**Seasonal patterns of living kidney donation in the United States from 1995 to 2023**

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Abbreviations: Living kidney donor (LKD)

End-stage renal disease (ESRD)

ABSTRACT

Living kidney donation in the United States has declined over the past two decades, with variations based on the donor-recipient relationship. The reasons for this decline remain unclear. We investigated seasonal patterns in living kidney donation to explore potential modifiable factors, prompted by a study on seasonal variations in kidney transplantation, focusing on living donors for timely transplant. Using donor-registry data from 1995 to 2023, analyzed through Poisson regression, we found a consistent summer surge in donations during June, July, and August, across all decades (1980-2020). The increase was 14%-23% for biologically related donors and 10%-20% for unrelated donors. This surge was statistically significant in some groups (IRR range for related donors: 1.08-1.33; IRR for unrelated donors: 1.07-1.25). Notably, this pattern was observed across all income tertiles and regardless of donor-recipient relationship. Our findings suggest that seasonal variations play a partial role in shaping living kidney donation trends, pointing to underlying structural factors that could be addressed to enhance donation rates. This knowledge can inform interventions to improve living kidney donation rates and benefit patients in need of timely transplantation and with little luxury to wait for the summer.

INTRODUCTION

The historical analysis of living kidney donation in the United States has primarily focused on annual trends, depicting exponential growth from 1987 to 2004, partly attributed to the adoption of laparoscopic donor nephrectomy after 1995 (1). Subsequently, a plateau and decline in donation occurred from 2005 to 2017, with no identified cause for the annual decrease (2). Notably, the decline was most pronounced among biologically related donors. However, a positive shift in live kidney donation emerged between 2017 and 2019, representing the first "sustained" increase in 15 years, mainly driven by unrelated donors (3).

Concurrently, seasonal trends have been observed, showing fluctuations in kidney transplants during the summer months (June, July, and August). However, these patterns have not been specifically studied in the context of living donation (4). Recognizing the role of seasonal trends alongside annual trends could provide a more comprehensive understanding of donation dynamics beyond the well-documented exponential growth phase. Identifying persistent barriers year after year could aid in further investigation and design solutions to facilitate timely transplants for vulnerable patients on the kidney transplant waitlist.

Motivated by the notion that social-structural barriers may impact living kidney donation (Purnell PMID PMID: [22732044](https://pubmed.ncbi.nlm.nih.gov/22732044), 2012), we specifically examine household income as a potential factor influencing the observed patterns. By delving into the differences in seasonal trends between donors from lower and higher income households, we aim to shed light on how socioeconomic factors may play a role in shaping living kidney donation patterns. In this study, we explore whether seasonal fluctuations in donation during fall, winter, spring, and summer months can better explain recent changes in living kidney donation compared to the traditional assessment of annual trends. Utilizing linear mixed models, we formally test whether seasonal variations better elucidate recent donation trends and investigate potential differences in seasonal patterns between donors from lower and higher income households.

METHODS

**Study Population**

Data for this study was obtained from the Scientific Registry of Transplant Recipients (SRTR), which contains information on all living kidney donors, wait-listed candidates, and transplant recipients in the United States. The SRTR data is submitted by members of the Organ Procurement and Transplantation Network (OPTN), overseen by the Health Resources and Services Administration (HRSA), U.S. Department of Health and Human Services (5). A total of 174,024 adult living kidney donors between October 1, 1987, and March 2, 2023, were included in the analysis.

**Trends in Living Kidney Donation**

The donor population was divided into related and unrelated groups due to differences in demographics and historical trends (2, 3). Paired donors were excluded from the study due to their small sample size (N=10,645). Donors were further categorized into income tertiles based on the median household income associated with their home zip code, as reported by the 2021 American Community Survey (6). To understand historical trends, donors were grouped by decade of donation. The primary outcome of interest was the change in live kidney donation per month (within-year variation) as contrasted with the change in donation per year (between-year variation).

To assess the contributions of within-year and between-year variation to changes in living kidney donation, a linear mixed-effects model was utilized for the number of donors per month and year. The model's coefficients for between-year variation (τ) and within-year variation (σ) were used to calculate the intraclass correlation (ICC) using the formula: τ2 / (τ2 + σ2). Separate calculations were performed for trends before and after 2005 due to previously observed differences.

