

Decreased access to pediatric liver transplantation during the COVID-19 pandemic

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Abstract

Background: The COVID-19 pandemic has affected all aspects of the US healthcare system, including liver transplantation. The objective of this study was to understand national changes to pediatric liver transplantation during COVID-19.

Methods: Using SRTR data, we compared waitlist additions, removals, and liver transplantations for pre-COVID-19 (March–November 2016–2019), early COVID-19 (March–May 2020), and late COVID-19 (June–November 2020).

Results: Waitlist additions decreased by 25% during early COVID-19 (41.3/month vs. 55.4/month, $p < .001$) with black candidates most affected ($p = .04$). Children spent longer on the waitlist during early COVID-19 compared to pre-COVID-19 (140 vs. 96 days, $p < .001$). There was a 38% decrease in liver transplantations during early COVID-19 (IRR 0.62, 95% CI 0.49–0.78), recovering to pre-pandemic rates during late COVID-19 (IRR 1.03, NS), and no change in percentage of living and deceased donors. White children had a 30% decrease in overall liver transplantation but no change in living donor liver transplantation (IRR 0.7, 95% CI 0.50–0.95; IRR 0.96, NS), while non-white children had a 44% decrease in overall liver transplantation (IRR 0.56, 95% CI 0.40–0.77) and 81% decrease in living donor liver transplantation (IRR 0.19, 95% CI 0.02–0.76).

Conclusions: The COVID-19 pandemic decreased access to pediatric liver transplantation, particularly in its early stage. There were no regional differences in liver transplantation during COVID-19 despite the increased national sharing of organs. While pediatric liver transplantation has resumed pre-pandemic levels, ongoing racial disparities must be addressed.

KEYWORDS

access to care, COVID-19, outcome, pediatric liver transplantation

Abbreviations: ALF, Acute Liver Failure; BA, Biliary Atresia; CI, confidence interval; COVID-19, Coronavirus Disease 2019; DDLT, Deceased donor liver transplant; IR, Incidence rate; IRR, Incidence rate ratio; LDLT, Living donor liver transplant; LSAM, Liver Simulated Allocation Model; LT, Liver transplantation; MELD, Model for end-stage liver disease; MVA, motor vehicle accident; NAT, Non-accidental trauma; NDD LDLT, non-directed living donor liver transplant; PELD, Pediatric end-stage liver disease; SD, standard deviation; SRTR, Scientific Registry of Transplant Recipients; US, United States; WL, waitlist.

1 | BACKGROUND

On March 13, 2020, the US declared a state of emergency due to the SARS-CoV-2 virus that causes COVID-19.¹ Since that time, COVID-19 has had a profound impact on every aspect of the US healthcare system, including solid organ transplantation. Although the Centers for Medicare and Medicaid Services classified solid organ transplantation as a Tier 3b procedure that should not be postponed during COVID-19, uncertainty about mechanisms of transmission, availability of hospital resources, intensive care unit beds, supplies, and personal protective equipment as well as the potential risk of COVID-19 for donors, recipients, and staff led many transplant centers across the country to reconsider their transplantation practices.² There was also concern regarding the ethics of LDLT during that a healthy donor could be exposed to COVID-19 while in the hospital.³⁻⁵ A national survey of high-volume adult US LT centers performed in March 2020 revealed that 68% of LDLT programs were completely suspended, and 73% of DDLT programs were under some level of restriction due to COVID-19.⁴ A follow-up study using data from the SRTR demonstrated that in the adult LT population, COVID-19 resulted in fewer WL additions, DDLTs, and LDLTs. This study also found significant differences in COVID-19's impact on adult LT at both the state and regional levels, with centers in states with the highest incidence of COVID-19 having 49% more WL deaths and 34% fewer DDLTs.⁶

Children with end-stage liver disease, ALF, and unresectable hepatoblastoma are dependent on LT for long-term survival. Many children with end-stage liver disease require urgent transplantation due to complications such as portal hypertension, recurrent cholangitis, and refractory malnutrition. With a shortage of size appropriate grafts, LDLT is a critical option for children on the LT WL. Studies have demonstrated that LDLT has equal if not superior outcomes to DDLT.⁷⁻⁹ In 2019, LDLT accounted for 14% of all pediatric LTs and 18% of all LTs for children under the age of six.¹⁰

