The Kidney Transplant: Maintaining Excellent Outcomes While Increasing Skills Acquisition

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OBJECTIVE/BACKGROUND: Kidney transplantation is a complex operation that incorporates multiple fundamental surgical techniques and is an excellent opportunity for surgical skill development during residency training. We hypothesized that increasing resident competency, measured as anastomosis time, could be demonstrated while maintaining high-quality surgical outcomes during the learning process.

METHODS: We performed a retrospective cohort study of surgical resident involvement in kidney transplantation and recorded the anastomosis time. The study population comprised adult, single organ kidney transplants (n = 2052) at a large academic transplant center between 2006 and 2019. Descriptive statistics included frequencies, medians, and means. A mixed model of anastomosis time on number of procedures was fitted. Poisson models were fitted with outcomes of the number of patients with delayed graft function and number of patients that underwent reoperation postoperatively, with the exposure being number of kidney transplants performed by resident.

RESULTS: Results from the mixed model suggest that as the number of times a resident performs the surgery increases, the time to conduct the operation decreases with statistical significance. The Poisson regression demonstrated no significant relationship between the operative volume of a resident and postoperative complications.

CONCLUSION: This study demonstrated statistical evidence that with an increase in the number of renal transplantations performed by a surgical resident, anastomosis time decreased. It also demonstrated no significant relationship between number of kidney transplants performed by a resident and postoperative complications, suggesting that patient outcomes for this operation are not adversely affected by resident involvement. (J Surg Ed 80:1850−1858. © 2023 Published by Elsevier Inc. on behalf of Association of Program Directors in Surgery.)

ABBREVIATIONS: BMI, body mass index DGF, delayed graft function CAD, coronary artery disease CHF, congestive heart failure HTN, hypertension KDPI, kidney donor profile index PGY, postgraduate year ASA, American Society of Anesthesiologists LOS, length of stay GFR, glomerular filtration rate NSQIP, National Surgical Quality Improvement Program VASQIP Veteran Affairs Surgical Quality Improvement Program

KEY WORDS: renal transplantation, anastomosis time, postoperative complications, patient outcomes

COMPETENCIES: Practice-Based Learning and Improvement

INTRODUCTION

The primary goal of surgical education is to maintain patient safety for current patients while training

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surgeons who can care for patients of the future. It is essential for trainees to be able to operate independently and competently at the completion of their residencies. Repetition is essential to master the many technical and cognitive skills required for surgery. Kidney transplantation is a complex operation that incorporates multiple essential surgical skills including retroperitoneal exposure, iliac vessel dissection, and anastomoses (both vascular and urologic). Many specialties and situations require knowledge and mastery of the skillset required for vascular anastomosis so experience is often gained on rotations in surgical oncology, cardiothoracic, vascular, trauma, and transplant surgery during core residency and specialty training in fellowship.

Previous studies have used renal transplantation as a model of competency based education in surgical skill acquisition. It was demonstrated that when comparing surgical residents and fellows performing renal transplantation, there is not a significant difference in surgical outcomes.[1,2] Additionally, competency in performance of the operation has been evaluated in regard to fellow and surgical attending performance, demonstrating that approximately 30 operations are necessary to improve surgical skill (anastomosis time) with equivalent surgical outcomes.[3,4] However, the impact of resident level on the quality of care has not yet been evaluated. Additionally, as a core residency involves trainees who are by definition less experienced in the skill, it is important to evaluate patient safety in the setting of surgical resident participation in and learning of these essential surgical skills.

The vascular anastomoses in renal transplantation represents a clinically correlated measure of direct outcomes in surgical technique. Warm ischemia time is defined as the time it takes to perform the vascular anastomoses. This is the time the kidney is off ice while anastomosing the arterial and venous supply to the recipient. Prolonged anastomosis time (warm ischemia time) is associated with oxidative injury to the transplanted organ,[5] which can affect postoperative kidney function. Both short-term and long-term outcomes have been evaluated in regard to anastomosis time, demonstrating that it is independently associated with delayed graft function (DGF), specifically an anastomosis time of greater than 29 minutes is associated with a 3.5 fold higher risk of DGF.[6,7] Hence, a shorter anastomosis time is desired. Evaluation of the anastomosis time and surgical outcomes has not been evaluated in the setting of surgical resident involvement in renal transplantation. It is important to understand the effect of surgical resident involvement in renal transplantation as it pertains to both education and quality of care for transplant patients. We hypothesized that as experience increased as defined by the number renal transplantations performed, anastomosis times and postoperative complications would decrease.