**Within-Year Seasonal Variation in Living Kidney Donors**

To estimate the change in the number of donors between months, Poisson regression was employed, resulting in the calculation of the incidence rate ratio (IRR). The IRR reflects the proportional decline or increase in the number of donors compared to January, which served as the reference month. Additionally, IRRs were estimated for different seasons (Spring, Summer, Fall, Winter) to identify trends throughout the year. To adjust for varying month lengths, case numbers were normalized based on the number of days in each month, using the formula: (Number of cases) / (Number of days in that month) x (Average number of days in a month, 365.25/12)(4).

Statistical Analysis

All analyses were conducted using RStudio Version 1.3.959 for Windows, running R 4.0.2. Hypothesis tests were two-sided, with a significance level α = 0.05.

RESULTS

**Study Population**

The study included a total of 174,024 living kidney donors from the Scientific Registry of Transplant Recipients (SRTR). The characteristics of donors remained consistent across the seasons of donation but varied between related and unrelated donors. Among related donors (65% of total donors), the median age at donation was 38 years, with 57% being female, 69% white, 15% Black, and 16% Hispanic. Most donors (83%) were younger than 50 years, and 17% were older than 50. Diabetes was rare, but 1.5% had hypertension. Median systolic/diastolic blood pressure was 120/74 mm Hg, and the median body mass index was 27 kg/m2. Approximately 24% had a history of smoking, 17% graduated from college, and 7% had postgraduate education. In terms of income tertiles, 32% of donors were in the highest income category ($84,220 and over), 33% were in the middle category ($60,599-$84,220), and 36% in the lowest category (below $60,599) Their median year of donation was 2005.

Unrelated donors (35% of total donors) tended to be older, with a median age at donation was 44 years. Of the unrelated donors, 64% were female, 82% white, 7% Black, and 10% Hispanic. A higher proportion of unrelated donors (70%) were younger than 50 years, with 30% being older than 50 years. Similar to related donors, diabetes was rare, but 3% had hypertension. Median systolic/diastolic blood pressure was 120/74 mm Hg, and the median body mass index was 27 kg/m2. Around 24% had a history of smoking, 25% graduated from college, and 13% had postgraduate education. In terms of tertiles, 37% of unrelated donors were in the highest income category (over $84,220), 33% in the middle category ($60,599-$84,220), and 30% in the lowest category (under $60,599). Unrelated donors were more recent, with a median year of donation of 2011 (Table 1).

**Trends in Living Kidney Donation**

Over the study period, kidney donations displayed a monotonically increasing trend from 1987 to 2004, followed by a decline from 2005 to 2017. A resurgence in donations occurred from 2017-2019, but since the COVID-19 pandemic, donation levels have stagnated. Notably, within-year seasonal variance increased after 2004 (Figure 1). Between-year variance prior to 2005 was 157 donations per month, and within-year variance was 42 donations per month, resulting in a high intraclass correlation (ICC) of 0.93. However, from 2005 onward, between-year variance was 32 donations per month, while within-year variance increased to 52 donations per month, leading to a lower ICC of 0.19.

Similar patterns were observed when analyzing related and unrelated donors separately. For related donors, ICC was 0.93 prior to 2005 and 0.33 thereafter, with intra-year variation increasing by 27% from 45 to 57. For unrelated donors, ICC was 0.92 prior to 2005 and 0.26 thereafter. Intra-year variation increasing by 21% from 48 to 58 between these time periods.

**Within-Year Seasonal Variation in Living Kidney Donors**

Monthly trends in kidney donation showed higher rates during the summer months, particularly in June and July, across all subgroups. This seasonal pattern has remained stable historically (Figure 2). Incidence rate ratios (IRRs) compared to January were calculated for each month. For related donors, IRRs in the highest income tertile ranged from 1.06 to 1.33, in the middle tertile from 1.01 to 1.25, and in the lowest tertile from 1.00 to 1.24. For unrelated donors, IRRs in the highest income tertile ranged from 1.00 to 1.17, in the middle tertile from 1.01 to 1.25, and in the lowest tertile from 1.03 to 1.24. Statistically significant IRRs were observed for all income tertiles in June and July, as well as for the top income tertile in August. (Figures 3A, 3B).

**Between-Year Seasonal Variation in Living Kidney Donors**

Between-year trends varied between related and unrelated groups, with additional interactions with income group. For related donors, trends were uniformly positive until 2004 and uniformly negative from 2005 to 2022 (Supplemental Figure 1A). For unrelated donors, slopes were uniformly positive in both winter and summer for all income groups from 1996 to 2004 (Supplemental Figure 1B). However, post-2004 the dynamics for unrelated donors became more complex, with varying slopes by season and income group. The largest seasonal gap in absolute donation numbers for all group occurred in the post-2020 period (Supplemental Figure 1B, Supplemental Table 1).

