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Int J Organ Transplant Med 2025; 16(2), 18–23

Donor–Recipient Relationship and Donor Educational Attainment in Living Liver Donation in the United States

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ABSTRACT

Living donor liver transplantation expands access to transplant and may reduce waitlist mortality among patients with end-stage liver disease, yet its use remains limited and unevenly distributed across donor subgroups. While prior national work has shown that living liver donation varies by donor–recipient relationship and demographic characteristics, the role of donor educational attainment in shaping these trends remains insufficiently studied. We examined whether growth in living liver donation in the United States from 2012 to 2022 differed jointly by donor–recipient relationship and donor educational attainment. We conducted a national registry study of living liver donors in the United States between January 1, 2012 and December 31, 2022 using Scientific Registry of Transplant Recipients data. The primary outcome was change in the annual number of living liver donors over time. Donors were stratified by donor–recipient relationship (biologically related versus unrelated), educational attainment (high school or less, technical school, bachelor's/associate degree, and graduate degree), and age (< 40 versus ≥ 40 years). Negative binomial regression was used to estimate the incidence rate ratio for change in donor counts per 3-year increment. A total of 4,122 living liver donors were identified during the study period, including 2,845 biologically related donors and 1,277 unrelated donors. Growth in living liver donation was uneven across educational strata. Among biologically related donors, the greatest increase was observed in donors with graduate education (IRR 1.44, 95% CI 1.31–1.58), whereas among unrelated donors, the strongest rise also occurred in donors with graduate education (IRR 1.52, 95% CI 1.38–1.67). Lower-education donor groups demonstrated the smallest increase over time, with IRRs ranging from 1.00 to 1.15, compared with 1.31 to 1.62 in higher-education strata. Age-stratified analyses showed that the largest increase occurred among unrelated donors aged < 40 years in the graduate education group (IRR 1.62, 95% CI 1.45–1.81). Living liver donation in the United States increased over the past decade, but the increase was concentrated in donor subgroups with higher educational attainment, especially among unrelated donors. These findings identify unequal growth in completed donation across donor subgroups, but they do not establish the mechanisms responsible for that pattern. Additional studies incorporating donor evaluation pathways, socioeconomic measures, and center- or region-level data are needed to clarify the processes underlying these differences.

KEYWORDS: living liver donation; educational attainment; donor–recipient relationship; registry study; negative binomial regression; health equity

1 Introduction

Living donor liver transplantation remains an important strategy for increasing transplant access among patients with end-stage liver disease. Compared with continued waiting for a deceased donor organ, living donor transplantation has been associated with favorable recipient outcomes in adult transplantation [1]. Living donor liver

transplantation has also demonstrated survival benefit in the Model for End-stage Liver Disease allocation era [2]. Despite these advantages, living donor liver transplantation remains underutilized in the United States [3]. National analyses have also shown substantial center-level variation in adult living donor liver transplantation, suggesting that opportunities for expansion remain unevenly distributed across programs [4].

Previous national work has documented racial and ethnic disparities in access to and utilization of living donor liver transplantation [5]. Donation is shaped not only by clinical suitability and interpersonal motivation but also by the social and financial consequences experienced by living donors [6]. Meeting-level consensus work has further highlighted financial, policy, and ethical barriers to broader expansion of living donor liver transplant programs [7]. These considerations indicate that the ability to navigate donor evaluation may be influenced by structural and informational factors in addition to medical eligibility.

Educational attainment may therefore represent a meaningful but understudied dimension of inequity in living liver donation. Individuals with higher educational attainment may be better positioned to understand complex medical information, communicate within healthcare systems, complete administrative tasks, and manage the logistical and financial burdens associated with donor evaluation. Conversely, individuals with lower educational attainment may face greater friction in progressing from donor interest to completed donation, even when motivation is strong. These barriers may be particularly pronounced among unrelated donors, for whom the social impetus to persist through evaluation may be weaker than in biologically related family networks.

