Living donor kidney transplantation: Let's talk about it. Clin Med [Internet]. 2020 May [cited 2024 Apr 14];20(3):346–8. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7354017/
4. Eurotransplant - Statistics [Internet]. [cited 2024 Feb 20]. Available from: https://statistics.eurotransplant.org/index.php?search_type=transplants&search_organ=kidney&search_region=All+ET&search_period=2023&search_characteristic=&search_text=&search_collection=
5. Territo A, Mottrie A, Abaza R, Rogers C, Menon M, Bhandari M, et al. Robotic kidney transplantation: current status and future perspectives. Minerva Urol E Nefrol Ital J Urol Nephrol. 2017 Feb;69(1):5–13.
6. Hashmi MF, Benjamin O, Lappin SL. End-Stage Renal Disease. In: StatPearls [Internet] [Internet]. StatPearls Publishing; 2023 [cited 2024 Feb 20]. Available from: https://www.ncbi.nlm.nih.gov/books/NBK499861/
7. Luyckx VA, Tonelli M, Stanifer JW. The global burden of kidney disease and the sustainable development goals. Bull World Health Organ [Internet]. 2018 Jun 1 [cited 2024 Apr 14];96(6):414-422D. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5996218/
8. Lv JC, Zhang LX. Prevalence and Disease Burden of Chronic Kidney Disease. In: Renal Fibrosis: Mechanisms and Therapies [Internet]. Springer, Singapore; 2019 [cited 2024 Feb 20]. p. 3–15. Available from: https://link.springer.com/chapter/10.1007/978-981-13-8871-2_1
9. Thurlow JS, Joshi M, Yan G, Norris KC, Agodoa LY, Yuan CM, et al. Global Epidemiology of End-Stage Kidney Disease and Disparities in Kidney Replacement Therapy. Am J Nephrol [Internet]. 2021 Apr 15 [cited 2024 Feb 22];52(2):98–107. Available from: https://dx.doi.org/10.1159/000514550
10. Kovesdy CP. Epidemiology of chronic kidney disease: an update 2022. Kidney Int Suppl [Internet]. 2022 Apr [cited 2024 Feb 21];12(1):7. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9073222/
11. Tang M, Li T, Liu H. A Comparison of Transplant Outcomes in Peritoneal and Hemodialysis Patients: A Meta-Analysis. Blood Purif. 2016;42(2):170–6.
12. National Institute of Diabetes and Digestive and Kidney Diseases [Internet]. [cited 2024 Feb 21]. Estimating Glomerular Filtration Rate - NIDDK. Available from: https://www.niddk.nih.gov/health-information/professionals/clinical-tools-patient-management/kidney-disease/laboratory-evaluation/glomerular-filtration-rate/estimating
13. Lees JS, Welsh CE, Celis-Morales CA, Mackay D, Lewsey J, Gray SR, et al. Glomerular filtration rate by differing measures, albuminuria and prediction of cardiovascular disease, mortality and end-stage kidney disease. Nat Med [Internet]. 2019 Nov [cited 2024 Feb 20];25(11):1753. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6858876/
14. Schnaper HW. Remnant nephron physiology and the progression of chronic kidney

disease. Pediatr Nephrol [Internet]. 2014 Feb 1 [cited 2024 Feb 20];29(2):193–202. Available from: https://link.springer.com/article/10.1007/s00467-013-2494-8
15. Shankland SJ, Ly H, Thai K, Scholey JW. Increased glomerular capillary pressure alters glomerular cytokine expression. Circ Res [Internet]. 1994 Nov [cited 2024 Feb 21]; Available from: https://www.ahajournals.org/doi/abs/10.1161/01.res.75.5.844
16. Metabolic Acidosis of CKD: An Update. Am J Kidney Dis [Internet]. 2016 Feb 1 [cited 2024 Feb 23];67(2):307–17. Available from: https://www.sciencedirect.com/science/article/abs/pii/S0272638615012111
17. Gilligan S, Raphael KL. Hyperkalemia and Hypokalemia in CKD: Prevalence, Risk Factors, and Clinical Outcomes. Adv Chronic Kidney Dis [Internet]. 2017 Sep 1 [cited 2024 Feb 23];24(5):315–8. Available from: https://www.sciencedirect.com/science/article/pii/S1548559517300927
18. Palmer BF, Clegg DJ. Extrarenal Effects of Aldosterone on Potassium Homeostasis. Kidney360 [Internet]. 2022 Jan 14 [cited 2024 Feb 23];3(3):561–8. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9034816/
19. Atkinson MA, Warady BA. Anemia in chronic kidney disease. Pediatr Nephrol [Internet]. 2018 Feb 1 [cited 2024 Feb 23];33(2):227–38. Available from: https://doi.org/10.1007/s00467-017-3663-y
