Who Gets to Live? Statistically Investigating Heart, Kidney, and Liver Transplant Allocation

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Introduction

- Significant healthcare inequities exist in the United States
- Organ transplantation is a rare and expensive medical procedure
  - Goal of the study is to see if organs are fairly allocated by race and sex
- Research Questions:
  - 1) Do significant differences exist for cardiovascular, liver, and kidney disease mortality rates by sex and race?
  - 2) Do significant differences exist for heart, liver, and kidney transplant recipients by sex and race?
  - 3) Do certain demographic groups receive transplants at rates disproportionate to their disease-specific mortality burdens?

Data

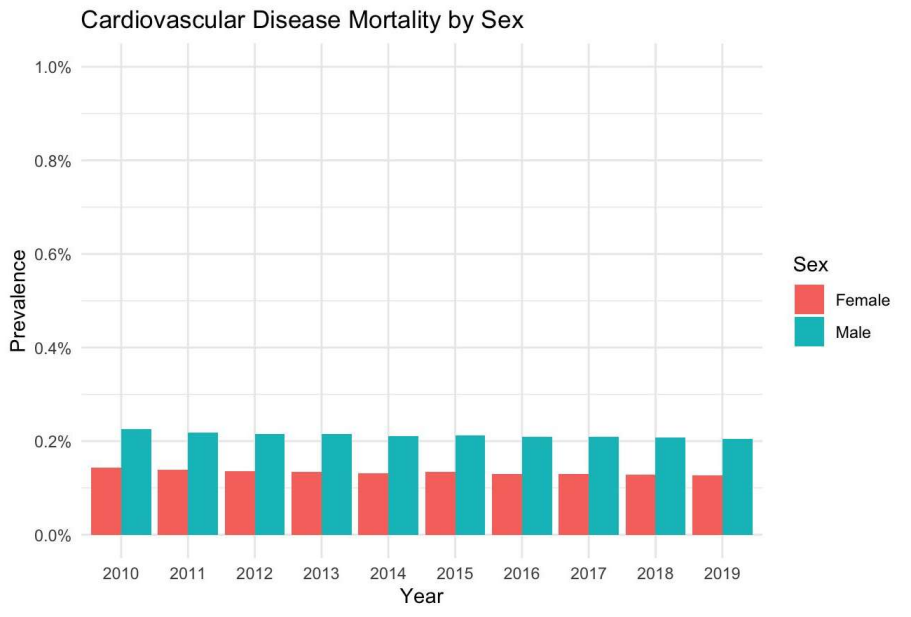
- Disease burden data are sourced from the Centers for Disease Control and Prevention (CDC)
  - Sample taken from 1997-2019
- Organ transplant recipient data sourced from the Health Resources and Services Administration (HRSA)
  - Sample taken from 2019-2024
- Due to missing data issues in the HRSA data:
  - Race data limited to four groups: White, Black, Hispanic, and Asian Americans
  - Transplant data limited to three organs: heart, liver, and kidney

Methodology

- One-way ANOVA tests determine if statistically significant differences exist between sex and race
  - Used both for transplant recipient and disease burden data
- Tukey's Honest Significant Difference (HSD) test used to examine significant differences between pairs of racial groups
  - Second test for transplant recipient and disease burden data
- ANOVA and Tukey's HSD tests verified and justified
  - Assumptions (normality, variance, independence) are satisfied

