

Donor Anatomical Variations and Surgical Complexity in Living-Donor Renal Transplantation: A Multi-Center Experience in The Iraqi Kurdistan Region

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Abstract

Background: Kidney transplantation remains the optimal treatment for end-stage renal disease (ESRD), with living-donor transplantation offering superior graft survival and quality of life compared to deceased-donor transplantation. Renal vascular anatomical variations are common, with multiple renal arteries reported in literature to be as high as 18–30% of the general population, potentially increasing surgical complexity and affecting outcomes. In the Iraqi Kurdistan Region, living-donor transplantation is the only form of kidney transplantation available. However, published data on donor anatomical variations and their surgical implications in this population are limited.

Aim: To evaluate the impact of donor anatomical variations on surgical complexity and perioperative outcomes in living-donor renal transplantation in the Iraqi Kurdistan Region.

Methods: This retrospective case series included 52 living kidney donors and their corresponding recipients who underwent renal transplantation at the Duhok Kidney Disease and Transplant Center and the Department of Urology at Rizgary Teaching Hospital between February 2025 and December 2025. Preoperative CT angiography was used to assess renal vascular anatomy. Operative details, including operative time, anastomosis technique, and complications, were recorded. Chi-square tests, logistic regression, linear regression, and Cox regression were used to examine factors associated with surgical complexity and outcomes.

Results: In this cohort, multiple renal arteries were present in 40.4% of donors, with 30.8% having unilateral and 9.6% having bilateral variations. Meanwhile, multiple renal veins were present in 23.1% of donors. The mean donor operative time was 98.1 minutes, while the mean recipient operative time was 126.8 minutes. Multiple renal arteries were significantly associated with prolonged operative time ($\beta = 31.25$ minutes, $p = 0.001$) and increased risk of intraoperative bleeding complications (OR = 3.08, $p = 0.007$). DSA Class II positivity was the strongest predictor of recipient complications (OR = 6.00, $p = 0.003$). A Donor Anatomical Complexity Score was developed from the weighted contribution of the anatomical variations examined in the study.

Conclusion: Donor anatomical variations, particularly multiple renal arteries, were common in this cohort and were associated with greater surgical complexity. With appropriate preoperative imaging and surgical expertise, however, these variations were not associated with worse short-term graft outcomes.

Preoperative CT angiography is important for defining vascular anatomy and planning the operation.

Keywords: Living-donor renal transplantation; Renal vascular variations; Multiple renal arteries; Surgical complexity; CT angiography; Iraqi Kurdistan.

1. Introduction

The Burden of End-Stage Renal Disease

Chronic kidney disease (CKD) represents a major worldwide health challenge, currently affecting more than 800 million people and corresponding to an estimated global prevalence of approximately 11–13% [1]. With continued deterioration of renal function and progression to end-stage renal disease (ESRD), patients ultimately require renal replacement therapy, most commonly through maintenance dialysis or kidney transplantation.

Kidney transplantation remains the treatment of choice for eligible patients, offering superior survival rates, better quality of life, and lower healthcare costs compared to chronic dialysis [2,3].

Living-Donor Renal Transplantation

Living-donor renal transplantation is an important strategy to address the organ shortage crisis and in areas where deceased-donor organs are not available or not suitable, due to many reasons.

While, ironically, the living-donor offers several advantages over deceased-donor transplantation, including shorter waiting times, better graft survival, and the ability to perform transplantation electively under optimal conditions

[4,5]. The success of living-donor transplantation depends on careful donor selection, thorough preoperative evaluation, and meticulous surgical technique.

Renal Vascular Anatomy and Variations

The renal vascular system exhibits considerable anatomical diversity, an important consideration when planning renal surgery and anticipating operative outcomes [6,7]. Arterial and venous variants are relatively frequent, with the presence of multiple renal arteries reported in approximately 18–30% of the general population [8,9]. Recognized patterns of variation include accessory renal arteries, pre-hilar or early arterial branching, duplicated or multiple renal veins, a retroaortic left renal vein, and a circumaortic venous configuration [10,11].

These anatomical patterns are largely attributable to the complex embryological development of the renal circulation. As the developing kidneys migrate cranially from the pelvic region toward their definitive abdominal position, their blood supply changes sequentially through arterial branches originating at progressively higher levels of the aorta. Persistence of vessels that would normally regress during this process can give rise to accessory renal arteries [12,13]. The venous circulation follows an equally complex developmental pathway involving the cardinal, subcardinal, and supracardinal venous systems. Differential persistence and involution of these embryonic venous channels account for many of the renal venous configurations observed in clinical practice [14,15].

Clinical Significance in Transplantation

Knowledge and preoperative information of renal vascular variations is crucial for several reasons.

First, variations in renal vasculature can influence the selection of the appropriate kidney for donation, as the left kidney is typically preferred due to its longer renal vein [16,17].

Second, multiple renal arteries may increase the complexity of the surgical procedure, prolong operative time, and increase the risk of intraoperative complications [18,19].

Third, variations in the venous system, particularly retroaortic or circumaortic left renal vein, may pose additional technical challenges during donor nephrectomy, adding to extra time to do the operation [20,21].

The Iraqi Kurdistan Context

In the Iraqi Kurdistan Region, living-donor renal transplantation is the only available form of kidney transplantation, as till now we don't have legislative framework and laws defining brain death and making deceased donation accessible.

The Duhok Kidney Disease and Transplant Center and the Transplant Center in the Department of Urology at Rizgary Teaching Hospital in Erbil are among the centers performing these procedures for over twenty years. But published data on donor anatomical variations, surgical complexity, and outcomes in this population remain limited.

Understanding the local prevalence of anatomical variations and their impact on surgical outcomes is essential for optimizing donor selection, surgical planning, and patient counseling [22,23].

Aim and Objectives

We aimed to evaluate the impact of donor anatomical variations on surgical complexity and perioperative outcomes in living-donor renal transplantation in the Iraqi Kurdistan Region.

The study objectives were:

1. To determine the prevalence and patterns of renal artery and vein variations among living kidney donors in the Kurdistan Region of Iraq.
2. To compare operative time and intraoperative complication rates between donors with single versus multiple renal arteries and between donors with single versus multiple renal veins.
3. To identify independent preoperative predictors of prolonged operative time and intraoperative bleeding complications using multivariate regression analyses.
4. To compare recipient outcomes, including complication rates and graft function, between grafts originating from donors with simple vascular anatomy and those with complex vascular anatomy.
5. To evaluate the role of recipient immunological factors, including PRA and DSA status, in modifying the relationship between donor anatomical variations and clinical outcomes.