Racial and ethnic disparities are well described in both pediatric and adult liver transplantation. Specifically, LDLT is less likely to be used for black pediatric liver transplant candidates.¹¹ Understanding that COVID-19 resulted in center-specific transplant policy changes, with known suspension of many LDLT programs, we sought to utilize SRTR data to quantify changes in national pediatric LT WL additions, WL removals, WL mortality, LDLT, and DDLT between three time periods: pre-COVID-19 (March–November 2016–2019), early COVID-19 (March–May 2020), and late COVID-19 (June–November 2020). We also sought to understand how existing racial and ethnic disparities within pediatric liver transplantation were impacted by COVID-19.

2 | METHODS

2.1 | Study population

The Scientific Registry of Transplant Recipients and Organ Procurement Transplant Network (SRTR/OPTN) database was retrospectively reviewed for all pediatric LT WL additions and removals,

along with all pediatric LT performed from March 1, 2016 through November 30, 2020. Candidates and recipients 18 years and older and multi-organ listings and transplants were excluded from the analysis. Time periods were defined as pre-COVID-19 (March 1–November 30, 2016–2019), early COVID-19 (March 1–May 31, 2020), and late COVID-19 (June 1–November 30, 2020). These time periods were chosen to reflect two distinct waves of COVID-19 cases in the US during the 2020 calendar year, with a relative plateau in between the two.¹ We compared counts during the same monthly periods (March–May, June–November) pre-COVID-19 and during COVID-19.

2.2 | Counts of WL and transplant events and evaluation of recipient and donor characteristics by time period

Monthly counts of new additions to the WL, removals due to worsening illness or death, and LTs along with concordant transplant candidate characteristics were determined for each defined time period (pre-COVID-19, early COVID-19, and late COVID-19). Deceased and living donor characteristics were similarly collected per time period.

2.3 | Statistical analysis

Categorical variables were presented as counts and percentage and compared using chi square analyses, with pre-COVID-19 pandemic as the reference time period. Pairwise comparisons were then performed for any categorical variables with overall statistical significance in order to determine, which specific variable(s) contributed to its significance. Continuous variables were presented as mean and SD, and compared using two-sample Student's *t* test or ANOVA as appropriate. The IR for each WL event per time period was calculated by dividing the total event count by the cumulative person-time contributed by each candidate on the WL during the time period of interest. To evaluate for differential impact of COVID-19 on WL events by race/ethnicity, IR were also stratified as white versus non-white candidate/recipient race/ethnicity, with non-white including black, Hispanic, Asian, and other non-white categories as defined in the SRTR/OPTN database. Incidence rates were compared using IRR. An α of 0.05 was used to define statistical significance. Forest plots of IRR were created using GraphPad Prism 9.1.0 (San Diego, CA: www.graphpad.com). All other analyses were performed using Stata 16.1 (College Station, TX: StataCorp LLC.)

3 | RESULTS

3.1 | WL events during COVID-19

Characteristics of candidates added to the WL are presented in Table 1. Overall, WL additions were 25% fewer during early

COVID-19 compared to pre-COVID-19 (41.3/month vs 55.4/month, $p = .004$). Candidates ages 1–10 years were less likely to be added to the WL during early and late COVID-19 (23% and 19%, respectively, compared to 28% pre-COVID-19, $p = .004$) compared to pre-COVID. There were significant differences in WL additions based on race, with proportion of black candidates added to the WL dropping significantly in early COVID-19 (11%) compared to pre-COVID-19 (16%), and rebounding in late COVID-19 (21%) ($p = .04$). Underlying diagnosis, listing PELD and MELD scores, gender, and insurance type were similar in early and late COVID-19 as compared to pre-COVID-19. There were no significant differences across the different time periods in WL additions based on OPTN region (Table S1). There were no differences in overall proportion of WL dropouts from death or worsened condition during pre-COVID-19, early COVID-19, or late COVID-19 periods (5% vs. 6% vs. 5%, $p = .5$). There were no differences in underlying diagnosis, PELD/MELD, gender, age, weight, or race for those who did dropout from the WL. (Table S2).