Heart Disease by Sex

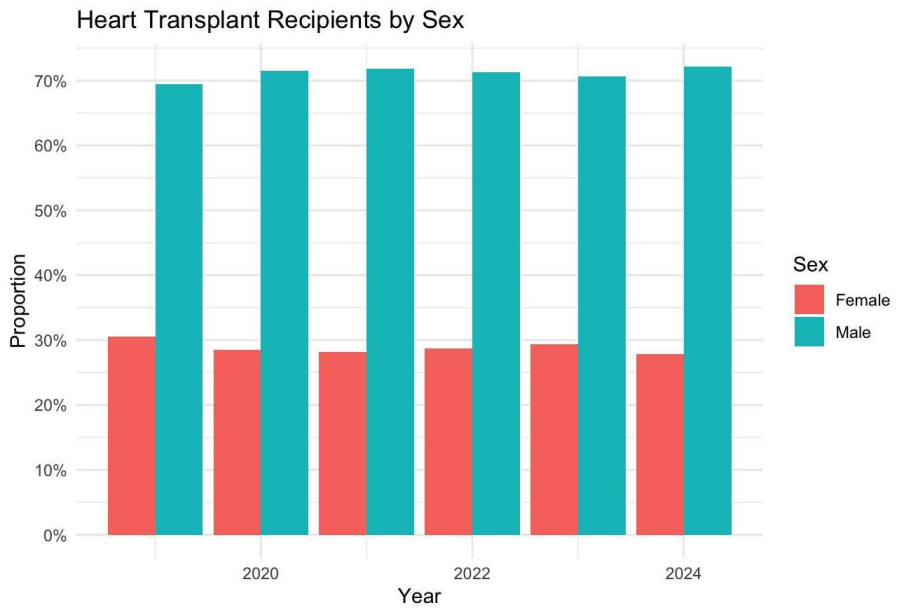
- One-way ANOVA: Mean cardiovascular disease mortality from 1997 - 2019 was significantly higher among males than females




```
Heart
            Df    Sum Sq  Mean Sq F value   Pr(>F)
Sex          1 9.450e-06 9.45e-06    52.6 4.88e-09 ***
Residuals   44 7.905e-06 1.80e-07
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Heart Transplants by Sex

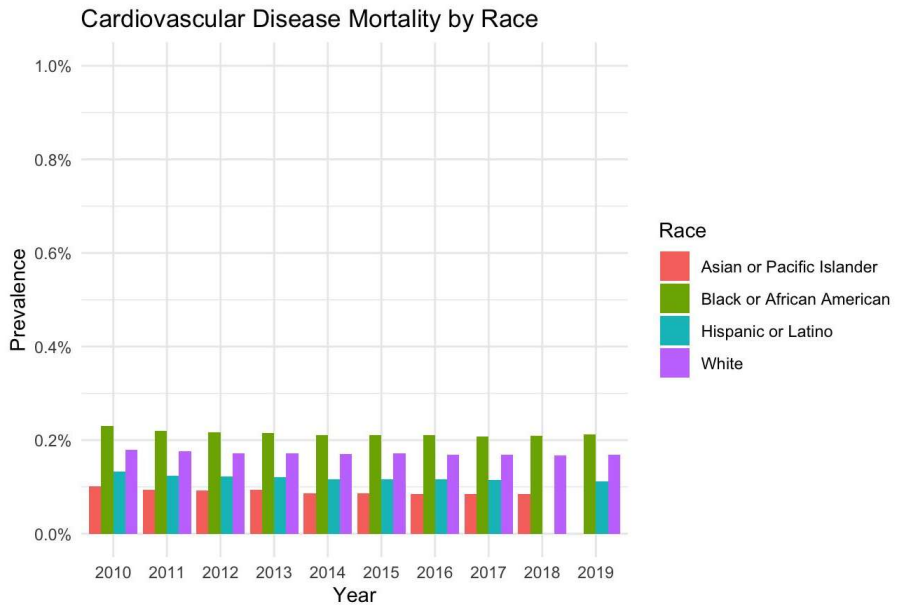
- One-way ANOVA indicates a statistically significant difference in heart transplants by sex, with males receiving significantly more transplants than females




```
==== Heart ====
            Df Sum Sq Mean Sq F value   Pr(>F)
Sex          1 0.5364  0.5364    5575 4.53e-15 ***
Residuals   10 0.0010  0.0001
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Heart Disease by Race