METHODS

Study Design and Population

We conducted a retrospective cohort study utilizing our academic center's kidney transplant database. This included 2358 consecutive patients who underwent kidney transplant between the years 2006 and 2019. All procedures were performed by 13 different transplant surgeons, each with either a transplant fellow or surgical resident assisting. Involvement of the resident in the performance of the anastomosis is typically standardized at our institution. The resident will place stay sutures at either end of the anastomosis and sew the anterior row of the arterial and venous graft with the attending surgeon sewing the back row. The approval of the Institutional Review Board at our institution was obtained.

Clinical Data

The database was constructed of all eligible cases, and the following demographic and clinical data were collected: gender, race, age at time of transplant, BMI, comorbidities (diabetes, CAD, CHF, HTN), donor type, transplant side, number of arteries, antigen mismatch, number of transplants received, multiorgan transplant, KDPI, attending performed, resident/fellow assisted, PGY level, cold ischemia time, anastomosis time, additional procedures, total procedure time, ASA classification, LOS, month/year, creatinine/GFR, rejection w/in 3 months, graft failure, date of graft failure, death, and date of death. Data on postoperative complication included the following: need for reoperation during hospital stay, delayed graft function, surgical complication, or urologic complication. Urologic complication was defined as ureteral stenosis or urine leak requiring percutaneous nephrostomy or surgical intervention within 1 year of operation. Delayed graft function was defined as the requirement of dialysis within 1 week of operation due to dysfunction of transplanted organ.

The exposure inclusion criterion was that the surgical resident involved in the transplant must be a general surgery resident (PGY 1-5). Inclusion criteria for the patients undergoing kidney transplant were the following: single organ transplant, operation performed between the years 2006 and 2019, adult kidney transplant age $>$ 18 years old and clinical factors consistent with transplant eligibility. The exposure exclusion criteria is that if the kidney transplant was performed with a urology surgical resident or transplant fellow. Exclusion

criteria for patient undergoing kidney transplant were the following: age <18 years old, performed with heart or liver transplantation (multiorgan transplantation) or a transplant performed through a midline incision.

The primary outcome of interest was anastomosis time (warm ischemia time), defined as the time that the kidney is removed from ice to the time that the vascular clamps are released to restore blood flow to the transplanted kidney organ, which was recorded in the operative report. The secondary clinical outcomes evaluated were the following: delayed graft function, reoperation, and urinary complications. Additionally, the correlation between number of kidney transplants performed during general surgery residency was compared to the total number of cases recorded of any type at completion of general surgery residency.

Statistical Analysis

We calculated descriptive statistics such as frequencies, medians, and means. These descriptive statistics were stratified by anastomosis quartiles in minutes. Graphical displays such as scatterplots, boxplots, and spaghetti plots were created to evaluate the data. A mixed model of anastomosis time on number of procedures was fitted with residents nested in attending, which was where the largest amount of variance came from and demonstrated significant differences between attendings and within the attending-resident relationship. Other covariates fitted in the model were BMI, side of the kidney transplant, and heart disease. Poisson models were fit with outcomes of the number of patients with delayed graft function and number of patients that underwent reoperation postoperatively with the exposure being number of kidney transplants performed by resident. A random intercept model was fitted to evaluate the relationship between total number of kidney transplants performed by residents to the total number of cases performed at completion of general surgery residency. All analysis was conducted using R version 4.0.4 (2021-02-15).