3.2 | Liver transplant recipients during COVID-19

There was a 38% decrease in the rate of pediatric LT in early COVID-19 as compared to pre-COVID-19 (IRR 0.62, 95% CI 0.49–0.78), with non-white candidates significantly more impacted (IRR 0.56, 95% CI 0.40–0.77) than white candidates (IRR 0.70, 95% CI 0.50–0.95). By late COVID-19, overall and race/ethnicity stratified IRRs had returned to pre-pandemic level (Table 2) (Figure 1A). Overall, there were no differences in LDLT during early or late COVID-19 compared with pre-COVID-19 (IRR 0.54, 95% CI 0.25–1.05, IRR 0.87, 95% CI 0.56–1.30). However, when stratifying by race, non-white candidates were significantly less likely to undergo LDLT in early COVID-19 compared to pre-COVID-19, with an 81% decrease in LDLT (IRR 0.19, 95% CI 0.02–0.76) that resolved by late COVID-19 (IRR 0.86, 95% CI 0.44–1.56) (Table 3) (Figure 1B).

Characteristics of children who underwent LT during the three time periods are presented in Table 4. Underlying diagnosis, race/ethnicity, gender, and insurance type were similar in early and late

TABLE 1 Pediatric liver transplant WL additions

<i>n</i> (%) or Mean ± SD	Pre-COVID (<i>n</i> = 1994)	Early COVID (<i>n</i> = 124)	Late COVID (<i>n</i> = 283)	<i>p</i> -value
Female	1014 (51%)	63 (51%)	155 (55%)	.5
Age, years				.001
≤1	972 (49%)	70 (56%)	138 (49%)	.2
1–10	559 (28%)	28 (23%)	54 (19%)	.004
≥10	463 (23%)	26 (21%)	91 (32%)	.003
Race/Ethnicity ^a				.04
White	976 (49%)	57 (46%)	121 (43%)	.1
Black	320 (16%)	14 (11%)	59 (21%)	.04
Hispanic	456 (23%)	36 (29%)	78 (28%)	.08
Asian	151 (8%)	9 (7%)	19 (7%)	.9
Other	91 (5%)	8 (6%)	6 (2%)	.09
Listing MELD/PELD				.08
≤20	1263 (63%)	80 (65%)	158 (56%)	
20–30	211 (11%)	14 (11%)	27 (10%)	
≥30	73 (4%)	6 (5%)	19 (7%)	
Status 1B	128 (6%)	12 (10%)	23 (8%)	
Status 1A	281 (14%)	11 (9%)	49 (17%)	
Inactive	38 (2%)	1 (1%)	7 (2%)	
Diagnosis				.4
BA	630 (32%)	43 (35%)	73 (26%)	
ALF	221 (11%)	13 (10%)	38 (13%)	
Other/Missing	1143 (57%)	68 (55%)	172 (61%)	
Non-private insurance	1216 (61%)	84 (68%)	161 (57%)	.3
WL additions/month	55.4 ± 8.4	41.3 ± 1.5	47.2 ± 6.6	.004

Bolded are significant *p* values, and italics are *p* values that were part of a pairwise comparison. If both bolded and in italics it is both statistically significant and part of a pairwise comparison.

^aPairwise comparisons included to determine which specific variables contributed to overall statistical significance.

Timing of transplant: all transplants	IRR (95% CI)	IRR (95% CI)	IRR (95% CI)
	All race/ethnicity	White	Non-White
2020 vs. 2016–2019, March–May (Early)	0.62 (0.49–0.78)*	0.70 (0.50–0.95)*	0.56 (0.40–0.77)*
2020 vs. 2016–2019, June–November (Late)	1.03 (0.90–1.19)	1.11 (0.90–1.36)	0.98 (0.80–1.18)
Early vs. Late 2020	0.68 (0.53–0.87)*	0.73 (0.51–1.03)	0.64 (0.45–0.90)*
Early vs. Late 2016–2019	1.14 (1.02–1.27)*	1.16 (0.99–1.35)	1.12 (0.95–1.31)

Bolded are significant *p* values, and italics are *p* values that were part of a pairwise comparison. If both bolded and in italics it is both statistically significant and part of a pairwise comparison.