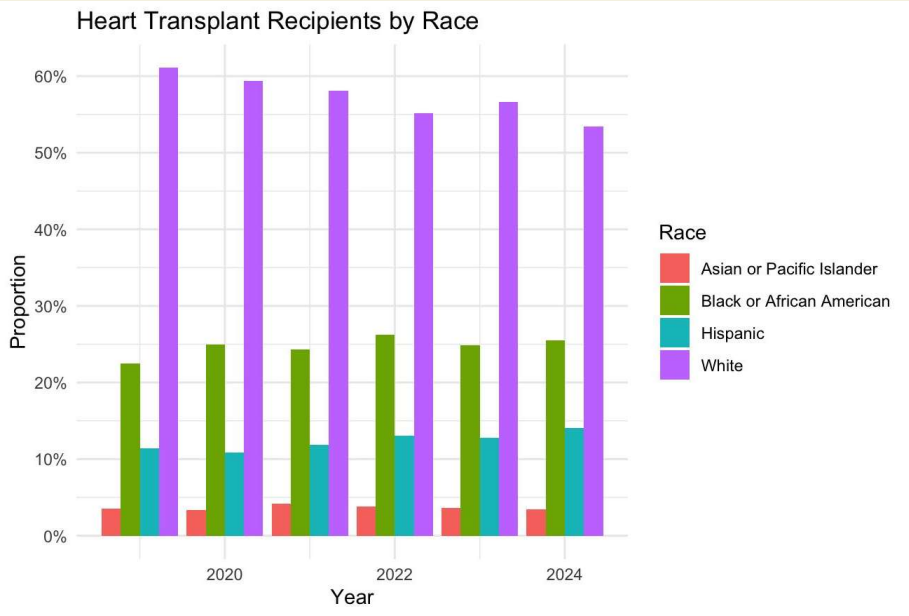
- Asian or Pacific Islander people experience the lowest rates of cardiovascular disease mortality
- Latine cardiovascular disease mortality is higher than that of Asian people, but lower than that of White and Black people
- Black people die of cardiovascular disease at the highest rates




```
Heart
             Df    Sum Sq   Mean Sq F value Pr(>F)
Race          3 2.431e-05 8.103e-06    60.5 <2e-16 ***
Residuals    82 1.098e-05 1.340e-07
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
6 observations deleted due to missingness


  Tukey multiple comparisons of means
    95% family-wise confidence level

Fit: aov(formula = as.numeric(Prevalence) ~ Race, data = Cardiovascular_Disease_Mortality_Burden_Race_Test)

$Race
                                                                 diff           lwr           upr
Black or African American only-Asian or Pacific Islander only  0.0014412571  0.0011413973  0.0017411170
Hispanic or Latino-Asian or Pacific Islander only              0.0004319000  0.0001353832  0.0007284168
White only-Asian or Pacific Islander only                      0.0009475304  0.0006540992  0.0012409617
Hispanic or Latino-Black or African American only             -0.0010093571 -0.0013021526 -0.0007165617
White only-Black or African American only                     -0.0004937267 -0.0007833969 -0.0002040565
White only-Hispanic or Latino                                  0.0005156304  0.0002294222  0.0008018386
                                                                   p adj
Black or African American only-Asian or Pacific Islander only 0.0000000
Hispanic or Latino-Asian or Pacific Islander only              0.0014510
White only-Asian or Pacific Islander only                      0.0000000
Hispanic or Latino-Black or African American only              0.0000000
White only-Black or African American only                      0.0001442
White only-Hispanic or Latino                                  0.0000550
```

Heart Transplants by Race

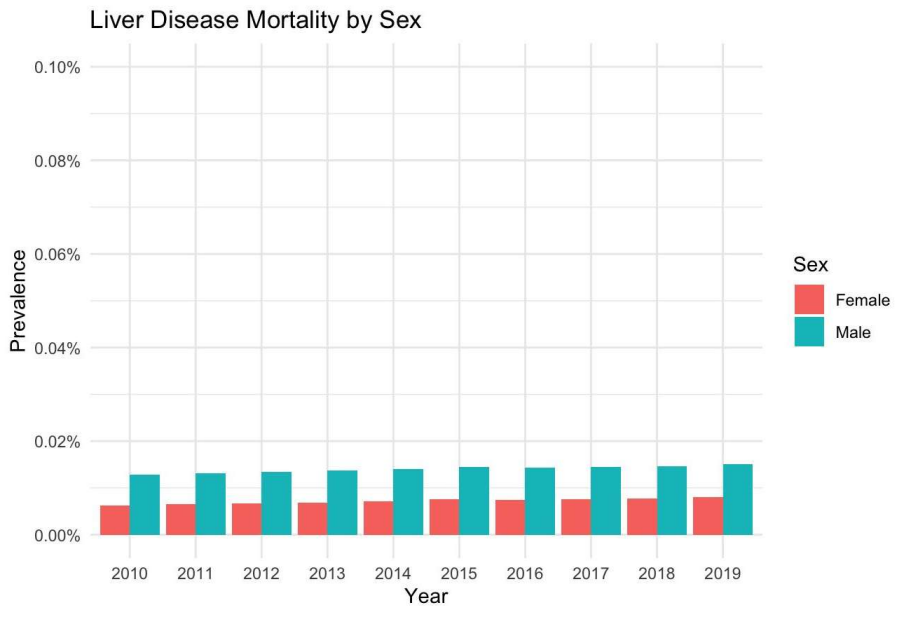
- One-way ANOVA shows statistically significant differences, with White Americans receiving a disproportionately higher number of heart transplants compared to other racial groups




```
==== Heart ====
            Df Sum Sq Mean Sq F value Pr(>F)
Race         3 0.9947  0.3316    1219 <2e-16 ***
Residuals   20 0.0054  0.0003
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

==== Tukey HSD for Heart ====
  Tukey multiple comparisons of means
    95% family-wise confidence level

Fit: aov(formula = Proportion ~ Race, data = df)

$Race
                      diff         lwr         upr p adj
Black-Asian      0.21058497  0.18393809  0.23723186 0e+00
Hispanic-Asian   0.08654537  0.05989848  0.11319225 1e-07
White-Asian      0.53626218  0.50961530  0.56290907 0e+00
Hispanic-Black -0.12403961 -0.15068649 -0.09739272 0e+00
White-Black      0.32567721  0.29903033  0.35232409 0e+00
White-Hispanic   0.44971682  0.42306993  0.47636370 0e+00
```