Accordingly, this study examined the interplay of donor–recipient relationship and donor educational attainment in living liver donation in the United States from 2012 through 2022. We used a national registry and a stratified count-regression framework to quantify temporal changes in donation across joint strata of donor relationship, education, and age. We hypothesized that the strongest growth would occur among unrelated donors with higher educational attainment, whereas lower-education groups would demonstrate less pronounced increases over time. By identifying donor subgroups with limited growth, the study aims to inform targeted future investigation on equity in living donor liver transplantation.

2 Methods

2.1 Data Source and Study Population

We performed a retrospective registry-based study using data from the Scientific Registry of Transplant Recipients (SRTR), which captures donor, candidate, and recipient information for all transplant activity in the United States. The study population included all living liver donors between January 1, 2012 and December 31, 2022. Donors with missing donation year were excluded. Additional exclusions applied to donors with missing educational attainment, missing donor–recipient relationship, or missing age, as detailed in the analytic cohort derivation below.

Because this study used deidentified registry data, it was exempt from institutional review board review or qualified for non-human-subjects determination according to local institutional policy.

2.2 Study Variables

The primary analytic framework was based on donor–recipient relationship and donor educational attainment. Donor–recipient relationship was categorized as biologically related or unrelated. Educational attainment was categorized into four groups: high school or less, technical school, bachelor's/associate degree, and graduate degree.

Donor age was categorized as < 40 years and ≥ 40 years to distinguish younger and older donor subgroups and to preserve consistency with prior trend-based analyses of living donation. Additional descriptive variables included sex, body mass index, and insurance status.

2.3 Outcome

The primary outcome was the change in the annual number of living liver donors over time. Annual donor counts were aggregated within strata defined by donor–recipient relationship, educational attainment, and age category. The primary estimand was the incidence rate ratio (IRR) representing proportional change in donor counts per 3-year increment.

2.4 Statistical Analysis

Continuous variables were summarized using medians and interquartile ranges, whereas categorical variables were described using counts and percentages. Baseline donor characteristics were summarized across donor–recipient relationship and educational attainment strata.

To model temporal change in donor counts, we used negative binomial regression. This approach was selected to account for overdispersion in annual donor counts and to improve stability in subgroups with relatively small numbers.

Let $Y_{s,t}$ denote the number of donors in subgroup s during calendar year t. The negative binomial model was specified as

$$Y_{s,t} \sim \mathrm{NB}(\mu_{s,t}, \theta_s), \tag{1}$$

with mean structure

$$\log(\mu_{s,t}) = \beta_{0s} + \beta_{1s} t. \tag{2}$$

To express temporal change on a 3-year scale, the incidence rate ratio for subgroup s was computed as

$$\mathrm{IRR}_s = \exp(3\beta_{1s}). \tag{3}$$

An $\mathrm{IRR}_s > 1$ indicated an increase in donor counts over time, whereas an $\mathrm{IRR}_s < 1$ indicated a decline.

Primary models were fitted separately within strata of donor–recipient relationship, educational attainment, and age. Two-sided $p < 0.05$ was considered statistically significant. All analyses were performed using R version 4.3.1. No center-level or region-stratified analyses were performed in the present study.

2.5 Analytic Cohort Derivation

From the initial SRTR living donor file (January 1, 2012 to December 31, 2022), we identified 4,612 potential living liver donors. After excluding donors with missing donation year ($n = 47$), missing educational attainment ($n = 312$), missing donor–recipient relationship ($n = 89$), or missing age ($n = 42$), the final analytic cohort comprised 4,122 donors (89.4% of the initial sample). Missingness did not differ significantly over time or across donor subgroups (p for trend = 0.34).

3 Results

3.1 Study Population

A total of 4,122 living liver donors were identified between 2012 and 2022. Of these, 2,845 (69.0%) were biologically related to the recipient and 1,277 (31.0%) were unrelated donors. The median age of donors was 38 years (interquartile range 30–46), and 52.3% were female. Baseline characteristics of the study cohort stratified by donor–recipient relationship and educational attainment are presented in Table 1.