6. To assess the diagnostic utility of preoperative CT angiography in predicting surgical complexity and guiding preoperative surgical planning.
7. To propose a Donor Anatomical Complexity Score based on the weighted contribution of individual anatomical variations to surgical complexity and operative outcomes.
8. To identify independent predictors of graft failure using Cox regression analysis and develop a prognostic model combining donor anatomical and recipient immunological factors.
9. To describe the demographic and clinical characteristics of living kidney donors and recipients in this cohort from the Kurdistan Region of Iraq.

2. Methods

Study Design

We retrospectively reviewed consecutive living kidney donors and their corresponding recipients who underwent renal transplantation at the Duhok Kidney Disease and Transplant Center and the Department of Urology at Rizgary Teaching Hospital in the period, between February 2025 and December 2025.

The study adhered to the ethical standards outlined in the Declaration of Helsinki and received approval from the Medical Research Ethics Committee of the Kurdistan Higher Council of Medical Specialties. Given the retrospective design, minimal risk to participants, and exclusive use of de-identified information, the requirement for obtaining individual informed consent was waived by the ethics committee.

Study Setting

The study included patients from two centers in the Iraqi Kurdistan Region:

- Duhok Kidney Disease and Transplant Center
- Department of Urology, Rizgary Teaching Hospital, Erbil

Both centers provide renal transplantation services to patients from the Kurdistan Region and surrounding areas, including other parts of Iraq, for the last twenty plus years.

Study Population

A total of 52 living kidney donors and their 52 corresponding recipients were included in the study.

Inclusion Criteria for Donors:

- All living kidney donors who underwent donor nephrectomy at the Duhok Kidney Disease and Transplant Center and the Department of Urology at Rizgary Teaching Hospital between February 2025 and December 2025
- Age 18 years or older at the time of donation
- Complete preoperative imaging data (CT angiography and ultrasound) available for review
- Complete operative records available for review
- Complete laboratory investigations available for review
- Donors who provided written informed consent for transplantation

Inclusion Criteria for Recipients:

- All recipients who underwent living-donor renal transplantation at the Duhok Kidney Disease and Transplant Center and the Department of Urology at Rizgary Teaching Hospital during the same period
- All ages
- Complete preoperative evaluation data available for review
- Complete operative records available for review

Exclusion Criteria for Donors:

- Donors with incomplete medical records or missing key data (imaging, laboratory, or operative records)
- Donors who underwent nephrectomy for reasons other than transplantation
- Donors with congenital anomalies of the kidney other than vascular variations (e.g., horseshoe kidney, pelvic kidney)
- Donors with known renal pathology that could confound the analysis

Exclusion Criteria for Recipients:

- Recipients with incomplete medical records or missing key data

Data Collection

We reviewed electronic and paper medical records, imaging and laboratory reports, operative notes, and immunology reports. The primary investigator was present during the surgical procedures and collected the study data.

Data Collection Process:

The primary investigator reviewed each patient's paper chart and recorded the relevant clinical information on standardized data collection sheets prepared for the study. The information was then entered into a digital database for analysis.

During the transplant procedures, the primary investigator recorded the surgical approach, operative time, anatomical findings, and intraoperative complications.

Laboratory results, imaging findings, and immunological reports were obtained from the relevant hospital departments and laboratories. The information collected from the records and operative observations was then entered into the study database.

Data Access:

Only the primary investigator accessed the healthcare records for the purposes of this study. No other individuals, research assistants, or collaborators were involved in the data collection process. The hospital records were accessed on-site at the medical records department and the surgical wards of the Duhok Kidney Disease and Transplant Center and the Department of Urology at Rizgary Teaching Hospital. All data were collected during direct clinical involvement with the transplant program. The records were not removed from the hospital premises, and all data extraction was performed within the hospital setting under the supervision of the treating physicians.

After completing the data collection, all information was entered into a secure electronic database created and maintained by the primary investigator. This database is stored on a password-protected personal computer with restricted access. No other individuals have access to the raw data or the electronic database. The data are de-identified, with unique study codes replacing patient names and identifiers, ensuring that participant confidentiality is maintained throughout the research process.

Ethical Considerations and Informed Consent

Ethical Approval:

The study was approved by the Medical Research Ethics Committee of the Kurdistan Higher Council of Medical Specialties. The protocol was approved before data collection began. The ethics approval number is (2117), optioned on (September 17, 2026).

Consent Process:

Consent for participation in this study was obtained together with the routine preoperative consent for surgery at the Duhok Kidney Disease and Transplant Center and the Department of Urology at Rizgary Teaching Hospital. This integrated approach was practical and ethically sound, as patients were already engaged in discussions about their clinical care during the preoperative period.

During the consent process, all donors and recipients were informed about the purpose of the study, the procedures involved, the minimal risks, and the absence of direct personal benefits. They were assured that participation was entirely voluntary and that they had the right to refuse or withdraw at any time without affecting their clinical care or their relationship with the healthcare team.

Participants were informed that the study involved review of their medical records, observation of the surgical procedure, and collection of postoperative outcome data. They were assured that no additional procedures or interventions would be performed specifically for the study and that all data would be de-identified and kept confidential. Only the primary investigator would have access to the raw data, and results would be reported in aggregate form without individual identification.

For minor recipients, consent was obtained from their parents or legal guardians, and assent was obtained from the minor when appropriate. The consent form was available in Kurdish, Arabic, and English to accommodate participants' language preferences. Verbal explanation was provided alongside written consent to ensure understanding.

Written consent was documented using a consent form that included the study title, purpose, procedures, risks, benefits, voluntary participation statement, right to refuse and withdraw, confidentiality provisions, and contact information. The form was signed by both the participant and the person obtaining consent, and a copy was provided to the participant.

Confidentiality:

All data were de-identified and securely stored to protect participant confidentiality. Only the primary investigator had access to the raw data. Results are presented in aggregate form without individual identification.