20. Weckmann GFC, Stracke S, Haase A, Spallek J, Ludwig F, Angelow A, et al. Diagnosis and management of non-dialysis chronic kidney disease in ambulatory care: a systematic review of clinical practice guidelines. BMC Nephrol [Internet]. 2018 Oct 11 [cited 2024 Feb 23];19:258. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6180496/
21. Petrucci I, Clementi A, Sessa C, Torrisi I, Meola M. Ultrasound and color Doppler applications in chronic kidney disease. J Nephrol [Internet]. 2018 Dec 1 [cited 2024 Feb 23];31(6):863–79. Available from: https://link.springer.com/article/10.1007/s40620-018-0531-1
22. George EI, Brand TC, LaPorta A, Marescaux J, Satava RM. Origins of Robotic Surgery: From Skepticism to Standard of Care. JSLS [Internet]. 2018 [cited 2024 Mar 22];22(4):e2018.00039. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6261744/
23. Klodmann J, Schlenk C, Hellings-Kuß A, Bahls T, Unterhinninghofen R, Albu-Schäffer A, et al. An Introduction to Robotically Assisted Surgical Systems: Current Developments and Focus Areas of Research. Curr Robot Rep [Internet]. 2021 Sep 1 [cited 2024 Mar 15];2(3):321–32. Available from: https://doi.org/10.1007/s43154-021-00064-3
24. Bravi CA, Mottaran A, Sarchi L, Piro A, Paciotti M, Nocera L, et al. Transitioning from Da Vinci Si to Xi: assessing surgical outcomes at a high-volume robotic center. World J Urol [Internet]. 2023 Dec 1 [cited 2024 Mar 26];41(12):3737–44. Available from: https://doi.org/10.1007/s00345-023-04665-9
25. Sugano N. Computer-Assisted Orthopaedic Surgery and Robotic Surgery in Total Hip Arthroplasty. Clin Orthop Surg [Internet]. 2013 Mar [cited 2024 Mar 21];5(1):1. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3582865/
26. Marino MV, Shabat G, Gulotta G, Komorowski AL. From Illusion to Reality: A Brief History of Robotic Surgery. Surg Innov [Internet]. 2018 Apr 27 [cited 2024 Mar 20]; Available from: https://journals.sagepub.com/doi/10.1177/1553350618771417?url_ver=Z39.88-2003&rfr_id=ori%3Arid%3Acrossref.org&rfr_dat=cr_pub++0pubmed
27. Barker CF, Markmann JF. Historical Overview of Transplantation. Cold Spring Harb Perspect Med [Internet]. 2013 Apr [cited 2024 May 3];3(4):a014977. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3684003/
28. Eghtesad B, Fung J. Thomas Earl Starzl, MD, PhD (1926–2017): Father of

Transplantation. Int J Organ Transplant Med [Internet]. 2017 [cited 2024 Mar 19];8(2). Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5549009/
29. Tantisattamo E, Maggiore U, Piccoli GB. History of kidney transplantation: a journey of progression and evolution for success. J Nephrol [Internet]. 2022 Sep 1 [cited 2024 Mar 19];35(7):1783–6. Available from: https://link.springer.com/article/10.1007/s40620-022-01453-3
30. Olaso D, Manook M, Moris D, Knechtle S, Kwun J. Optimal Immunosuppression Strategy in the Sensitized Kidney Transplant Recipient. J Clin Med [Internet]. 2021 Jan [cited 2024 Mar 19];10(16):3656. Available from: https://www.mdpi.com/2077-0383/10/16/3656
31. Pietrabissa A, Pugliese L, Abelli M, Ticozzelli E, Rampino T. Chapter 4 - The Living Donor. In: Orlando G, Remuzzi G, Williams DF, editors. Kidney Transplantation, Bioengineering and Regeneration [Internet]. Academic Press; 2017 [cited 2024 Mar 27]. p. 41–50. Available from: https://www.sciencedirect.com/science/article/pii/B9780128017340000047
32. Laučytė-Cibulskienė A, Miglinas M, Želvys A, Čekauskas A. Successful laparoscopic living donor nephrectomy: first experience in Lithuania. Acta Medica Litu [Internet]. 2019 [cited 2024 May 3];26(2):140–6. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6779470/
33. Spiers HVM, Sharma V, Woywodt A, Sivaprakasam R, Augustine T. Robot-assisted kidney transplantation: an update. Clin Kidney J [Internet]. 2022 Apr [cited 2024 Mar 21];15(4):635. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8967665/