Table 1. Baseline characteristics of living liver donors between 2012 and 2022, stratified by donor–recipient relationship and educational attainment.

Characteristic	Biologically related				Unrelated			
	HS or less	Technical	Bachelor/Assoc	Graduate	HS or less	Technical	Bachelor/Assoc	Graduate
Number of donors, *n*	685	521	1030	609	163	198	494	422
Age, median (IQR)	41 (33–49)	39 (31–47)	37 (29–45)	36 (28–44)	39 (31–48)	37 (29–46)	34 (27–43)	33 (26–41)
Female sex, *n* (%)	378 (55.2)	281 (53.9)	567 (55.0)	335 (55.0)	88 (54.0)	105 (53.0)	267 (54.0)	228 (54.0)
BMI, median (IQR)	26.4 (23.1–30.2)	26.1 (22.9–29.8)	25.7 (22.5–29.4)	25.3 (22.2–28.9)	26.0 (22.8–29.5)	25.6 (22.4–29.1)	25.2 (22.1–28.7)	24.8 (21.9–28.2)
Insured, *n* (%)	589 (86.0)	458 (87.9)	937 (91.0)	566 (93.0)	143 (87.7)	178 (89.9)	455 (92.1)	392 (92.9)
Age < 40, *n* (%)	310 (45.3)	260 (49.9)	557 (54.1)	347 (57.0)	78 (47.9)	100 (50.5)	271 (54.9)	245 (58.1)
Age ≥ 40, *n* (%)	375 (54.7)	261 (50.1)	473 (45.9)	262 (43.0)	85 (52.1)	98 (49.5)	223 (45.1)	177 (41.9)

Among biologically related donors, the distribution of educational attainment was 24.1% for high school or less, 18.3% for technical school, 36.2% for bachelor's/associate degree, and 21.4% for graduate education. Among unrelated donors, the corresponding proportions were 12.8%, 15.5%, 38.7%, and 33.0%, respectively. Donors with lower educational attainment were more likely to be biologically related, whereas donors with higher educational attainment were more likely to be unrelated.

3.2 Reported Donor Counts at the Beginning and End of the Study Period

The total annual number of living liver donors increased from 312 in 2012 to 498 in 2022. Among biologically related donors, the reported number of donors with graduate education increased from 42 to 89, while those with bachelor's/associate education increased from 78 to 132. In contrast, biologically related donors with high school education or less changed from 54 to 61, representing the smallest increase across the educational strata explicitly summarized in the text.

Among unrelated donors, growth was more concentrated in higher-education subgroups. The reported number of unrelated donors with graduate education increased from 18 to 67, and those with bachelor's/associate education increased from 24 to 58. Unrelated donors with high school education or less remained relatively uncommon, changing from 9 to 14 during the same period.

Age-stratified descriptive analyses showed that among biologically related donors, the increase was greatest among donors aged < 40 within the graduate education stratum. Among unrelated donors, the steepest increase was observed among donors aged < 40 in the graduate education group.

3.3 Incidence Rate Ratios for Living Liver Donation From 2012 to 2022

In negative binomial regression models, the number of biologically related donors with graduate education increased by 44% per 3-year increment (IRR 1.44, 95% CI 1.31–1.58). Biologically related donors with bachelor's/associate education increased by 31% per 3-year increment (IRR 1.31, 95% CI 1.20–1.43), whereas the increase among donors with high school or less was smaller (IRR 1.08, 95% CI 0.98–1.19).

Among unrelated donors, the strongest increase occurred in the graduate education group (IRR 1.52, 95% CI 1.38–1.67), followed by the bachelor's/associate education group (IRR 1.38, 95% CI 1.25–1.52). The weakest increase was observed in unrelated donors with high school or less education (IRR 1.04, 95% CI 0.92–1.17).