RESULTS

Of the 2358 transplant procedures from the years 2006 to 2019, 2052 transplant patients fulfilled the inclusion and exclusion criteria for the primary analysis of anastomosis time on number of procedures performed by a resident. Recipient, transplant, and resident characteristics are shown in Table 1. Of the patients evaluated, the distribution of gender, age and BMI is represented in quartiles of anastomosis time with 58% male patients, median age of 50 and median BMI of 28. Patient comorbidities were evenly distributed across anastomosis time quartiles with the majority of patients having HTN, as expected with end-stage renal disease. The majority of transplanted organs were from deceased donors with a majority of anastomosis times comprising the third and fourth anastomosis quartiles (>27 minutes) and living donor transplants comprising the majority of first and second anastomosis quartiles (<26 minutes). As expected, based on assigned rotations during residency at the institution, 80% of renal transplants were performed with a PGY3 resident. Of the PGY3 performed transplants, they were evenly distributed across anastomosis quartiles with 28% of the anastomoses performed in less than 21 minutes. For transplants performed with PGY4 residents, 43% of the anastomoses were performed in less than 21 minutes. There was nonsignificant distribution of the number of transplants throughout the quarters of the year and importantly, were evenly distributed across anastomosis quartiles. The median number of transplants performed by a single resident was 22 with a median anastomosis time of 26 minutes.

Results from the mixed model (Table 2) of anastomosis time on number of procedures was fitted, with residents nested in attending, and suggest that the residents' time for anastomosis and the number of operations is significant. The total number of transplants included in the analysis was 2052 patient transplants with 53 residents and 13 attendings involved in the transplants. Data from this series would suggest that the more operations performed, the less the time was necessary to conduct the anastomosis. The highest variance was associated with the attendings, as there were 13 different attendings involved in the renal transplantations. This was controlled for by fitting the time on number of procedures with residents nested in attending. There is also evidence that as BMI increases, the time to perform the operation increases, which has been demonstrated in prior studies. We also found a significant decrease in time when the surgery was conducted on the transplant patient's right side.

The Poisson regression models (Table 3) the postoperative complications as the outcome including the following: delayed graft function and reoperation during hospitalization. The exposure evaluated is the number of kidney transplants performed by the resident overall controlled for BMI average, cold ischemia time, and multiple other factors represented in the appendix. For each model (each postoperative outcome), the number of kidney transplants performed by a resident was not significant, suggesting that resident involvement in kidney transplantation does not alter surgical outcomes and maintains quality of care for patients. This model also demonstrated that as the cold ischemia average time

TABLE 1. Descriptive Statistics by Anastomosis Quartiles (min)*

	Total	<21 (Q1) N = 530	22-26(Q2) N = 521	27-36 (Q3) N = 503	37+ (Q4) N = 499
Patient					
Gender					
Male	58% (1193)	62% (330)	57% (297)	56% (283)	57% (283)
Female	42% (858)	38% (199)	43% (224)	44% (219)	43% (216)
Age at Transplant	median	48.6	49.6	51.2	51.3
BMI	median	27.4	28.5	28.7	29.2
Patient w/comorbidities:					
DM	32% (487)	28% (135)	32% (130)	30% (98)	40% (124)
CAD	18% (246)	19% (70)	16% (57)	18% (56)	21% (63)
CHF	10% (139)	10% (36)	10% (35)	11% (35)	11% (33)
HTN	94% (1449)	95% (467)	94% (388)	93% (305)	94% (289)
ASA					
2	2% (50)	4% (21)	3% (13)	2% (11)	1% (5)
3	74% (1526)	81% (428)	76% (396)	72% (364)	68% (338)
4	23% (470)	15% (79)	21% (110)	25% (128)	31% (153)
5	0% (2)	0% (2)	0% (0)	0% (0)	0% (0)
Donor type					
Cadaver	66% (1342)	28% (151)	57% (299)	85% (426)	93% (466)
Living	34%(706)	72% (379)	43% (222)	15% (72)	7% (33)
Donor # of arteries					
1	81% (1639)	94% (459)	85% (445)	75% (378)	72% (357)
2	17%(338)	6% (32)	14% (71)	24% (113)	25% (122)
3	2% (35)	0% (2)	1% (5)	2% (11)	3% (17)
Transplant side					
L	14% (292)	8% (43)	14% (74)	16% (81)	19% (94)
R	86% (1761)	92% (487)	86% (447)	84% (422)	81% (405)
Postoperative complications					
Delayed graft fxn	12% (245)	6% (32)	9% (49)	16% (78)	17% (86)
Reoperation	9% (76)	6% (9)	7% (17)	10% (25)	11% (25)
Resident assisting					
PGY2	13% (270)	2% (12)	9% (49)	15% (77)	26% (132)
PGY3	80% (1640)	88% (466)	83% (432)	79% (399)	69% (343)
PGY4	5% (104)	9% (45)	6% (27)	3% (16)	3% (16)
PGY5	2% (37)	1% (5)	2% (13)	2% (11)	2% (8)
Time of academic year by quarter					
1	24% (495)	24% (125)	23% (118)	23% (118)	27% (134)
2	25% (514)	24% (126)	25% (132)	25% (127)	26% (129)
3	25% (518)	28% (146)	22% (117)	27% (135)	24% (120)
4	26% (526)	25% (133)	30% (154)	24% (123)	23% (116)