Definitions

- Multiple renal arteries: More than one renal artery supplying the kidney
- Early branching: Division of the main renal artery within 1.5 cm of its origin from the aorta
- Multiple renal veins: More than one renal vein draining the kidney
- Retroaortic left renal vein: Left renal vein passing posterior to the abdominal aorta
- Circumaortic left renal vein: Presence of both anterior and posterior venous channels encircling the aorta
- Standard donor surgery: Left kidney procurement
- Non-standard donor surgery: Right kidney procurement
- Standard recipient surgery: Graft placement in the right iliac fossa
- Non-standard recipient surgery: Graft placement in the left iliac fossa
- Prolonged operative time: Operative time >120 minutes

Statistical Analysis

Data were analyzed using the Statistical Package for Social Sciences (SPSS, version 26.0; IBM Corp., Armonk, NY, USA). Categorical variables were expressed as frequencies and percentages, while continuous variables were expressed as means with standard deviations or medians with interquartile ranges. Chi-square tests, Fisher's exact tests, independent t-tests, and Mann-Whitney U tests were used for comparative analyses. Logistic regression, linear regression, and Cox regression were performed to identify independent predictors of complications, operative time, and graft failure. A p-value ≤ 0.05 was considered statistically significant.

3. Results

Demographic Characteristics of Donors

A total of 52 living kidney donors were included in the study. The mean donor age was 29.2 ± 7.4 years (range, 19–45 years). The majority of donors were male (73.1%, $n = 38$), while 26.9% ($n = 14$) were female. The most common age group was 20–29 years (51.9%, $n = 27$), followed by 30–39 years (26.9%, $n = 14$), 40–49 years (11.5%, $n = 6$), and 10–19 years (9.6%, $n = 5$).

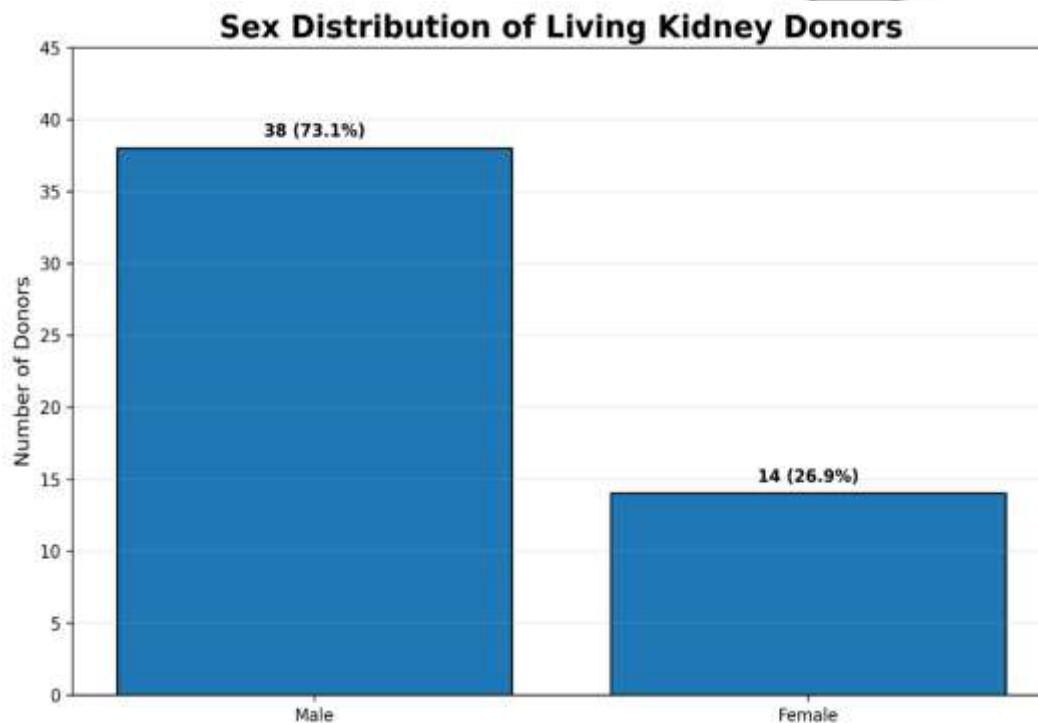


Fig 1: Sex Distribution of Living Kidney Donors

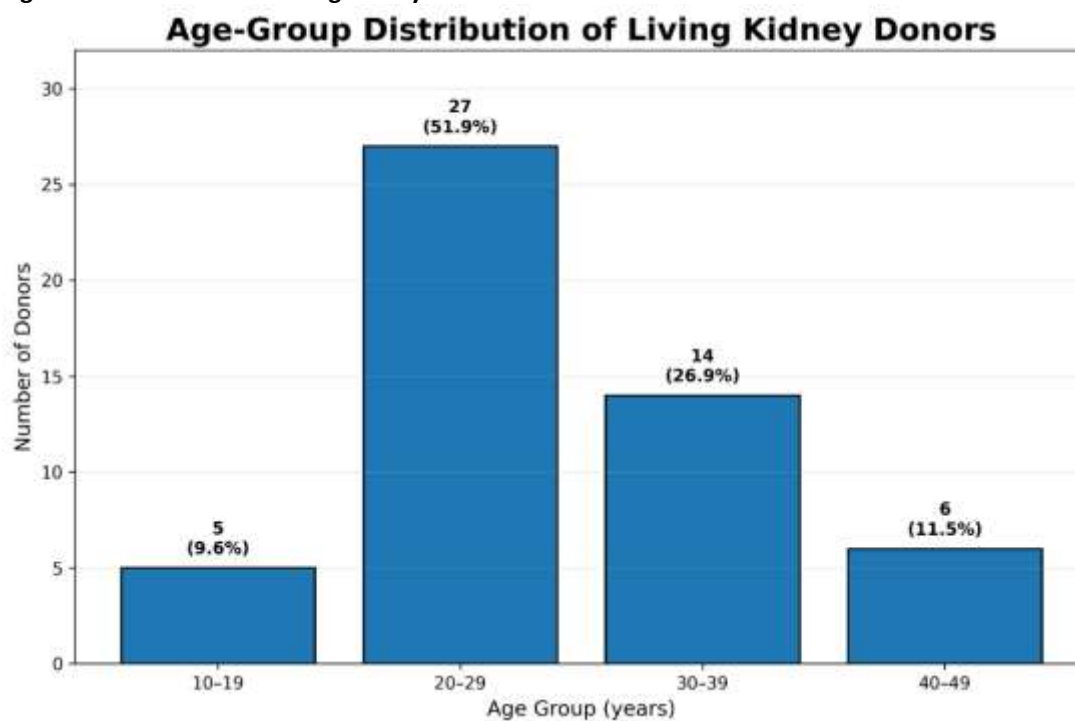


Fig 2: Age-Group Distribution of Living Kidney Donors

Blood group distribution showed that O positive was the most common (40.4%, n = 21), followed by B positive (19.2%, n = 10), A positive (17.3%, n = 9), O negative (11.5%, n = 6), A negative (7.7%, n = 4), and AB positive (3.8%, n = 2).