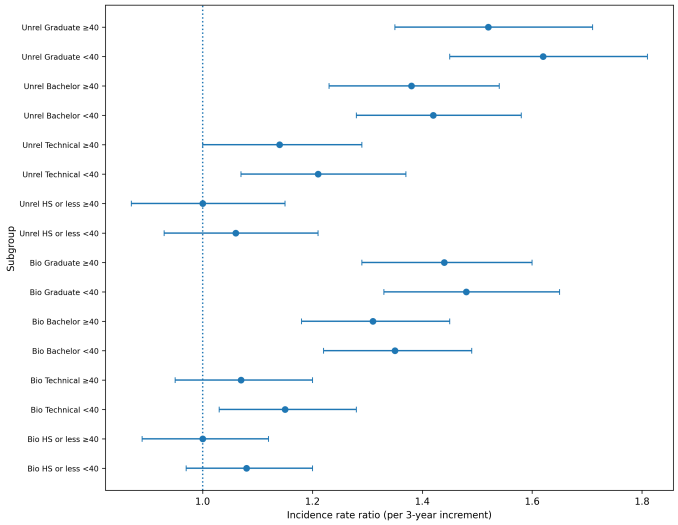

Figure 1. Incidence rate ratios for change in living liver donor counts per 3-year increment by donor–recipient relationship, educational attainment, and age category. Error bars indicate 95% confidence intervals.

In age-stratified models, the largest increase overall was observed among unrelated donors aged < 40 with graduate education (IRR 1.62, 95% CI 1.45–1.81). The smallest increase, and no statistically significant increase, was observed among biologically related donors aged ≥ 40 with high school or less education (IRR 1.00, 95% CI 0.89–1.12). Detailed incidence rate ratios and confidence intervals for all relationship, education, and age strata are shown in Table 2. These subgroup-specific trend estimates are also illustrated graphically in Figure 1.

Table 2. Incidence rate ratios for the change in annual living liver donor counts per 3-year increment, stratified by donor–recipient relationship, educational attainment, and age.

Relationship	Education	Age group	IRR (95% CI)	*p*-value
Biologically related	High school or less	< 40	1.08 (0.97–1.20)	0.16
Biologically related	High school or less	≥ 40	1.00 (0.89–1.12)	0.98
Biologically related	Technical school	< 40	1.15 (1.03–1.28)	0.01
Biologically related	Technical school	≥ 40	1.07 (0.95–1.20)	0.28
Biologically related	Bachelor/Associate	< 40	1.35 (1.22–1.49)	<0.001
Biologically related	Bachelor/Associate	≥ 40	1.31 (1.18–1.45)	<0.001
Biologically related	Graduate	< 40	1.48 (1.33–1.65)	<0.001
Biologically related	Graduate	≥ 40	1.44 (1.29–1.60)	<0.001
Unrelated	High school or less	< 40	1.06 (0.93–1.21)	0.38
Unrelated	High school or less	≥ 40	1.00 (0.87–1.15)	0.96
Unrelated	Technical school	< 40	1.21 (1.07–1.37)	0.002
Unrelated	Technical school	≥ 40	1.14 (1.00–1.29)	0.05
Unrelated	Bachelor/Associate	< 40	1.42 (1.28–1.58)	<0.001
Unrelated	Bachelor/Associate	≥ 40	1.38 (1.23–1.54)	<0.001
Unrelated	Graduate	< 40	1.62 (1.45–1.81)	<0.001
Unrelated	Graduate	≥ 40	1.52 (1.35–1.71)	<0.001

4 Discussion

In this national registry study, we found that living liver donation increased in the United States between 2012 and 2022, but the increase was not uniform across educational subgroups. Growth was greater among donors with higher educational attainment, particularly in the unrelated donor group, whereas lower-education donor groups showed smaller increases over time. These findings demonstrate an association between donor educational attainment and temporal patterns of completed living liver donation in the registry, rather than a direct effect of education itself on donor behavior or donor conversion.