**p* is significant (<.05) based on 95% CI.

TABLE 2 IRR of all pediatric liver transplantation compared across pandemic time periods and stratified by race/ethnicity

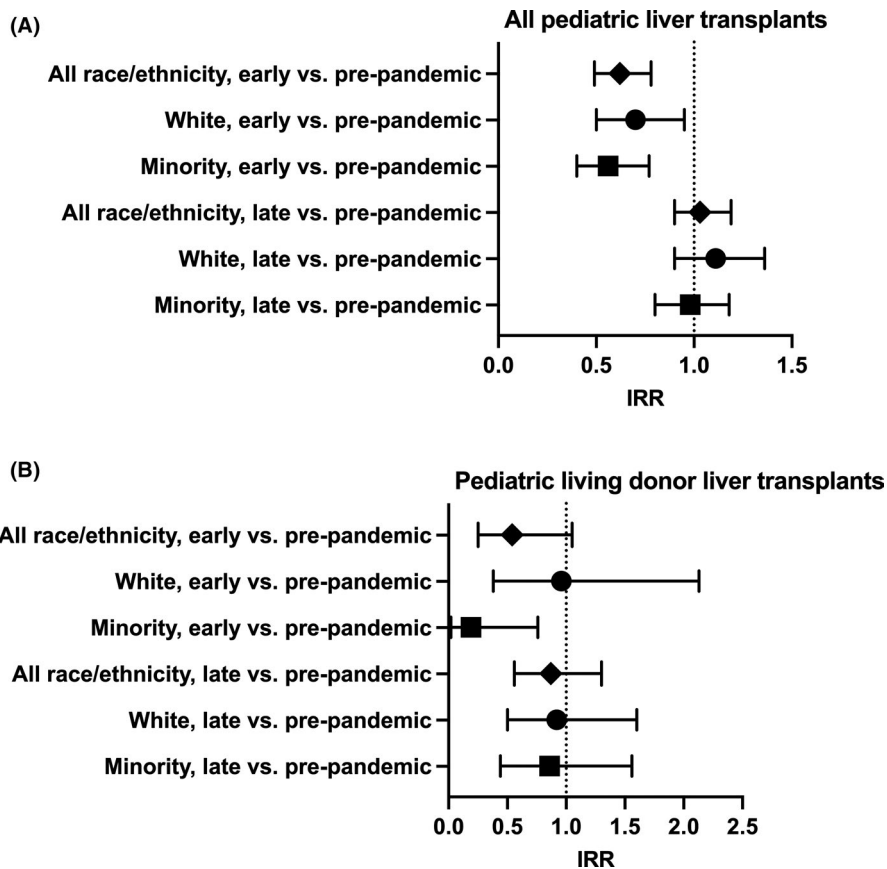


FIGURE 1 Forest plot of IRRs and 95% CI of (A) all pediatric liver transplantation and (B) pediatric living donor liver transplantation compared across pandemic time periods and stratified by race/ethnicity. Pre-pandemic (Early and Late, 2016–2019) versus Early and Late Pandemic (2020). Early: March–May. Late: June–November

COVID-19 as compared to pre-COVID-19. Graft type (deceased whole, deceased partial, and living donor) was also similar in early and late COVID-19 compared to pre-COVID-19. However, PELD/MELD at time of transplant was significantly different, with increased proportion of LT for those with PELD/MELD ≤ 20 and those listed as status 1B ($p < .001$, $p = .04$) and decreased proportion of transplants for those listed as status 1A ($p = .04$) in early COVID-19. Age at the time of transplant was also different between time periods, with those at least 10 years old undergoing LT at a higher proportion (30%) in late COVID-19 as compared to pre-COVID-19 (21%) and early COVID-19 (22%) ($p = .01$). For

those candidates who did undergo LT, time on WL was significantly longer in both early COVID-19 (139 ± 201 days) and late COVID-19 (127 ± 197 days) compared to pre-COVID-19 WL times (96 ± 133 days) ($p < .001$). The proportion of transplants with cold ischemia time > 7 h increased in early (42%) and late COVID-19 (35%) compared to pre-COVID-19 (30%) ($p < .001$). Finally, national sharing significantly increased from 17% in pre-COVID-19 to 55% and 54% in early and late COVID-19 ($p < .001$); subsequently, the proportion of local and regional sharing decreased. There were no significant differences across the different time periods in distribution of LT based on OPTN region (Table S3).