DISCUSSION

This national study on trends in living kidney donation revealed significant effects of seasonal variation over time. The interclass correlation coefficient (ICC) for seasonal donations decreased from 0.93 before 2005 to 0.19 thereafter, indicating reduced between-year variation and increased within-year variation. Notably, these changes were more pronounced in related donors. The study also found that living kidney donations consistently showed 14-23% higher numbers in summer months for related donors and 10-20% higher numbers for unrelated donors across all decades of living kidney donation.

In the study, a high inter-class correlation between years versus within years (between seasons) signifies the influence of social and structural factors on donation patterns over time. The consistent trends in donation rates from 1987 to 2005 were affected by long-term clinical dynamics due to the emergence of laparoscopic nephrectomy. Conversely, the high correlation within years (between seasons from 2005-2023) highlights the importance of short-term factors like holidays, weather, and cultural practices in kidney donation rates. Understanding these variations can aid in targeted interventions to address season-specific challenges and promote a stable and equitable living kidney donation system year-round, given the high mortality rate among US dialysis patients awaiting kidney transplantation (7, 8).

While this study reaffirms our previous findings of a decline in related donors and a slight increase in unrelated 2005 to 2017 (2, 3), it also introduces seasonal variation as a standalone phenomenon and a modifier of historical trends in kidney donation. The study suggests that within-year seasonal variation in donation may reflects barriers that all potential donors, regardless of their relationship to the recipient, with such barriers being less significant during the summer months. We further suggest that these barriers might relate to work-school calendars that allow much more freedoms to a potential donor candidate in the summer months than in the non-summer months.

The study acknowledges certain limitations, including the use of zip code data to approximate donor socioeconomic status, which may not fully capture individual-level characteristics. But this only means that we may underestimate the individual differences reported. Additionally, due to limited statistical power, the analysis could not be stratified by all potential factors influencing donation. Nevertheless, the study’s strength lies in its national-level identification of a novel category of barriers that may impact potential donors, particularly during non-summer months and perhaps in times of financial crises.

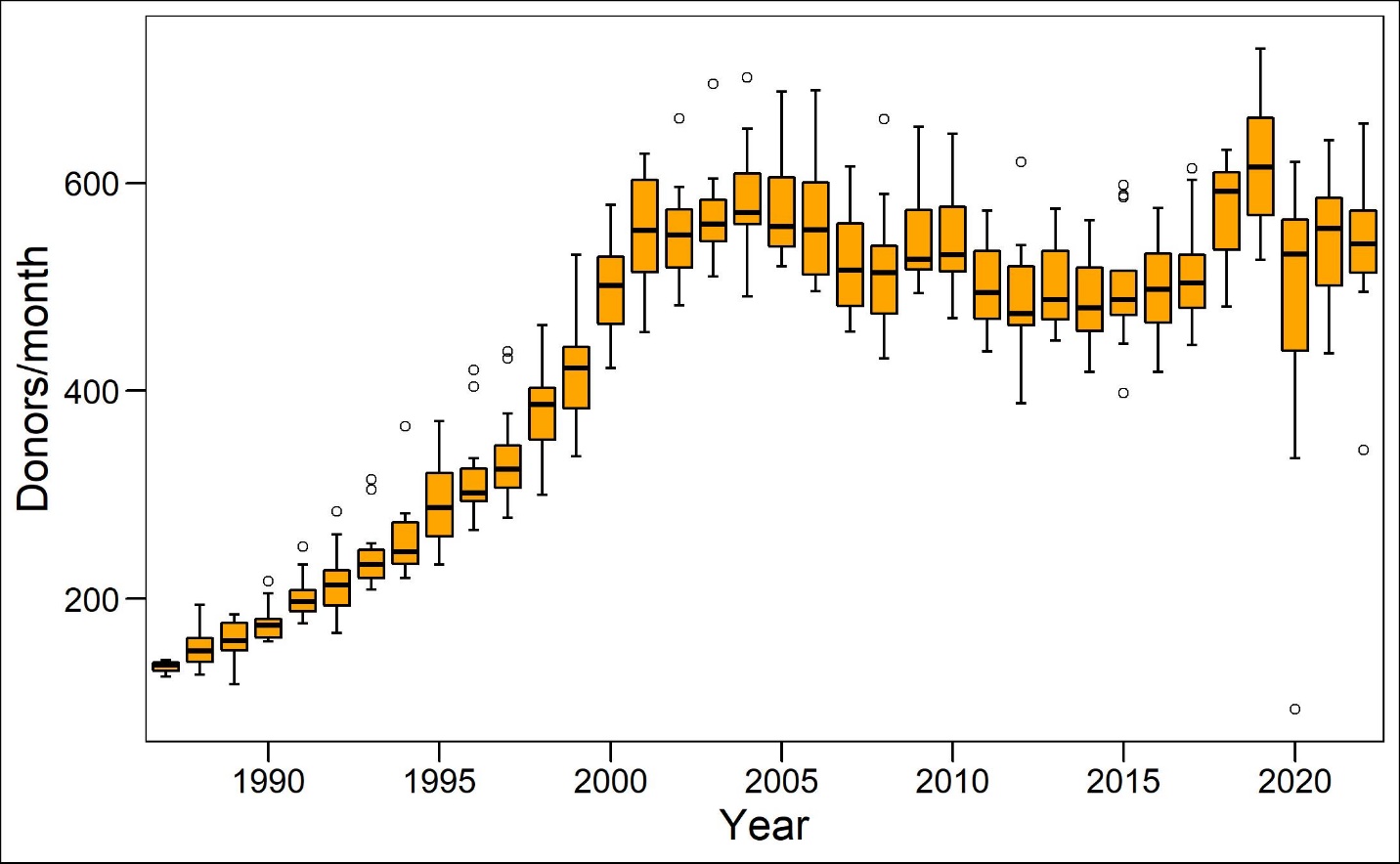
In conclusion, the study suggests that seasonal variation in living kidney donation rates among lower-income individuals may be influenced by indirect costs related to donation, affecting work and school schedules. Timely kidney transplantation remains crucial for those with end-stage renal disease on dialysis, making **season-independent transplant** an important issue. Further research is required to comprehend specific structural barriers and develop targeted policy recommendations to address these disincentives for living kidney donation. Overall, this study provides valuable insights into the complex dynamics of living kidney donation trends, offering potential areas for intervention to improve donation rates.