Liver Disease by Sex

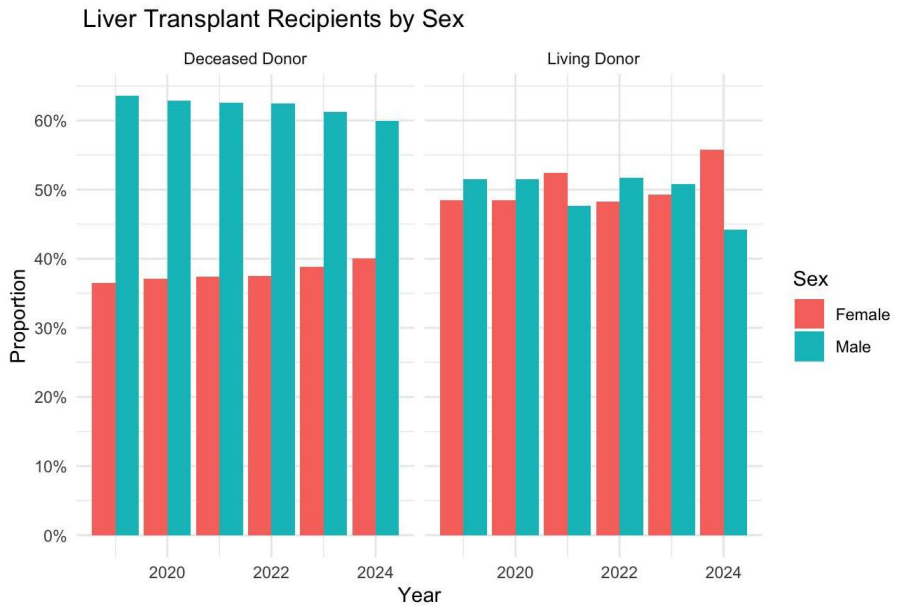
- One-way ANOVA: Liver disease mortality is significantly higher among males than females




```
Liver
            Df    Sum Sq   Mean Sq F value Pr(>F)
Sex          1 5.393e-08 5.393e-08   928.9 <2e-16 ***
Residuals   44 2.550e-09 6.000e-11
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Liver Transplants by Sex

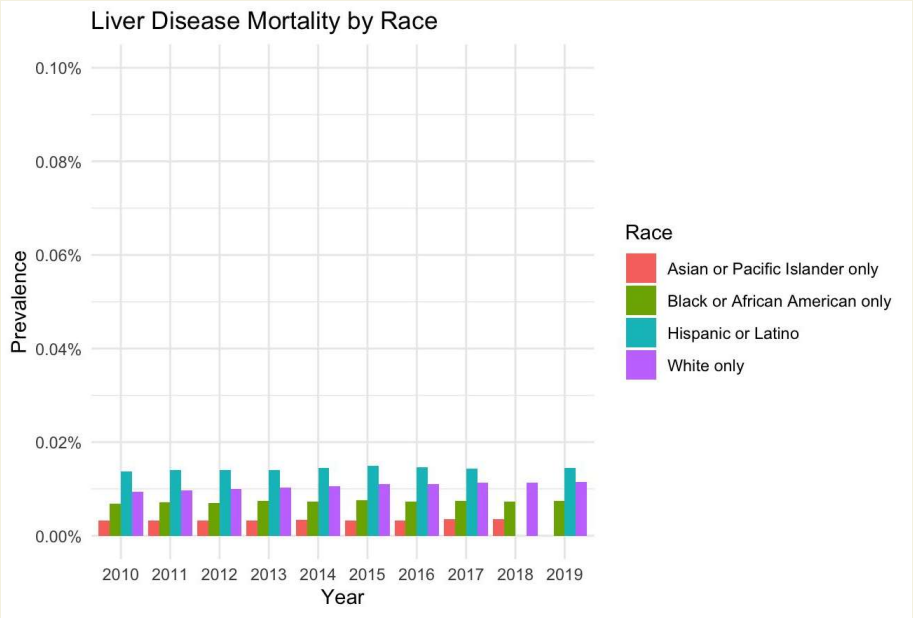
- One-way ANOVA: Liver disease mortality is significantly higher among males than females