*Descriptive statistics regarding recipient, transplant, and resident characteristics organized by anastomosis time quartile.

increased by one minute, the expected rate of delayed graft function increases by 0.32%.

We also evaluated the co-relation between the average anastomosis time performed by a resident for all of their performed renal transplantations during residency to the total number of cases that they logged during general surgery residency (Fig. 1). This corelation demonstrates a negative relationship (r = -0.24, CI: -0.45, 0.01) between the average anastomosis time and total number of cases logged, suggesting that the residents with a lower average anastomosis time logged more cases overall during their general surgery residency. This may demonstrate that as residents strive to get into the operating room more their skills improve and efficiency, which overall leads to improved patient care and obtaining competence in essential surgical skills.

DISCUSSION

Resident involvement in renal transplantation provides repetitive exposure to the vascular anastomosis, an essential skill learned in surgical residency. With the increase in endovascular interventions in vascular

TABLE 2. Multilevel Model Results of Anastomosis Time on Covariates With Students Nested in Postgraduate*

Model Estimates	Name	Variance	Std. Deviation	Lower CI	Upper CI
Random effects					
Residents:attending	Intercept	35.55	5.96	5.20	6.77
Attending	Intercept	91.75	9.58	6.21	14.76
Residuals	Within	32.57	5.71	5.44	5.98
Fixed effects	**Estimate**	**Std. Error**	**T-value**	**Lower CI**	**Upper CI**
Intercept	33.41	3.00	11.14	27.29	39.36
No. operations	**−0.19**	**0.03**	**−7.19**	**−0.24**	**−0.14**
BMI	0.17	0.03	5.73	0.11	0.23
Transplant side: right	−1.94	0.50	−3.86	−2.93	−0.96
Vascular disease	0.14	0.63	0.22	−1.10	1.38

*A mixed model of anastomosis time on number of procedures was fitted with residents nested in attending, adjusting for: age of patient, BMI of patient, quarter of year transplant performed, PGY of resident, attending involved, patient vascular disease (as evident on transplant evaluation CT imaging), side of transplant preformed.

surgery, a rotation where residents historically performed additional anastomoses, as well as the potential effects of work-hour restrictions on case numbers, repetition with vascular anastomoses on cases such as the kidney transplant is important to ensure residents have adequate operative time and experience for this procedure. Our retrospective, single institution cohort study showed that the more operative volume a resident has, the faster his or her anastomosis times are. This negative relationship demonstrates the potentially intuitive finding that competency in a skill can be achieved with repetition. Although in this study we did not evaluate how many procedures are needed to achieve this competency, the inverse relationship with experience and warm ischemia time likely reflects improvement in surgical skills such as suturing, exposure, and operative technique.

Besides skills acquisition, however, it is potentially more important to demonstrate safety in patient care during skills acquisition, allowing for both learning and patient care to happen simultaneously. Multiple studies have demonstrated that decreasing anastomosis time is associated with improved kidney function and survival.[8-10] Therefore, there would be concern that allowing learning would also negatively impact safety. The learning curve for kidney transplantation has previously been evaluated at the attending level for surgical outcomes by Wolff et.al.[4] these investigators found no evidence for a learning curve at this training level. Takagi et.al. evaluated the achievement of competency by performing a cumulative sum analysis to evaluate fellow and attending transplant surgeons; they identified the inflection point of anastomotic time improvement plateaus after 31 cases.[3] This study did not evaluate residents and it would be interesting to evaluate this set of trainees' learning curves in comparison to fellows.