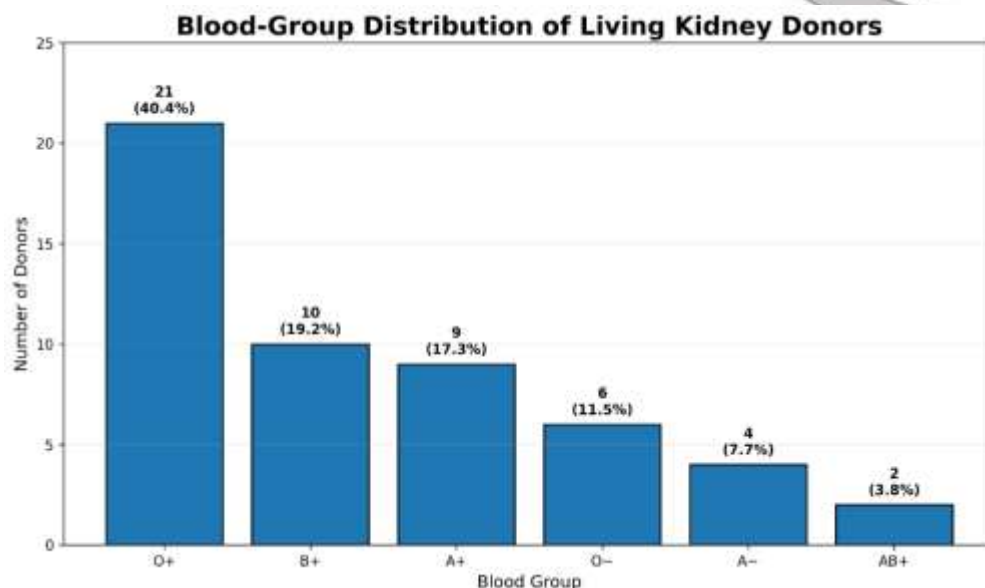


Fig 3: Blood-Group Distribution of Living Kidney Donors

Past medical history was negative in 98.1% (n = 51) of donors, with only one donor (1.9%) having a positive history (undiagnosed hypertension). Past surgical history was negative in 84.6% (n = 44) of donors, while 15.4% (n = 8) had a positive history of previous surgery.

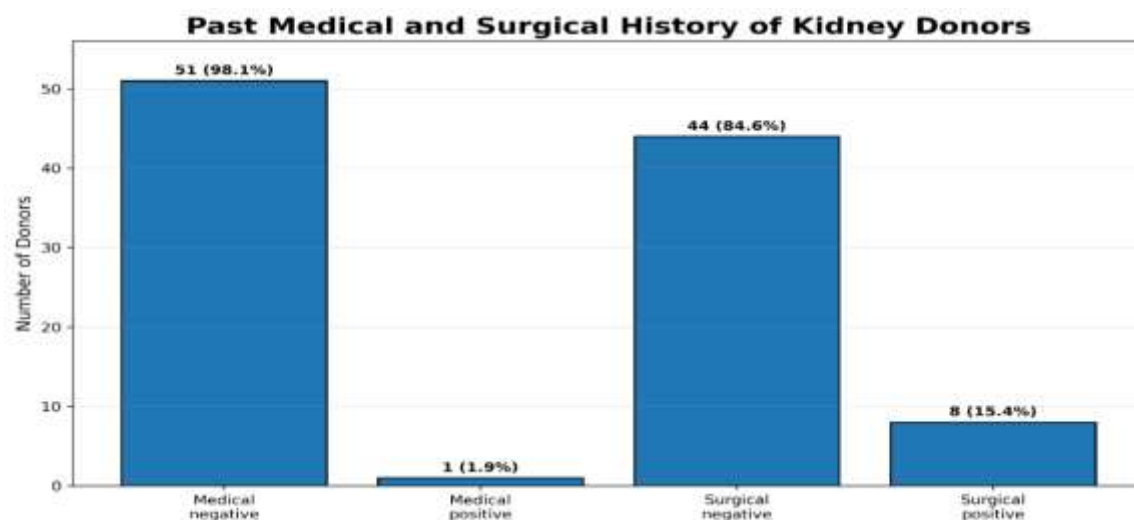


Fig 4: Past Medical and Surgical History of Kidney Donors

Demographic Characteristics of Recipients

The mean recipient age was 42.8 ± 14.2 years (range, 8–65 years). The majority of recipients were male (63.5%, n = 33), while 36.5% (n = 19) were female.

The most common age groups were 40–49 years (26.9%, n = 14) and 50–59 years (26.9%, n = 14), followed by 20–29 years (17.3%, n = 9), 30–39 years (11.5%, n = 6), 9–19 years (7.7%, n = 4), 60–69 years (7.7%, n = 4), and 1–9 years (1.9%, n = 1).

The majority of recipients had a history of hypertension (50.0%, n = 26), followed by diabetes mellitus (26.9%, n = 14), and ischemic heart disease (23.1%, n = 12).

All recipients had ESRD; glomerulonephritis was the most common underlying cause.

Past surgical history was negative in 46.2% (n = 24) of recipients, while 53.8% (n = 28) had a positive history of previous surgery.