TABLE 3 IRR of pediatric living donor liver transplantation compared across pandemic time periods and stratified by race/ethnicity

Timing of Transplant: LDLT	IRR (95% CI)	IRR (95% CI)	IRR (95% CI)
	All race/ethnicity	White	Non-White
2020 vs. 2016–2019, March–May (Early)	0.54 (0.25–1.05)	0.96 (0.38–2.13)	0.19 (0.02–0.76)*
2020 vs. 2016–2019, June–November (Late)	0.87 (0.56–1.30)	0.92 (0.50–1.60)	0.86 (0.44–1.56)
Early vs. Late 2020	0.63 (0.28–1.33)	0.90 (0.33–2.22)	0.28 (0.03–1.24)
Early vs. Late 2016–2019	1.03 (0.75–1.39)	0.87 (0.56–1.32)	1.25 (0.78–1.98)

Bolded are significant *p* values, and italics are *p* values that were part of a pairwise comparison. If both bolded and in italics it is both statistically significant and part of a pairwise comparison.

**p* is significant (<.05) based on 95% CI.

3.3 | Liver transplant donors during COVID-19

DDLTL and LDLTL donor characteristics were compared across the time periods, with overall DDLTL and LDLTL proportions unchanged regardless of time period (Table 5). For DDLTL (Table 5A), donors aged 10–18 years were a significantly higher proportion of donors in early (34%) and late (34%) COVID-19 than in pre-COVID-19 (23%) ($p < .001$), and donors aged >18 years decreased significantly in early COVID-19 (17%) before returning closer to pre-COVID-19 numbers (29%) in late COVID-19 (26%) ($p = .048$). Cause of donor death differed across time periods, with a decrease in proportion of donor deaths from natural causes in early and late COVID-19 (10% and 18%) compared to pre-COVID-19 (21%, $p = .04$). There was a trend toward significant increase in proportion of donor deaths from NAT in early COVID-19 (16%) compared to pre-COVID-19 (9%) and from non-MVA accidental trauma in late COVID-19 (30%) compared to pre-COVID-19 (23%) ($p = .06$, $p = .06$). No differences in race or graft type were noted among DDLTL donors.

LDLTL donor characteristics (Table 5B) were unchanged across the time periods. 28 centers performed LDLTL during the pre-pandemic study period, and 19 continued to do so during the COVID-19 pandemic. Thirteen centers performed NDD LDLTL during the pre-pandemic study period and 7 centers continued to do so during the pandemic. Despite these center-specific changes, the proportion of overall NDD LDLTL performed did not differ across time periods.

4 | CONCLUSIONS

In this national study of pediatric LT during the COVID-19 pandemic, we found that early on (March–May 2020) there were significantly fewer additions to the pediatric LT WL, with children spending longer on the WL prior to LT, and a remarkable 38% decrease in the rate of transplantation. Later in the pandemic (June–November 2020) WL additions began to increase and the number of pediatric LTs performed approached pre-pandemic levels. Interestingly, there was no significant rise in pediatric LT in late COVID-19 to compensate for the decreases seen early in the pandemic, which may reflect

that WL additions had only begun to increase but were not yet back to pre-pandemic levels during the study time period.