At our institution, from 2006 to 2019 there was a total of 13 transplants surgeons (Fig. 2) involved in renal transplants with 6 being kidney only (A, B, C, I, K, and M) and 7 being multiorgan transplant surgeons (D, E, F, G, H, J, and L). This variability was demonstrated in our

TABLE 3. Poisson Regression for Postoperative Complications

	Model	Odds Ratio	Z Value	p Value
Intercept	Delayed graft function	0.0139	−1.56	0.1194
	Reoperation	4.4304	0.27	0.7872
No. kidney transplants	**Delayed graft function**	**0.9855**	**−0.43**	**0.7338**
	Reoperation	**0.9515**	**−0.37**	**0.7129**
BMI average	Delayed graft function	1.0720	0.73	0.4648
	Reoperation	0.7636	−1.17	0.2431
Cold Ischemia time average	**Delayed graft function**	**1.0032**	**2.77**	**<0.01**
	Reoperation	1.0076	2.18	0.0291

*Poisson regression models were fit with outcomes of the number of patients with delayed graft function, number patients with postoperative bleeding complications and number of patients that underwent reoperation postoperatively with the exposure being number of kidney transplants performed by resident. These models were adjusted for: transplant patient age, transplant patient BMI, quarter of year transplant performed, PGY of resident, patient hx of vascular disease, intraoperative vasopressor use, intraoperative transfusion, donor type.