```
==== Liver ====
            Df  Sum Sq Mean Sq F value   Pr(>F)
Sex          1 0.08168 0.08168   17.09 0.000435 ***
Residuals   22 0.10517 0.00478
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Liver Disease by Race

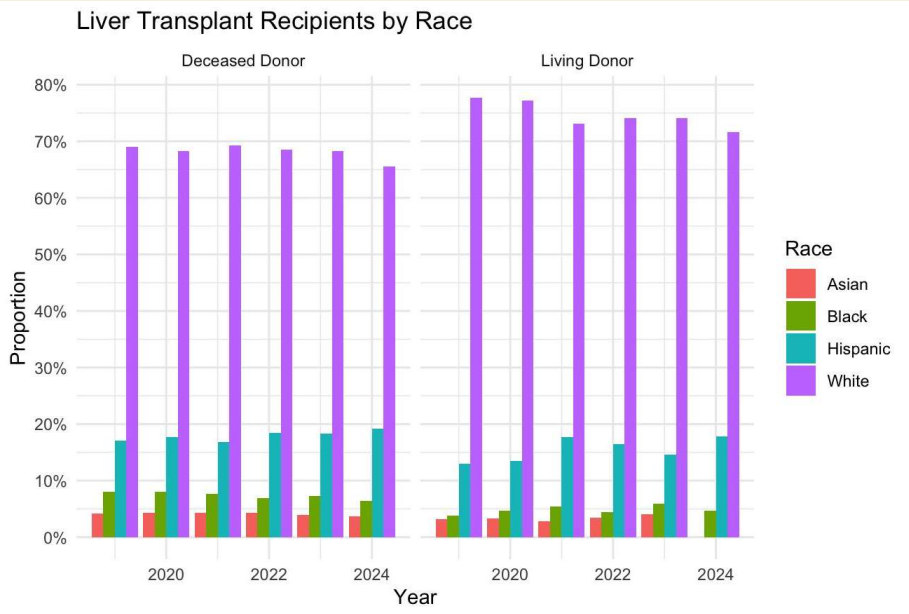
- One-way ANOVA reveals statistically significant differences among racial groups, with Hispanic/Latino individuals experiencing the highest mortality




```
Liver
             Df    Sum Sq   Mean Sq F value Pr(>F)
Race          3 1.403e-07 4.678e-08   644.8 <2e-16 ***
Residuals    82 5.950e-09 7.000e-11
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
6 observations deleted due to missingness

  Tukey multiple comparisons of means
    95% family-wise confidence level

Fit: aov(formula = as.numeric(Prevalence) ~ Race, data = Liver_Disease_Mortality_Burden_Race_Test)

$Race
                                                          diff           lwr           upr p adj
Black or African American only-Asian or Pacific Islander only  4.397143e-05  3.699234e-05  5.095052e-05     0
Hispanic or Latino-Asian or Pacific Islander only              1.138091e-04  1.069078e-04  1.207104e-04     0
White only-Asian or Pacific Islander only                      6.287826e-05  5.604879e-05  6.970773e-05     0
Hispanic or Latino-Black or African American only              6.983766e-05  6.302299e-05  7.665233e-05     0
White only-Black or African American only                      1.890683e-05  1.216490e-05  2.564876e-05     0
White only-Hispanic or Latino                                 -5.093083e-05 -5.759218e-05 -4.426948e-05     0
```