These patterns are similar to those observed in the adult LT population and suggest adaptability and resiliency of the transplant community.^{6,12} Despite the ongoing spread of SARS-CoV-2, transplant programs were able to apply rapidly evolving knowledge and data, implement needed safety precautions, and update practice guidelines to allow transplantation to quickly resume.^{13,14} This study demonstrates that children's access to LT was not as severely impacted as adults' access to transplant. A study by Charnaya, et al. on the effect of the COVID-19 pandemic on pediatric kidney transplant in the US noted similar results.¹⁵ This aligns with overall impact of COVID-19 in pediatrics, whereby significantly fewer children become severely ill with disease compared to adults. As a result, many pediatric hospitals were not faced with the same critical shortages of hospital beds and resources as adult hospitals who were operating in crisis mode.^{16,17}

Of those children who underwent LT in early COVID-19, we found higher proportion of transplants for those with low PELD/MELD and listed as status 1B, and lower proportion of transplants for those listed as status 1A. It is not surprising that those listed as status 1B would maintain their transplantation rates given their critically ill status. However, the increased proportion of transplants for low PELD/MELD scores and decreased proportion of transplants for status 1A is an unexpected finding that requires further investigation. Perhaps social distancing and masking guidelines prevented transmission of viral illnesses that historically lead to non A-E ALF and listing of a patient as status 1A. Another possibility is that more deceased donor organs were available for children with lower PELD/MELD scores because they weren't competing with adults, which would also help explain the increase in national sharing of organs and cold ischemia time >7 h (discussed further below). Alternatively, the increase in pediatric transplantation at lower PELD/MELD scores may be a result of the UNOS policy change implemented in February 2020, which replaced the use of geographic boundaries of donation service areas and transplant regions with acuity circles between donor and transplant hospitals.¹⁸ Mogul's application of the LSAM to this allocation change suggested that acuity circle

<i>n</i> (%) or Mean ± SD	Pre-COVID (<i>n</i> = 1468)	Early COVID (<i>n</i> = 92)	Late COVID (<i>n</i> = 256)	<i>p</i> -value
Female	726 (49%)	50 (54%)	135 (53%)	.4
Age, years ^a				.03
≤1	696 (47%)	49 (53%)	108 (42%)	.1
1–10	457 (31%)	23 (25%)	71 (28%)	.3
≥10	315 (21%)	20 (22%)	77 (30%)	.01
Race/Ethnicity				.6
White	736 (50%)	47 (51%)	116 (45%)	
Black	241 (16%)	12 (13%)	47 (18%)	
Hispanic	331 (23%)	26 (28%)	65 (25%)	
Asian	101 (7%)	5 (5%)	21 (8%)	
Other	59 (4%)	2 (2%)	7 (3%)	
Match MELD/PELD ^{a,b}				.001
≤20	187 (13%)	21 (23%)	52 (20%)	<.001
20–30	120 (8%)	6 (7%)	24 (9%)	.7
≥30	609 (41%)	31 (34%)	100 (39%)	.3
Status 1B	338 (23%)	29 (32%)	48 (19%)	.04
Status 1A	210 (14%)	4 (4%)	30 (12%)	.04
Diagnosis				.6
BA	483 (33%)	31 (34%)	77 (30%)	
ALF	129 (9%)	4 (4%)	21 (8%)	
Other/Missing	856 (58%)	57 (62%)	158 (62%)	
Non-private insurance	904 (62%)	59 (64%)	129 (50%)	.8
Time on WL, days	96.26 ± 133.04	139.49 ± 200.47	126.84 ± 197.03	<.001
Graft type				.5
Deceased whole	855 (58%)	58 (63%)	162 (63%)	
Deceased partial	415 (28%)	24 (26%)	64 (25%)	
Living donor	198 (13%)	10 (11%)	30 (12%)	
Sharing ^a				<.001
Local	610 (42%)	16 (17%)	57 (22%)	<.001
Regional	615 (42%)	25 (27%)	60 (23%)	<.001
National	243 (17%)	51 (55%)	139 (54%)	<.001
Cold ischemia >7 h	436 (30%)	39 (42%)	89 (35%)	<.001

TABLE 4 Characteristics of liver transplant recipients

Bolded are significant *p* values, and italics are *p* values that were part of a pairwise comparison. If both bolded and in italics it is both statistically significant and part of a pairwise comparison.

^aPairwise comparisons included to determine, which specific variables contributed to overall statistical significance.