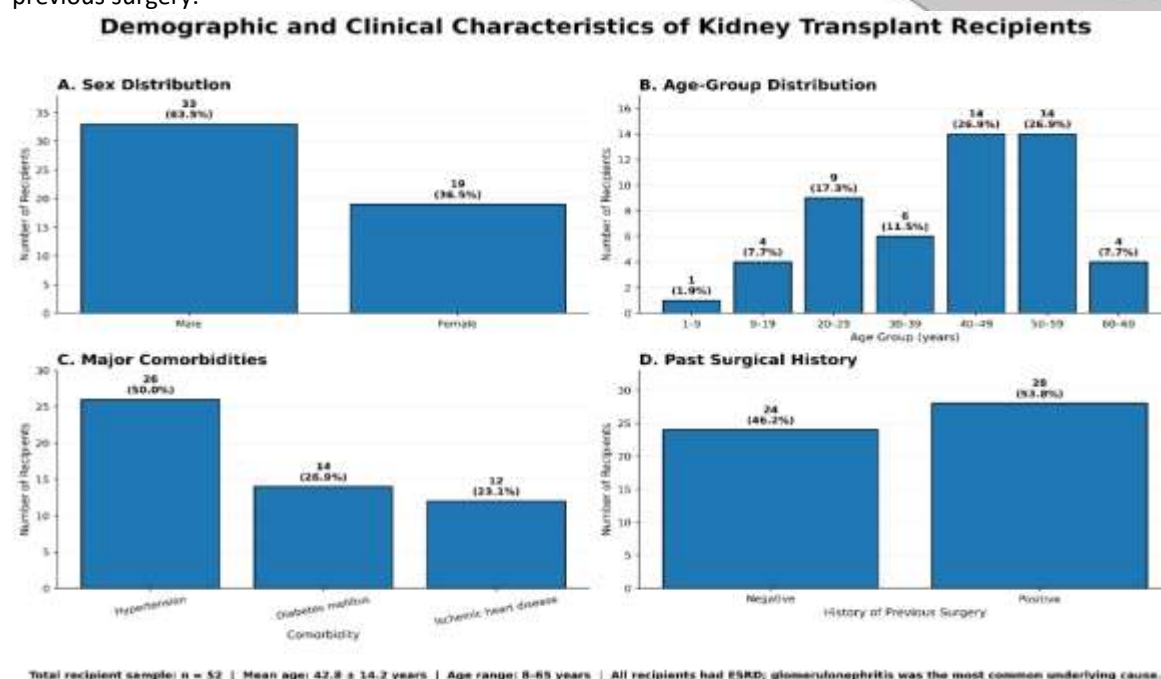


Fig 5: Demographic and Clinical Characteristics of Kidney Transplant Recipients Prevalence of Renal Vascular Variations

Arterial Variations

Multiple renal arteries were present in 40.4% (n = 21) of donors. Of these, 30.8% (n = 16) had unilateral multiple arteries and 9.6% (n = 5) had bilateral multiple arteries. Single renal arteries were present in 59.6% (n = 31) of donors. The distribution of arterial variations is summarized in Table 1.

Table 1: Distribution of Renal Arterial Variations

Arterial pattern	Frequency, n	Percentage, %
Single artery bilaterally	31	59.6
Unilateral multiple arteries	16	30.8
Bilateral multiple arteries	5	9.6
Total	52	100.0

Footnotes:

- Single artery = one renal artery to each kidney
- Unilateral multiple arteries = multiple arteries on one side
- Bilateral multiple arteries = multiple arteries on both sides

The most common type of accessory artery was the lower polar artery, followed by the upper polar artery and hilar artery. Early branching of the main renal artery was observed in 15.4% (n = 8) of donors. The origin of the main renal artery was most commonly at the L1–L2 vertebral level, consistent with normal anatomy.

Venous Variations

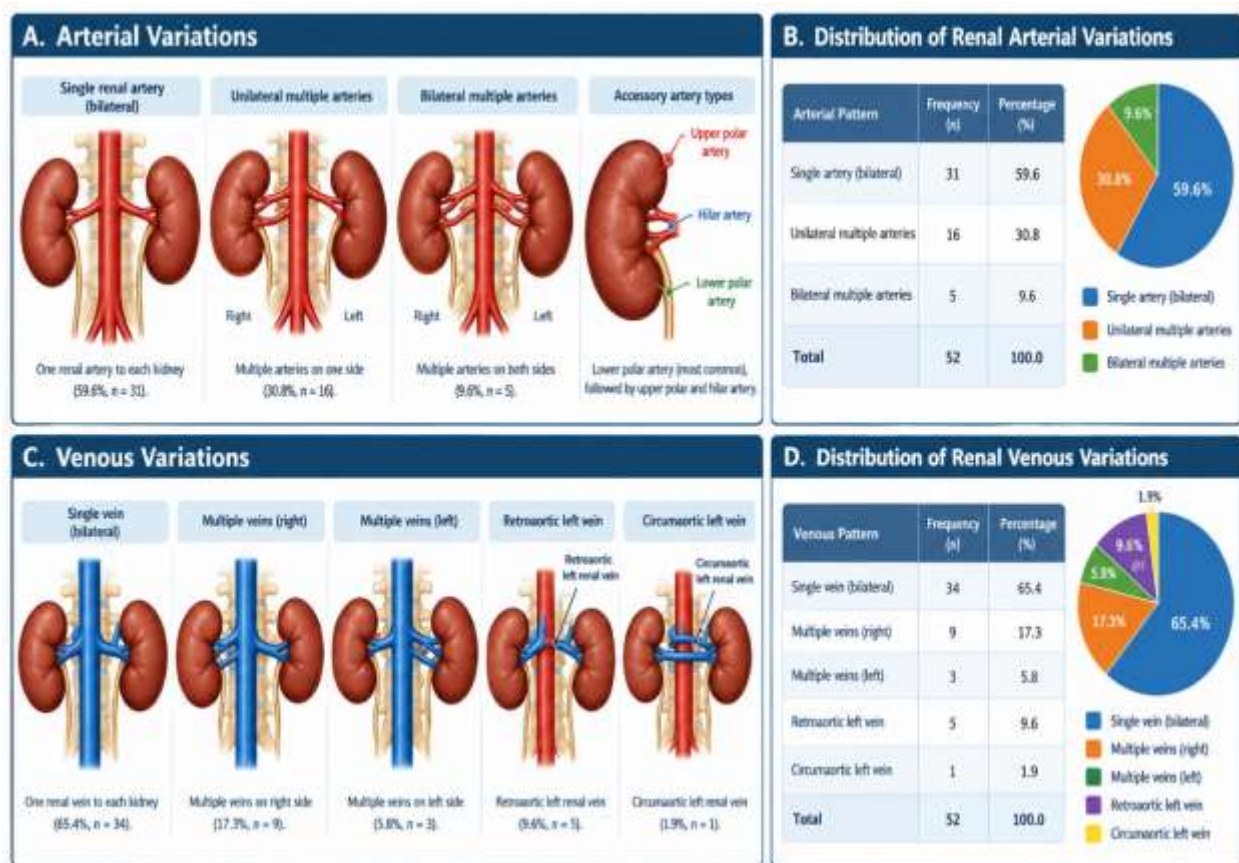
Multiple renal veins were present in 23.1% (n = 12) of donors. Of these, the majority were on the right side (75.0%, n = 9), while 25.0% (n = 3) were on the left side. Retroaortic left renal vein was present in 9.6% (n = 5) of donors, and circumaortic left renal vein was present in 1.9% (n = 1) of donors. The distribution of venous variations is summarized in Table 2.