Table 1. Characteristics of live kidney donors in the United States from 1987-2023.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Related donor | | Unrelated | |
|  | Summer | Non-Summer | Summer | Non-Summer |
|  | (N=31,775) | (N=81,260) | (N=16,554) | (N=44,435) |
| Age, Median [IQR] | 38 [30-47] | 38 [30-47] | 44 [35-52] | 44 [35-52] |
| Age Range, % |  |  |  |  |
| 18-39 | 57.2 | 56.8 | 39.3 | 39.8 |
| 40-49 | 26.4 | 25.9 | 31.1 | 30.4 |
| 50+ | 16.4 | 17.3 | 29.6 | 29.9 |
| Recipient Age, Median [IQR] | 41 [27-55] | 43 [29-56] | 49 [39-58] | 49 [39-58] |
| Year of Donation, Median [IQR] | 2005 [1998-2012] | 2005 [1998-2012] | 2011 [2005-2017] | 2011 [2005-2017] |
| Female, % | 59.1 | 56.6 | 65.3 | 63.8 |
| Blood Pressure, mmHg [IQR] |  |  |  |  |
| SBP | 120 [111-130] | 120 [112-130] | 120 [112-130] | 120 [112-130] |
| DBP | 74 [68-80] | 74 [68-80] | 74 [68-80] | 74 [68-80] |
| BMI, Median [IQR] | 27 [24-30] | 27 [24-30] | 27 [24-30] | 26 [24-30] |
| Hypertension, % | 1.5 | 1.5 | 3.1 | 3 |
| Diabetes, % | 0.02 | 0.02 | 0.04 | 0.03 |
| Smoke, % | 23.4 | 24.9 | 23.4 | 24.3 |
| Race, % |  |  |  |  |
| Black | 14.6 | 14.4 | 7.5 | 7.3 |
| Hispanic | 15.8 | 15.9 | 10.2 | 10 |
| White | 69.6 | 69.7 | 82.3 | 82.8 |
| Income Tertile, % |  |  |  |  |
| 1st ($84,220+) | 32 | 31.4 | 36.2 | 36.8 |
| 2nd ($60,599-$84,220) | 32.6 | 32.9 | 33.7 | 33.4 |
| 3rd ($0-$60,599) | 35.3 | 35.7 | 30.2 | 29.8 |
| Highest Education Level, % |  |  |  |  |
| ≤ High School | 18.3 | 19.5 | 20.4 | 20.9 |
| Attended College | 15.9 | 16.1 | 20.9 | 21.2 |
| College Graduate | 17 | 16.7 | 25.1 | 25.2 |
| Not reported | 41.9 | 41.1 | 19.6 | 20.1 |
| Post College | 6.9 | 6.6 | 14 | 12.5 |

Abbreviations: IQR: interquartile range; mmHg: millimeters of mercury; SBP, systolic blood pressure; DBP: diastolic blood pressure; BMI: body mass index; HS: high school.