^bMatch MELD/PELD data missing for a total of 7 transplant recipients.

allocation would lead to decreased median PELD/MELD scores at time of liver transplant.¹⁹

We expected to find a decrease in the percentage of LDLTs performed during COVID-19, as many programs were concerned about the ethics of bringing a healthy donor into the hospital and potentially exposing them to COVID-19. Unlike in the adult population where LDLTs were 42% fewer during early COVID-19,⁶ our study found no decrease in overall LDLT in pediatric candidates during early or late COVID-19. Although we do not have data to understand center-level policy changes regarding LDLT during COVID-19,

our data demonstrate that only 9 centers performing LDLT pre-pandemic did no LDLTs during COVID-19. Perhaps pediatric LT programs, understanding the critical importance of LDLT grafts for children in particular, pushed to keep LDLT going during COVID-19.

Although the overall rate of DDLT did not change during COVID-19, we found a significantly increased proportion of donors aged ten to eighteen and a trend toward increased proportion of donor death due to NAT and non-motor vehicle accidental trauma during COVID-19 (*p* = .06). There are several potential explanations for these noted changes. Economic recession and natural disasters in

TABLE 5 Deceased and living donor characteristics for pediatric liver transplant recipients during Pre-, Early, and Late COVID time periods

(A) Deceased donor characteristics				
	Pre-COVID	Early COVID	Late COVID	
n (%)	(n = 1270)	(n = 82)	(n = 226)	p-value
Donor age, years ^a				.004
≤1	273 (21%)	20 (24%)	38 (17%)	.2
1–10	335 (26%)	20 (24%)	53 (23%)	.6
10–18	294 (23%)	28 (34%)	77 (34%)	<.001
≥18	368 (29%)	14 (17%)	58 (26%)	.048
Race/Ethnicity				.4
White	745 (59%)	43 (52%)	116 (51%)	
Black	246 (19%)	19 (23%)	55 (24%)	
Hispanic	223 (18%)	17 (21%)	47 (21%)	
Asian	25 (2%)	0	3 (1%)	
Other	31 (2%)	3 (4%)	5 (2%)	
Cause of death (circumstance) ^a				.04
MVA	245 (19%)	22 (27%)	36 (16%)	.1
Suicide	164 (13%)	11 (13%)	34 (15%)	.7
Homicide	77 (6%)	6 (7%)	15 (7%)	.9
NAT	118 (9%)	13 (16%)	16 (7%)	.06
Non-MVA accidental trauma	290 (23%)	19 (23%)	68 (30%)	.06
Natural	264 (21%)	8 (10%)	40 (18%)	.04
Other	112 (9%)	3 (4%)	17 (8%)	.2
Graft type				.4
Whole	855 (67%)	58 (71%)	162 (72%)	
Partial	415 (33%)	24 (29%)	64 (28%)	
(B) Living donor characteristics				
	Pre-COVID	Early COVID	Late COVID	
n (%)	(n = 198)	(n = 10)	(n = 30)	p-value
Age >40 years	48 (24%)	2 (20%)	11 (37%)	.3
Race/Ethnicity				.9
White	125 (63%)	8 (80%)	20 (67%)	
Black	19 (10%)	0	2 (7%)	
Hispanic	34 (17%)	2 (20%)	6 (20%)	
Asian	14 (7%)	0	1 (3%)	
Other	6 (3%)	0	1 (3%)	
Living donor relationship ^b				.4
Parent	89 (45%)	2 (20%)	10 (33%)	
Directed, biological	37 (19%)	1 (10%)	5 (17%)	
Directed, non-biological	46 (23%)	3 (30%)	3 (10%)	
Non-directed	26 (13%)	3 (30%)	5 (17%)	

Bolded are significant *p* values, and italics are *p* values that were part of a pairwise comparison. If both bolded and in italics it is both statistically significant and part of a pairwise comparison.

^aPairwise comparisons included to determine, which specific variables contributed to overall statistical significance.