Table 2: Distribution of Renal Venous Variations

Venous Pattern	Frequency (n)	Percentage (%)
Single vein (bilateral)	34	65.4
Multiple veins (right)	9	17.3
Multiple veins (left)	3	5.8
Retroaortic left vein	5	9.6
Circumaortic left vein	1	1.9
Total	52	100.0

Footnotes:

- Single vein = one renal vein to each kidney
- Multiple veins = more than one renal vein draining the kidney
- Retroaortic left vein = left renal vein passing posterior to the abdominal aorta
- Circumaortic left vein = presence of both anterior and posterior venous channels encircling the aorta

**Fig 6: Distribution of renal vasculature variation****Surgical Approach and Operative Details****Donor Surgery**

The left kidney was procured in 73.1% (n = 38) of donors, while the right kidney was procured in 26.9% (n = 14) of donors.

Kidney Procurement Side

Distribution of kidneys procured from donors (n = 52).



Fig 7: Kidney Procurement Side

The right kidney was selected when the left kidney had more complex vascular anatomy, such as multiple arteries, or when other anatomical considerations favored right-sided procurement.

The mean operative time for donor nephrectomy was 98.1 ± 13.9 minutes. Most donor procedures (98.1%, n = 51) were completed within 90–120 minutes, while one procedure (1.9%, n = 1) was completed in ≤ 90 minutes.

Donor Nephrectomy Operative Time

Distribution of donor nephrectomy procedures by operative-time category (n = 52).

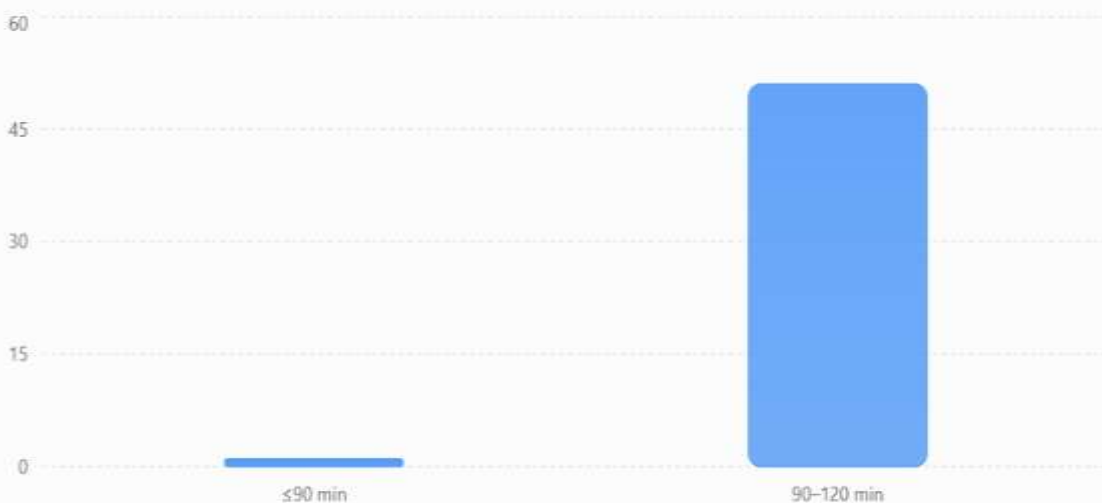


Fig 9: Donor Nephrectomy Operative Time

Recipient Surgery

The graft was placed in the right iliac fossa in 90.4% (n = 47) of recipients, while the left iliac fossa was used in 9.6% (n = 5) of recipients. The left iliac fossa was used in cases where the right side was not suitable due to previous surgery or anatomical considerations or due to being occupied by previous renal transplantation.

Recipient Graft Placement

Distribution of renal graft placement by iliac fossa (n = 52).



Fig 10: Recipient Graft Placement

The mean operative time for recipient surgery was 126.8 ± 38.7 minutes. The distribution of recipient operative time is summarized in Table 3.

Table 3: Distribution of Recipient Operative Time

Operative time	Frequency, n	Percentage, %
≤90 minutes	3	5.8
90–120 minutes	33	63.5
>120 minutes	16	30.8
Total	52	100.0

Recipient Operative Time

Distribution of recipient operations by operative-time category (n = 52).

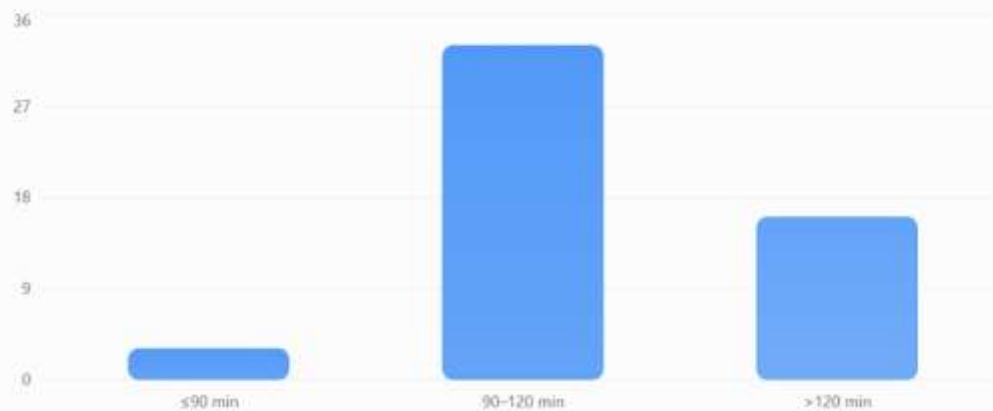


Fig 11: Recipient Operative Time

Vascular Anastomosis

Arterial Anastomosis: The arterial anastomosis was performed to the common iliac artery in 63.5% (n = 33) of recipients, while the internal iliac artery was used in 36.5% (n = 19) of recipients. The choice of anastomosis site was based on the surgeon's preference and the anatomical suitability of the vessels.