Liver Transplants by Race

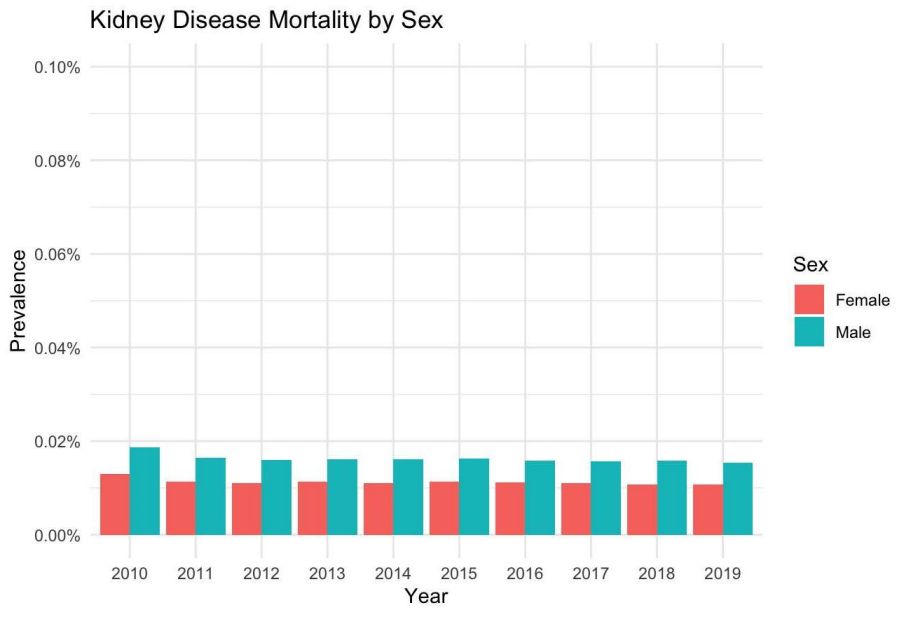
- One-way ANOVA: Liver disease mortality rate is significantly higher among White individuals compared to other demographics




```
==== Liver ====
            Df Sum Sq Mean Sq F value Pr(>F)
Race         3  3.590  1.1967    2197 <2e-16 ***
Residuals   43  0.023  0.0005
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
1 observation deleted due to missingness

==== Tukey HSD for Liver ====
  Tukey multiple comparisons of means
    95% family-wise confidence level

Fit: aov(formula = Proportion ~ Race, data = df)

$Race
                    diff          lwr        upr     p adj
Black-Asian    0.02345158 -0.002583258 0.04948642 0.0908427
Hispanic-Asian 0.12939900  0.103364164 0.15543384 0.0000000
White-Asian    0.67634043  0.650305596 0.70237527 0.0000000
Hispanic-Black 0.10594742  0.080484850 0.13141000 0.0000000
White-Black    0.65288885  0.627426281 0.67835143 0.0000000
White-Hispanic 0.54694143  0.521478859 0.57240400 0.0000000
```