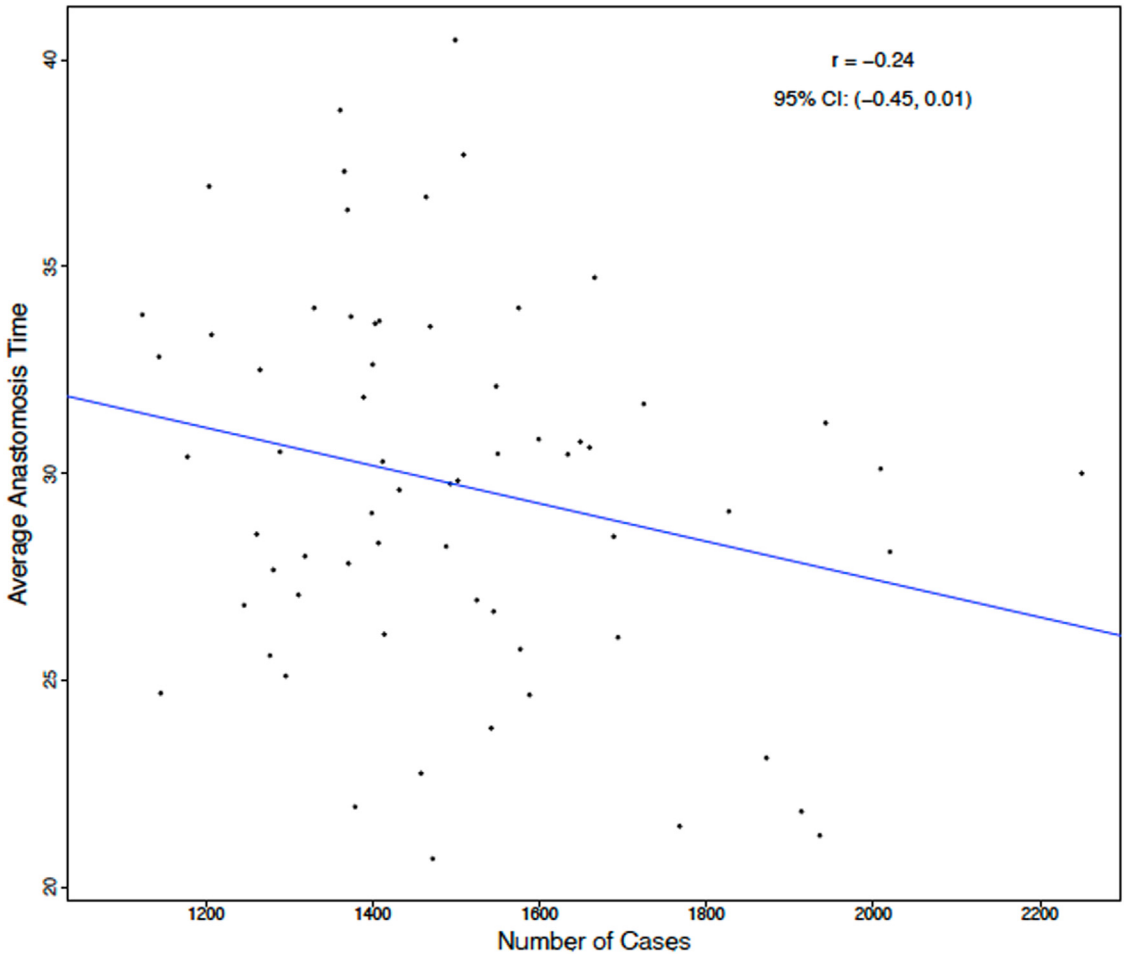

FIGURE 1. Relation of Average Anastomosis Time by Total Cases, Figure 1: Corelation between the average anastomosis time performed by a resident for all of their performed renal transplantations to the total number of cases that they logged during general surgery residency.

mixed effects model analysis that demonstrated the highest variability in anastomosis time outcome was associated not with the residents, but actually with the attendings involved. This is likely due to differences in experience, technique in performance of anastomosis and case volume between those who are primarily kidney transplant surgeons vs. those who also spend time performing liver transplants. This suggests also that learning curves or a relationship to repetition may persist even in expert status. Additionally, there may be an interaction between junior and senior attendings and the residents assisting, as senior attendings tend to be paired with more senior trainees. Technique, teaching skills, and individual surgeon skills can affect the anastomosis time and can also demonstrate or potentially negatively impact a resident's performance as well. The interaction of the attending learning curve with the resident learning curve has not yet been evaluated, and will be an important next step with this data set.

There have been multiple studies that have evaluated the relationship between resident involvement in operations and the effect on surgical outcomes. The evaluation of NSQIP data by Kiran et.al. demonstrated that resident involvement in surgical procedures is safe, with small increase in mild complications such as surgical site infections.[11] Specifically, operative time was evaluated by Uecker et.al.,[12] showing that there was no difference in operative time for common general surgery procedures with or without resident involvement. The VASQIP data from the large VA data source has also been evaluated and demonstrated that the level of resident supervision in the OR did not affect clinical outcomes adversely[13] and also that an increase in resident autonomy was not associated with increase in all-cause mortality or composite morbidity.[14] Overall resident involvement in selected patients and operations has been shown to be acceptable in regard to patient safety and outcomes.[11-15] Thus, although one might intuit that