Venous Anastomosis: The venous anastomosis was performed to the external iliac vein in 3.8% (n = 2) of recipients, while the common iliac vein was used in 96.2% (n = 50) of recipients. The common iliac vein was preferred due to its larger caliber and easier accessibility.

Association Between Anatomical Variations and Operative Time

The relationship between donor arterial variations and operative time is summarized in Table 4.

Table 4: Association Between Arterial Variations and Operative Time

Arterial Pattern	Operative Time ≤90 min	Operative Time 90–120 min	Total
Single artery	1 (3.0%)	32 (97.0%)	33
Multiple arteries	0 (0.0%)	19 (100.0%)	19
Total	1 (1.9%)	51 (98.1%)	52

Footnote: Pearson Chi-Square = 0.587, p = 0.444

Chi-square test showed no statistically significant association between arterial variations and operative time (Pearson Chi-Square = 0.587, p = 0.444). Notably, all donors with multiple arteries had operative time between 90–120 minutes, suggesting a trend toward longer operative time in this group.

The relationship between donor venous variations and operative time was also analyzed. All donors with venous variations had operative time between 90–120 minutes. However, statistical analysis could not be performed because venous system was a constant in the analysis. See Table 5.

Table 5: Association Between Venous Variations and Operative Time

Venous Pattern	Operative Time ≤90 min	Operative Time 90–120 min	Total
Single vein	1 (2.9%)	33 (97.1%)	34
Multiple veins	0 (0.0%)	18 (100.0%)	18
Total	1 (1.9%)	51 (98.1%)	52

Footnote: Statistical analysis could not be performed because all donors with venous variations had operative time between 90–120 minutes.

Association Between Anatomical Variations and Complications

Chi-square test showed no statistically significant association between arterial variations and complications (Pearson Chi-Square = 0.064, p = 0.800). The correlation analysis also showed no significant correlation (Pearson's R = 0.035, p = 0.805).

For venous variations, all donors with venous variations had no bleeding complications. Statistical analysis could not be performed because venous system was a constant.

Association Between Anastomosis Type and Complications

Arterial Anastomosis: All recipients who received arterial anastomosis to the common iliac artery had no bleeding complications (100%, n = 33). Among recipients who received arterial anastomosis to the internal iliac artery, 15 (78.9%) had no bleeding and 4 (21.1%) had bleeding complications. However, statistical analysis could not be performed because arterial anastomosis was a constant.

Venous Anastomosis: Among recipients who received venous anastomosis to the external iliac vein, all (n = 2) had no bleeding complications. Among recipients who received venous anastomosis to the common iliac vein, 31 (62.0%) had no bleeding and 19 (38.0%) had bleeding complications. Chi-square test showed no statistically significant association (Pearson Chi-Square = 1.198, p = 0.274). The correlation analysis showed no significant correlation (Pearson's R = 0.152, p = 0.283).

Predictors of Operative Time and Complications

Linear Regression Analysis

Linear regression analysis was used to identify predictors of operative time. The results are summarized in Table 6.

Table 6: Linear Regression Analysis for Operative Time

Variable	Coefficient (β)	p-value
Multiple arteries	31.25	0.001
DSA Class II positive	48.75	<0.001
Recipient age >60 years	32.50	0.038
Surgery type (non-standard)	28.75	0.007

Multiple renal arteries were significantly associated with prolonged operative time ($\beta = 31.25$ minutes, $p = 0.001$). DSA Class II positivity was also significantly associated with prolonged operative time ($\beta = 48.75$ minutes, $p < 0.001$). Recipient age >60 years, non-standard surgery, and PRA Class II positivity were also significant predictors.

Logistic Regression Analysis

Logistic regression analysis was used to identify predictors of complications. The results are summarized in Table 7.

Table 7: Logistic Regression Analysis for Complications

Variable	Odds Ratio (OR)	95% CI	p-value
Multiple arteries	3.08	1.36–6.99	0.007
PRA Class II positive	4.40	1.58–12.26	0.004
DSA Class II positive	6.00	1.81–19.92	0.003
Operative time	1.03	1.00–1.05	0.023

Multiple renal arteries were significantly associated with increased risk of complications (OR = 3.08, $p = 0.007$). DSA Class II positivity was the strongest predictor of complications (OR = 6.00, $p = 0.003$). PRA Class II positivity and operative time were also significant predictors.

Recipient Outcomes

All recipients produced urine immediately after graft reperfusion, which was recorded as evidence of early graft function.

Donor Anatomical Complexity Score

Based on the results of the regression analyses, a Donor Anatomical Complexity Score was developed. The score assigns points based on the presence of specific anatomical variations and their contribution to surgical complexity. The score is summarized in Table 8.

Table 8: Donor Anatomical Complexity Score

Parameter	Score
Single artery and single vein	0
Multiple arteries, unilateral	1
Multiple arteries, bilateral	2
Multiple veins, unilateral	1
Multiple veins, bilateral	2
Retroaortic left renal vein	

Footnotes:

- Total score range: 0–7
- Scores of 0 = simple complexity

- Scores of 1–2 = moderate complexity
- Scores of ≥ 3 = high complexity

Scores of 0, 1–2, and ≥ 3 were classified as simple, moderate, and high anatomical complexity, respectively.

The Donor Anatomical Complexity Score was developed as an exploratory, study-specific framework based on the anatomical variables observed in this cohort. The assigned weights were not derived from an externally validated prediction model. Accordingly, the score should be considered hypothesis-generating and should not be interpreted as a validated measure of surgical risk until independently evaluated in larger cohorts.”

4. Discussion

Prevalence of Anatomical Variations

The prevalence of multiple renal arteries in this cohort was 40.4%, which is higher than the 18–30% range commonly reported in the literature [8,9]. Similar rates have been reported in other Middle Eastern populations, including Turkey (35.4%) and Iran (43.2%) [24,25]. Differences in population characteristics and imaging practices may contribute to this variation. Multiple renal veins were found in 23.1% of donors, which falls within the reported range of 15–30% [26,27].