^bLiving donor relationship data missing for a total of 8 living donors.

general are often associated with increases in NAT.^{20,21} Child abuse and intimate partner violence hotline phone calls and text messages have increased 14% during COVID-19 compared to the same time period in 2019, likely due to the stress of children and their parents being confined at home.²² During COVID-19, there has also been a significant increase in firearm purchases,²³ and many of these purchases have been made by people living with children in the home.²⁴

Our study demonstrated a significant increase in national sharing of organs during COVID-19, with a concurrent increase in percentage of transplants with cold ischemia time >7 h. We posit that as certain regions of the country were severely impacted by COVID-19, they were not able to accept organs and thus the organs were used nationally instead of locally. Although our data do not suggest that there were overall regional differences in WL additions or LTs during COVID-19, there may have been certain time periods during that individual centers were more or less likely to accept organs based on local COVID-19 prevalence. Additionally, based on local COVID-19 prevalence, centers may have chosen to only accept optimal organs for candidates not at imminent risk of death, and these optimal organs may have traveled from further distances with longer cold ischemia time. Alternatively, the increase in national sharing may have had little to do with COVID-19 and instead resulted from the aforementioned allocation policy change, which prioritized pediatric donors (<18 years old) to pediatric recipients.¹⁸ Mogul's simulations projected that this policy change would lead to increased median transport distance for deceased donor livers.¹⁹

Our study demonstrated significant racial differences in access to pediatric LT during COVID-19. Black children had a significant decrease in WL additions and non-white children had a significant decrease in overall LTs and LDLTs during early COVID-19. Racial and ethnic disparities, particularly for black patients, have been previously described in adult²⁵⁻³⁰ and to a lesser degree pediatric transplant.^{11,28,31} Although the MELD score has eliminated disparities while on the LT WL, black patients are less likely to be referred for LT evaluation, are less likely to pursue care at an LT center, and have lower listing to death and transplant to death ratios.^{25,29,32} Recent studies have also found a significant burden of COVID-19 infection, as well as lack of access to care during COVID-19, among racial and ethnic minorities and communities and children disproportionately affected by COVID-19, structural racism, and poverty.^{23,33} These groups may also be disproportionately impacted by essential personnel status during COVID-19^{23,34,35} and by general distrust of the healthcare system and delays in seeking care.^{23,36} It is concerning that previously existent disparities in access to pediatric LT may have been worsened early on in the COVID-19 pandemic. Further research to guide future interventions is urgently needed to ensure that all children have equal access to LT.

The main limitation to this study is the use of a registry database, which is dependent on data reporting by individual transplant centers. Despite rigorous data quality control within SRTR, any database registry research has the potential for missing data, incomplete data, or inaccurate data. Although transplant centers have mandatory

reporting requirements set forth by OPTN, it is also possible that there may be a delay in data transmission, particularly considering the impact of COVID-19 on workflow. However, given that manuscript preparation occurred five months after the last reported data, we are optimistic that the majority of data has been reported and the effect of COVID-19 on pediatric LT accurately reported. Additionally, the findings of this manuscript may have been confounded by the aforementioned organ allocation policy change,¹⁸ which went into effect February 2020 when the COVID-19 pandemic was occurring.

In summary, we found that the COVID-19 pandemic, particularly early on, decreased access to pediatric LT. Though not to the degree of the adult LT population, WL additions and incidence rate of transplantation decreased significantly. While differences in impact were not observed on the regional level, there were significant racial differences. Future studies are needed to evaluate the outcomes for both living donors and LT recipients during COVID-19 to understand if they were at higher risk for infectious complications or poor outcome. This information will be critical in informing future recommendations for pediatric LT centers.

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CONFLICT OF INTEREST

The authors of this manuscript have no conflicts of interest to disclose as described by the American Journal of Transplantation.

AUTHOR CONTRIBUTIONS

Dr. Kemme wrote the first draft of the manuscript and did not receive any honorariums, grants, or forms of payment to produce the manuscript. All authors listed on the manuscript meet the ICMJE definition of authorship and have approved the manuscript being submitted.

DATA AVAILABILITY STATEMENT

The raw data that support the findings of this study are available in the SRTR/OPTN database at <http://www.srtr.org/>. Derived data supporting the findings of this study are available from the corresponding author [AF] on request.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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