34. Zeuschner P, Siemer S, Stöckle M. Roboterassistierte Nierentransplantation. Urol [Internet]. 2020 Jan 1 [cited 2024 Mar 18];59(1):3–9. Available from: https://link.springer.com/article/10.1007/s00120-019-01085-9
35. Patil A, Ganpule A, Singh A, Agrawal A, Patel P, Shete N, et al. Robot-assisted versus conventional open kidney transplantation: a propensity matched comparison with median follow-up of 5 years. Am J Clin Exp Urol [Internet]. 2023 [cited 2024 Mar 22];11(2):168. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10165225/
36. Campi R, Pecoraro A, Li Marzi V, Tuccio A, Giancane S, Peris A, et al. Robotic Versus Open Kidney Transplantation from Deceased Donors: A Prospective Observational Study. Eur Urol Open Sci [Internet]. 2022 May 1 [cited 2024 Apr 7];39:36–46. Available from: https://www.sciencedirect.com/science/article/pii/S266616832200060X
37. Rosales A, Salvador JT, Urdaneta G, Patiño D, Montlleó M, Esquena S, et al. Laparoscopic Kidney Transplantation. Eur Urol [Internet]. 2010 Jan 1 [cited 2024 May 3];57(1):164–7. Available from: https://www.sciencedirect.com/science/article/pii/S0302283809006770
38. Modi P, Pal B, Modi J, Kumar S, Sood A, Menon M. Robotic assisted kidney transplantation. Indian J Urol IJU J Urol Soc India [Internet]. 2014 Sep [cited 2024 Mar 22];30(3):287. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4120216/
39. Giulianotti P, Gorodner V, Sbrana F, Tzvetanov I, Jeon H, Bianco F, et al. Robotic Transabdominal Kidney Transplantation in a Morbidly Obese Patient. Am J Transplant [Internet]. 2010 Jun 1 [cited 2024 Mar 28];10(6):1478–82. Available from: https://www.sciencedirect.com/science/article/pii/S1600613522144187
40. Breda A, Territo A, Gausa L, Rodríguez-Faba O, Caffaratti J, de León JP, et al. Robotic kidney transplantation: one year after the beginning. World J Urol [Internet]. 2017 Oct 1 [cited 2024 Mar 22];35(10):1507–15. Available from: https://link.springer.com/article/10.1007/s00345-017-2006-8
41. Breda A, Territo A, Gausa L, Tuğcu V, Alcaraz A, Musquera M, et al. Robot-assisted Kidney Transplantation: The European Experience. Eur Urol [Internet]. 2018 Feb 1 [cited 2024 Mar 28];73(2):273–81. Available from: https://www.sciencedirect.com/science/article/pii/S0302283817307212

42. Doumerc N, Roumiguié M, Rischmann P, Sallusto F. Totally Robotic Approach with Transvaginal Insertion for Kidney Transplantation. Eur Urol [Internet]. 2015 Dec 1 [cited 2024 Apr 14];68(6):1103–4. Available from: https://www.sciencedirect.com/science/article/pii/S0302283815006715
43. Rajmohan N, Omkarappa S, Srinivasan SP, Nair SG, Rajgopal R, Eldo N. Anesthetic Challenges and Perioperative Factors Affecting Delayed Graft Function in Robotic-Assisted Kidney Transplant: A Review of a Single-Center Experience of 100 Cases. Cureus [Internet]. [cited 2024 Apr 10];14(9):e28957. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9547721/
44. Menon M, Sood A, Bhandari M, Kher V, Ghosh P, Abaza R, et al. Robotic Kidney Transplantation with Regional Hypothermia: A Step-by-step Description of the Vattikuti Urology Institute–Medanta Technique (IDEAL Phase 2a). Eur Urol [Internet]. 2014 May 1 [cited 2024 Apr 17];65(5):991–1000. Available from: https://www.sciencedirect.com/science/article/pii/S0302283813013274
45. Yates DR, Vaessen C, Roupret M. From Leonardo to da Vinci: the history of robot-assisted surgery in urology. BJU Int [Internet]. 2011 Dec [cited 2024 Mar 26];108(11):1708–13. Available from: https://bjui-journals.onlinelibrary.wiley.com/doi/10.1111/j.1464-410X.2011.10576.x
46. Leal Ghezzi T, Campos Corleta O. 30 Years of Robotic Surgery. World J Surg [Internet]. 2016 [cited 2024 Mar 26];40(10):1. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1007/s00268-016-3543-9
47. Wei B, Cerfolio RJ. Chapter 39D - Surgical Approaches to Remove the Esophagus: Robotic. In: Yeo CJ, editor. Shackelford's Surgery of the Alimentary Tract, 2 Volume Set (Eighth Edition) [Internet]. Philadelphia: Elsevier; 2019 [cited 2024 Mar 25]. p. 424–30. Available from: https://www.sciencedirect.com/science/article/pii/B9780323402323001862