Most venous variations in our cohort were on the right side (75.0%). This is consistent with previous reports describing a higher frequency of multiple renal veins on the right [28,29]. The difference has been related to the embryological development of the renal venous system [30].

Impact on Surgical Complexity

In this study, the presence of multiple renal arteries was associated with longer operative time ($\beta = 31.25$ minutes, $p = 0.001$) and a higher risk of intraoperative complications ($OR = 3.08$, $p = 0.007$).

This result is consistent with previous studies in which multiple renal arteries were associated with greater technical difficulty during donor nephrectomy and transplantation [31,32].

Kok et al. reported longer operation times in laparoscopic donor nephrectomy when multiple arteries were present (245 vs. 221 minutes, $p = 0.023$), together with increased blood loss [16]. Aremu et al. also reported an association between renal artery variations and longer operating times [31]. Our findings are broadly consistent with these observations.

The longer operative time is clinically understandable because multiple arteries may require additional reconstruction or anastomoses. In this cohort, the regression analysis showed a significant association between multiple arteries and operative time.

Impact on Recipient Outcomes

Despite the additional surgical complexity, we did not find a significant difference in short-term graft function between grafts with single and multiple renal arteries. This finding is consistent with previous reports showing that grafts with multiple arteries can achieve comparable outcomes when appropriate vascular reconstruction is used [35,36].

Roth et al. reported 5-year graft survival of 84.3% for kidneys requiring arterial reconstruction compared with 86.1% for those without reconstruction, with no significant difference ($p = 0.275$) [35]. Chedid et al. likewise found no significant difference in 5-year graft survival between single- and multiple-artery kidneys (83.5% vs. 82.6%, $p = 0.82$) [36]. Taken together, these findings suggest that the presence of multiple renal arteries does not, by itself, preclude successful transplantation.

Immunological Factors

DSA Class II positivity was associated with recipient complications in this cohort ($OR = 6.00$, $p = 0.003$). This finding highlights the importance of immunological assessment during transplant evaluation. Donor-specific antibodies have been recognized as an important risk factor for antibody-mediated rejection and subsequent graft injury or loss [37,38].

DSA Class II positivity was also associated with longer operative time ($\beta = 48.75$ minutes, $p < 0.001$). Because this association has not been extensively examined in relation to operative outcomes in living-donor renal transplantation, it should be interpreted cautiously and evaluated in larger prospective studies.

The Donor Anatomical Complexity Score

The Donor Anatomical Complexity Score was developed from the anatomical variables examined in this study. It assigns points according to the presence of selected anatomical variations and is intended to summarize the degree of anticipated surgical complexity. At this stage, the score should be regarded as a preliminary study-specific tool rather than a validated clinical prediction model.

1. Preoperative counseling of donors and recipients regarding surgical risks
2. Planning the surgical approach and anticipating the need for vascular reconstruction
3. Allocating surgical resources and expertise based on anticipated complexity
4. Standardizing reporting of anatomical complexity in future studies

Comparison with International Data

The overall findings are broadly comparable with published experience from other settings. Short-term graft function in this cohort was consistent with outcomes reported by Ali et al. from Baghdad [39], Al-Bazzaz et al. from Erbil [40], and data reported by the US Scientific Registry of Transplant Recipients [41].

The prevalence of multiple renal arteries in this cohort (40.4%) was higher than the 19.1% reported by Sagban et al. [42] and the 21.4% reported by Hassan et al. in a study of renal vascular anatomy conducted in Kuwait [43]. Differences in study populations, imaging protocols, sample sizes, and definitions of anatomical variation may contribute to the observed differences in prevalence.

Clinical Implications

The findings have several practical implications for donor and recipient assessment:

1. Preoperative CT Angiography: Because vascular variations were common in this cohort, CT angiography provides important information for operative planning and should be considered an important component of donor evaluation.
2. Surgical Planning: Donors with multiple renal arteries should be identified before surgery so that the operative approach and possible need for vascular reconstruction can be anticipated. Selection of the right or left kidney should take the vascular anatomy of both kidneys into account.
3. Vascular Reconstruction: Grafts with multiple arteries can be transplanted using appropriate reconstruction techniques. The choice among side-to-side anastomosis, end-to-side anastomosis, patch reconstruction, or other techniques depends on the individual vascular anatomy.
4. Immunological Assessment: The association observed between DSA Class II positivity and recipient complications supports careful immunological assessment as part of pre-transplant evaluation.
5. Risk Stratification: The Donor Anatomical Complexity Score may be useful for describing anatomical complexity and discussing anticipated operative difficulty, but it requires validation before it can be used as a clinical prediction tool.

Study Limitations

This study has several limitations.

First, the retrospective design and relatively small sample size limit the generalizability of the findings. Second, the study was conducted at two centers, so the results may not apply to centers with different surgical expertise or perioperative protocols. Both participating centers have more than 20 years of experience in renal transplantation, which may also limit how directly these findings can be applied to less experienced programs. Third, the follow-up period was relatively short, so long-term graft and patient outcomes could not be assessed. Fourth, the absence of a control group limits the ability to draw causal conclusions from the observed associations. Despite these limitations, the study provides local data on the frequency of renal vascular variations and their association with operative findings in living-donor renal transplantation. The results can serve as a basis for further prospective work with larger samples and longer follow-up.

Conclusion

In this cohort, donor anatomical variations were common, particularly multiple renal arteries, and their presence was associated with greater surgical complexity. Multiple renal arteries were associated with longer operative time ($p = 0.001$) and a higher risk of intraoperative complications ($p = 0.007$). Despite this, no clear adverse effect on short-term graft outcomes was identified. DSA Class II positivity was associated with recipient complications ($OR = 6.00$, $p = 0.003$), supporting the role of immunological assessment in pre-transplant planning. The Donor Anatomical Complexity Score provides a preliminary way of summarizing anatomical complexity, but it requires validation in larger and independent cohorts before clinical use. Preoperative CT angiography provides important information about renal vascular anatomy and can assist with operative planning. Prospective studies with larger samples and longer follow-up are needed to confirm these associations and to determine whether the proposed complexity score has predictive value.

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