The observed pattern is notable when interpreted alongside donor–recipient relationship. In our data, the largest increases were seen among unrelated donors with higher educational attainment, whereas lower-education subgroups showed comparatively limited growth. This pattern may reflect differences in the composition of donor pools, referral pathways, candidate selection, evaluation completion, or other unmeasured features of transplant practice [4]. However, because this study was based on registry data for completed donors, it cannot determine why these subgroup differences occurred or at what stage potential donors may have been lost.

Several possible explanations for these findings can be

considered, but they should be interpreted as hypotheses rather than conclusions directly established by the present dataset. Educational attainment may correlate with factors such as familiarity with medical systems, comfort with complex consent processes, employment flexibility, or other socioeconomic resources that are not directly measured here. Likewise, the smaller increases observed in lower-education subgroups may reflect broader structural differences rather than education alone. Prior work has shown that social and financial outcomes are important in living liver donation [6]. Meeting-based consensus work has also emphasized financial, policy, and ethical barriers to broader expansion of living donor liver transplantation [7]. In addition, neighborhood-level social determinants have been associated with access to living donor liver transplantation in the United States [8]. The current analysis cannot isolate the contribution of health literacy, paid leave, transportation burden, indirect costs, or donor navigation barriers, because those variables were not available in the registry. Future studies that link registry data to candidate evaluation pathways, center practices, or social determinants of health measures would be better suited to test these mechanisms directly.

The findings nonetheless remain relevant for program development. The uneven growth observed across educational subgroups suggests that transplant programs should consider whether donor information, evaluation procedures, and support pathways are equally accessible across different populations. These observations support further work on communication strategies, donor support models, and evaluation processes that can be tested in studies specifically designed to measure their effects. Telemedicine-based donor services may offer one practical avenue for reducing evaluation burden in future implementation studies [9].

This study also supports the value of examining growth in living donation through an equity-focused lens. Aggregate increases in living donor volume do not necessarily indicate that growth is occurring uniformly across all donor subgroups. Stratified analyses such as the present one can help identify populations in which growth has been more limited and can therefore guide future hypothesis-driven investigation. The broader expansion of living donor liver transplantation remains clinically important because living-donor liver transplant has been associated with survival benefit in contemporary practice [10].

Several limitations should be acknowledged. First, registry data identify completed donors rather than all individuals who expressed interest in donation or entered donor evaluation, so the analysis cannot determine where attrition occurred. Second, educational attainment is an indirect marker and does not fully capture income, occupation, health literacy, social support, employment protections, or other structural factors that may be relevant to donation. Third, this study did not include center-level or region-level analyses, and it did not evaluate transplant program practices, outreach strategies, or geographic variation. Accordingly, the present results should not be interpreted as evidence that any particular center, region, or operational practice explains the observed subgroup differences. Despite these limitations, the use of national registry data provides a useful descriptive picture of how growth in living liver donation has differed across educational and relational subgroups over time. Continued programmatic development is also consistent with calls to expand living donor liver transplantation within transplant practice [11, 12]. The evolving role of unrelated donation in the United States further supports the need for continued study in this area [13–15].

5 Conclusion

The temporal rise in living liver donation in the United States was not evenly distributed across donor educational subgroups. In this registry-based analysis, higher educational attainment was associated with greater growth in completed donation, particularly among unrelated donors. These results should be interpreted as descriptive evidence of differential growth across subgroups rather than proof of the mechanisms responsible for that pattern. Future research should directly evaluate candidate evaluation pathways, social and economic barriers, and center- or region-level variation to determine which factors contribute most to these differences.

Acknowledgments

The authors thank the SRTR for data access and the living donor programs for their contributions.

Funding

This study was supported by National Institutes of Health grant R01MD017344.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the Scientific Registry of Transplant Recipients (SRTR). The authors obtained data under SRTR project number 2023-012-A. Researchers may request data access directly from SRTR following standard data use agreement procedures. Analytic code used for this study is available from the corresponding author upon reasonable request.

Ethics Statement

This study used deidentified registry data and was exempt from institutional review board review or qualified for non-human-subjects determination in accordance with local institutional policy.

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