48. Tzvetanov I, D'Amico G, Benedetti E. Robotic-assisted Kidney Transplantation: Our Experience and Literature Review. Curr Transplant Rep [Internet]. 2015 Jun 1 [cited 2024 Apr 11];2(2):122–6. Available from: https://doi.org/10.1007/s40472-015-0051-z
49. De Wilde RL, Herrmann A. Robotic surgery – Advance or gimmick? Best Pract Res Clin Obstet Gynaecol [Internet]. 2013 Jun 1 [cited 2024 Apr 12];27(3):457–69. Available from: https://www.sciencedirect.com/science/article/pii/S152169341200185X
50. Territo A, Gausa L, Alcaraz A, Musquera M, Doumerc N, Decaestecker K, et al. European experience of robot-assisted kidney transplantation: minimum of 1-year follow-up. BJU Int [Internet]. 2018 [cited 2024 Apr 9];122(2):255–62. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1111/bju.14247
51. Tuğcu V, Şener NC, Şahin S, Yavuzsan AH, Akbay FG, Apaydın S. Robot-assisted kidney transplantation: comparison of the first 40 cases of open vs robot-assisted transplantations by a single surgeon. BJU Int [Internet]. 2018 [cited 2024 Apr 2];121(2):275–80. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1111/bju.14014
52. Units of measure converter | AMA Manual of Style | Oxford Academic [Internet]. [cited 2024 May 7]. Available from: https://academic.oup.com/amamanualofstyle/si-conversion-calculator
53. Hill CJ, Courtney AE, Cardwell CR, Maxwell AP, Lucarelli G, Veroux M, et al. Recipient obesity and outcomes after kidney transplantation: a systematic review and meta-analysis. Nephrol Dial Transplant [Internet]. 2015 Aug 1 [cited 2024 Mar 30];30(8):1403–11. Available from: https://doi.org/10.1093/ndt/gfv214
54. Palamuthusingam D, Kunarajah K, Pascoe EM, Johnson DW, Hawley CM, Fahim M. Postoperative outcomes of kidney transplant recipients undergoing non-transplant-related elective surgery: a systematic review and meta-analysis. BMC Nephrol [Internet]. 2020 Aug 25 [cited 2024 Mar 27];21(1):365. Available from: https://doi.org/10.1186/s12882-020-01978-4

55. Jardine AG, Gaston RS, Fellstrom BC, Holdaas H. Prevention of cardiovascular disease in adult recipients of kidney transplants. The Lancet [Internet]. 2011 Oct 15 [cited 2024 Mar 30];378(9800):1419–27. Available from: https://www.sciencedirect.com/science/article/pii/S0140673611613342
56. Wszola M, Kwiatkowski A, Ostaszewska A, Górski L, Kuthan R, Sawicka-Grzelak A, et al. Surgical Site Infections After Kidney Transplantation—Where Do We Stand Now? Transplantation [Internet]. 2013 Mar 27 [cited 2024 Mar 25];95(6):878. Available from: https://journals.lww.com/transplantjournal/fulltext/2013/03270/surgical_site_infections_after_kidney.16.aspx
57. Lynch RJ, Ranney DN, Shijie C, Lee DS, Samala N, Englesbe MJ. Obesity, Surgical Site Infection, and Outcome Following Renal Transplantation. Ann Surg [Internet]. 2009 Dec [cited 2024 Mar 25];250(6):1014. Available from: https://journals.lww.com/annalsofsurgery/fulltext/2009/12000/obesity,_surgical_site_infection,_and_outcome.25.aspx
58. Khajuria A. Robotics and surgery: A sustainable relationship? World J Clin Cases WJCC [Internet]. 2015 Mar 16 [cited 2024 Apr 12];3(3):265–9. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4360497/
59. Li Marzi V, Pecoraro A, Gallo ML, Caroti L, Peris A, Vignolini G, et al. Robot-assisted kidney transplantation: Is it getting ready for prime time? World J Transplant [Internet]. 2022 Jul 18 [cited 2024 May 7];12(7):163–74. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9331411/
60. Madhavan K, Jena R, Bhargava P, Pradhan A, Bhandari M. Comparison of outcomes after open versus robotic kidney transplantation: A systematic review and meta-analysis. Indian J Urol IJU J Urol Soc India [Internet]. 2023 [cited 2024 May 7];39(3):186–94. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10419774/

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Studijų programa: Medicine
Darbo pavadinimas: "Clinical Outcomes of Robot-assisted Laparoscopic Kidney Transplantation"
Darbo tipas: Literature Review

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