Kidney Disease by Sex

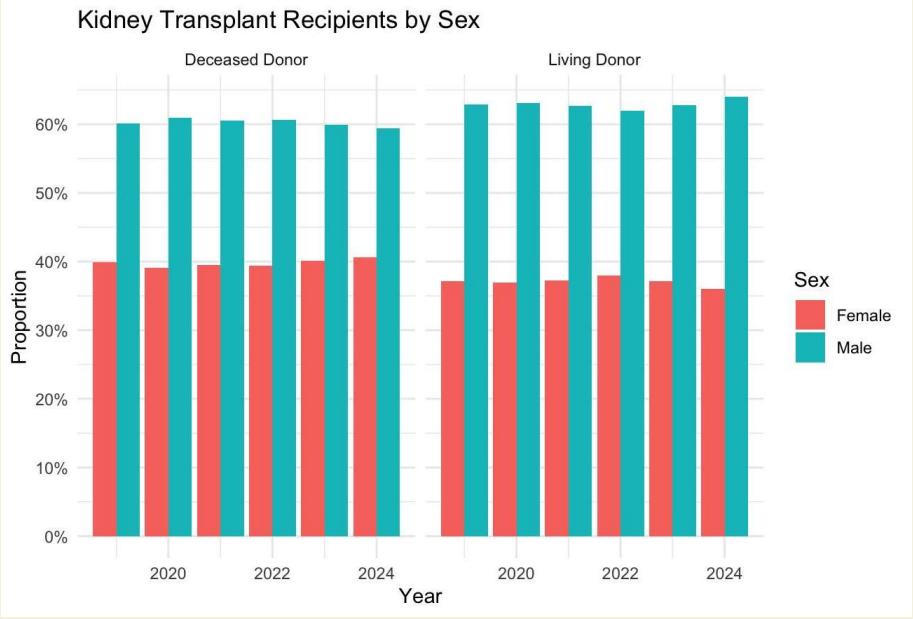
- One-way ANOVA: Kidney disease mortality rate is significantly higher among males than females




```
Kidney
             Df    Sum Sq   Mean Sq F value   Pr(>F)
Sex           1 3.079e-08 3.079e-08   133.6 6.36e-15 ***
Residuals    44 1.014e-08 2.300e-10
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Kidney Transplants by Sex

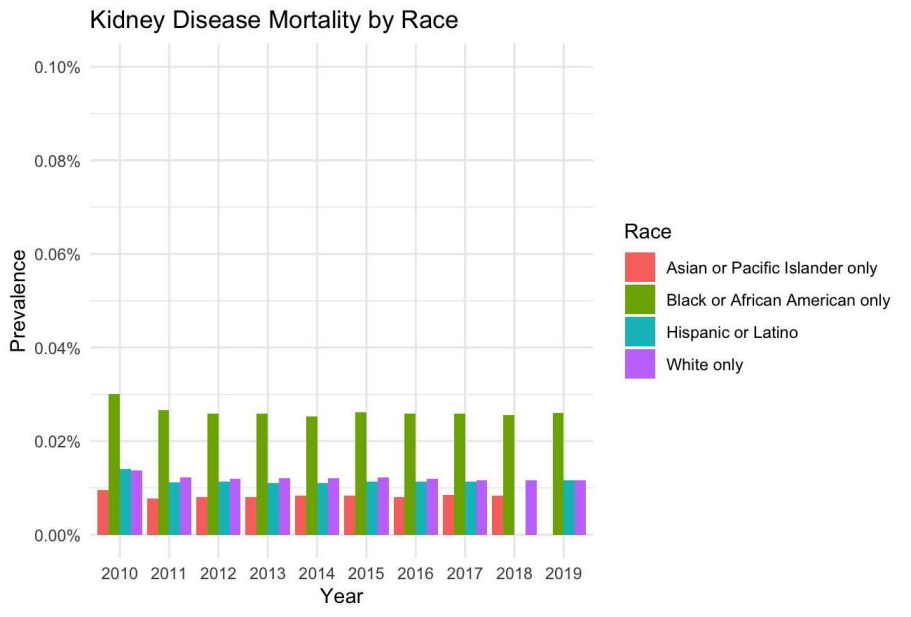
- One-way ANOVA: Kidney disease mortality is significantly higher among males than females




```
==== Kidney ====
            Df Sum Sq Mean Sq F value Pr(>F)
Sex          1 0.3221  0.3221    1426 <2e-16 ***
Residuals   22 0.0050  0.0002
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Kidney Disease by Race