Hypertension was defined as predonation documented use of antihypertensive therapy/history of hypertension (% missing)

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**Figure 1.**  Monthly number of living kidney donation across time. Boxplots reflect the distribution of donations for the 12 months of each year. Bold line reflects the median, shaded box the interquartile range, and the tails 1.5 IQRs from the median, with outliers displayed as circles. Based on the median of each year, between-year donations increased exponentially from 1987-2004, declined from 2004-2016, surged from 2017-2019, and stagnated from 2020-2022. However, based on the interquartile range, month-to-month variation in donation substantially increased over time. The interclass-correlation coefficient comparing between-year vs. within-year variation decreased from 0.93 in the period 1987-2004 to 0.19 in the period 2005-2023.

**A graph of different colored lines

Description automatically generated**

**Figure 2.** Average living kidney donations per month by decade for related and unrelated donors. Each data point reflects the mean number of donations in the month over the years of the labelled time period. Summer donations for related donors were 49 donations per month (23%) higher than non-summer donations prior to 2000, 54 (16%) higher in the 2000s, 34 (14%) higher in the 2010s, and 38 (20%) higher in the 2020’s. For unrelated donors these numbers were 6 donations per month (19%) higher prior to 2000, 17 (10%) higher in the 2000s, 22 (11%) higher in the 2010s, and 42 (20%) higher in the 2020’s.

A graph showing the amount of income per month

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**Figure 3A**. Incidence rate ratio of living kidney donation by biological relatives based on month of donation. The dot reflects the IRR relative to January and error bars represent the 95% confidence interval. Orange reflects the highest income tertile ($84,220+), green the middle tertile ($60,599-$84,220), and blue the lowest tertile (<$60,599).

A graph showing the number of income levels

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**Figure 3B**. Incidence rate ratio of living kidney donation by nonrelatives based on month of donation. The dot reflects the IRR relative to January and error bars represent the 95% confidence interval. Orange reflects the highest income tertile ($84,220+), green the middle tertile ($60,599-$84,220), and blue the lowest tertile (<$60,599).

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SUPPLEMENTAL FIGURES

Figure S1A. Related DonorsA graph of different seasons

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**Supplemental Figure 1A.** Living kidney donations per month by season in all three income groups for related donors. Each data point reflects the number of donations each season of the given year (December donations are included in winter of the following year). Trends are displayed using local polynomial regression (loess curve).

Figure S1B. Unrelated Donors

A graph showing different seasons

Description automatically generated

**Supplemental Figure 1B.** Living kidney donations per month by season in all three income groups for unrelated donors. Each data point reflects the number of donations each season of the given year (December donations are included in winter of the following year). Trends are displayed using local polynomial regression (loess curve).

**Table S1.** Rates of change in living kidney donations during different time periods. Rates of change for related and unrelated donors during each time period were computed via linear regression.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Related** | | | | **Unrelated** | | | |
|  | **Pre-2005** | **2005-2017** | **2017-2019** | **Post-2020** | **Pre-2005** | **2005-2017** | **2017-2019** | **Post-2020** |
| 1st Tertile |  |  |  |  |  |  |  |  |
| Winter | 21.77 | -6.91 | 7.5 | -18 | 12.74 | 3.08 | 31 | -53 |
| Summer | 28.41 | -9.49 | 3 | -5.5 | 14.08 | 3.58 | 51.5 | -27.5 |
| 2nd Tertile |  |  |  |  |  |  |  |  |
| Winter | 24.66 | -11.59 | 10.5 | -13 | 11.72 | 2.28 | 44 | -33 |
| Summer | 30.21 | -12.28 | -6 | -10 | 14.36 | 0.54 | 26 | 2 |
| 3rd Tertile |  |  |  |  |  |  |  |  |
| Winter | 28.92 | -15.73 | -9 | -43 | 12.89 | -2.45 | 16 | -34 |
| Summer | 34.3 | -18.46 | 3.5 | -4 | 13.16 | -2.92 | 10.5 | 8 |