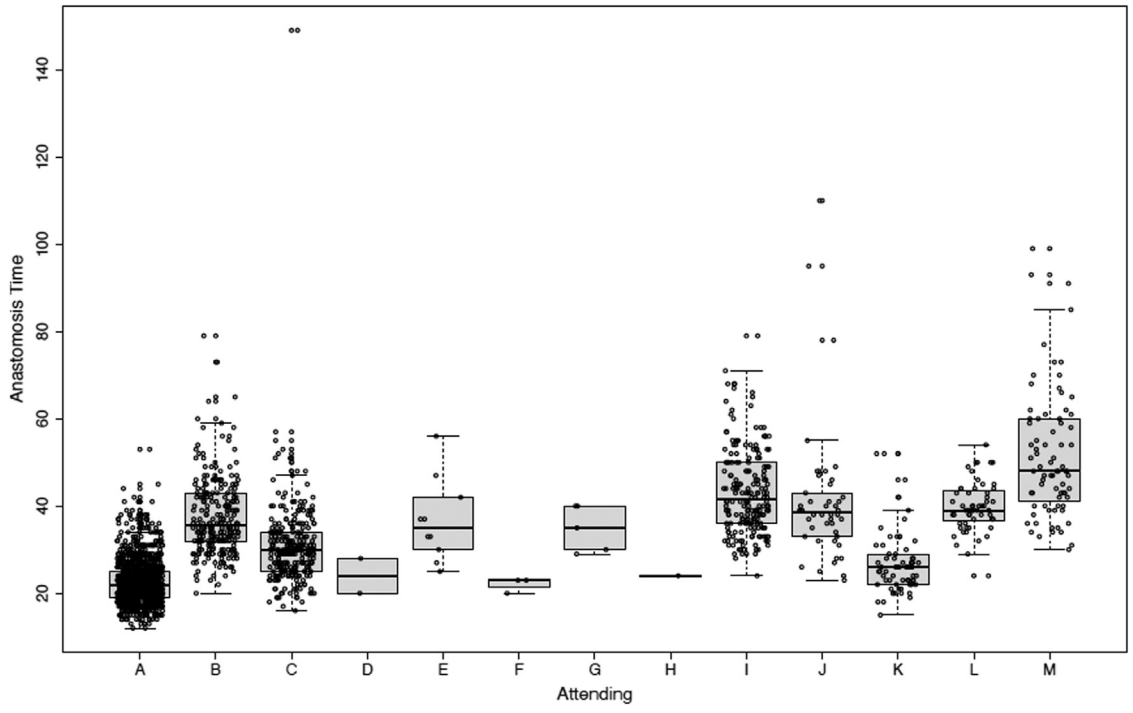

FIGURE 2. Comparison of anastomosis by attending involved in renal transplantation*, * Descriptive statistics (box plots) utilized to compare the anastomosis time by attending that performed renal transplantations. Kidney only transplant attendings (A, B, C, I, K, and M) and multiorgan transplant attendings (D, E, F, G, H, J, and L). Junior attendings at some point during study duration 2006-2019 (C, I, and M).

the learning curve would negatively impact patient outcomes, the data do not demonstrate that, which is similar to our findings.

Regarding resident involvement in renal transplantation, research has suggested that resident involvement in renal transplantation also does not impact the surgical outcomes of delayed graft function or early allograft function and that it is safe to involve residents while they are gaining surgical skills.[1,16] Our study also demonstrated that with an increase in the number of kidney transplants performed by a resident, there was no change in the operative outcomes evaluated, supported by the large database and an increase in power comparably to prior studies. This suggests that resident involvement in renal transplantation does not affect surgical outcomes and maintains quality of care for patients. As this is a highly specialized procedure in which high quality outcomes are required and represent a case type for residents to learn these skills to become competent in vascular anastomosis and retroperitoneal exposure, this is reassuring and suggests that both priorities (learning and safety) may be honored simultaneously.

Limitations

There are multiple limitations for this retrospective cohort study. Specifically, the duration of the study from the years 2006 to 2019 necessitated a large and time-consuming chart review. This could lead to fatigue and an absence of data on potentially confounding factors, specifically regarding surgical outcomes. Another limitation of concern is the generalizability of the study to other surgical residencies and academic surgical centers. The transplant center database utilized is a large academic center with a continually increasing census of transplant patients, which may not be the case nationally. Additionally, this is a specialized center with a high value on surgical education and experience that may not be the standard elsewhere. Finally, the majority of our kidney transplants are performed with a PGY3 general surgery resident, which would not be generalizable across surgical residencies without a dedicated kidney transplant rotation or with an associated transplant fellowship.

CONCLUSION

The maintenance of quality of care for surgical patients is crucial in delivery of surgical care, and this quality is focused on current as well as future patients. An essential aspect of general surgery residency is to ensure residents complete their residency with experience and competence, while also maintaining patient safety.

Competency at completion of residency is achieved by mastering many specific skills, one of which is the vascular anastomosis. Resident involvement in renal transplantation allows for repetitive exposure to the anastomosis technique, enabling residents to acquire and retain these skills.

This study demonstrated statistical evidence that with an increase in the number of renal transplantations performed by a surgical resident, anastomosis time decreased, while supporting ongoing learning and skill acquisition. It also demonstrated no significant relationship between resident operative volume and postoperative complications, suggesting patient outcomes are not affected during the learning curve. There was high variability associated with the resident and attending relationship, which is likely attributable to attending factors in addition to trainee ones. This relationship is something that warrants further investigation, as it is also well-known that the interactions between a resident and attending can also impact patient care and quality.

DATA ACCESS STATEMENT

Research data supporting this publication are not available for the public.

CONFLICT OF INTEREST DECLARATION

The authors declare that they have no affiliations with or involvement in any organization or entity with any financial interest in the subject matter or materials discussed in this manuscript.

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SUPPLEMENTARY INFORMATION

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