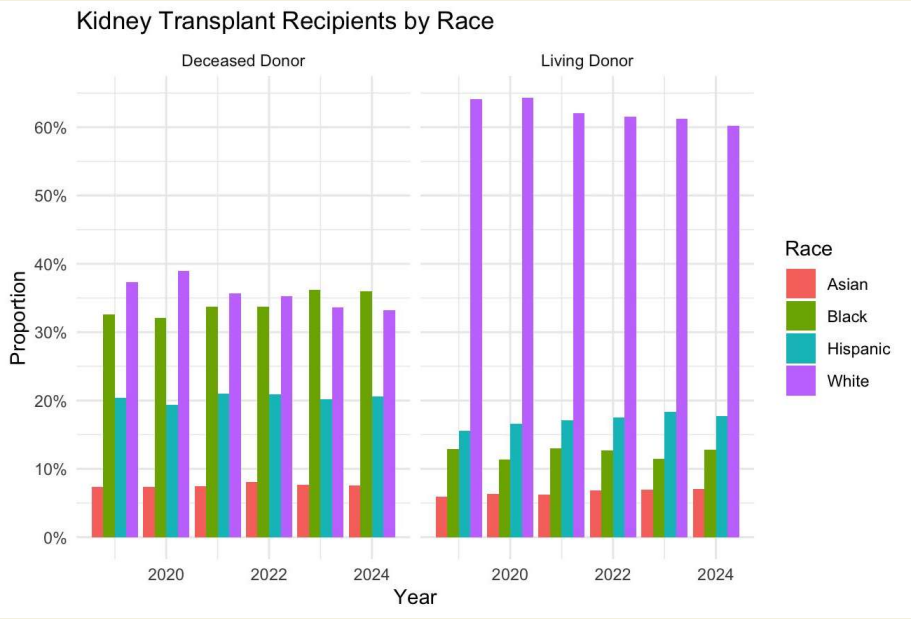
- One-way ANOVA demonstrates statistically significant differences among racial groups, with Black or African American individuals exhibiting the highest mortality rates




```
Kidney
             Df    Sum Sq   Mean Sq F value Pr(>F)
Race          3 4.999e-07 1.666e-07   636.5 <2e-16 ***
Residuals    82 2.150e-08 2.600e-10
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
6 observations deleted due to missingness


  Tukey multiple comparisons of means
    95% family-wise confidence level

Fit: aov(formula = as.numeric(Prevalence) ~ Race, data = Kidney_Disease_Mortality_Burden_Race_Test)

$Race
                                                                 diff           lwr           upr
Black or African American only-Asian or Pacific Islander only  1.977667e-04  1.845086e-04  2.110247e-04
Hispanic or Latino-Asian or Pacific Islander only              3.150909e-05  1.839884e-05  4.461935e-05
White only-Asian or Pacific Islander only                      3.505652e-05  2.208269e-05  4.803035e-05
Hispanic or Latino-Black or African American only             -1.662576e-04 -1.792033e-04 -1.533119e-04
White only-Black or African American only                     -1.627101e-04 -1.755177e-04 -1.499026e-04
White only-Hispanic or Latino                                  3.547431e-06 -9.107036e-06  1.620190e-05
                                                                   p adj
Black or African American only-Asian or Pacific Islander only 0.0000000
Hispanic or Latino-Asian or Pacific Islander only              0.0000001
White only-Asian or Pacific Islander only                      0.0000000
Hispanic or Latino-Black or African American only              0.0000000
White only-Black or African American only                      0.0000000
White only-Hispanic or Latino                                  0.8826521
```

Kidney Transplants by Race

- White Americans received a disproportionately higher number of kidney transplants from both deceased and living donors compared to other racial groups




```
==== Kidney ====
            Df Sum Sq Mean Sq F value   Pr(>F)
Race         3  1.124  0.3746   45.53 1.52e-13 ***
Residuals   44  0.362  0.0082
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

==== Tukey HSD for Kidney ====
  Tukey multiple comparisons of means
    95% family-wise confidence level

Fit: aov(formula = Proportion ~ Race, data = df)

$Race
                     diff         lwr       upr     p adj
Black-Asian     0.16144985  0.06258170 0.2603180 0.0004349
Hispanic-Asian  0.11723340  0.01836525 0.2161015 0.0143692
White-Asian     0.41892917  0.32006102 0.5177973 0.0000000
Hispanic-Black -0.04421645 -0.14308459 0.0546517 0.6337654
White-Black     0.25747933  0.15861118 0.3563475 0.0000001
White-Hispanic  0.30169577  0.20282763 0.4005639 0.0000000
```

Limitations and Future Research

- Population Representation: Limited to specific demographics, excludes many underrepresented groups
- Aggregated National Data: National Data Overlooks Local/Regional Disparities
- Statistical Methodology: Methods identify disparities but not causes
    - Cannot establish cause-effect relationships
- Utilize local datasets to uncover regional disparities
- Understand psychosocial and institutional factors affecting transplantation
- Investigate differences in outcomes between living and deceased donors

Conclusion

- Study results:
  - Heart, liver, and kidney organs were fairly allocated by sex
    - Men received more organs than females, but had a higher share of the disease burden
  - Heart, liver, and kidney organs were not equitably distributed by race
    - White Americans received a disproportionate amount of heart, liver, and kidney organs relative to their share of the disease burden
      - Often at the expense of Black and Hispanic Americans
- Future research is needed to uncover other potential disparities